School of Education

Exploring the Intersection between Socioeconomic Status and Effective Multimedia Text Design for Secondary School Science Learning

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**This thesis is presented for the Degree of
Doctor of Philosophy
of
Curtin University**

December 2020

DECLARATION

To the best of my knowledge and belief, this thesis contains no material previously published by any other person except where due acknowledgement has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number RDSE-15-15.

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21 December 2020

ABSTRACT

Accompanying an international decline in achievement standards within secondary science education is the negative impact of social disadvantage in senior science participation and achievement. This trend is particularly evident within public schooling in developed countries and results in a lack of expertise for science employment and broader economic concerns. Exacerbating this sector specific ‘socioeconomic achievement gap’ is an outdated model of cognition which affects science text design. This model is computationalist, as it adheres to cognitivist principles which identify specific neural architectural features and constraints in stimuli processing. By contrast, this doctoral thesis presents findings on the utility of ‘socially congruent’ text design as a design variable hitherto absent in multimedia learning and details an alternative model of the cognitive architecture. This conceptual model emphasises an embodied mind-body dualism and the developmental role of socioeconomic status as a modulator of neuroendocrine activity in cognitive processes.

This study involved a quantitative approach and a quasi-experimental research design which was considered expedient given the desire to leave students in classroom groupings. Despite lacking individual randomization, the use of a cluster randomised trial acted as a safeguard against threats to internal validity while retaining an external validity that was considered realistic and robust in the interpretation of findings. The study setting was an international primary to year twelve school located in Sharjah, United Arab Emirates (UAE); 214 of the school’s grade 7, 8, and 9 middle school students and five middle school teachers consented and participated in this multimedia learning research study. Theoretical and methodological inconsistencies in multimedia learning theory, as well as personal experience in teaching across a range of socioeconomic settings, helped inform the study objectives. These objectives included: (a) an examination of how textual visual-verbal modality affects retention of content in learners differentiated by social standing; (b) the parsing of socioeconomic status into objective and subjective measures as covariates in learning; (c) analysis of student-held attitudes towards science (as a learning area) and science learning texts that differ in degree of textual visual-verbal modality and (d) the development of a model of cognitive architecture consistent with the study results and existing neurological literature.

In analysis of the interaction of science learning, social standing, and textual visual-verbal modality, several research instruments were adapted or designed during the study. To assess science learning, a novel instrument, the Middle School Science Achievement Test (MSSAT) was developed and validated by the researcher. This instrument, including pre- and post-test measures, was designed in accordance with school assessment at the research site in containing subsections conforming to science understanding, application of science content and analysis / evaluation questions and was presented in three grade-level variants for participating students. Social standing, meanwhile, was measured in objective and subjective forms and included modification of an existing instrument. Modified for measurement of objective SES, the instrument used in the study presented families with a range of socioeconomic indices including income, employment and educational achievement data; the subjective SES version of the instrument, meanwhile, contained two self-anchoring ladders in which each participating student ranked him / herself according to perceived position in (a) society and (b) the school. Lastly, textual visual-verbal modality was operationalised via the researcher's design of a series of graphic novel worksheets (three worksheets per grade level) with each worksheet presented as either Multimodal Social (MS) text with graphics and corresponding speech bubbles or Bimodal Social (BS) text with the same graphics as the MS worksheets though with columnar text replacing speech bubbles. The control text was the corresponding section of the textbook used at the site.

In summation of science cognitive outcomes, socialised multimedia text enhanced both recall and transfer learning for participating middle school students. Additional findings revealed that auditory mode distinctions (i.e. speech bubbles vs columnar text) between the Multimodal Social and Bimodal Social texts were less important than social congruence per se and that subjective SES, but not objective SES, covaried with student learning. Of the former SES measure, modelling subjective SES as a multivariate analysis of covariance covariate strengthened the associations between dependent variables and each of the cognitive domains and reduced extraneous variance in the model; objective SES, meanwhile, failed to satisfy pre-test checks for variance and covariance homogeneity and was removed as a study covariate.

Additional to cognitive outcomes as a measure of science learning with socialised multimodal text was the gathering and analysis of student attitudinal data. As mentioned above, this study objective included attitudinal data pertaining to (i) science as a learning area and (ii) socialised text. Correspondingly, an existing instrument was modified and administered before and after the interventions to assess subject-area attitudes, while a researcher-developed instrument, was used to gather affective responses towards the textual variants used in the study (i.e. Multimodal Social, Bimodal Social or control text). Analysis of questionnaire data revealed specific trends: (i) multimodal text was perceived as more engaging than control text; (ii) multimodal text was associated with cognitive gains though did not facilitate greater student interest in the subject area, and (iii) multimodal text did not disproportionately benefit low SES learners. These results are indicative of a learning effect whereby positive feelings towards the learning material correspond to cognitive gains via enhanced affective involvement. Nonetheless, unlike the previously described cognitive benefits for low SES learners, multimodal text – presented in a graphic novel format – appears to appeal to a wide grouping of middle school students.

The final research objective, a conceptual model of the cognitive architecture, was formulated in accordance with the cognitive and affective findings from the study. This model, informed also by recent findings in developmental and cognitive neuroscience, provides an account of normal and abnormal processes in stimuli processing and presents an alternative picture of cognition to that forwarded by theorists in multimedia learning.

The study contributes to the emerging multimedia learning theory literature. The primary contribution of the study is the development of a cognitive architecture inclusive of perceptual, cognitive and affective components that helps ground cognitive processes to developmental SES differences including the role of learner affect. Secondary contributions of the study pertain to pedagogy, material design, student administration and suggestions for further research. Key theoretical implications of the research suggest a reconsideration of neural modularity as a basis of the cognitive architecture, a revision of basic multimedia learning principles to emphasise socially congruent audiovisual elements of text and the primacy of SES as a developmental factor for learners.

ACKNOWLEDGEMENTS

This PhD thesis is the culmination of a long and arduous apprenticeship in scholarship. Thanks are due, accordingly, to those who supported me academically, financially and professionally over the course of my tutelage. Nonetheless, while paramount in their importance to this journey, these influences are incomplete without acknowledgement of the unwavering support received from my wife and family. This acknowledgement is especially heartfelt when I reflect on my long periods of self-imposed isolation, school holidays spent in the office and weekends cancelled so I can just ‘finish off a section before Monday.’

My most immediate and sincere gratitude extends to my primary supervisor, Professor Jill Aldridge. Jill has been an amazing supervisor as she provided excellent and timely advice and unfailingly addressed any issues I had with my research or its communication. Jill was also instrumental in encouraging me to present my work in additional outlets, including submission of manuscripts for conference presentations and journals. I feel extremely blessed to have had Jill ‘in my corner’ and for the fortuitous circumstances that brought us together while I was working in the United Arab Emirates back in 2014. In this regard, I am grateful for the outreach provided by Curtin University to Australian teachers in the UAE and specifically for sharing information of HDR courses with staff at the Australian International School of Sharjah, UAE. In a related way, I am extremely appreciative for the financial support I received for this research through an Australian Government Research Training Programme Scholarship and for the support I received from Annette Wilson, principal at the Australian International School, in permitting me to conduct my research project at the school.

As associate supervisor, my thanks extend to Professor Barry Fraser. Barry’s editing style and keen humour helped me see beyond the content of the thesis and to appreciate the importance of clear, coherent communication. Indeed, the importance of mentors for the ‘apprentice’ are exemplified in Jill and Barry’s academic guidance; further gratitude is extended to Curtin University in its excellent staff, facilities and HDR programs which provide a basis for such mentoring.

Finally, as I reflect on the many areas of support I have received during my study, recognition is due to the participating teachers in my study. My hard-working colleagues, and their counterparts in science education throughout the world, are to be commended for their commitment to a cause they know is worth fighting for. It can be hard work, and some learners harder to engage than others, though when the dust settles, science teachers are entitled to a sense of achievement in their quest for scientific literacy in an increasingly illiterate world.

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ACRONYMS

ACC – anterior cingulate cortex

ANCOVA – analysis of covariance

ANOVA – analysis of variance

AOS – affective outcomes scale

AV – audiovisual

BA – bimodal asocial text

BS – bimodal social text

CLT – cognitive load theory

CNS – central nervous system

CRH – corticotropin releasing hormone

CTML – cognitive theory of multimedia learning

DCT – dual coding theory

FDI – field dependence / independence

fMRI - functional magnetic resonance imaging

HPA – hypothalamic-pituitary axis

ITC – inferotemporal cortex

lPFC – lateral prefrontal cortex

MANCOVA – multivariate analysis of covariance

mPFC - medial prefrontal cortex

MS – multimodal social text

MSSAT – middle school science achievement test

MSSS – MacArthur scale of Subjective Social Standing

OFC – orbitofrontal cortex

pACC – perigenual anterior cingulate cortex

PFC - prefrontal cortex

SES – socioeconomic status

Chapter 1

INTRODUCTION

1.1 Introduction

The study reported in this thesis was motivated by an understanding of learning styles and learning effects accompanying gradients of socioeconomic status. Social standing is a universal moderator of neural structure and function, and the neurological literature offers causal relationships in accounting for this aspect of individual development and specific biobehavioural correlates (Gianaros et al., 2007; Miller, Chen & Cole, 2009; Nobles, Weintraub, & Adler, 2013). Accounts of social stratification and learning inequities also feature in educational research and draw from the social sciences as well as behavioural and cognitive psychology (see for example, Gee & Ford, 2011; Shavit, Arum, & Gamoran, 2007). This is ascertained by the rich variety of approaches and methods, as well as theoretical frameworks, in the research corpus. In enquiring about the relevance of social standing with respect to education, this research project poses questions of instructional methods and principles predictive of learning outcomes across the socioeconomic gradient. A particularly active area of educational research, in this regard, is that of textual learning which is influenced by the findings and principles, as well as applications, of the cognitive theory of multimedia learning (Mayer, 2005a) and cognitive load theory (Chandler & Sweller, 1991; Sweller, 1999).

The educational theories drawn on for the study reported in this thesis derive from parent disciplines of psychology and present various architectures of mind and behaviour. In turn, prominent learning theories assert methodological frameworks and assumptions in applied research. This thesis explores the cognitive architectures of cognitive theory of multimedia learning (CTML) and cognitive load theory (CLT), and their research traditions in the development of a suitable heuristic for text design within the discipline of secondary school science. Specific deficits within the dominant model are outlined, as well as methodological shortcomings within applied multimedia learning research.

This chapter presents an introduction to the thesis. To this effect, it provides a conceptual framework of the study (Section 1.2) which includes current views on the relationship between socioeconomic status and science outcomes in secondary education. Furthermore, a summary of theoretical and practical developments within the field of textual discourse comprehension is included to ground the study within the broader discipline of multimedia learning. Section 1.3 builds on these preliminary details with a discussion of current understandings in multimedia learning, before detailing the rationale for the current study (Section 1.4) and providing an overview of the current research (Section 1.5). Finally, Section 1.6 provides an overview of the theoretical and methodological significance of the current study and Section 1.7 summarises the organisation of the thesis.

1.2 Conceptual framework of the study

The study advances theory in a bipartite manner, drawing from developmental neuroscience and multimedia learning as framing influences. Of the former discipline, socioeconomic status is considered to act in a central role in learning given its association with the developing brain; specifically, this involves hypothalamic–pituitary–adrenal (HPA) axis pathophysiology and related learning dysfunction. In preliminary discussion, Section 1.2.1 describes the association between socioeconomic status (SES) and the so-called ‘socioeconomic achievement gap’ (Chmielewski, 2019; Huang & Sebastian, 2015) facing students in secondary science. As SES functions as an experimental variable in the study, Section 1.2.1 helps to define and operationalise social status as a study variable (described more fully in Sections 4.5.1.1 and 4.5.1.2). Following this, the psycholinguistic basis of multimedia learning is addressed to explore cognitive modularity and computationalism within the field and their theoretical and pragmatic influences on learning text design.

1.2.1 Socioeconomic status and science outcomes

Identification of socio-economic disadvantage features as a worldwide funding and reporting protocol in education systems (Agasisti et al., 2021). The tacit acknowledgement of educational attainment corresponding to social background reflects the large achievement gaps observed between high and low socioeconomic status (SES) groups in technical subjects (Goodrum & Rennie, 2007), including science. Education lobby group Save Our Schools, for example, presents data on the 41% of students from low SES families failing to complete Year 12 compared to 22% of students from high SES families (SOS, 2008). Moreover, 22 to 23% of students from low SES families do not achieve expected international proficiency standards in middle-years science, and this is further reflected in the poor uptake into senior technical subjects (Kennedy et al., 2014). This latter point becomes even more concerning when considering the concentration of low SES students. Within Australia, for example, the Nous Group's (2011) 'Gonski Report' aligns targeted funding with SES and reports that a third of all schools serve a student body with a below-national average socioeconomic standing. These discrepancies have influenced educational reforms within Australian education, including funding and assessment protocols. With relevance to this thesis, such reforms influence international schools following the Australian curriculum, including the school site used in this study (see Sections 4.4.1 and 4.4.2 for details of the site and student body comprising the sample).

While socioeconomic inequities in educational outcomes are well reported, disagreement exists in the measurement of social standing as well as elucidation of specific mechanisms of impairment accompanying social disadvantage. Illustrative of the former point, the Australian Council for Educational Research (ACER, 2000) identify inconsistencies between area-based measures and individual/familial accounts of social standing in accounting for learning outcomes. A multitude of area and familial data sources encompassing survey data, national census data, school records, and enrolment data exist within government and independent school systems in Australia. Nonetheless, aggregate area-based measures most commonly inform school practice and include the Australian Bureau of Statistics (ABS) subgroup of Socioeconomic Indices for Areas (SEIFA) and derived measures such as the Index of Relative Socio-economic Disadvantage (IRSD) and Index of Community Socio-Educational Advantage (ICSEA). However, considerable variation exists between individual and aggregate area measures, with individual student outcomes more accurately described via individual measures (ABS, 2018). Area-based statistical issues involve misclassification errors such as assumed population homogeneity and can also include poor interrelationship between categorical indicators of social standing (e.g. occupational prestige scales) and socioeconomic indices using continuous measures (e.g. level of education; earnings) (Lim & Gemici, 2011). Despite the high correlation between each aggregate measure and the social gradient, greater predictive and explanatory power is afforded with individual-level measures (ACER, 2000). Notwithstanding its statistical utility, individual measurement of disadvantage has not yet extended beyond normative objective measures, and when used, simply reflects a narrowing of area statistics to the familial level.

Measurement of socioeconomic status, as seen, involves potential misclassification and operationalisation in research. Moreover, the tension between aggregated and individual SES measures extends beyond the definition and analysis of indicators of social standing in that such measures are not standardized to any particular set of circumstances. By contrast, Nobles and colleagues (2013) report that self-anchored accounts of social standing, relative to the subject's community, or schoolyard, yield greater explanatory power in health outcomes than traditional SES measures, either aggregated or individual. With the important caveat that research involving subjective SES measures typically involves health (see for example, Nobles et al., 2013) and not educational outcomes, the use of self-anchoring subjective SES measurement likely represents a more precise measure of social position than objective measurement given the monotonic relationship between health and the social and economic resources relative to all levels of society. In short, operationalizing SES in a subjective form offers a statistical averaging across all possible measures of social standing, and as such, offers predictive utility in its aggregation of relative social ranking as well as objective resources.

Alongside disagreement in measurement of SES in education, a neurologically informed model of cognitive impairment for socioeconomically deprived individuals does not feature in Australian educational legislature or within its key informing documents. This is notable given the development of the Socio-Economic Indexes for Areas (SEIFA) measure which, as mentioned above, contains separate indices widely used in educational research and assessment reporting. These measures are descriptive and lack acknowledgement of any specific mechanisms of impairment. Compounding this is a lack of granularity and consistency in identifying a neurology of deprivation within educational psychology, including multimedia learning (Paas & Sweller, 2014). This is a significant omission given the expansive literature on socioeconomic educational disparities (Chmielewski, 2019) including the association of low social standing with cognitive dysfunction (Farah, 2017; Foulkes & Blakemore, 2018).

Understandably, disagreement in measurement of socioeconomic status, coupled with a limited understanding of stress-system dysfunction (Chrousos, 2009), has led to theoretical and methodological shortcomings. This is apparent in the aggregation of unrelated social determinants of learning in multimedia research, such as grouping immigrant status or English as second language (ESL) learners alongside social disadvantage (Neuman et al., 2011). As discussed in Section 3.8, this translates to a resistance in operationalisation of SES as an individual learning effect as well as preferential treatment of established multimedia effects in applied research. Compounding these effects is an outdated computationalist model of information processing. As described in Sections 2.4.1 and 2.4.2 the cognitive architectures of CLT and CTML are critiqued with respect to their alignment of perceptual and other cognitive processes with socioemotional processing and for their conception of memory processing.

Having identified the importance of SES in education and establishing a basic distinction between objective and subjective social standing, the following section examines the origins of psycholinguistic models of textual discourse comprehension. This is of relevance to the thesis as it helps to contextualise contemporary understandings in multimedia learning research.

1.2.2 Textual discourse comprehension

Textual learning is an enduring classroom practice. Of importance to the conceptual framework under discussion is how current multimedia research approaches have drawn from established research traditions in textual discourse comprehension. An early distinction in text comprehension research saw the shift from a purely audio-linguistic reinforcement of grammar and vocabulary, to psycholinguistic models of reading comprehension (Pearson & Cervetti, 2015). This movement mirrored the historic behaviourist-cognitive paradigm divergence in psychology, in which learning theories increasingly sought cognitive explanations for learning processes. Learner attributes in the newly diversified approaches corresponded to ‘reading components’ and so-called ‘metaphoric’ approaches (Chun & Plass, 2005, pp. 105-107) and both reflected stage-based Piagetian development in the emphasis on learner experience and competence in textual comprehension (Chun & Plass, 1997). Stages of comprehension within these approaches were considered analogous to Piagetian cognitive development in progression between automatic recognition skills, formal discourse structure knowledge, content/world background knowledge and metacognitive knowledge and skills monitoring (Grabe, 1991).

Modularised memory and perceptual systems also came to represent key learner attributes in psycholinguistic models of reading comprehension. Modularity reflected Fodor’s (1983) definition of a mental module, in which some, or all, of the following apply to a given cognitive structure: domain specificity; mandatory operation; limited central accessibility; fast processing; informational encapsulation; ‘shallow’ outputs; fixed neural architecture; characteristic and specific breakdown patterns, and characteristic ontogenetic pace and sequencing.

Of these, limited central accessibility and information encapsulation are synonymous with the ‘cognitive impenetrability’ (Pylyshyn, 1984, p.30) of ‘sensory’ input and ‘perceptual’ output in computer systems. Borrowing from computer science, Fodor (1983, p. 85) saw information encapsulation as a prerequisite for modularity, including that of perception in its auditory and visual modes. Analogous to computer systems, also, is the necessity of specialised (mode dependent) central and working memory systems. Fodor’s (1983) functionalism is apparent in subsequent computationalist accounts of memory processes, despite Fodor’s own rejection of the computationalist model in this context (Fodor, 2000, p. 105; Fodor & Pylyshyn, 1988). Accounting for the influence of linguistic input and prior knowledge in moment-by-moment processing, divergent views of working memory have influenced accounts of representational activation, comprehension and recall (see for example, Cowan, 1988, 1999; D’Esposito & Postle, 2015). Within the field of textual discourse comprehension, the memory-based or resonance view suggests an automatic semantic or phonological activation of related concepts held in memory, either in serial or simultaneous schematic networking. Conversely, the constructivist view of working memory suggests a meaningful generation of inferences upon an effortful strategic ‘search after meaning’ (Graesser et al., 1994). Despite the apparent inapplicability of the former approach to biological systems, subsequent views of memory have absorbed Fodor's conception of modularity and have morphed into current computational models including Resonance (Myers & O'Brien, 1998), Landscape (van den Broek et al., 1999, p. 71) and Construction-Integration (Kintsch, 1998) models of discourse comprehension. Common to these models is propositional networking, with localist or distributed nodes encoding discourse properties, memory trace or world knowledge. Such nodes have variously been theorised as activating either one-to-one mapping between represented object and processing network (Bower & Morrow, 1990; Kintsch, 1998; Zwaan et al., 1998) or adopting a non-symbolic representativeness, relatively unconstrained by novelty (Simen, 2011). Either way, such approaches are reliant on stored rules and mental modules specific to the input of sensory features.

In reference to Mayer's (1984) description of aids in textual comprehension, including information selection and construction of internal and external connections, strategies have been nominated for the optimisation of propositional representation of textual information. Such strategies have formed templates for multimedia research in their prioritization of specific design and learner variates. Within Plaas and Chun's (1997) model of cognitive architecture, for example, invested mental effort and perceived self-efficacy in ideation modulate the efficiency of cognitive processes, aspects of learning which, in line with Fodor's (1983) modal-dependent processing, necessitate the differentiation of textual components into verbal and non-verbal components. Specifically, Plaas and Chun's (1997) multiple-components model (see Figure 1.1) highlights the joint effects of cognitive constraints and learner attributes on the comprehension of verbal and non-verbal information. Mechanistically, the additive effect of split visual-verbal presentation on recall is an extension of dual-coding theory (DCT; Paivio, 1986), itself an extension of Fodorian modularity, and while the model represents a departure from prior accounts of discourse comprehension, it is consistent with contemporary understanding in multimedia learning. For example, learner attributes here are typical to the field of textual discourse comprehension in the modelling of prior knowledge (Kendeo & van den Broek, 2007) amongst other broad contextual variates.

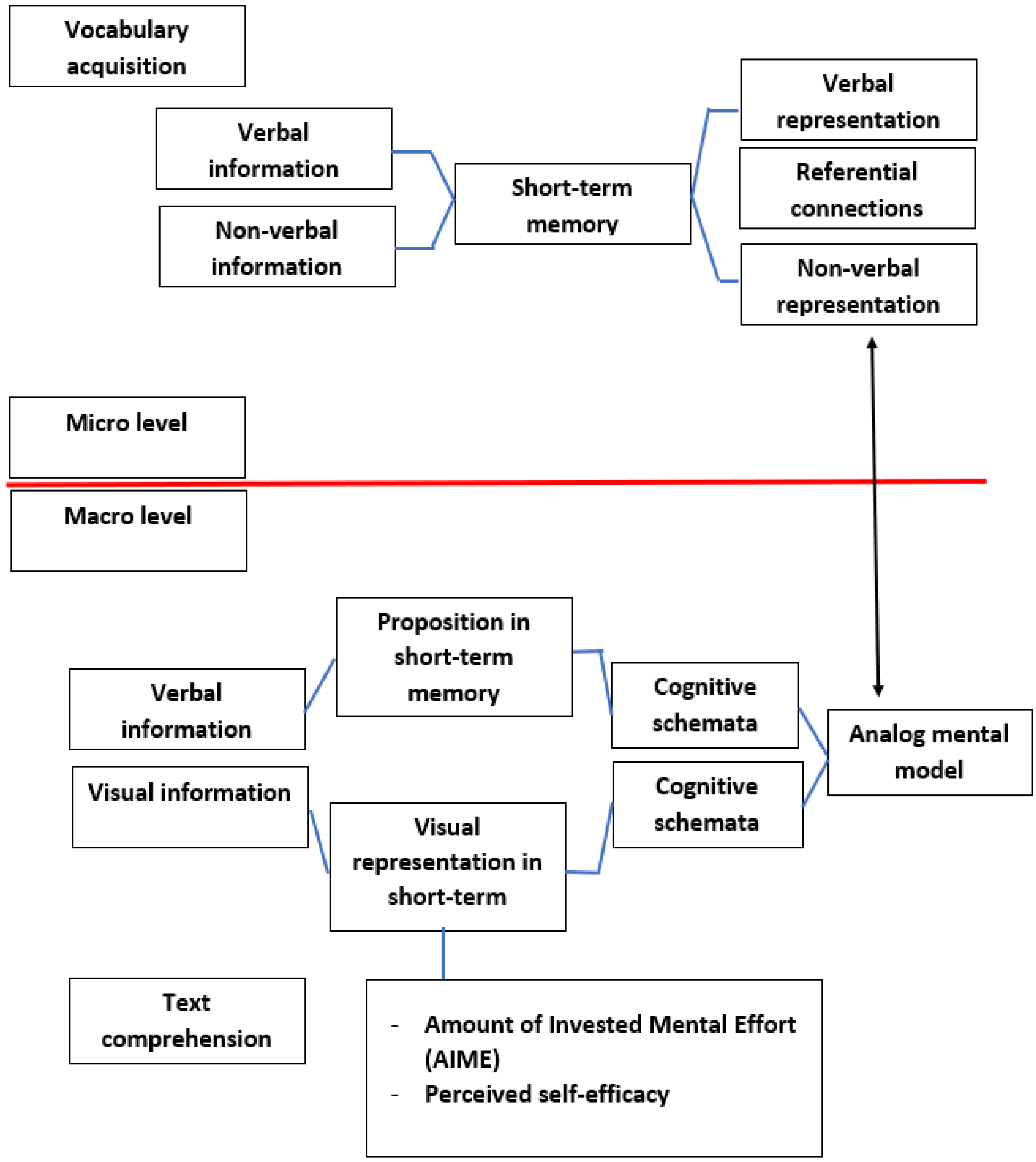

Figure 1.1 Multiple components model of text comprehension with multimedia aids (Plaas & Chun, 1997)

The multiple-components model of Plaas and Chun (1997) modularises short and long-term memory, responsive to dedicated audio-visual sensory systems. Code-additive effects upon contiguous presentation of visual and verbal information are hypothesised and explained in this context as enhanced referential connections between audio / visual representations in separate channels at the micro (input) level. It is noted that Plaas and Chun (1997) did not actually present graphics alongside text for learners, only proposing that comprehension or design strategies be employed to represent visual or verbal textual components. This modularised approach visualises discrete audio-visual subsystems, which as mentioned, is a cognitive feature that remains unchanged in current multimedia research.

As seen in this brief overview, historical developments in textual comprehension reflect developments in cognitive psychology. Chief amongst these is the metaphor of cognition as computational, an associated emphasis on cognitive modularity influencing text design, and prior knowledge and aptitude as key learner attributes. Notably absent from any existing discussion of textual comprehension is the role of individual brain development and / or the primary influence of social standing. This study addresses these gaps by advancing the idea of cognition as a dynamic interplay between environments and immersed bodies. As discussed in Section 1.4 and again in Chapter 2 (Sections 2.7 and 2.8), the theory of embodied cognition advances a more direct interface between cognitive processes and sensorimotor processing, replacing the abstractness of computationalism and its rigid age-stage model of development with an individualized account of the learner.

1.2.3 Textual learning: Theory to praxis

Attempts have been made to relate science outcomes in education to textual comprehension. Best and colleagues (2005), for example, describe learner difficulties in understanding science learning texts due to the typical 'low cohesiveness' of science exposition. Students are described as often lacking word-level cohesion let alone sentence or paragraph-level comprehension due to poor understanding of terminology. This forces the generation of inferences, on the part of the learner, in filling conceptual gaps spanning sentences and paragraphs, and involves logic, syntactic knowledge, semantic memory recall as well as efficient recall of previously described material. Extending beyond a purely text-level comprehension, learners may require prior domain knowledge, alongside efficient recall of previously stated facts which may have initially been poorly understood (Ibid.). Accordingly, construction of a deep global understanding of a text involves competence beyond the lexicogrammar level (i.e. morphology, syntax, semantics) and involves representations beyond the words explicitly stated in the text.

Research traditions within textual discourse comprehension have thus focused on bridging gaps in understanding and span three main areas: reader ability including prior knowledge; development of reading strategies; and text design (Gruber & Redeker, 2014). As an example, the Construction-Integration model promoted the use of local and global cohesion features in reducing the need for reader inferencing which may have involved science misconceptions (Désiron et al., 2020). Knowledge deficits have also been addressed by researchers, with the acknowledgement that low prior knowledge may pose the greatest challenge to understanding (see for example, Lundeberg, 1987; Means & Voss, 1985). This is unfortunate given that science texts are intended to impart new knowledge to students. Additionally, reading strategies have bridged the 'reading components' and 'metaphoric' approaches mentioned previously (Section 1.1.2). Within metaphoric 'feedforward' and 'feedback' levels of comprehension, a disconnect may exist between decoding skills and higher-level comprehension processes such as meta-comprehension and backward causal inferencing. This interacts with the 'reading approaches' compartmentalisation of skills and domain areas, in that subject areas such as science may not involve the intensive comprehension skill development as mandated within other discipline areas. Text design, meanwhile, has been influenced by considerations of textual 'concreteness,' author voice, and integrated visual-verbal information (McTigue & Slough, 2010). Unlike multimedia learning, however, multimodal integration in the field of textual discourse comprehension has mainly considered the quantity and quality of visual elements and the enhancement of textual readability and accessibility.

Mirroring the rise of computing in education and computational approaches in psychology, multimedia learning has largely superseded the field of textual discourse comprehension (Niegemann & Heidig, 2012). Correspondingly, technological developments since the 1980s have theoretically and methodologically influenced textual learning research (Ozcinar, 2009; Samaras et al., 2006). Influences of dual-coding theory and other developments in educational psychology have coincided with the proliferation of learning technologies and approaches such as computer-based training (Bedwell & Salas, 2010), computer-assisted learning (CAL; Mayer, 2017), and educational information and communications technology (ICT; McDougall & Jones, 2007). Moreover, such technological innovations have emerged as dominant features in educational research, including textual discourse comprehension (Clark &

Mayer, 2011). Consequently, since the mid-1990s educational multimedia has become virtually synonymous with multimedia learning in the presentation of five basic media formats: text; video; sound; graphics; and animation.

1.3 Current understandings in multimedia learning

This section builds on Section 1.2 in outlining current understandings in multimedia learning theory and practice. As seen in Section 1.2, multimedia learning has largely subsumed the field of textual discourse comprehension though maintains a basic theoretical and methodological continuity from its predecessor. This amalgamation has been influenced by various audio-visual and computer technologies, as well as eye-tracking research highlighting fixation patterns influenced by textual modality (see Alemdag & Cagiltay, 2018, for a systematic review). Reflecting the influence of dual coding theory (Paivio, 1986) and cognitive modularity (Fodor, 1983), two lines of research surviving the transition are a focus on learner ability and text design. Reflecting the role of the individual learner, multimedia research has examined individual-level variables in textual comprehension, including novice-expertise effects, and offers support for enhanced retrieval structures and task-relevance allocation of attentional resources (e.g. Gegenfurtner et al., 2011). Meanwhile, the importance of text design is seen in the high proportion of design features as variates of primary influence in published multimedia research (see Section 3.2.2.4). As a virtually ubiquitous research framework for these matters is found in cognitive theory of multimedia learning (CTML, Mayer, 2005b) and cognitive load theory (CLT, Chandler & Sweller, 1991; Sweller, 1999), an understanding of learning effects inherent to these paradigms is a necessary basis in defining and delimiting the purpose, methodology and significance of the current research project. As such, this section explores these dominant frameworks by presenting a theoretical (Section 1.3.1) and methodological (Section 1.3.2) overview of CTML and CLT. Section 1.3.3 then examines derived learning effects in the field of multimedia learning and suggests that such effects align well with existing theory though neglect individual differences in the prioritisation of CTML and CLT design features.

1.3.1 Theoretical overview

Learning outcomes within multimedia learning research are often interpreted from an understanding of the cognitive architectures of CTML and CLT and are assessed in applied research via derived design and contextual variates (see Section 2.4 for more information). Multimedia learning research, correspondingly, is widely animated by the desire to test specific learning effects such as the multimedia (Mayer, 2001) or spatial and temporal contiguity principles (Clark & Mayer, 2011) as these effects are considered to mirror and facilitate normal perceptual and memory processes. Nonetheless, the influence of socioeconomic status has not influenced multimedia theory as a source of individual development (see Section 3.8.1.2) despite its wide acceptance as a moderator of learning outcomes in multimedia learning research (see for example, Dickerson & Kubasco, 2007; Neuman et al., 2011). A theoretical overview of CLT and CTML is important, therefore, in exploring architectural features that offer to explain developmental differences contributing to the socioeconomic learning divide evident within schooling systems.

CTML and CLT are premised on assumptions within cognitive psychology supportive of a modularised view of human cognition (Li et al., 2019; Sweller et al., 2019). Domain-general processors include long and short-term memory, interfacing with autonomous sensory faculties in the serial processing of encapsulated, modality-defined information. Rapid, mandatory processing of sensory data occurs within dedicated neural sites with verbal and non-verbal stimuli processed either as modelled analogues or one-to-one neural representatives within a rule-bound neural syntax. Derived instructional design principles draw from the foundational disciplines of Fodorian modularity, dual-coding theory (DCT, Paivio, 1986) and Baddeley's (1992, 1998a) model of working memory. Three assumptions permeate the literature on multimedia learning: the dual channel assumption; the limited capacity assumption; and the active processing assumption. Figure 1.2 presents a visual overview of processing stages within CTML. This model is compared with Figure 1.1 regarding the influence of distinct auditory / visual channels and purported learner attributes.

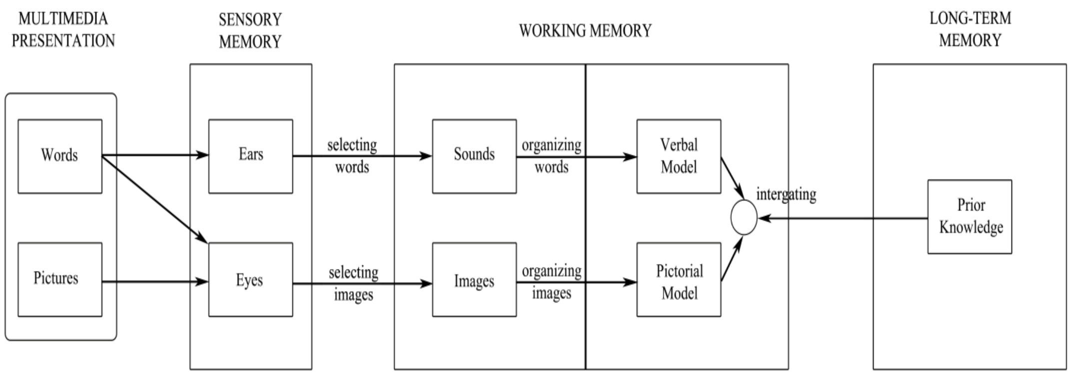

Figure 1.2 Visual representation of the Cognitive Theory of Multimedia Learning (adapted from Mayer, 2001)

The efficacy of learning materials, in this system, is determined by content, delivery and contextual characteristics. Dominant design recommendations within the field are topologised in CTML's basic principles (Sorden, 2005). These principles conform to content, delivery, and the learning context and aim to reduce cognitive load associated with to-be-learnt material, germane loading inherent to the learning process, and the learning process itself. The eponymous multimedia principle states that people learn better from graphics and narration than from words alone, though this has been amended by numerous other basic and 'advanced' principles following experimental ambiguity in the testing of design and context characteristics. Twenty-one basic and advanced principles are now found in CTML (detailed, respectively, in Tables 2.1 and 3.2); the abundance of learning effects is critiqued in the current work as a conceptual and definitional consequence of the multimedia principle as currently understood.

1.3.2 Methodological overview

The multimedia learning research tradition features a methodology influenced by the theoretical framework of dual coding theory (DCT), CTML and CLT. Reviewing the literature reveals a recurrent conceptualisation of separate streams of information, modality-specific and limited capacity working memory subsystems, and active sensory processing (see Sections 2.3.1 & 2.3.2). Learner attributes, such as age, aptitude / prior knowledge, and race / social background, are often acknowledged though treated as boundary conditions, and rarely feature as primary learning effects

(Section 3.8.1.1). Moreover, variates of disadvantage typically represent loose groupings of contextual factors including normative individual or aggregated accounts of socioeconomic status. Focus on established multimedia learning principles and outcome variables take precedence over learner and contextual factors within published research, including that of systematic and meta-reviews (see Section 3.5 for more details).

Multimedia research can be summarised, methodologically, as fulfilling three purposes: (a) examination of established multimedia effects; (b) assessment of multimedia resources; and (c) reading enhancement. Research aims in multimedia research are thus consistent with the aims of textual discourse comprehension, though are inclusive of differing multimedia formats. Experimental variates relate to CTML basic principles, and cover aspects of design and outcome and programmatic variates alongside the previously described influence variables of context. A notable absence amongst outcome variates is that of subject- or domain-specific attitudinal outcomes. Where qualitative and subjective self-accounts feature in multimedia research, they often occur as rating-scaled accounts of interest, effectiveness, or mental effort and pertain to CTML influenced design features. A broad summary of psychometric measures, provided in Section 3.8.2.2, incidentally, highlights the perception of multimedia in applied research as beneficial for learning though not interesting. Scales of perceptual measurement map to learning efficacy / interest from CTML basic principles and do not attempt to measure equivalent dimensions of the subject-area itself. Outcome variates in multimedia research are common to educational psychology and include transfer, recall, and comprehension type measures as well as subjective mental loadings. Consistent with above, mental loading is attributable to textual design and not considered in relation to the subject area.

1.3.3 Multimedia learning effects

Multiple learning effects within Multimedia Research are reported in the multimedia literature and conform with CTML basic principles (Sorden, 2012). These effects have important methodological implications as multimedia research often treats such principles as assumptions inherent to learning and textual design. Multimedia, modality and spatial / temporal contiguity principles are regularly presented as primary learning effects and have generated longstanding research efforts in isolating moderating factors (see for example, Mayer, 2001, p. 63; Mayer & Moreno, 1998; Yue et al., 2013). Experimental inconsistencies, though, have prompted the development of ‘advanced’ boundary conditions augmenting basic principles and have been defended as an evolution of the principles into a more realistic framework (Mayer, 2010). Boundary conditions relate to design or task characteristics with similar constraints theorised at the design-organisational or cognitive architectural levels as that of basic principles. The prior knowledge principle, meanwhile, is the sole effect relatable to the individual learner and is generally operationalised as low / medium / high. This partitioning of domain knowledge, along with aptitudinal measures, reflects the Piagetian influence within CLT and CTML theory, described in Section 1.1.2, which anchors learning efficacy to schema formation and automation. Individual learning effects within this system are treated as discrete developmental stages consistent with the computational architecture of multimedia learning theory.

Experimental inconsistencies in CTML learning effects are reflected in primary analysis heterogeneity and effect size variation in follow-up study. As summarised in Section 3.5, most reviewed multimedia learning studies are premised on CTML principles and thus seek tautological confirmation of their efficacy. Accordingly, apparent contradiction exists in the development of seemingly discordant boundary conditions for learning. Examples of this are seen within the collaboration, guided-discovery and self-explanation principles which purportedly demonstrate the beneficial effects of peer or expert assistance alongside benefits of individual learning. Also, within multimedia research, learning with multimedia has often been demonstrated as less effective with information presented at system pace, with rich texts, or with redundant auditory features (Ainsworth, 1999; Mayer et al., 2001; Mayer, 2008). These conditions have been explored as modality principle confounds although may more parsimoniously reflect a lack of appropriate textual contextualisation (see Section 2.3 for full details of the Modality principle as a recommendation for multimodal text design). By way of example, an alternate approach to the modality principle was raised by Schueler et al. (2008) who dispute the enhancement of cognitive resources governed by dual-coding, instead claiming that a more parsimonious explanation lies in the splitting of attention that can occur in non-successive presentations.

Methodological issues in multimedia learning follow the focus on CTML design principles as primary research variates. These design features are often arbitrary and lack meaningful social contextualisation in their presentation. Considering the structural constraints of the cognitive architecture inherited from cognitive psychology, though, this situation can be interpreted as a prioritisation of management of cognitive load attributable to external and internal conditions of learning. Nonetheless, contextualisation, as a feature of text design is developed via the CTML personalisation principle (Clark & Mayer, 2011) - perhaps in recognition of the potential fallibility of a fixed neural architecture and development amongst learners. To this end, Mayer (2005a, p. 32) emphasises instructional design involving a multimedia message as ‘a presentation consisting of words and pictures designed to foster meaningful learning.’ Additive to this premise is the personalisation of learning text in establishing a communicative connection between teacher and learner (Mayer, 2005b) and is achievable with the presentation of textual features in a socially congruent manner. Notwithstanding these design ideals, multimedia research principles and learning effects can be critiqued for emphasising design features to the exclusion of individual developmental effects including the need for social contextualisation. In iteration of the computational cognitive architecture of CTML and CLT, current instructional design principles prioritise the enhancement of cognitive resources, while lacking a corresponding focus on individual development.

1.4 Rationale for the current study

This study sought to address proposed theoretical and methodological shortcomings within multimedia research. These pertain to current understandings of the cognitive architecture within cognitive and educational psychology and the methodological implications that they carry. As seen from existing research, the field of multimedia learning seeks cognitive explanations for learning text design though discounts the influence of personal development. By contrast, a dynamic view of developmental plasticity, amendable by environmental deprivation / enrichment may offer greater descriptive and explanatory power in learning styles and educational outcomes. A fundamental moderator of cognitive style is hypothesised in this study as socioeconomic status and is parsed into objective and subjective measures. This is intended to provide a richer measure of development than that currently used, and socioeconomic status is presented as a primary learning effect. In methodological enactment of this learner variate, relevant neurological literature is unpacked and applied to multimodal textual learning. Furthermore, specific textual design characteristics are unveiled and applied to science learning amid the metamorphosis of adolescence and its social reorientations. To this end, the influences of embodied cognition are interpreted and applied to perceptual and attentional processes within memory, with hypothesised accounts of normal and aberrant abstractive ability amongst socioeconomically defined learners informing a revised cognitive architecture (Section 5.4).

The following section examines attempts to address the current theoretical and methodological impasse facing multimedia research. Current theoretical and methodological inconsistencies are discussed, and novel learning effects are addressed and related to a redefined modality effect in multimedia learning. This is intended to act as a precursor to further discussion of the current research in addressing research gaps existing within this important field. As such, Section 1.4.1 addresses proposed theoretical inconsistencies in the field, including computationalism and cognitive modularity as components of the cognitive architecture. Section 1.4.2, then discusses methodological issues emanating from the current view of brain structure and function.

1.4.1 Theoretical inconsistencies

Approaches in cognitive psychology emerged alongside the rise of computers which, as a field, offered a terminology and metaphor in understanding human cognition. Information processing is central to the discipline and is typically nomothetic in its appraisal of general coding processes and the nature of stimuli input and behavioural output. Educational psychology has co-opted this approach and McLeod (2015) includes in its assumptions the following:

1. Environmental information is processed by a series of processing systems (e.g. attention, perception, short-term memory);
2. These processing systems systematically transform the information;
3. The aim of research is to specify the processes and structures that underlie cognitive performance;

4. Information processing in humans is analogous to computer processing.

Processing deficits, described in Section 1.2, are typically related in the field of multimedia learning to design and cognitive features. A fundamental assumption is that learning efficacy is amendable by manipulating inherent or extraneous loads associated with respective educational materials and learning processes. However, successful learning within this approach may reflect inadvertent learning upon congruent alignment of stimuli features within the presentation of learning material. An example of this is in modality effect research where learning gains cease upon student control of the learning pace (Tabbers, 2002). Coupled with the established superiority of presentation of graphics alongside text in learning, and the observation of learning difficulties with incongruent presentations, a simple amendment may be added to established principles – that of appropriate contextualisation. Multimedia research typically presents educationally relevant material, though devoid of social context including normal cues of social discourse. While images appear to provide deeper referential connections than text alone, audio-visual integrated text may represent an artifactual influence of social contextualisation, unintentionally reminiscent of Mayer’s (2005c) communicative connection (Section 1.3.3). Central to the theoretical framework of the study reported in this thesis is the assertion that understanding the basis of appropriate contextualisation requires examination of embodied memory systems; such a view emphasises modal simulation of experience without invoking discrete verbal and visual memory constituents.

Embodied cognition is a system of semantic representativeness, in which perceptual and memory processes act in concert with embedded simulations and contrasted with the demands of current attentional foci (Koziol et al., 2012). Goal-directed processes activate representational and discriminative processing between corticolimbic bodies with automatisation of sensory and motor features a consequence of cerebro-cerebellar interactivity in initial learning stages (Koziol & Lutz, 2013). Relevant biological or mechanical stimuli attract preferential attention and prime the amygdala in episodic encoding – with privileged access and consolidation of socioemotional stimuli. Efficient recall is thus a collaboration between congruent stimuli features, including procedural motor analogues, within memory centres regulated by socioemotional salience in encoding ecologically relevant information. In short, learning within this model is modulated by information processing in specific modalities that are also involved in later recall and recognition. Contrary to the dominant dual-channel model with separate audio-visual semantic processing, the embodied cognition model treats stimuli properties holistically and is inclusive of all modality codes. The inability to recode olfactory or haptic representations into visuospatial or verbal codes, for example, is a critique levelled at CTML in this regard.

Theoretical inconsistencies within multimedia learning extend beyond static mechanistic shortcomings in the absence of individual models of development. As discussed, socioeconomic status and other contextual variables motivate multimedia research yet specific mechanisms of impairment have resisted elucidation. Nonetheless, plasticity attributable to developmental stress-dysfunction is mechanistically and evolutionarily consistent with an embodied model of cognition. The neurological literature provides wide coverage of the processes underpinning hypothalamic-pituitary-adrenal (HPA) glucocorticoid dysfunction in chronic (developmental) stress and a comprehensive literature review is provided in Chapter 2. For present purposes, material and social deprivation is linked with stress dysfunction and consequent hippocampal and prefrontal pathophysiology. Inhibitory hippocampal / prefrontal dysfunction is contrasted with amygdala dendritic growth under chronic stress and is relatable to the amygdala's role in regulating emotion. These emotional-cognitive pathways underpin observed cognitive trajectories shaped by development and highlight broad divergence between cognitive-regulatory and affective-reactive modes of cognition. This is addressed in neurological literature as a consequence of the stress susceptibility of prolonged prefrontal / language system development (see for example, Hackman & Farah, 2010; Urscahce & Noble, 2015).

Abstractive ability was viewed in the study reported in this thesis as an extension of basic executive function within an embodied cognitive model. This view is consistent, for example, with hippocampal-prefrontal contextual modulation of memory, downstream and dependent on amygdala integrity. In this framework, it is hypothesised that abstractive ability will be modified in stress-impaired regulatory networks due to inhibitory amygdala activation. Abstractive ability, in this regard, may be considered plastic in response to stress with impaired amygdala functionality pivotal in disengaging attention from salient emotional qualities. Accounts of abstractive function and prefrontal-cerebellar and parietal-cerebellar cortical dysconnectivity as targets of stress insult are further explored within the literature review (Section 2.3.4) and help inform a revised cognitive architecture (Section 5.4).

Returning to the computational metaphor of multimedia research, we can see that the proposed deficits force a rethinking of the computer analogy. Ideally, the brain is viewed not as serial or modular but as a massively parallel machine. This view precludes discrete stimuli properties and relegates Baddeley's (1996) central executive homunculus to a localised goal-directed bias system. Thus, sensorimotor anticipation is antecedent to goal-directedness with procedural knowledge forms foundational to declarative memory and higher-order cognition (Pezzulo, 2011). By contrast, implicit and explicit memory ontologies in serial computer systems resist automation (Barsalou, 2008). Within the field of artificial intelligence this is highlighted via the 'common sense' semantic knowledge problem which highlights the processing discordance between propositional declarative and procedural knowledge forms (Levesque, 2017). Specifically, AI systems have generated deep domain knowledge which can mimic human expertise, but all attempts to translate implicit (subconscious) procedural representations to declarative 'consciousness' within serial networks have failed. With reference to the current study, this suggests that refinements to the cognitive architecture of CTML are needed due to its inadequacy in generating semantic meaning beyond a baseline syntax in symbol manipulation.

Important for a holistic view of memory, sensorimotor processes are forms of procedural knowledge with supra-additive properties. Normal memory processes rely on integration of stimuli properties in congruent presentation within heteromodal cortex – with task-relevance modulating hippocampal and amygdala connectivity with the PFC (Von Kriegstein & Girraud, 2006). In turn, multimodality is a reliable ecological feature and imaging research has shown the heteromodality of phonological, lexical, and semantic aspects of language processing (see for example, Fiebach et al., 2006). Meanwhile, brain imaging research, premised on natural receipt of sensory information, highlights normal cross-modal and cross-temporal stimuli associations (Ghazanfar et al., 2005; Pekkola et al., 2005). Such associations occur across multiple stimuli such as face-voice and tone-colour pairings, highlighting: (a) prefrontal cortex as integrated networker of behaviourally meaningful cross-modal AV associations; and (b) that reactivation is linked to the (original) simulation of perception and involves cortical activity as occurring during initial encoding. It is possible, therefore, that the serial processing of CTML theory is inadequate in representing multimodal stimuli in contextual isolation. Embodied cognition, meanwhile, could present a viable alternative to our considerations of the cognitive architecture in its assumptions of situatedness and perceptual, affective and cognitive decentralization. As seen, it is also appropriate in the context of individual socioemotional brain development.

1.4.2 Methodological issues

Methodological issues permeate the multimedia learning literature. This critique is premised on the experimental variability of CTML learning effects and the presumed modulatory influence of age or level of prior knowledge. As previously stated, these points are not intended to detract from general findings in multimedia learning research, as the superiority of integrated texts is not disputed. Accordingly, CTML design features often present moderate to high published effect size, although outcomes are inconsistent with the inclusion of contextual moderators in comparative analysis (see for example, Ginns, 2005; Reinwein, 2012). Two commonly reported contextual factors used to modulate learning outcomes are that of age and measures of aptitude, including prior knowledge and self-efficacy (Gegenfurtner et al., 2014; Mayer, 2002). However, no consistent patterns emerge from related multimedia findings. For example, while a low level of prior domain knowledge has been associated with better transfer test outcomes in simultaneous versus successive animation presentation (Reinwein, 2012; Tricot & Sweller, 2014), degree of self-efficacy has emerged independent of multimedia characteristics in positive learning transfer (Gegenfurtner et al., 2014). Also, as discerned in the literature, effects of spatial contiguity appear contingent to age and high prior knowledge and this has necessitated the so-called expertise reversal effect and the generation of numerous boundary condition appends (see Section 2.4.2). By contrast, the stability of spatial contiguity disappears when temporal contiguity is controlled, such as in learner-paced (versus system-paced) learning (e.g. Gyselinck et al., 2008; Rummer et al., 2010). Learning gains are seemingly independent of prior knowledge or age in such conditions, a situation that has attracted criticism of multimedia theory such as that mentioned above in Section 1.3.3.

Nonetheless, aptitudinal measures typically help to remove experimental variability and are instructive in understanding the breaking down of established CTML principles. To overcome inconsistencies such as those noted above in the formulation of a more nuanced measure of the individual learner, the current study attempted to conflate learner aptitude with abstractive ability (as defined in Section 1.4.1 and elaborated on in Sections 2.7 and 2.7.2) with the use of individual social standing as a primary study variable. Aptitudinal measures can thus be equated with individual development in determination of meaningful variables of context. Numerous biobehavioural determinants of learning are associated with socioeconomic status and help flesh out a more meaningful aptitude-treatment interaction framework than that currently influencing multimedia research (Astleitner & Wiesner, 2004; Roberts et al., 2007). For example, socioeconomic status has been associated with learning style (Lupien et al., 2001) including the field dependence / independence psychometric (Alevriadou et al., 2004; Garner & Cole, 1986). Regardless of construct definition, SES presents a well-established causal influence in cognition and should ideally supplant existing aptitudinal measures in multimedia research. Two arguments support this view: firstly, SES is predictive of cognitive development including abstractive ability and offers a transparent mechanistic and developmental etiology; secondly, SES features as a proximate, though often unacknowledged, aptitudinal measure in existing research. This latter point bestrides the current arrangement of accepting, though not modelling, SES as a learning determinant.

Attitudinal measures, additionally, are potentially misapplied to the field of multimedia learning. This is discerned from the tendency in published research to align affective orientations with established CTML principles and / or the learning process itself. In most studies reviewed, learner perception is mapped to CTML basic principles with modality, coherence, signalling, redundancy, and contiguity principles predominating (Chapter 3 presents a systematic review of multimedia research literature). Subjective mental effort is often used as an auxiliary measure of ease of learning from material – and usually presented as a continuum of compliance to the tested principle or effect. In multimedia research, additionally, no located studies feature perceptual measurement of the domain / content material being presented which represents a deficit in that attitudinal measures ideally relate to instructional content (see Section 3.8.2.1). Domain-specific attitudinal data also offers a measure of classroom climate which may be modelled alongside socioeconomic status as a finer measure of interest and effectiveness of modality-defined science texts.

Individual learning effects attributable to social standing thus offer specific methodological features not demonstrated in multimedia learning research. This was relayed to me personally in communication with John Sweller, founder of cognitive load theory and Emeritus Professor within the school of education, UNSW. The following section outlines how the present study attempts to fill the gaps identified within existing multimedia research which according to Sweller is a ‘field wide open’ when applying effects of development to textual learning.

1.5 Present research

This thesis describes a research program carried out at an Australian international high school within the United Arab Emirates (UAE) to discern the utility of social standing as a variate in science text design and its export to the field of multimedia learning more broadly. A brief overview of research objectives (Section 1.5.1), research paradigm and methodology used in the study (Section 1.5.2), and significance of the research (Section 1.5.3) are outlined in the following pages.

1.5.1 Research objectives

To address the identified deficits and inconsistencies within existing multimedia research, the study posed specific research objectives. As seen in Section 1.4.1, memory is hypothetically enhanced upon receipt of congruent stimuli although subject to individual attentional and processing differences including abstractive ability. This differs from CTML in its assumed domain specificity and fixed developmental (ontogenetic) pace and sequencing (see Section 1.2.2). In the decentralised cognitive architecture of embodied cognition, deep semantic representativeness occurs on a simulatory basis, and is supra-additive in terms of holistic stimuli modulating normal cerebrocerebellar processes in encoding and recall. Importantly, goal-directedness influences affective involvement, either positively or negatively, which positions learner affect as a potential gatekeeper of perceptual and cognitive processes. These theoretical positions within embodied cognition prioritised examination of text design in relation to its effects on positive affective-motivational states of learners as well as in discerning student attitudes towards socialised multimedia compared with the subject area itself. Specifically, visual-verbal modality, as a design component of paper-based text, was defined as a form of socialised text with personalisation and personification of scientific content.

Additionally, unlike previous studies influenced by CTML and CLT principles, the current research program takes, as an assumption, that social standing is a better predictor of learning efficacy than other learner variates such as age, aptitude or prior knowledge. Allostasis, the systemic and adaptive responsiveness of body systems to environmental enrichment and deprivation, is put forward in the literature review (Section 2.7.1) as a likely mechanism underlying brain plasticity and cognitive style. As an evolutionary explanation of behaviour (Tinbergen, 1963), this concords with biological reasoning in viewing allostatic pathophysiology as a system of ‘fine tuning’ stereotyped behavioural responses to environmental stability early in development. ‘Real time’ developmental mechanisms, meanwhile, are mediated by common physiological mediators such as glucocorticoids (McEwen, 2001), which in chronic overexpression in development, compromise hypothalamic-pituitary-adrenal axis (HPA) activity and memory processes including hippocampal- / prefrontal cortical- and amygdala-dependent cognition (Sections 2.7.3 and 2.8). Thus, social standing is likely associated with not only cognitive-regulatory, but also socioemotional processing; in the context of affective dysfunction in low SES learners (addressed in Section 2.7.2) this latter consideration has important implications in the design of learning texts. This includes the study context where research has demonstrated a similar link between SES and schooling outcomes (Bhoulila, 2017; Chmielewski, 2015) as in other world regions Specifically, if a text fails to engage a learner’s affective network, simulatory modelling is disturbed within reciprocal cerebrocerebellar regions, resulting in disruptions to learning. Therefore, research objective 1 included SES as a primary contextual variable alongside the design variable of degree of textual visual-verbal modality. In summary:

Research Objective #1: To examine how the degree of textual visual-verbal modality affects retention of content in learners differentiated by social standing.

In addition to the usage of SES as a primary variable in multimedia research, it is instructive to consider its measurement. As detailed in the literature review, SES is fractionated into objective and subjective components (see Section 2.7.2 for a discussion of socioeconomic status). While objective SES is strongly predictive of subjective SES, the latter measure predicts a host of mental and physical health outcomes even after controlling for traditional objective measures including education, occupation or income (Andersson, 2018). This can be explained by the more nuanced measurement of variables of social standing that are unaddressed by objective SES instruments; also, as a multidimensional quality, subjective SES records a relative rather than an absolute social position which can account for perceived differences in areas such as education and employment. Thus, social standing was operationalised as subjective as well as objective SES within the study and modelled to detect its influence on student learning from socialised multimedia texts. Research objective 2 is presented below:

Research Objective #2: To explore whether objective and subjective accounts of social standing covary with retention of content.

Attitude represents a key variable in the current study given the central position of affect in cognition and learning. Akin to its role in adaptive behaviour, emotional regulation is highly interconnected with neural systems that underlie perception, cognition, homeostasis and learning behaviour (Pessoa, 2008). As discussed within Section 2.7.3 ('Stress and brain plasticity'), socioemotional stimuli are salient and engage attention though influence cognitive-regulatory processes to a differing degree in individuals based on upbringing. This SES distinction appears to be due to the influence of circulating glucocorticoids and HPA dysfunction in chronic overactivation of the stress-response with implications for amygdala hypertrophy and hyperactivity. In low SES populations, including that of the study setting, this is often marked by impulsiveness, lack of cognitive-regulatory ability and low abstractive ability (Taylor et al., 2006). Attitudinal measures are thus important for what they can tell us about student engagement with learning materials; additionally, assessing learner's feelings of science, unlike other multimedia learning research, can help inform us of attitudinal distinctions between an intervention text and the learning area itself.

Research Objective #3: To investigate how student-held attitudes toward science and science learning materials differ based on degree of textual visual and verbal modality integration.

Cognitive models reflect an attempt to reduce complex neural processes to a formalised structure. Within the context of evaluating an existing model of the cognitive architecture, that of CTML, combining and generalising the theoretical framework of chapter 2 and the study findings of chapter 5 motivated a posteriori development of a revised cognitive model. This process proceeded from critiques of the existing model of cognition in CTML and was guided by the findings for research objectives 1-3. In reiteration of Section 1.4.1, specific theoretical inconsistencies in current CTML research stem from two sources: the influence of dual coding theory with its spatial and categorical separation of verbal and nonverbal symbolic systems and the developmental linearity associated with Piagetian schema theory. The incompatibility of these mechanistic and developmental processes with modern neuroscience literature are outlined in Section 2.3 and Section 5.4 presents an alternative model of the cognitive architecture with specific implications for normal and abnormal stimuli processing.

Research Objective #4: To present a model of cognitive architecture consistent with the study results and existing neurological literature.

1.5.2 Research paradigm and study methodology

Research paradigms reflect presuppositions inherent to our understanding of the nature of reality as well as the best ways to comprehend natural phenomena (Howell, 2012, p. 1). In approaching research, therefore, it is essential to identify ontological and epistemological belief structures in formulating specific approaches and methods of data collection. The study described in this thesis was informed by a positivist ontology and can be described as realist in its assumptions of a context-free reality including the temporal and spatial constancy of certain social phenomena. Allied to this position is an objectivism in viewing a broadly immutable basis for human development and behaviour.

Since Comte (1856), the role of probabilistic explanation has extended beyond the physical sciences into the social sphere. A major criticism of positivism, though, is identified in its insistence on objectivity. In defence of the approach and methodology taken in this thesis, key arguments against positivism (aligned with post-positivism) are identified and rebutted. Firstly, criticism exists of positivism and its generalisations of social phenomena particularly when 'positive reasoning' extends beyond the confines of the rational and enters methodology (Giddens, 1977). Quine (1961), to this effect, asserts that any claim of certainty is corrupted by the perceptual machinery of the observer and, correspondingly, that 'there is no way of classifying, or even describing, experience without interpreting it.' Furthermore, Marsh and Furlong (2018) identify distinctions between the natural and social world in which positivism is unable to bridge. In this view, social structures and processes are a lived experience, shaped by the idiographic nature of physical and ideological interactions.

In answer to such criticism, it can be asked whether any post-positivistic approach, with its methodological diversity, has a consistency necessary for meaningful interpretation and communication of research. To this end, Biestecker (1989) notes that 'however desirable it may be to open research to methodological pluralism and relativism, post- positivist scholarship does not offer us any clear criteria for choosing among the multiple and competing explanations it produces.' In addition, the claim of subjectivity in the lived experience is limited in post-modernism and critical theory given the purported lack of objectivity resident in the observer. As this extends to research methodology, the best outcome in such a paradigm is the triangulation of multiple fallible measures and observations. Objectivity, though, is arguably situated to a research paradigm by adherence to a suitably holistic etiological framework, free of rational interpretation. Such an etiology is offered in the premises of the biological sciences, including its genetic and epigenetic basis.

This position should not, however, be taken as deterministic in analysis of social phenomena as it is acknowledged that individual development involves multiple levels of causation inclusive of general evolutionary principles as well as the varying context of individual development. Such a framework was postulated by Tinbergen (1963), who, in appreciation of Aristotle's final causes, observed that any meaningful causal framework in behavioural analysis requires an aggregation of evolutionary and developmental history. This complementary analysis offers proximate and ultimate explanations of the costs, benefits and evolutionary pathways governing individual behaviour. In reference to the conceptual framework of the currently described study, socioeconomic status can be viewed as a determinant of real-time learning behaviour as social gradients are predictive of psychopathology and variations in cognitive style (Gruenewald et al., 2011; Oort et al., 2010). Moreover, socioeconomic status, as a universal feature of social species, offers a diachronic framework of adaptive value. Taken together, this forms the basis of a 'life-history' model of cognitive development, developed further in Section 2.7. Important for methodology, this approach does not invoke a separation of epistemology from ontology, as in critical realism (Scott, 2010) whose proponents suggest that causality is inherently unobservable in its stratification of empirical, real and actual phenomena. Instead, it can be said that in lacking suitable levels of causality and related analysis, such an approach is condemned to a subjectivity rightly questioned by critics.

Owing to these personal convictions, and the nature of the study constructs and their assumed co-dependencies, empirical analysis was deemed appropriate. Regardless of paradigm, standards of quality research dictate a methodology measurable by guidelines of validity and reliability and the adoption of a suitable experimental approach (Craner, Brewer & Lac, 2014). In consideration of such standards, a quantitative approach was considered expedient and, as educational research, a quasi-experimental research design avoided the unnecessary manipulation of subjects within a school environment with fixed class groupings. Usage of a cluster randomised trial, furthermore, helped isolate extraneous variables as a safeguard against threats to internal validity while retaining an external validity that was both realistic and robust in the export of study findings. Section 4.7 explores these safeguards to research quality more specifically, where threats to internal and external validity are categorised and discussed.

Having discussed the principles governing the current research, the study tested specific research hypotheses (presented below) in a quasi-experimental, cluster-randomised trial with 214 consenting grade 7, 8 and 9 international school students (see Section 4.4). Within the study, independent variables were formulated to represent the research objectives pertaining to the analysis of textual design and social standing. Details about the development and testing of the intervention texts are presented in Section 4.3. Social standing, acting as a proxy of individual development, formed an additional independent variable and is discussed in Sections 4.5.1.1 and 4.5.1.2. Additionally, existing and researcher-developed instruments were used to gather cognitive and attitudinal outcome data which were operationalised as dependent study variables. Full details of dependent variable conceptualisation, operationalisation, pilot testing and implementation in the study design are provided in Chapter 4.

Research hypotheses were formulated from personal experience and educational and neurological literature and offer directional predictions from the intervention. These included:

H_a1: Students will retain more information from multimodal learning texts.

H_a2: Subjective SES will be associated with enhanced learning from multimodal learning texts.

H_a3: Low SES students will exhibit greater learning from multimodal learning texts than high SES students.

H_a4: Students will benefit most from the highest degree of visual-verbal integration.

H_a5: Multimodal texts are perceived as more engaging than regular learning text.

H_a6: Multimodal texts will enhance student enjoyment of the subject area.

H_a7: Low SES students will perceive greater learning benefits from multimodal learning texts than high SES students.

1.6 Significance of the current research

This research has theoretical, methodological and practical implications for multimedia learning research and offers value in addressing socioeconomic disparities in education. To this end, remedies are provided in addressing the ‘socioeconomic achievement gap’ (Chmielewski, 2019; Huang & Sebastian, 2015) facing science education and are aligned with prominent recommendations for legislative enactment. Theoretical suggestions for multimedia research are provided in the conclusion chapter (Section 6.3) and include three major areas of benefit for educators and educational administrators as well as for ongoing research in this field. An initial task is the reframing of the cognitive architecture within multimedia learning to match current thinking in applied neurology on stimuli representation and memory processes. A third area of significance of the current study is the inclusion of subjective social standing as a multimedia instructional principle. Where social standing has been used in prior multimedia learning research, it has never involved subjective measurement, thus failing to involve this important social determinant as a rich measure of learning.

Socioeconomic inequities in educational outcomes motivate this study. A major area of significance provided to educators are theoretically informed recommendations (summarised in Section 6.5) premised on the distributed, dynamic, and plastic neural circuitry physiologically and behaviorally responsive to stress in development. As informed by the study findings (Section 5.4), administrative recommendations concern instrumentation in appropriate measurement of SES in schools as well as adoption of specific textual design principles. Paramount amongst these is the socialised contextualisation of information, as a key factor in modulation of abstractive ability and learning efficacy. At a legislative level, equitable funding for socioeconomically defined student populations is suggested. Funding would ideally include resources for graphic novels as science learning texts as well as development of SES measures involving aggregated subjective / objective indices of social standing. Additionally, the alignment of best and standard teaching practice is raised. This can occur via understanding of SES-mediated dysfunction amongst school leadership, early intervention programs and ongoing in-service opportunities for staff. As mentioned above, these points are expanded on in the final chapter.

1.7 Organisation of the thesis

In the chapters that follow, a quasi-experimental intervention involving the design, testing and analysis of multimedia learning text for secondary science students is described. The thesis is structured as a monograph, with sections recognizable as such. This approach was chosen for the afforded latitude in detailing multiple assumptions and exploring theory in depth, a decision necessitated by the theoretical framework drawing from multimedia as well as neurological research traditions.

The first chapter presents a review of the literature with two broad aims. These relate to the theoretical inconsistencies and methodological issues described in Section 1.4 which can be summarised as an inadequate formulation of the cognitive architecture as regards stimuli processing and an inappropriate focus on individual determinants of learning, including the role of development and social standing. As such, Chapter 2 reviews developments within the field of textual learning, drawing attention to the role of cognitive psychology and the influence of computationalism in areas such as dual coding theory (DCT; Paivio, 1986) working memory, cognitive load theory (CLT; Sweller & Chandler, 1994) and the information processing model of cognitive theory of multimedia learning (CTML; Mayer, 2005a). In separate sections, the research traditions of CLT and CTML are summarised and it is shown that where individual learning factors inform research methods, they are viewed in terms of cognitive load, simplistic age / stage / competence measures, or, in interpretation of inconsistent results, as potential boundary conditions requiring further study.

The second major aim of this literature review was to review cognitive and developmental neuroscience literature pertaining to individual development. This was conducted to provide a theoretical framework comprising both ultimate (evolutionary) and proximate (mechanistic) factors in the formulation of a cognitive architecture realistic in a phylogenetic as well as an ontogenetic sense. To address these concerns, this sub-section opens by linking brain development to environmental background with trends in cognitive style categorized as variations in life history traits. Viewing cognitive style as a necessary by-product of environmental enrichment or deprivation frames ongoing discussion of allostasis as a mechanism of adaptation and socioeconomic status as its agent of adaptive change.

Additional to this narrative literature review, a systemic review of the literature was deemed necessary to delve more deeply into multimedia learning research. Specifically, where Chapter 2 established a basis for instructional design principles, Chapter 3 examines specific patterns of theory and method within the extant literature. To this end, a systematic review of multimedia learning literature was conducted to examine the extent to which individual learner differences have influenced published research as well as to examine how student attitudinal measures are obtained and used within the field. With these aims, the chapter consists of two quantitative reviews and related analysis and discussion. The first quantitative review, a collation and analysis of published multimedia meta-reviews, was conducted to examine broad trends within the field. The second review, meanwhile, was conducted as a systematic review in order to examine how socioeconomic status, as a contextual variable, is treated in multimedia research. The analysis revealed that while attitudinal measures are used in assessment of multimedia design principles and other programmatic variables, measures of student affect regarding the subject-area itself are notably absent. This chapter concludes by restating the influence of the computational basis of CTML stimuli processing as a primary feature of multimedia research and relates the lack of personal learning characteristics as primary study variables to a diminished sense of their importance in a modular system.

Following the literature review chapters, Chapter 4 describes the study methods used in this quasi-experimental research project. Firstly, research objectives are reiterated, as per Section 1.5.1, and are related to the study's rationale of exploring the intersection between science learning, textual visual-verbal modality, socioeconomic status and perceptions of learning in middle school science students. The study design, a cluster randomised trial, with classrooms as fixed units of randomization, is then described; accompanying this is a brief discussion of the design's rigor and suitability for the site – an Australian international primary to Year 12 (P-12) school, in Sharjah, United Arab Emirates (UAE). Within the study design, a pilot test is outlined which has the aim of validating two of the instruments used to gather data pertaining to two of the study's dependent variables. Instruments are then described and categorized according to the experimental variable they represent. Two researcher-developed instruments, a measure of science outcomes and a measure of student affect associated with science learning text, were pilot tested and full details of this procedure and its outcomes are provided. The chapter describes potential ethical concerns, and the avoidance of such issues, in adherence to the ethical framework of the National

Statement on Ethical Conduct in Human Research (NHMRC, 2015) and ends with a chapter summary.

Chapter 6 presents details of the research analyses and findings of the quasi-experimental, cluster randomised trial described in Chapter 4. This chapter is structured according to the four research objectives described above in Section 1.5.1, and accordingly, present an overview of the specific analyses and findings. These results are then summarised and aligned with the research objectives and hypotheses and a conceptual model is derived as per research objective 4. This model presents a generalized view of the cognitive architecture that follows from the study findings and is framed in terms of normal and abnormal stimuli processing (Section 5.4).

Chapter 7, finally, presents a discussion of the study results and juxtaposes them against the theoretical and methodological tenets of multimedia learning. While the theoretical framework for the study includes research and theory from developmental and systems neuroscience, it does not attempt to relate its findings to these disciplines given the primary focus on multimedia learning. As such, research objectives 1 to 4 are unpacked and presented for further discussion within the context of multimedia learning and the identified inadequacies in its research methodology. Implications of the study are then discussed and related to connectionism and modularity as cognitive features in multimedia learning, the need to redefine multimedia principles on the basis of social contextualisation and the inclusion of socioeconomic status as a multimedia instructional principle. Limitations and recommendations of the research are then given. Of the former, a reiteration and justification is made of the internal and external threats to validity, raised initially in Chapter 4, while of the latter, recommendations are made for future research, in addition to those for material design, administrative purposes and pedagogy. The chapter continues with a section detailing theoretical, methodological and practical contributions, and ends with some concluding remarks.

Chapter 2

REVIEW OF THE LITERATURE

2.1 Introduction

This chapter, one of two literature reviews, involves a review of literature that informed my research design. It establishes the theoretical framework of the research project described in this thesis and presents a critique of existing models of cognition and learning, as outlined within multimedia learning research. Furthermore, the chapter identifies neurological details pertinent to individual differences in development and relates these to textual learning for secondary school students. These broad areas of review are divided into subsections which correspond to: theoretical advances in multimedia learning (Sections 2.2 and 2.3); individual development (Sections 2.4, 2.5 and 2.6); and instructional design principles as informed by current multimedia theory (Section 2.7). In Chapter 3, quantitative reviews of multimedia learning literature are provided to elucidate specific methodological developments within the field. In that chapter, thematic analysis of meta-review research and systematic review of multimedia learning literature are assessed, and the findings are related to the research objectives (presented in Section 1.5.1).

Various trends and gaps in the literature motivated the currently described study. As discussed in Section 1.2.1, the prevailing view of human cognition within multimedia learning co-opts core tenets of cognitive psychology (e.g. the multi-store model of Atkinson & Shiffrin, 1968). Correspondingly, multimedia theorists view the cognitive architecture as computationally analogous (e.g. Ginns, 2006; Mayer, 2001) and this theoretical basis has influenced specific multimedia learning effects and principles (Section 2.7). Furthermore, these concepts are operationalised as related design and task variates within multimedia research (described in Section 2.3 and elaborated on in Section 3.8.1). A deficit within this linear-processing view of perception and memory is the lack of meaningful learner variates that pertain to individual development. As mentioned in the introduction (Section 1.3), a rationale for the current study is the inclusion of social standing as a learner variate, divided into measurement of perceived and objective socioeconomic status as learning effects in multimedia learning. Furthermore, the study attempts to forge a causative and mechanistic model of individual development via identification of adaptive homeostasis (allostasis) as a key agent of stimulatory and anticipatory neural pathophysiology (Section 2.7.1). The research objectives (outlined in Section 1.5.1) thus draw from theoretical and methodological issues inherent to the computational view of human cognition and acknowledge individual influences in neural development.

The chapter is organised under the following headings:

- 2.2 Textual learning
- 2.3 Instructional design principles: theory
- 2.4 Individual development
- 2.5 Hippocampal, amygdala, and prefrontal-dependent cognition
- 2.6 Cross-modal cognition
- 2.7 Instructional design principles: praxis
- 2.8 Chapter summary
- 2.9 Chapter synthesis

2.2 Textual learning

> "The medium is the message." (McLuhan, 1964, p. 24)

Successful learning requires the extraction, manipulation and, most importantly, comprehension of information. Information has long been presented to learners via media chosen or designed by educators to facilitate learning and has spawned substantial investigation in the field of text and discourse analysis (see Graesser et al., 1997 for a review). An understanding of the effectiveness of texts in learning has influenced research given the ubiquity of texts in modern society, though the benefits of learning media employed to deliver instruction have been called into question (e.g. Clark, 1983). Central to the debate over the effectiveness of learning media are questions about the nature of cognitive and perceptual processes and individual differences in learning. In the following two subsections (Sections 2.2.1 and 2.2.2), I review the basis of theoretical advances in multimedia text design before discussing prominent multimedia design guidelines in Sections 2.3 and 2.4. These preliminary sections of the literature review help develop the research objectives described in Section 1.5.1 in the articulation of currently held assumptions guiding theory and practice in multimedia research.

2.2.1 Theoretical framework of multimedia design

In the early nineties, the 'media debate' influenced educational media design. Clark (1983), taking a utilitarian view, downplayed the existence of any single media attribute being essential for learning, and argued for the replaceability of any chosen medium for another more cost-effective one. Kozma (1994) rebutted Clark by raising three particular characteristics of media: different technological capabilities of media; the usage of symbol systems within media; and related neural processing capabilities. Echoing Kozma, Mayer (2003) reported that deeper understanding in learners was capable with multimedia presentations, as integrated verbal and visual forms can promote student understanding. Mayer (2001) dubbed the facilitative quality of multimedia texts the 'multimedia effect', operating according to principles of his cognitive theory of multimedia learning (CTML).

Combining static visualisations with complementary words has regularly been shown to improve learning outcomes with various tasks and measures (Gellevij & Leutner, 2007). As an example, procedural instructions using combinations of text and pictures have led to better recall, verification of the order of steps, and reduced time in verifying the order of steps, compared with conditions using either text or pictures alone (Brunye et al., 2006). This effect was seen even when each separate modality contained all necessary information for the lesson. In another study, improvements in recall and transfer were obtained when visual illustrations were added to a verbal-descriptive summary used to instruct students on how lightning is formed. Additionally, adding visual screen shots to a text instruction manual led to a stronger mental model of a complex software application, and improved identification and manipulation of related elements and objects (Gellevij et al., 2002).

Combinations of media, however, need to be carefully considered to aid learning (Scanlon, 1998). While recall and transfer following learning from textbooks can be improved by replacing the visual text with equivalent audio-narrations (Mayer &

Moreno, 1998; Moreno & Mayer, 1999; Mousavi et al., 1995) or by integrating text and pictures instead of keeping them separate (Chandler & Sweller, 1992), numerous studies have also shown that learners fail to benefit from the use of multimedia instructional materials (Ainsworth, 1999; Mayer & Anderson, 1992). This includes when information is not presented as student-paced instruction (Tabbers, 2002), when the text is very rich on its own (Mayer, 2001), or if redundant auditory information is presented (Mayer, 2008).

The integration of verbal and pictorial information, and related theoretical frameworks, have thus come to define current research on multimedia learning. Moreover, specific cognitive processes involved in retention and transfer of presented information have generated interest within multimedia research. Contemporary assumptions within multimedia research identify specific neural architectural features and constraints including modality-specific subsystems within working memory (Baddeley, 1986, 1998a; Paivio, 1986), limited subsystem processing capacity (Baddeley, 1986; Baddeley & Logie, 1999, p. 30; Chandler & Sweller, 1991) and active processing of sensory information. Such assumptions of the nature of information processing, including its representational organisation and integration within long-term memory, are important considerations as they help to frame the multimedia learning research tradition.

2.2.2 The role of accompanying text in multimodal presentations

Multimodality, in the current context, can be defined as the concurrent presentation of visual and verbal modalities (Mayer, 2002). This follows as graphics have historically been used to represent elements and relations that are visuospatial or metaphorically visuospatial (Schmandt-Besserat, 1992). Graphics provide utility in providing two codes of represented information (pictorial and verbal) and help to save words for relating naturally hard-to-describe items such as maps, systems or faces. Furthermore, a natural spatial correspondence exists between objects and their graphical representations which gives visual depictions an essentially concrete reality. Accompanying text, however, usually is necessary as visualisations alone aren’t always self-explaining (Serafini, 2010; 2011).

Language, in contrast to visualisations, is highly formalised and abstract (Gurr, 1999). Phonemes and letters constitute a finite set of basic characters in human language from which the symbols (words) are constituted. Arbitrary relations exist between the physical properties of language and depicted concepts, which are semantically connected according to social or linguistic convention (Yah & Barsalou, 2006). Moreover, language relies on explicit relational symbols such as prepositions and a finite set of syntactic production rules to construct clauses from single words. These properties of language allow us to describe concepts to any degree of abstraction required (Shatz, 2008).

Visual depictions carry an emergent ‘meaning’ that maps to a natural cognitive correspondence in physical properties (such as distance or motion) via structural similarities (Tversky et al., 2002). However, as visual depictions lack explicit relational symbols between their constituent parts, verbal text is usually necessary to express the relations of specific visual entities (Kosslyn, 1989). Learning outcomes featuring incidental rather than conceptual learning can result unless visualisations are presented alongside verbal discourse. For example, Rieber et al. (2004) reported implicit learning outcomes from realistic video game simulations of Newtonian mechanics. Conceptual understanding was reported as occurring only upon receiving explicit verbal explanations of the underlying physical principles in addition to the graphic-only presentation.

Accompanying text is usually required and, therefore, serves numerous purposes. Textual information can change in role depending on the nature of the depicted content but, most commonly, provides an indication of how the visualisation is to be understood (Ware, 2004). Often, expository text is necessary even to recognise the purpose and instructional message of the illustration (Gajria et al., 2013). Besides helping to understand what an illustration actually represents, accompanying text can serve as a guide for visual attention. At times, added text is descriptive (and informationally equivalent) and explains the salient concepts, or may be instructive in giving directions for ‘reading’ the visualisation.

Yarbus (1967) conducted research on the mechanics of the oculomotor system and concluded that eye-movement patterns were task dependent and responsive to high-level cognitive demands. His work incorporates earlier findings, including Buswell (1935), on the interaction of an observer's cognitive goal and past experiences with a given visual stimulus. Figure 2.1 shows Yarbus' (1967) results from seven eye-tracking patterns, from one observer, within differing instructional contexts in a graphic-only presentation. In this instance, observed saccades – a measure of binocular visual coordination in goal-directed tracking (Seassau et al., 2014) – were seen to produce striking differences upon different instructions.

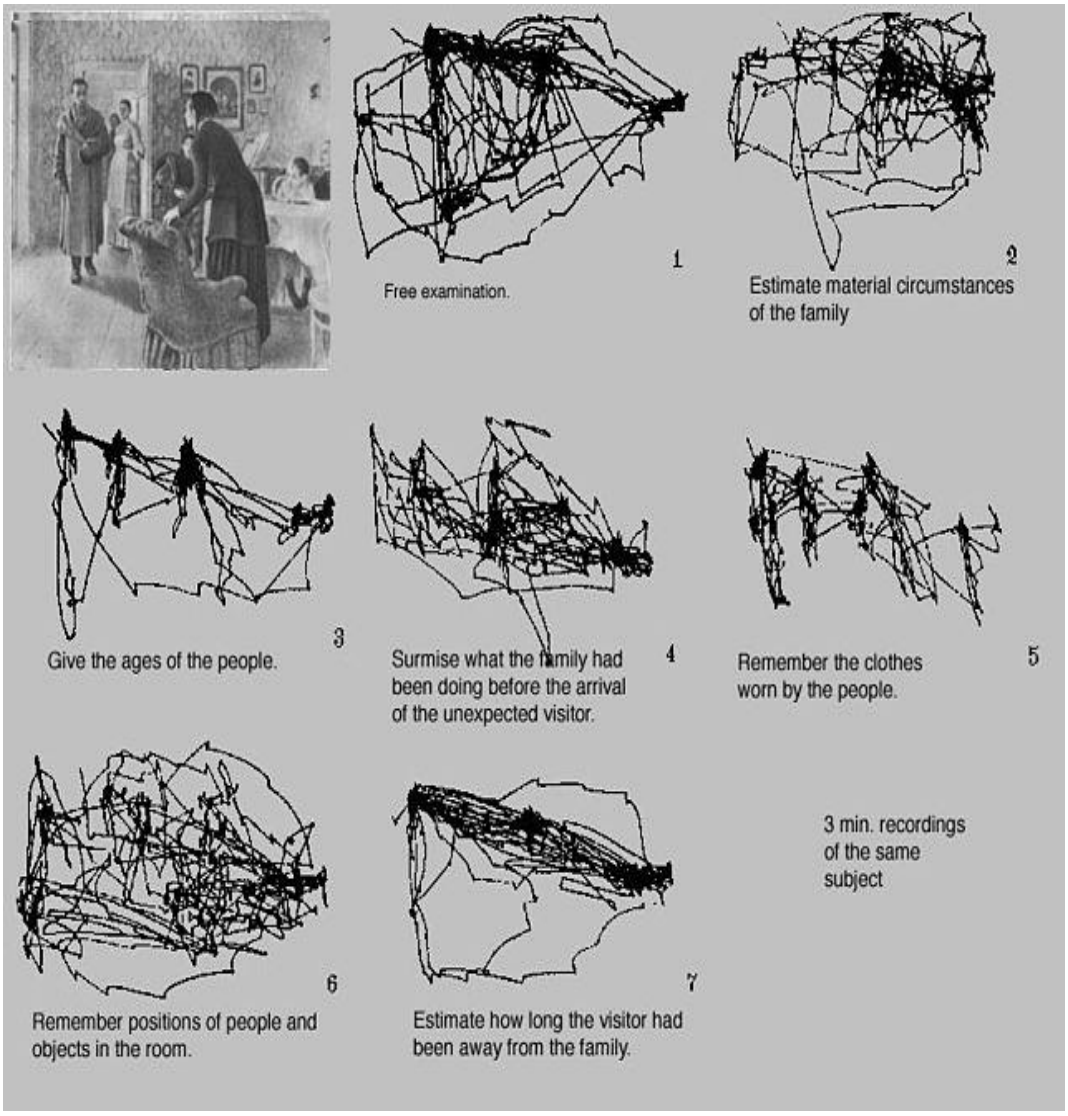

Figure 2.1 Patterns of eye fixation in differing contexts in a graphic-only presentation (Yarbus, 1967)

With the recognition that gaze behaviour can be indicative of current attentional processes, provided that the available visual area is pertinent to a given task (Hyona, 2010), eye movement studies give us an idea of how learners use integrated texts. An example of this is provided by Rayner et al. (2001) who examined fixation patterns and saccade length in people viewing print advertisements in order to learn important details in a self-paced presentation format. Figure 2.2 shows recorded eye-tracking in these integrated texts.

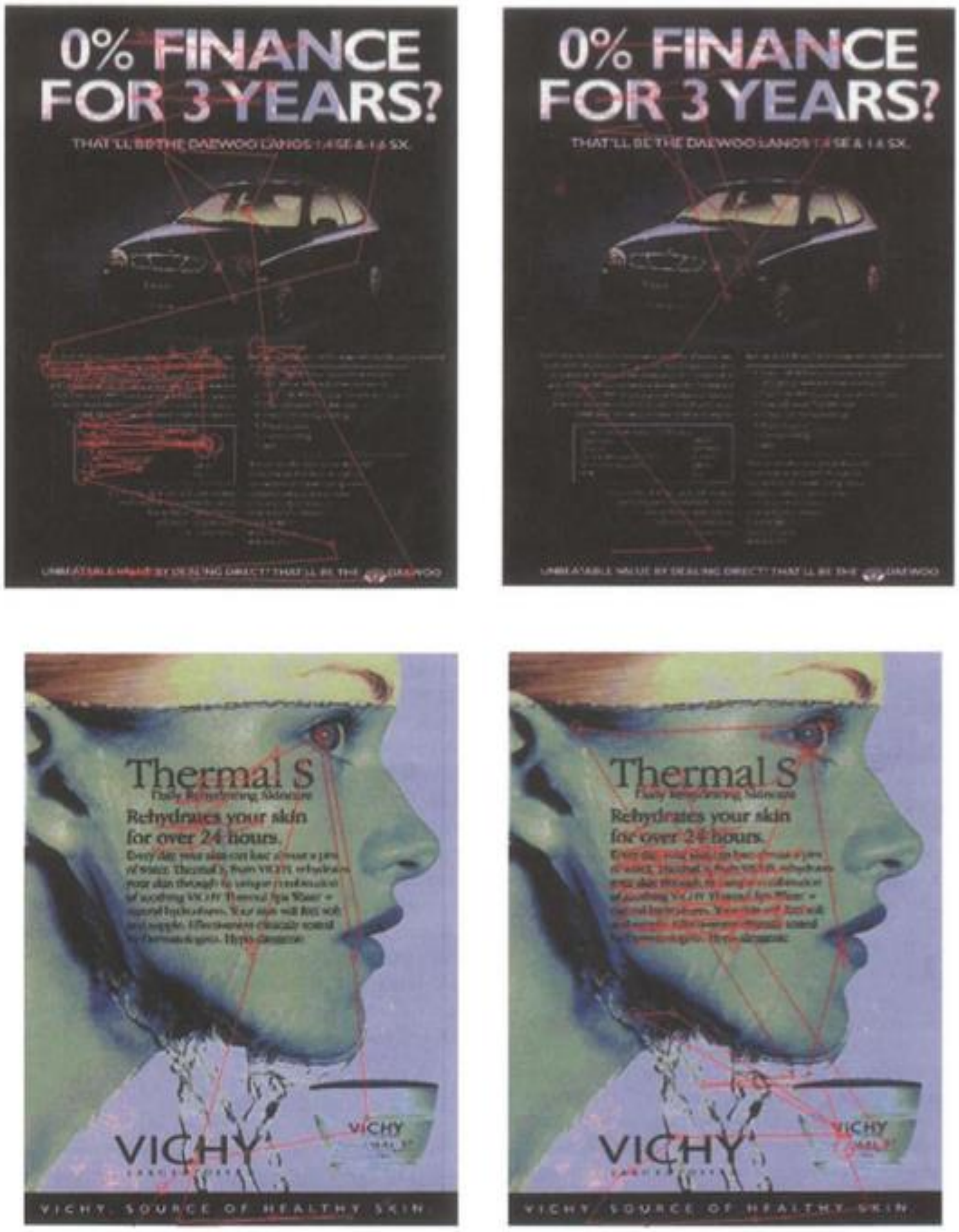

Figure 2.2 Eye tracking in an integrated text (Rayner et al., 2001)

Rayner et al. (2001) noted idiosyncrasies among people examining integrated advertising texts and made generalisations about attentional processes. Firstly, processing of the pictorial and verbal components of text were relatively isolated events which didn't involve eye gaze changes between picture and caption. Second, the caption was initially read before attention moved to the picture. When picture viewing preceded that of text, it was seen to be a quick, cursory viewing. When the viewing order of captions and pictures was alternated, viewing time was consistent. However, when the caption was presented first, more time was spent looking at it than when it was presented second. Andrews and Coppola (1999) found that, in comparisons of eye movement between scene perception and reading, however, fixation durations and saccade (rapid eye movement) length tended to be longer in scene perception. Rayner et al. (2001) speculate that this could be indicative of the denser informational content of visualisations than text as a consequence of including both visual and verbal content. This can also be seen as a consequence of a working memory constraint whereby visual and auditory modalities are presented in an incongruent manner.

When Hegarty (1992a, 1992b) presented text and diagrams describing pulley systems to learners, construction of the representation was largely text directed. It was found that learners attempted to interpret clauses or sentences prior to inspection of graphical referents. Viewers tended to inspect the diagram at the ends of sentences or clauses, with around 40% of fixations on referent diagrams to the most recently read clause. Diagram inspection was considered as a confirmatory process in aligning certain types of configural or kinematic knowledge to the information presented textually. Other eye tracking studies have confirmed this pattern of multimedia inspection (e.g. Faraday & Sutcliffe, 1996; Underwood et al., 2004) though Rayner et al. (2001) caution that this could be a consequence of textual conditioning or could operate due to graphical information being less information dense than that of language.

Accompanying text is thus seen as important for explicating conceptual understanding which is possibly absent from graphical representations alone. As described in Section 1.5.1, a current research objective is to examine the role of social congruence as a feature of text design. This text design feature is informed by specific findings in neurological research that identify probable (a) evolutionary patterns of brain development and (b) related mechanistic differences in individual development, including attentional, perceptual and cognitive intervariability to stimuli classes. Guided by these assumptions, current multimedia learning recommendations and theoretical frameworks are presented in the following section, Section 2.3, in relation to current guidelines on multimedia presentation.

2.3 Instructional design principles: theory

Two prominent recommendations for the design of multimodal texts are encapsulated within the principles of *modality* (Mayer, 2001) and *spatial contiguity* (Clark & Mayer, 2011). Mayer and Moreno (1999), for example, found positive learning experiences associated with concurrently presented narration and animations versus learners with concurrent on-screen text and animations. Also, the physical proximity of the on-screen text and animations was manipulated to be either close / integrated or separate from each other. Superior learning in the integrated condition was observed and conclusions were drawn about modality and contiguity effects inherent to textual design. In short, the modality principle states that learning is benefitted by presenting text aurally rather than visually. The spatial contiguity principle states that enhanced learning with multimedia is promoted if illustrations are presented physically close to associated text. Consequently, both principles emphasise separate stimuli modality in audiovisual processing.

The idea that visual and auditory stimuli should be considered as discrete modalities that require separate processing is derived from dual-coding theories of working memory. Mayer and Moreno (1998) describe a general assumption of dual coding theories as including auditory working memory and visual-spatial working memory components, analogous to Baddeley's (1986, 1998b) theory of working memory. A limited capacity for each working memory store is associated with modality-specific processing, and meaningful learning occurs upon retention and organisation of information into coherent representations. This can only occur, within dual-coding theories of learning, when corresponding pictorial and verbal information is concurrently held in working memory. Accordingly, visually presented information is processed initially in visual working memory, while auditorily presented information is processed in auditory working memory (Mayer & Moreno, 1998).

Discrepancies in the processing of verbal and pictorial information have been discussed extensively in the past without being conclusively explained. While some authors claim that pictorial and verbal information is processed in much the same way (Caramazza, 1996), proponents of dual coding theories (see for example, Glaser, 1992; Paivio, 1991) claim that information in pictures and words is processed separately and along distinct channels, thus creating separate semantic representations (Schlochtermeier et al., 2013)**.** Caramazza (1996), in arguing for shared information representation and similar processing of pictures and words, claimed that semantic information is represented in a functional unitary system that is directly accessed by both visual objects and words. Alternatively, Glaser postulated a distinction between a semantic system, to which pictures have a privileged access, and a lexicon, which includes only linguistic knowledge (e.g. Glaser, 1992; Glaser & Glaser, 1989). More recently, semantic processing theorists have proposed that meaning is represented as embodied simulations of previous experiences (e.g. Pulvermüller & Kiefer, 2012), suggesting a unitary experience-based representation system. Theoretical developments within multimedia research, however, have largely focused on associations between discrete verbal and visual constituents of memory (Brunye et al., 2008; Pylyshyn, 1973). This includes dual coding theory (Paivio, 1991) which draws from Baddeley and Hitch’s (1974) multicomponent model of working memory, as well as other developments within multimedia learning including cognitive load theory (Chandler & Sweller, 1991) and Mayer’s cognitive theory of multimedia learning (Mayer, 2005b). The theoretical framework and research findings of dual coding theory are discussed in the following sub-section.

2.3.1 Dual Coding Theory

According to dual coding theory, words and images are processed in separate, limited capacity working memory channels prior to crystallisation into a single, coherent mental model (Mayer, 2005b). Verbal and pictorial components of language provide unique contributions to mental model formation, with words contributing theory-based information, including explanations of complex relations, and images providing similarity-based information such as basic visual representations and exemplars (Bartholome & Brommel, 2009). Cognition within dual coding theory is considered as a generative process operating as a result of the interplay of the verbal and imaginal systems, and involves numerous aspects of cognition, including memory, language phenomena and executive control functions.

The verbal system is specialised for dealing with language, while the nonverbal (imaginal) system is specialised for processing nonlinguistic events and objects (Paivio, 1991). The theory incorporates *logogens* and *imagens* as internal verbal and nonverbal representational units that are activated when one manipulates, recognises or holds words or things in working memory (cf. *iconogens*, Morton, 1969; Seymour, 1973). These representations are connected to sensory input and response output and can function independently or cooperatively to mediate verbal and nonverbal behaviour. Cognition, broadly, is the interplay of this representational activity, which can be experienced consciously as imagery and mentalising (inner speech).

Although structurally independent, the two different systems share intersystem links which connect verbal and nonverbal symbolic systems to enhance the transformation of information between systems in schematic representation (Paivio, 1991). These links are theorised as being of two kinds: within-system and between-system connections. Within the dual coding theory framework, between-system links are referential links, which serve to activate the symbolic transformations of one kind of information from one system to the other (Paivio, 1976, 1982, 1986). Referential links are created, for example, when concrete objects are visualised within a particular context; the verbal information of the term is first encoded within the verbal system, and then the imagery is formed in the imaginal system via intersystem links. The corresponding visual to verbal linkage takes place for the naming of an object - i.e. a representational transfer from imagen to logogen. This process is portrayed in Figure 2.3.

Five steps within three stages have been identified to occur between systems in referential links. Taking the example of a student being asked to visualise a concrete noun, the initial stage involves this verbal input being processed in the verbal system. The verbal system interprets the instruction and transforms the information to the non-verbal system through between-system connections. The image is generated, and then interpreted back in the verbal system, before the culminating verbal output from the verbal system is generated (Paivio & le Linte, 1982).

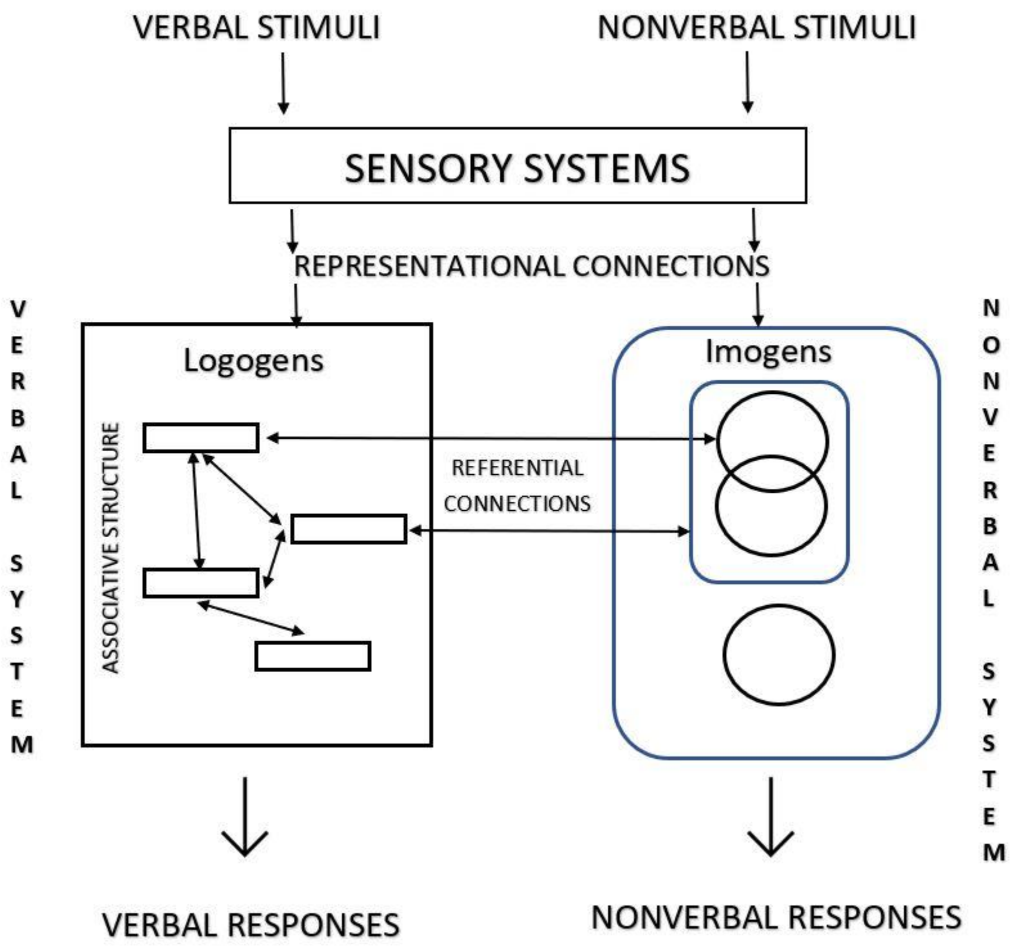

Figure 2.3 Separate streams for language and object information classes (figure adapted from Paivio, 1971)

Linguistic information in the verbal system is processed sequentially, whereas imaginal representations in the non-verbal system are organised in a holistic and parallel manner (Paivio, 1986). Cognitive representational units in the two systems serve the function of mediators of performance in different cognitive tasks, such as memory, perception and language. Although the two systems are independent, inter-system links connecting the verbal and non-verbal symbolic systems enhance transformation of information from one system to the other in schematic representation (Paivio, 1991).

Associative connections function to join words and images to related forms within either system. The function of such connections is to form complexes or networks by linking and integrating independent parts into unitary bodies of memory (Paivio, 1971, 1986). Particular words and images are built with linkages of associated logogens and imagens and, after visual components are transformed in the verbal system via referential connections, higher order cognition is a function of these linked, though independent systems.

Empirical evidence supports the superiority of recall of objects and their pictures to the recall of verbal representations (e.g. Bonin et al., 2018, Houts et al., 2006, Quak et al., 2015). Paired associate learning experiments distinguish verbal components into concrete and abstract nouns as the referential strength is assumed to be higher with concrete verbal categories. Imagery stimuli has been consistently found to facilitate better learning outcomes as it stimulates the non-verbal system and referentially activates the verbal system codes (Paivio & Yarmey, 1966). Additionally, images have been shown to have strong, consistent effects in paired-response learning as the role of the stimuli rather than that of the response.

A picture superiority effect has also been documented in free recall presentations (e.g. Gillund & Shiffrin, 1981; Kaplan et al., 1968; Paivio & Csapo, 1969). Paivio and Csapo (1973) conducted five experiments and concluded that pictorially presented information effectively doubled the recall rate of pictures-to-word presentations. Additionally, a decreasing order of processing speed occurred from non-verbal coding of pictures, to verbal coding of words and, finally, to the image coding of concrete and abstract words, respectively. A picture superiority effect is also seen in semantic memory tasks. The superiority of pictures over words in semantic categorisation, for example, is explainable by the fact that an extra acoustic-phonemic decoding step is needed before words are understood (Pellegrino et al., 1977). However, paired associate learning, free recall and semantic memory tasks all involve single words and pictures and aren't representative of normal texts used for middle or high school students. Research has also been conducted on whole sentences / full text with picture presentations and is outlined below.

Within experiments examining children's comprehension and memory of sentences, recall has been associated strongly with picture presentation. Even with partial pictures that aren't informationally equivalent, recall has been stronger than with verbal cues, and use of incongruent verbal / imaginal cues has raised the issue of congruency as a feature of textual design. Pressley et al. (1982) arranged preschool learners in seven experimental presentations which involved the delivery of 25 concrete sentences with a narrative technique. Matching congruent pictures to sentences had the greatest facilitative effect, though incongruent pictures led to the poorest recall of verbal information. No significant effects were found between presentations of partial pictures, which suggests a propositional format between sentence and picture during encoding (Carpenter & Just, 1975). Guttman et al. (1977) had kindergarten children learn a sentence in four conditions: control group with no picture; a complete picture condition; an action-position condition; and a static-position condition. For the action-position, no picture was presented but imagery conditions were given under partial picture conditions. The static-position condition involved a picture depicting the concrete reality of the sentence without associated context (imagery instructions). Subjects were found to correctly answer more questions in the three picture groups, suggesting that imagery instructions provide deeper referential connections than text alone.

Two hypothesised effects have emerged from dual coding theory research and appear well-supported by behavioural studies. The code-additive effect occurs when pictures enhance the activation of both non-verbal and verbal codes, resulting in shorter and more accurate processing (Paivio & Yarmey, 1966). When words are encoded in different modalities, verbal representational units alone within the verbal system are being activated. Unless verbal codes are transformed into non-verbal codes, no visual imagery can be evoked. This results in spoken or printed words having less imagery value and less concreteness than pictures, which leads to difficulty in memory processing and recall (Paivio et al, 1989). Abstract words are especially difficult to image and thus least likely to be dually coded.

The conceptual peg hypothesis states that compound images that link pairs are formed during presentation and are reintegrated during recall by a concrete stimulus. Paivio (1965) showed that stimulus-concreteness in a stimulus-response test using concrete (C) and abstract (A) nouns in every combination (CC, CA, AC, AA) strongly outperformed concreteness of to-be-recalled responses. Beggs (1973) found simultaneous support for the conceptual peg and additivity hypotheses using adjectivenoun phrases which were either concrete and high in imagery value, or abstract constructs. Asked to recall individual words from phrases or entire phrases given one word as cue, participants exceeded prediction with a doubling of recall of concrete phrases versus that of abstract phrases. These free-recall results were consistent with the conceptual peg hypothesis as recall was six times higher with concrete cues. Moreover, this lent support for the image superiority appendum to the code-additivity hypothesis given that concrete imagens could more easily reintegrate entire mediating images in the case of concrete phrases (Thompson & Paivio, 1994).

Behavioural and neuropsychological findings within dual coding theory offer mixed support for separate channels. Thompson and Paivio (1994) demonstrated additive effects on memory using object pictures and sounds. This finding supported the dual coding theory assumption of functional independence of sensory components of multimodal objects. Brain scanning and lesion studies have also lent support for dual coding theory in suggesting distinct representational substrates of most sensorimotor modalities (e.g. Metzler, 2001; Pobric et al., 2009; Lima et al., 2016). Scanning studies have also shown differential activation of brain regions of concrete and abstract words and pictures in comprehension and memory tasks (e.g. Sabsevitz et al., 2005; Schwanenflugel & Shoben, 1983). However, functional magnetic resonance imaging (fMRI) study conducted by Roxbury et al. (2014) found similar bilateral brain activation patterns for processing of concrete and abstract spoken words. The authors suggested that heteromodal association areas, which interface with a critical set of modality specific representations, were activated in a manner more consistent with a context availability theory (e.g. Schwanenflugel, 1991; Schwanenflugel et al., 1988; Wattenmaker & Shoben, 1987). Interestingly, region of interest analysis, conducted by Roxbury et al. (2014), showed greater activation in left posterior cingulate cortex for concrete than abstract words. This region, implicated in many semantic memory tasks as a connector hub and involving episodic encoding (see Binder et al., 2005), can be utilised in concrete recall as a larger set of concepts and associations are associated with concrete than abstract words.

Specific conclusions relevant for multimedia design can be drawn from dual coding theory. In comparison with pictures, words are considered less salient, which results in the superiority of pictures in memory tests. This is considered to occur because pictures evoke visual and mental images in the imaginal system which are then linguistically coded via between-system referential connections (Paivio, 1991). By contrast, words and especially abstract words, are more likely to be stored within a unitary verbal code. Consequently, dual code processing of pictures has a processing advantage over words encoded within the single verbal code. Picture-word associations are often used in pedagogy for this reason (Paivio, 2006). Pictures dramatically increase memory codes and strengthen memory trace, and mediational strategies which have learners generate imagery of written text could thus facilitate better recall. Concrete words, naturally high in imagery value, are assumed to be dually coded similarly to pictures, and holistic presentation of concrete words within memory is preferable in recall and transfer than serially-coded abstract verbal terms. Finally, while the learning implications of dual coding theory aren't disputed, the nature of dual coding can be called into question in light of functional brain imaging. Further analysis of sensory processing is provided in Section 2.6 where research on cross-modal cognition is explored and related to the concept of embodied cognition.

2.3.2 Working memory

Working memory in cognitive psychology refers to an evolved system that deals with the short-term maintenance and management of information needed for complex task performance such as learning (Baddeley, 1998a). Working memory has also been called short-term memory, primary-memory and immediate memory (Klatzky, 1975), and is typically defined functionally for its momentary storage of information required for performance of cognitive tasks (Baddeley, 1986, 1988). The role of working memory for the matter of learning and understanding is that it operates as a gateway between the sensory world and internal cognitive architecture. The nature of working memory is also central to theories of stimuli processing and is thus relevant to the research objectives presented in Section 1.5.1. Within current multimedia learning theory, two aspects of working memory share consensus within the literature: limitations of working memory resources and modality specific subsystems.

Logie (1996) surveyed the historical development of working memory and identified distinct theoretical stages of development. Beginning from the seventeenth century, distinctions in memory systems between short-term and permanent storage have been made, such as the English philosopher John Locke's division of 'idea in view' and 'storehouse of ideas.' In subsequent developments, working memory is described as 'primary memory' (Waugh & Norman, 1965) and rehearsal is seen as necessary for maintaining information in primary memory and transfer to secondary memory (long-term memory). Logie's third stage of development is defined by the shift of working memory as a passive storer of information to that of active processor. Atkinson and Shiffrin (1968) referred to short-term memory as a combination of storage and control processes and argued for a limited capacity system that is flexible in storage and processing capability. Cowan et al. (1994) extended the working memory as processor analogy of Craik and Tulving (1977) by proposing that working memory isn't a separate entity, and that expertise could expand attentional limitations of working memory. Currently, working memory has been most influenced by Baddeley (1992) in which working memory is considered as composed of two modality-specific components alongside a central coordinating system. Figure 2.4 shows the three main components of the original Baddeley and Hitch (1974) model.

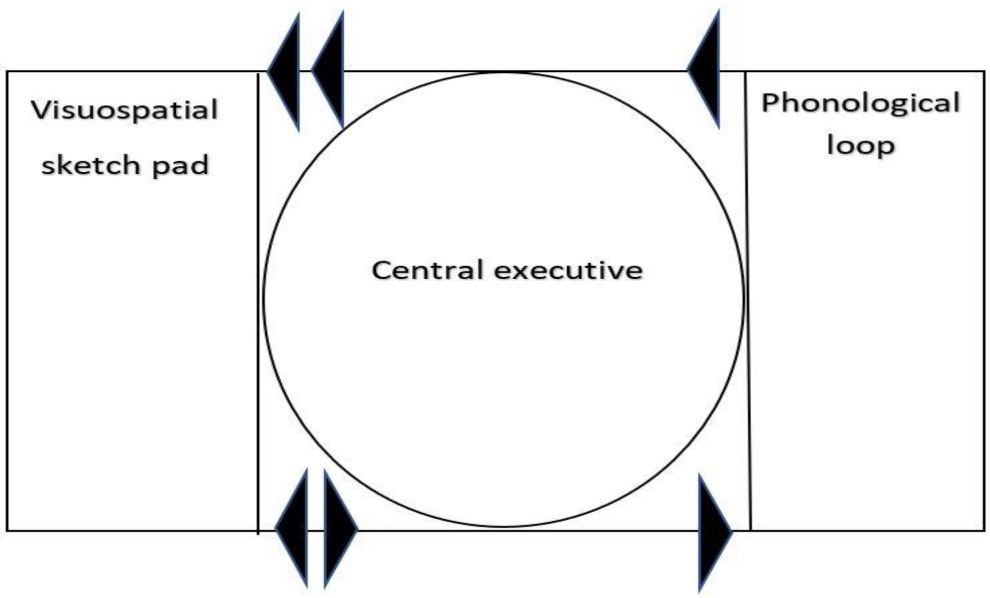

Figure 2.4 Baddeley and Hitch model of working memory (figure adapted from Baddeley & Hitch, 1974)

In Baddeley's (1992, 1996) model, working memory consists of a central executive and two types of storage: a visuo-spatial sketchpad and a phonological loop. Within the phonological loop, audio-based information enters and quickly decays within seconds unless rehearsed (Baddeley, 1996). Kemps et al. (2000) assumed that two subsystems reside within the phonological loop: a passive phonological store and an active mechanism that refreshes memory traces. The visuo-spatial sketch pad is assumed to be a more complicated component than the phonological loop (Baddeley, 1996), and places heavier cognitive demands on the central executive. It is responsible for temporary storage and manipulation of visual and spatial input, and can be divided into separate visual, spatial and possibly kinaesthetic components. Logie (1996) further divided the visuospatial sketchpad into the visual cache and inner scribe which store information about form and colour, and spatial and movement information, respectively.

The central executive is responsible for intentional control of working memory and coordinates the functions of other working memory components (Baddeley, 1996). It is an active component that is assumed capable of holding spatial and visual information concurrently. The three components of working memory are assumed to involve interactions amongst numerous brain regions (Baddeley, 1998b; Kemps et al., 2000) and are thus fractionalised. While not specifically raised by Baddeley or others, working memory would probably involve the critical role of lateral frontal cortex in specific aspects of executive spatial and non-spatial working memory (e.g. Owen et al., 1990, 1995, 1996; Petrides & Milner, 1982; for a review see Petrides, 1989).

2.3.2.1 Limitation of working memory

Hermann Ebbinghaus (1885) studied human memory and concluded that seven or less items could be learnt from a list in one attempt. This ‘memory span’ limit was expounded on by Miller in a 1956 paper titled ‘The magical number seven plus or minus two’ which suggested a capacity limit of five to nine items (see Broadbent, 1975 for related commentary). Cowan (2001) identified memory capacity as the maximal number of ‘chunks’ that could be recalled in a particular situation, while Baddeley (1986, 1998a) assumed that memory span is limited to a rehearsable number of items prior to representational decay. Temporal working memory constraints likewise exist. Researchers (e.g. Smith & Jonides, 1998; Smith et al., 1998) found a limiting range of zero to 60 seconds for items held in working memory. Furthermore, Baddeley (1998b) suggested that working memory duration was dependent on the length of time that an object could be held active without rehearsal.

Capacity limits of working memory have inspired research aimed at better understanding the architecture of working memory. Fougnie and Marois (2011) propose that the core question of working memory capacity centres around the issue of whether such limitations are mediated by subsystems specialised for maintaining distinct audiovisual representations, or whether limitations exist as a consequence of domain-general processing.

Domain-general models of working memory view working memory as a system for maintaining focus of attention on currently maintained episodic and semantic memory processes, rather than as a set of distinct systems (Cowan, 2005). Within this perspective, executive control is involved in activation and maintenance of memory representations, attentional control and inhibition of irrelevant information. Limitations to the capacity of this model of working memory, thus, come not from modality-specific subsystems but as a result of coordination of domain-general cognition. These theoretical assumptions have prompted different lines of reasoning, and related research, on working memory limitations. While multiple-components models postulate limiting architectural and organisational constraints, domain-general proponents focus on task limitations given inherent cognitive limitations (Logie, 2011).

Following the separate-streams hypothesis, as an example of a modular cognitive architecture, Shallice and Vallar (1990) reasoned that, when verbal information is presented as print, visual analysis occurs and is followed by re-coding from visual to phonological format before this re-coded information is received by the phonological store via articulatory rehearsal. Penney (2003) extended this to include modality-specific sensory processing streams that further contribute to retention of verbal information within working memory. He hypothesised that, in addition to activation of the phonological loop, auditory and visual stores are also automatically activated upon receipt of verbal information in the relevant modality, with the auditory store more durable and structured than the visual store. Numerous lines of experimental evidence from behavioural studies appear to support this hypothesis (Cowan, 2011):

1. Memory is improved when different items are presented in different modalities relative to presentation in a single modality.
2. Presentation of additional stimuli at the end of lists (the ‘suffix’ effect) has different effects upon recall as a function of modality.
3. Recall is enhanced when items are organised by modality rather than by time of presentation, and
4. Two concurrent verbal tasks can be more effectively performed when different input modalities are utilised in comparison with a single input modality.

Logie (2011) describes the separate-streams view of working memory as a conceptual and functional model, requiring no expectations of functional mapping of brain regions during memory tasks. Logie (2011) further theorizes that complex networks of brain function could overlap with other functional networks which would confuse brain imaging studies and render them less revealing than behavioural studies. Nonetheless, he presents evidence for differential patterns of brain activation associated with verbal immediate memory such as the angular gyrus and left hemisphere supramarginal gyrus. Additionally, localised brain damage patients provide examples of impediments to verbal memory, while retaining the ability to remember visual patterns, or vice versa depending on affected hemisphere.

Conversely, brain imaging research provides evidence for domain-general perceptual and executive processing. Such research has been motivated by examination of neural structural-functional correlates of cognitive performance, despite the likely heterogeneity of cortical association regions. Schumacher et al. (1996), for example, conducted positron emission tomography (PET) to examine regional blood flow in memory and control detection tasks as correlates of verbal working memory. Consistent with prior PET studies (e.g. Ardila, 2014; Jeon & Han, 2012; Schulze et al., 2010) memory-related regional cerebral blood flow (rCBF) was seen in left hemisphere dorsolateral frontal cortex, Broca’s area, premotor cortex, and bilaterally in anterior cingulate and superior and posterior parietal cortices. This showed almost complete overlap between verbal and spatial modalities, leading Schumacher et al. (1996) to suggest an amodal processing of verbal working memory. In summary, this demonstration of amodal processing casts doubt on assumptions of separate streams of visual and verbal processing.

2.3.2.2 Cognitive and neuroscience models of working memory

Computationalism plays a significant role in working memory research (Clark, 2008). For example, the existence of verbal and spatial storage buffers is a key component of Baddeley's (1992, 1996) working memory model. Such buffers are computationally analogous to random-access memory which serves as a short-term cache of information between central processing unit and hard drive. Proponents of separate-stream models of working memory assume that information is discrete and either *in* or *out* of working memory (D'Esposito & Postle, 2015), with retrievable representations stored in particular brain regions. However, this could be incommensurable with brain physiology because multidimensional coding (for example, involving odour or tactile sensations) would be extremely constrained within a system involving only verbal and visuospatial caches. Despite Baddeley's (2000) addition of an integrated episodic buffer, the integration and maintenance of all forms of sensory input are not currently accounted for within this system. The inability to recode olfactory or haptic representations into visuospatial or verbal codes thus marks a significant detraction for Baddeley's model of working memory.

Cowan's (1988, 1999) embedded processes model, by contrast, suggests that working memory contents are not stored within dedicated storage sites, but simply relate to information that is within the focus of attention at any given time. Within the embedded processes model, working memory is a subset of long-term memory (Cowan, 1999) and current attentional focus is made within hierarchically arranged faculties. With no separate working memory, task-oriented activation of representations has no constraints, and working memory performance is instead determined by the level of representational activation and discrimination between items based on task relevance (Kimberg et al., 1997). D'Esposito and Postle (2015) describe the embedded processes model as having the functional possibility of involving memory storage occurring within the same brain circuitry as that which supports the perceptual representation of information.

Evidence for embedded cognition (c.f. embodied cognition, Lakoff & Johnson, 1980; Tversky & Hard., 2009) comes from brain imaging research. Central to such research is the assumption of integrated executive function. For example, researchers have long known about the role of lateral prefrontal cortex (lPFC) as a site of executive control. Evidence has accumulated of neuronal activation in lPFC for tasks requiring information retention over time (e.g. Fuster & Alexander, 1971; Kubota & Niki, 1971; Sabsevitz et al., 2005). Also, lPFC activity in functional imaging is assumed to act as a bridge between the stimulus cue and its contingent response. In a functional imaging study involving oculomotor (eye motion) delay tasks in humans, Curtis and D'Esposito (2003) found that lPFC was involved in retention of information, but also that the magnitude of prefrontal cortex activity correlated accurately with memory-guided eye movement. Curtis et al. (2004) suggest that such neural activity is evidence of active maintenance of task-relevant information. Non-human primate lesion lPFC studies complement human lPFC imaging study in showing impaired performance on delay tasks (Funahashi et al., 1993).

Other integrated brain regions exhibit similar patterns of neuronal activity in processing of visuospatial task-relevant information such as cingulate and inferior temporal cortices and limbic regions such as the parahippocampal bodies (Pa et al., 2008). Zelano et al. (2005) reasoned that evidence for cortical processing activity in brain regions that support perceptual processing should be seen — in the absence of stimuli — in areas of primary sensory cortex. Such effects have been observed in primary olfactory cortex (Zelano et al., 2009), in auditory cortex (Kraemer et al., 2005) and in modeling of volumetric pixel [voxel] data in fMRI haemodynamic response study involving visual cortex (i.e. forward-encoding study) (Ester et al., 2013). This effect mirrors that of associational cortical regions that integrate sensory input with top-down (conscious) cognitive processes (Buckner & Krienen, 2013) and demonstrates retention of goal-directed information consistent with embodied cognition.

Behavioural studies of phonological working memory have found activation in left parietal lobe, posterior inferior frontal gyrus (Broca's area), premotor cortex and cerebellum (e.g. Paulesu et al., 1993). Neuroscience research has aimed to determine if these areas, implicated in verbal working memory behavioural studies, are also responsible for maintenance of non-phonological processing (Cohen & Dehaene, 2004). Fiebach et al. (2006) explored the existence of a discrete neural circuitry supporting the active maintenance of non-phonological linguistic representations. The researchers used a delay task to assess whether a 'word form' area within left inferotemporal cortex was involved in active processing of visually displayed words. Analysis showed that this area of interest was preferentially recruited for active maintenance of words, but not pseudowords. This demonstrated sustained activation of phonological, lexical and semantic aspects of language, because pseudowords (pronounceable and orthographically legitimate) should not elicit activation as no stored representations exist for them. With relevance to embodied cognition, these results highlight integrated processing in discrete brain regions.

Neurological research on attentional control, as an aspect of executive function, complements findings on integrated stimuli processing. Baddeley (1986), for example, described subvocal articulations as mediators of verbal rehearsal, alongside other forms of active rehearsal in directional attention to stored representations. D'Esposito and Postle (2015) consider that the observed neural activity in delay tasks could constitute a neuroscience equivalent of rehearsal, though the authors state that limited research has been conducted on facilitative neural interconnections owing to methodological limitations. In summation of this aspect of executive function, suggestions for working memory interactions between brain regions most commonly include synaptic reverberations between recurrent circuits (Durstewitz et al., 2000; Wang, 2001) or via interneuronal synchronous oscillations (Engels et al., 2001; Singer & Gray, 1995).

The lPFC has also been linked with working memory maintenance in accordance with its likely role as coordinator of executive control. Correspondingly, a broad range of lPFC executive roles have been proposed that extend its purported role in encoding of sensory features. For instance, the lPFC has shown a broad range of task variables in delay-response tasks in testing environmental versus representational memory. Task variables include differential preferences for task rules (Warden & Miller, 2010), contingent motor responses (Romo et al., 1999) and stimulus-response mappings (Wallis et al., 2001). An increasing number of population coding studies have shown multiple tasks within the same lPFC region (Barak et al., 2010; Meyers et al., 2008; Stokes et al., 2013). Additionally, Rigotti et al. (2010) showed that multiple working memory tasks in lPFC showed concurrent task-specific modulation in complex object-sequence tasks. This finding persisted even when interference was added to test for task selectivity and it highlights two conditions within embodied cognition: nonlinear responses of lPFC to sensory input; and neural networks supporting diverse and complex task-directed ends (Sussilo & Abbott, 2009).

A likely role of the lPFC, given its task-specific neural activity, is that of a top-down modulator of sensory input (Miller & Buschman, 2013). In the execution of stored rules or goals, emanating from situational contextual cues, sensory input must be differentially enhanced or suppressed in goal-directed behaviour. Alongside other heteromodal association regions such as the prefrontal cortex, parietal cortex and hippocampus, the lPFC likely operates as the processing component of working memory in its attendance and control of actively maintained representations within primary and unimodal association regions (D'Esposito, 2007). This functional view of working memory removes Baddeley and Logie's (1999) central executive homunculus and replaces it with a goal-directed bias system that acts to modulate visual and other sensory processes, as well as memory retrieval, response execution and emotional evaluation.

Taken together, the diversity of approaches in working memory research underscores inherent cognitive limitations in processing. Perhaps more fundamentally, differences in the research aims and units of analysis between neuroscience and cognitive psychology reveal a wide divergence in cognitive models as understood amongst the respective disciplines. In addressing this gap, the goal-directedness of embodied cognition forces a reconsideration of research methods in working memory study, including individual brain development and executive function. The following sections (Sections 2.4 to 2.6) thus review literature related to individual development as well as hippocampal, amygdala and prefrontal cortical-dependent cognition. This analysis forms an important component of the literature review as it outlines a mechanistic and causative framework in the development, analysis and interpretation of the study's research objectives (introduced in Section 1.5.1).

2.4 Individual development

The following three sections attempt to link established principles of multimodality and working memory, as forwarded within cognitive psychology (Section 2.3), with specific instructional design principles held by multimedia learning theorists (Section 2.7). Within this sub-section (Section 2.4), the role of socioeconomic status (SES), as a moderator of brain development and function, is explored for its developmental consequences including variations in cognitive style and abstractive ability. Section 2.5 builds on these developmental principles and presents analysis of hippocampal, amygdala and prefrontal-dependent cognition in elucidation of a working model of embodied cognition. Following this discussion of information processing and memory, Section 2.6 examines the neurological basis of multimodality and supra-additivity in ecologically consistent presentations.

Life history theory links trade-offs (strategies) between survivorship, reproduction and growth in response to cues such as resource availability and environmental stability (Pianka, 1970). While typically used by ethologists and evolutionary biologists, life history traits such as age of sexual maturation (adrenarche), sexual debut and care of young equally apply to educational research and can be broadly understood as trade-offs between bodily development (*somatic effort*) and reproduction (*reproductive effort)* (Griskevicius et al., 2011). Age of sexual debut (Santelli et al., 2000) and adolescent birth rate (Singh & Yu, 1996), for example, are correlated with the SES gradient as measures of *reproductive effort*; *somatic effort* indicators in low SES populations, meanwhile, include increased psychiatric illness (McLeod & Shanahan, 1996; Rutter, 2003; Seidman et al., 1998) and cardiovascular illness (Davis et al., 2000; Jones, 2013).

Cognitive styles, in this context, can be viewed as behavioural agents of cognitive processing, and can serve as a proxy for underlying neural development. Within the context of the currently described thesis, this has implications for abstractive ability, and thus text design. Cognitive styles have been characterised as the ways in which learners perceive, organise and cue environmental stimuli. Messick (1984) describe how cognitive style motivates a learner's attentional resources in perception and subsequent organisation and interpretation of information, and how these interpretations are used to guide behaviour. Cognitive style differences can also be viewed from the perspective of brain development. Nelson et al. (2016), for example, emphasise the differential development of brain nodes dedicated to executive control (frontal regions), perceptual and affective processing demands. Protracted, nonlinear frontal lobe development, relative to maturation of affective-perceptive nodes, can lead to distinctions between *cognitive-regulatory* and *affective-reactive* response to socialised stimuli. Within cognitive psychology, an analogous dimension is that of Field Dependence / Independence, which has been researched in the context of socioeconomic status and found to relate to a continuum of cognitive styles (Evans et al., 2013). These cognitive styles map broadly to that of brain development and could be consistent with a life history developmental model.

Field dependence / independence relates to two contrasting methods of processing information (Guisande et al., 2007). Individuals are placed on a continuum from extreme field dependence through to extreme field independence, with field dependent individuals purportedly having greater difficulty in separating incoming information from its contextual surrounds, and more likely to be influenced by external cues. Additionally, field dependent learners are more likely to be non-selective in their information uptake relative to field independent learners who have less difficulty in separating the most essential information from its context, are more highly influenced by internal rather than external cues, and exhibit greater selectivity in information uptake (Riding & Cheema, 1991; Zhang, 2004). Field dependence/independence has been linked with school performance, with field independent students showing greater learning efficacy across all areas of knowledge (e.g. Roszkowski & Snelbecker, 1987; Tinajero & Páramo, 1997).

Three lines of research have been conducted on field dependence/independence (Guisande et al., 2007) with focus on associations between cognitive style and vigilance tasks, the relationship between cognitive style and attentional resources, and selective attention tasks. While vigilance studies have proved rather inconclusive (Amador & Kirchner, 1999), selective attention tasks have shown two behavioural differences in stimuli processing. Field dependence and Field independence subjects show differences in global versus analytical approaches to information attention, and orientation of attention to relevant and irrelevant stimuli. Field dependent students in these studies have tended to focus their attention on global aspects of the information, while field independent students focused on partial aspects. Field dependence/independence also appears to affect responses to relevant stimuli. In the presence of distracting stimuli, in auditory and visual tasks, field dependent students found it difficult to selectively attend to relevant cues, relative to field independent students, when more salient distracting agents are present (Avolio et al., 1981; Burton et al., 1995). Studies of attentional resources have involved the extent to which subjects can focus and sustain attention on information of interest, while inhibiting attention towards irrelevant stimuli (e.g. Goode et al., 2002). Macizo et al. (2006) found that performance of field dependence and field independence subjects across a range of cognitive tasks, such as reading and listening comprehension, vocabulary acquisition, and complex learning in adults, adolescents and children, was modulated in efficacy by attentional resources. Specifically, field dependence subjects were characterised as having less effective process control and reduced efficiency in the use of attentional resources.

In relation to social standing, a key contextual variate in the currently described study, Garner and Cole (1986) researched locus of control and field dependence/independence between achieving and non-achieving low- and mid-SES 7th grade students. In this study, locus of control was defined as either *internal* (individual effort) or *external* (control by others). The Group Embedded Figures Test (Oltman et al., 1971) was used for measuring field dependence along with the School Attitude Measure (Dolan & Enos, 1980) for locus of control. The results indicated a significant difference between achievers and non-achievers in low-SES students, with the biggest failure predictors being external locus of control and field dependence. In another study on SES and cognitive style, Andrews (1990) describes the development of a learning style program in a low SES elementary school in North Carolina. When all students were given Kolb’s (1985) Learning Styles Inventory, 62% of low achievers showed a preference for tactile and kinaesthetic learning and all low-achieving students were profiled as field dependence.

Cognitive style is one of numerous biobehavioural correlates of social standing. Hackman and Farah (2010) reviewed the literature on social determinants of health, and report that a strong relationship also exists between SES and cognitive ability (IQ, and school achievement among other measures). Noting the basic inability of traditional IQ tests in determining specific neurocognitive systems responsible for performance differences, they used behavioural tests to support more specific inferences. To regionalise task performance, they parsed the brain into five relatively independent systems, drawing from lesion studies and functionality in healthy subjects. They describe their functional fractionalisation of language system (left perisylvian cortex), executive / declarative memory system (prefrontal cortices), memory system (medial temporal cortex), and spatial and visual cognitive systems (parietal / occipitotemporal lobes respectively). Analyses revealed significant language and prefrontal (executive function) disparities across SES in children (see also Mezzacappa, 2004) and adults. Likewise, Lipina (2005) reported that lower-SES infants were, on average, less advanced in working memory / inhibitory control, and adult studies using neuropsychological tests have also demonstrated SES disparities in executive function and language tests (Singh-Manoux et al., 2005; Turrell, 2002). By contrast, Hackman and Farah (2010) note that visual and spatial processing weren't associated with SES.

Hackman and Farah (2010) proposed mechanisms for SES disparities in cognitive tasks. They describe the prolonged process in which certain brain circuits and regions reach maturity and highlight the susceptibility of language and prefrontal regions to environmental influences in development. Perceptual and hippocampal / medial prefrontal memory systems innervate and mature relatively early in development (Pavlova et al., 2001; Tzourio-Mazoyer et al., 2002) and are presumably shielded from adverse environmental stressors. The authors conclude that lower SES is associated with higher levels of stress that can compromise physiological stress response systems. Highlighting this form of environmental stress, O'Donnell et al. (2014a,b) found that SES differences in the executive function of attention, planning and verbal working memory were mediated by maternal sensitivity and aspects of the child's home environment.

With further implications for the association between SES and cognitive style, in longitudinal study Wadsworth and Achenbach (2005) reported SES differences in scores of anxious / depressed behaviour, somatic complaints, thought problems, and delinquent and aggressive behaviour. In relation to accounts of elevated incidence of psychopathology as a feature of SES, Oort et al. (2010) tested the Social Causation Hypothesis (McLoyd, 1998) that suggests that SES adversity leads to poorer mental health outcomes. In contrast to the alternative hypothesis, that those with psychological problems drift down the social ladder, longitudinal assessment of Dutch and US children (whose behaviour cannot determine the family's social position) led to the conclusion that social causes lead to a number of syndromes, both emotional/behavioural and somatic. This effect strengthens the assumed link between SES and cognitive style in the context of resource availability; it also highlights the subjective nature of social gradients given the existence of universal health coverage in the Netherlands.

Social gradients are predictive, therefore, of psychopathology and disease incidence. Moreover, the direction of causality is suggestive of social rank as a mediator of disease sequela in multiple body systems. Related cognitive styles can be predictive of underlying neural development and are possibly receptive to cues of social adversity. Additionally, dimensions of cognitive style can modulate perceptual and attentional processes which possibly translate to differences in learning style. Having presented social standing as a moderator of cognitive style and ability, research on *allostasis* and related mechanisms of physiological impairment are presented in the following section. These details inform the research design via elucidation of specific mechanisms of SES stress impairment prior to further examination of the stress response in cognition.

2.4.1 Allostasis

Allostasis originates from the work of Hans Selye (1976) as bodily processes involved in insuring viability in the face of challenge and change. Homeostatic mechanisms tend to resist changes of state; allostatic mechanisms, by contrast, are responsive to anticipatory needs and function in adaptive responses to seasonal or daily environmental fluctuations (Schulkin, 2003, p. 17). Sterling and Eyer (1998) describe how allostasis involves the whole brain and body rather than the simple feedback loops of homeostasis. Allostasis involves feed-forward, cephalic roles in regulatory physiology and differs from homeostasis in the possibility of chronic overactivation of stress networks involved in preparative and stimulatory neuroendocrine function.

Allostasis highlights our evolved ability to anticipate and adapt to change. Schulkin (2003) describes key components of allostasis in terms of allostasis, allostatic state and allostatic overload. Allostasis, as mentioned, refers to processes by which an organism achieves internal viability through bodily changes of state. Behavioural and physiological processes are employed in the maintenance of internal parameters in limits essential for life, and common physiological mediators include glucocorticoids, dehydroepiandrosterone (DHEA), catecholamines, pituitary hormones, neuropeptides and cytokines (McEwen, 1998a; 2001). Allostatic state is the chronic overactivation of regulatory systems and the alterations of body set-points (Schulkin, 2003, p. 21). Allostatic overload refers to the expression of patho-physiology as a consequence of chronic overload of regulatory systems. Viewed from the short term, allostatic regulatory mechanisms are adaptive and serve a beneficial role (Dorries, 2001; Sapolsky et al., 2000). However, long-term arousal of regulatory systems in allostasis can compromise bodily function, both in the central nervous system (CNS) and in peripheral body systems (Sapolsky, 2000a).

Because glucocorticoids play a key role in stress reactivity, they have been the subject of allostatic research (e.g. Dallman et al., 2000; Schulkin, 2004, p.81). Sapolsky (2000b) reviewed glucocorticoids and stress and summarised their role in four contexts: permissive, suppressive, stimulatory and preparative actions. Adaptive, short-term allostatic responses include the stimulatory role of glucocorticoids in boosting immune mediators and amygdala-dependent memory formation (Cahill & McGaugh, 1998). Within the context of allostatic dysregulation, the stimulatory and preparative actions of glucocorticoids have downstream pathological effects in the cephalic regulatory role. With prolonged activation, glucocorticoids can compromise bodily function — stimulatory and preparative glucocorticoid action can compromise the function of the same immune mediators boosted in the glucocorticoid stimulatory role. Common examples of allostatic overload include loss of bone mass, immune dysfunction, depression and neural atrophy in the hippocampus and areas of neocortex (McEwen, 1998a). Compromising hippocampal function impairs normal hypothalamic-pituitary-adrenal axis (HPA) activity and memory processes and leads to greater allostatic overloading due to the HPA’s role in stress reactivity feedback (Sapolsky, 2000a). Glucocorticoids are multi-functional (pleiotropic) steroid hormones, although they primarily function in an immunological role and in the metabolism of glucose. Prolonged glucocorticoid secretion can therefore compromise glucose transport and use and energy storage and use which alongside its activation of excitatory amino acids, explains its effect on multiple body systems including metabolic, psychiatric and immunological conditions (McEwen, 2001, p. 23). For this reason, cortisol, the main human glucocorticoid, is often the focus of research on stress activated neuronal toxicity, dendritic atrophy and reduced neurogenesis (Bremner et al., 1995, 2000; McEwen & Sapolsky, 1995; Sapolsky, 1992, 2000b).

Schulkin (2003, p. 22) describes three forms of allostatic overload. Firstly, overstimulation by frequent stress results in excessive stress hormone exposure. As mentioned above, indicators of allostatic overload appear in multiple organs and organ systems and enhance susceptibility to disease from changes in immune sensitisation processes (Dhabhar, 2008). Secondly, allostatic overload is characterised as failure to inhibit allostatic responses when they aren't required, or an inability to habituate to the same stressor. Both conditions result in overexposure to stress hormones. The inability to stimulate allostatic responses when needed constitutes a third variant of allostatic overload, with resultant pathophysiology due to hyperactivity of other systems (e.g. inflammatory cytokines) normally suppressed by stress hormones.

An adaption becomes a pathology, within the allostasis literature, when its physiological expression continues for too long (Schulkin, 2003, p. 22). Correspondingly, the role of social gradients in allostasis was an initial impetus in the development of allostatic theory due to earlier work on social determinants of health inequality (e.g. Crimmins & Saito, 2001; Donkin et al., 2002). Seminal work by Eyer and Sterling (1977) on 'Stress related mortality and social organisation' addressed 'chronic arousal' as a feature of low social standing as causal to the onset of a variety of disease states. Such chronic arousal, according to Koob and LeMoal (2001), results in overactivation of allostatic anticipatory mechanisms, feedforward mechanisms and eventual allostatic overload. Social rank is thus linked with allostatic overload which results in inequitable disease load in poorer communities through the chronic overactivation and exaggerated expression of cortisol. Moreover, dysfunctional behavioural expression and altered appraisal signals to danger are noted in low SES populations (McEwen, 1988b, 1999; Van Cauter et al., 2000). Higher cortisol levels in non-human primates relate to fight initiation, inability to distinguish between threatening and neutral stimuli, defeat and lower social dominance (Sapolsky, 2001). Lupien, King, Meaney, and McEwen. (2000) found in children that SES and a mother's vulnerability to depression affect cortisol levels. Biobehavioural correlates of cortisol in human research therefore relate to the altered reproductive and somatic strategies outlined previously.

The ‘wear and tear’ of allostatic overload on body systems has been the focus of research on early-life socioeconomic disadvantage. Gruenewald and colleagues (2011), for example, note the inverse risk association between SES and health, including risk of disease-specific and all-cause mortality. The possibility of a common biological mechanism underlying health disparities linked with SES adversity was raised by the authors. To test this proposition, the researchers examined whether greater life course SES-adversity experience would be linked with higher scores in a multisystem allostatic load index of adulthood physiological function. Usage of a multisystem allostatic load index follows from the heightened risk that experiential and behavioural correlates of SES place on major morbid conditions affecting multiple body systems. Allostatic scores were aggregates of 24 biomarkers from seven distinct physiological systems. These systems included: sympathetic nervous system, parasympathetic nervous system, HPA axis, cardiovascular system, lipid metabolism, glucose metabolism and inflammatory immune activity. SES risk indices were computed at three time periods (childhood and two at adulthood - participants were a substudy of the Midlife in the US MIDUS longitudinal study). Childhood SES was computed by summing financial level while growing up, highest level of parental education and childhood welfare status. Adult SES measures were made by summing values at each time point: education level, family-adjusted income-to-poverty ratio, current financial situation, availability of money to meet basic requirements and difficulty in paying bills.

The findings indicate higher levels of allostatic load in middle and later adulthood in those who have experienced greater levels of SES adversity across the lifespan from childhood to adulthood. Moreover, greater allostatic load was associated with greater life course SES adversity, irrespective of whether cumulative SES adversity was measured as higher summary scores of SES adversity information from childhood and two points in adulthood, or as persistent SES adversity in both childhood and adulthood. Additionally, inclusion of covariates of ‘risky’ behaviours associated with low social standing from a wide domain of potential mediators (health, status, behavioural, psychosocial) in the analytical models resulted in little change in the magnitude of the associations between SES variables and allostatic load.

This study and others (e.g. Goyman & Wingfield, 2003) have addressed the time course of associations between allostatic load and social standing. Different theoretical frameworks have motivated research, including accumulation of risk models, status mobility models and sensitive / critical period models (Seeman et al., 2010). Accumulative versus additive processes of risk have been investigated within these frameworks, as have possibilities of amendment in status adjustment. Additive processes, for example, are acknowledged in the literature in that individuals who consistently hold low-SES positions are predicted to fare the worst, while the upwardly mobile are likely to benefit physiologically over the life span (Geronimus et al., 2006; Weinstein et al, 2003). Sensitive and critical period models are used, for example, in mapping purported HPA sensitivity to stress hormones in mid-gestational and perinatal development (e.g. Ben-Shlomo & Kuh, 2002).

Theorists assume differential effects on physiological functioning depending on the life course phase in which adversity is experienced, with early life SES adversity permanently affecting developing biological systems (Pollitt et al., 2005). The strongest experimental evidence points towards the cumulation of risk model as seen in cumulative health issues such as weight gain and inflammatory burden (Loucks et al., 2010). Gruenewald et al. (2011) describe less consistent support for protective effects and upward mobility, although some authors have reported adult measures as having greater explanatory power than childhood measures. Nonetheless, other researchers have found significant allostatic load associations for childhood SES that are independent of adult social standing (Tamayo et al., 2010).

Allostasis and allostatic load research highlights the effects of stress on development and provides mechanisms of cognitive impairment. In providing an explanatory account of disease, including psychiatric disease, as a feature of social standing, allostasis offers a diachronic / ontogenetic and sequential perspective of causation and function (c.f. Tinbergen’s ‘four questions’, 1963). What is required for a fuller synthesis, though, is elucidation of specific mechanisms underlying perceptual, affective and cognitive processing. This is important for the current study for two main reasons: firstly, SES should be viewed as a universal moderator of cognitive development and, in extension, (b) SES is likely associated with variations in abstractive ability. The specific association between social standing and stress hormone dysfunction is presented in the following sub-section (Section 2.4.2). After laying this developmental groundwork, analysis of stress-mediated neural plasticity is presented in Section 2.4.3 to establish mechanisms underlying perceptual and cognitive processes in learners.

2.4.2 Socioeconomic stress

When determining the cause of frequent stress activation, socioeconomic status is commonly implicated. Cohen et al. (2006) reason that people of lower SES are "embedded within environments characterised by high levels of psychosocial disruption that increase the risk of disease by continuously provoking stress-elicited dysregulation of key behavioural and biological systems" (p. 414). Lupien et al. (2001) suggest that individuals of lower SES are exposed to greater change and instability, and that instability has been found to produce a higher level of distress in lower-SES individuals.

The SES and stress literature has emphasised the link between quality of early environments and later-life disease patterns. Chrousos and Kino (2007), for example, state that elevated plasma low density lipoproteins (LDL), decreased sensitivity to insulin and impaired immune response are all mediated by modified patterns of neonatal stress hormone activity. A growing body of research into fetal origins of adult disease (FOAD) likewise connects perinatal socioeconomic stress with ongoing disease, including psychiatric disorders (Gillman & Rich-Edwards, 2000). Snowdon et al. (1989), for example, conducted a prospective longitudinal study of elderly nuns, relating survival and independence to childhood socioeconomic status. The living arrangements of the nuns allowed the researchers the ability to control for multiple confounds as the sisters all lived in similar housing with similar diet and healthcare. A strong relationship reported between measures of SES and longevity and patterns of disease links quality of early environment with health in later life. Sapolsky (2004a, p.178) comments that it is remarkable that background SES status so precisely tracks epidemiological data, including psychiatric pathology, in advanced age despite decades of uniformity in living conditions.

Socioeconomic gradients appear to exert the greatest effect in unequal communities (Elo, 2009). However, even in nominally egalitarian societies such as Canada, SES is associated with chronic activation of the stress response. Lupien et al. (2001) measured diurnal glucocorticoid levels of SES-differentiated public-school children in Montreal to further understanding of the global association between SES and health. Six groups of children aged between six and 16 years were formed and divided into two categories of SES - high and low. Parental interviews were conducted, using the Derogatis Stress Profile (DSP) and Family Inventory Life Experience (FILE) surveys to determine SES information in addition to objective SES measures gained from the Montreal Schooling database.

In this study, glucorticoid saliva assays showed marked rises in morning glucocorticoid levels in low SES students compared with high SES students. This effect persisted up until high school age. Moreover, the largest glucocorticoid difference occurred for 10-12 year olds, corresponding with the increased pubertal production of gonadal steroid hormones. Parental questionnaire data revealed how stress manifested in low- and high-SES households: low SES families reported greater environmental stressors, whereas high SES respondents attributed greater stress to work and family transitions.

Cohen et al. (2006a) found that lower income and education were associated with higher levels of glucocorticoid during the evening and at bedtime in a sample of 781 middle-aged adults in the CARDIA study. In a different study, Cohen et al. (2006b) found that lower levels of income and education were associated with higher levels of total glucocorticoid concentration over the day in a recruited sample of 193 adults aged 21–55 years. Data from 6335 participants in the 1958 British Birth Cohort Study with saliva collected at age 45 years found that lower lifetime SES was associated with a greater risk of extreme post-waking cortisol values.

Some researchers have noted the greater predictive ability of subjective versus objective social standing in studies of environmental stress. As an example, in an extension of Gianaros et al. (2005) study of subjective social standing and anterior cingulate morphology, Wright and Steptoe (2005) provide mixed results on SES and glucocorticoid awakening response (GAR). Specifically, they found a relationship between lower subjective social status and higher GAR, but a weak relationship between level of education or financial strain and GAR in adults aged 65–80 years. It is noteworthy that Braveman et al. (2005) found that conventional measures of SES only modestly correlate with markers of stress pathology, seemingly highlighting the validity of subjective social standing as a measure of SES-induced stress.

Drawing from 5486 British civil servants as a subset of the Whitehall II study, Singh-Manoux et al. (2005) reported objective and subjective SES as global measures of socioeconomic status and found both to be significantly associated with health outcomes. However, when objective and subjective SES measures were modelled simultaneously in an analysis of mental and physical component scores, along with self-rated health, only subjective accounts continued to be significantly predictive of health outcomes. Nonetheless, the authors consider measures of objective and subjective SES to be composite measures of SES and concluded from correlation analysis that this is the case. The authors speculate that three aspects of subjective social standing make it a better health measure than objective SES. Subjective SES as a multidimensional quality could be more precise than traditional SES measures which do not account for nuances, such as the perceived quality of one university versus another for those graduating with equivalent degrees. Secondly, the authors emphasise the hierarchical nature of subjective social standing. Subjective status reflects a 'relative' versus 'absolute' social position and emphasises the possibility of relative differences amongst environments of similar objective SES. Finally, the authors raise the point that subjective SES and health possibly represents a spurious association. It is possible that self-assessment of SES is mediated by health status, or that health ratings and measurement of subjective status are biased by a common variable such as response bias. However, previous research (e.g. Operario et al., 2009) and the method employed by Singh-Manoux et al. (2005) in this longitudinal study help to rule out response bias and reverse-causality. In explanation, Singh-Manoux et al. (2005) describe avoidance of validity issues in SES data being gathered at phase 4 (1997-1999) and health data at phases 5 and 6 (2001-2002). This reduces response bias through response set or social desirability issues where, for example, respondents who rank themselves highly in social rank also self-report better measures of health.

Additionally, when examining social and economic status and dysregulation of stress-emotion biological systems, it is essential to address the strength and direction of the relationship. Examining socioeconomic gradients and rates of mortality, Evans (2002) cites OPCS (1978) data which reveal a strong negative relationship between social class and mortality rate in longitudinal data drawn from British and Welsh men between 1911 and 1981. Moreover, Evans states that, despite improvements in living conditions and public health, and reduction of incidence of specific diseases, the SES-disease gradient persists. This indicates that absolute levels of income per se are less important than gradients of relative wealth. Indeed, Evans notes that the "roots [of the SES health gradient] lie beyond the reach of medical therapy" (p.19). The association between SES-gradients and disease has attracted criticism due to the incidence of risky behaviours in low SES populations (e.g. Pickett & Pearl, 2001). However, the multivariate analyses of the Whitehall studies (Marmot et al., 1991) helps to rule out risk factors such as incidence of smoking and lung cancer in low SES groups. The longitudinal prospective Whitehall studies involved social determinants of health from nearly 30,000 British civil servants over a 20-year period. When factors such as smoking, cholesterol, blood pressure and level of exercise were controlled, social standing still accounted for over 60 percent of disease incidence (Bartley et al., 2000).

Having established SES as a causative influence in stress activation and a likely contributor to dysfunctional allostasis, specific targets of stress are described in Section 2.4.3. As mentioned in Section 2.4, mediators of allostasis include brain networks involved in perceptual, affective and cognitive processes. Given the important role of affect as a contributor to cognitive style, including its hypothesised association with abstraction (see Sections 2.5 and 5.4) an understanding of stress and plasticity influences considerations of learning motivation and links with the learning objectives presented in Section 1.5.1.

2.4.3 Stress and brain plasticity

Donald Hebb (1949) wrote that man is the “most emotional of animals” in reference to the fact that, with the development of more sophisticated nervous systems, the degree of emotionality increases across species. Brosch et al. (2013) suggest that emotion can thus play an adaptive function, requiring a high degree of processing complexity in allowing for decoupling of stimuli from behavioural response. Flexible adaptation to environmental contingencies, such as that explored from the context of social standing, affords the individual specific physiological response such as in stimuli processing. Manifesting as motivated behaviour, attentional and cognitive strategies can be understood via emotional stimuli processing as opposed to inflexible stimulus-response action tendencies. To explore this further, this section reviews the mechanisms of brain plasticity associated with social environments of upbringing.

Emotions are central motivational states of the brain that underlie behavioural adaptation to our environments of upbringing (Schulkin, 2003). Emotional regulation occurs in the central nervous system and is regulated by the same neurotransmitters and neurohormones that moderate physiological response in areas peripheral to the central nervous system (Gunnar & Quevedo, 2007), such as in hypothalamic-pituitary-adrenal (HPA) axis function. Pessoa (2008) describes regions implicated in emotional regulation, such as amygdala and basal ganglia, as being highly interconnected with neural systems that underlie perception, cognition, homeostasis and behaviour. These networked areas share functional roles in processing social and emotional stimuli, and include the hippocampal bodies, amygdala, medial and ventromedial prefrontal cortex, cingulate cortex as well as areas of parietal and temporal lobe.

Studies have focused on key brain regions as hubs involved in the recruiting and integration of a wide range of the brain's computational resources in the processing of socioemotional stimuli (e.g. Sporns et al., 2007; Young et al., 1994). Such stimuli are salient and engage attention, effectively prioritizing social and emotional data for processing over other classes of information. Research consistently identifies the hippocampus (McGowan et al., 2009), amygdala (Fuchs & Flugge, 2003) and prefrontal cortex (Arnsten, 2009) as areas that integrate socioemotional stimuli, highlighting their importance when considering the developmental plasticity of these regions. Figure 2.5 shows a longitudinal section of the limbic system including infralimbic prefrontal cortex (Brodmann area 25).

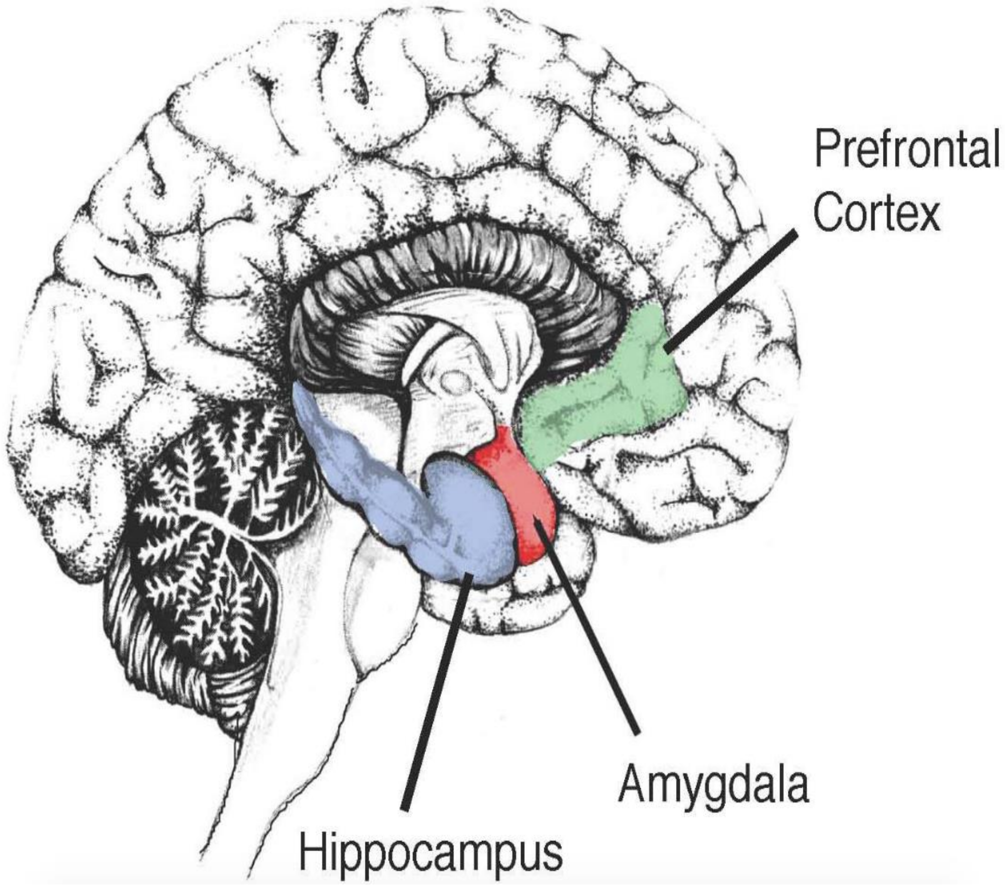

Figure 2.5 Hippocampus, amygdala and prefrontal cortex (Cooper & Mulvey, 2015)

When examining stress-induced dysfunction in these brain areas, it is necessary to consider the neurobiology of the stress-emotion system. In the paraventricular region of the hypothalamus, corticotropin releasing hormone (CRH) is produced and travels to the anterior pituitary gland where adrenocorticotrophic hormone (ACTH) is stimulated and released. ACTH is released into general circulation and stimulates the release of the corticosteroid *glucocorticoid (cort* in Figure 2.6*)* from the adrenal cortex (Sapolsky & Meaney, 1986). As previously mentioned, glucocorticoids mobilise the body for action through energy substrate availability and utilisation, and glucocorticoid blood serum concentration provides feedback to the stress system at the pituitary, hypothalamus, hippocampus and frontal cortex (Kaufman et al., 2000). This system is called the hypothalamic-pituitary-adrenal (HPA) axis for its interconnected components.

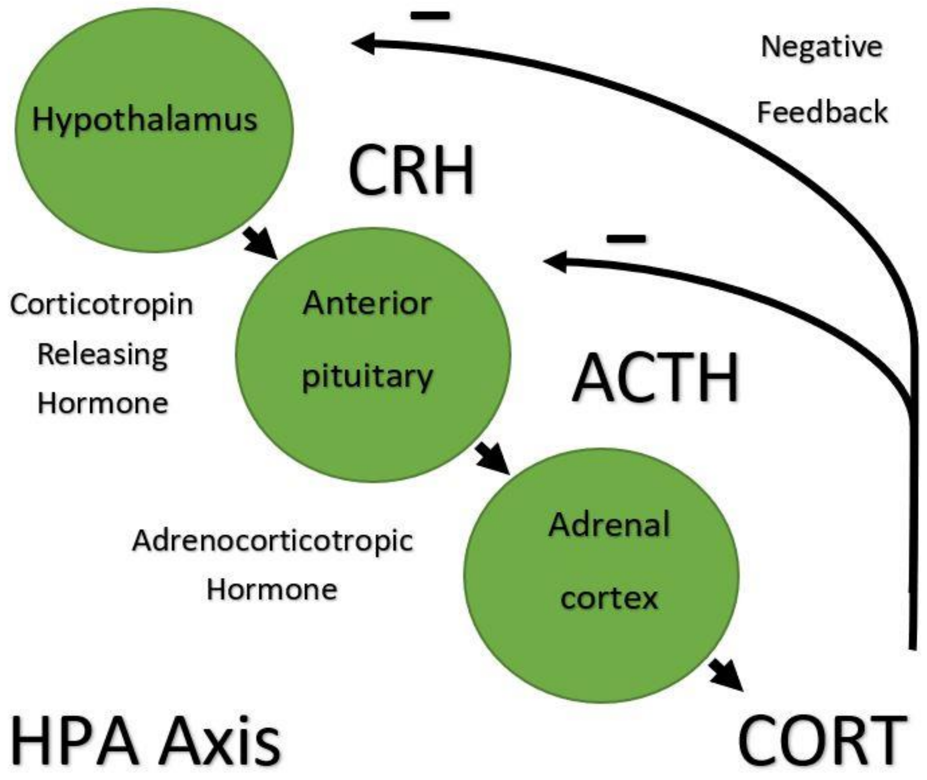

Figure 2.6 Stress and the HPA axis (figure adapted from Xiao, 2015)

Glucocorticoids play an essential role in physiology by readying the body for response to danger and for learning (Gunnar, 2007). Glucocorticoids produce their effect primarily through gene expression, and virtually all cells contain glucocorticoid receptors (Wu et al., 2006). Glucose production, for example, is initiated when glucocorticoids dock to receptors in liver or kidney cells. This transcription can take minutes or hours to mediate effects on brain or body and, as described above, glucocorticoids can broadly be defined as having four roles in stress: permissive, stimulatory, suppressive or preparatory (Sapolsky et al., 2000). The preparatory role appears to follow prolonged exposure to high levels of glucocorticoids and lowers the threshold for activation of the parasympathetic reverberating threat system, making it easier for mild threats to activate and maintain anxious, vigilant defensive responses (Rosen & Schulkin, 1998).

The structural and functional integration of cortical and limbic regions in the stress response is discussed by Kaufman et al. (2000). They describe how the medial prefrontal cortex (mPFC), anterior cingulate and orbitofrontal cortex (oPFC) relay information from primary sensory and association cortices to subcortical structures involved in glucocorticoid, dopamine and noradrenaline feedback. The medial and orbital PFCs are reciprocally interconnected, provide direct inputs to the hypothalamus and are reciprocally connected with the amygdala. The medial PFC also shares connections with brainstem nuclei, and the hippocampal bodies directly project to medial PFC via pyramidal CA1 cells and the subiculum of the hippocampal formation. Figure 2.7 provides a diagrammatic overview of corticolimbic system connectivity (Kaufman & Charney, 2001).

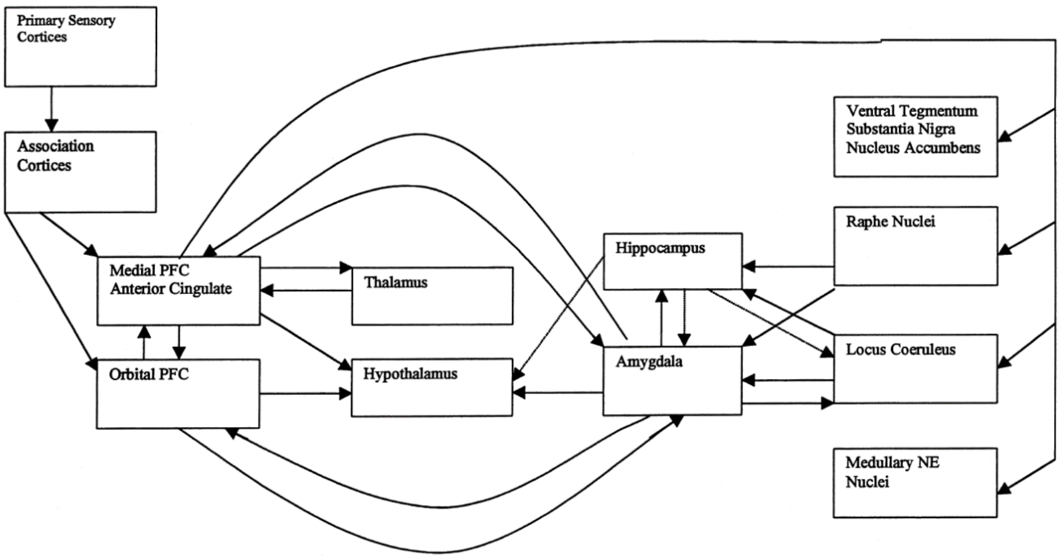

Figure 2.7 Connections between cortical and subcortical brain regions (Kaufman & Charney, 2001)

Additionally, Kaufman and colleagues (2001) describe inhibitory and stimulatory modulation of forebrain and limbic systems via glucocorticoid, dopaminergic and noradrenergic feedback. Notable inhibitory inputs exist between the hippocampus and amygdala, and between the hippocampus and prefrontal and association cortices. Glucocorticoid itself operates in a classic feedback loop, whereby elevated levels of the hormone inhibits CRH production in the hypothalamus and consequent production of ACTH from the anterior pituitary. In short, the hippocampus and prefrontal cortex are inhibitory bodies, while the amygdala and norepinephrine (NE) inputs from medullary nuclei exert stimulatory effects during stress. Impaired stress responsiveness results from inhibitory dysfunction and causes allostatic 'wear and tear' on multiple body systems (Sapolsky, 2004b, p. 38).

Studies demonstrate the putative link between childhood abuse and hippocampal inhibitory pathology. McGowan et al. (2009) examined levels of hippocampal-specific glucocorticoid receptor messenger RNA (mRNA) and methylation status – silencing – of the promoter region involved in glucocorticoid receptor transcription in suicide victims and controls. Suicide completers were from two populations: those with a history of childhood abuse (n=12) or without abuse (n=12). Additionally, a control sample of 12 participants who had died of sudden, accidental causes was included. The team found a significantly decreased level of glucocorticoid receptor mRNA and increased cytosine methylation of the receptor promoter region in suicide completers with childhood abuse compared with both other groups.

From these findings, McGowan and colleagues (2009) postulate that inhibition of glucocorticoid negative-feedback responsiveness to stress is a corollary of glucocorticoid receptor transcription downregulation in the hippocampus. The nature of causality between hippocampal glucocorticoid receptor density and suicide per se appears straightforward as suicide completers without abuse and controls both had higher glucocorticoid receptor mRNA expression with similar methylation status, thereby associating this effect with childhood abuse. Accordingly, McGowan and colleagues discuss research on maternal mood disorders being associated with decreased maternal sensitivity, depression in offspring and impaired mother-infant interactions. When it is considered that cytosine methylation is a highly stable epigenetic mark – i.e. environmentally determined – heightened stress reactivity is directly linked to the environment of development and can be intergenerational in nature (Kim & Costello, 2017).

While McGowan et al. (2009) provide a plausible mechanism underlying hippocampal plasticity in relation to stress in childhood, other studies demonstrate specific hippocampal morphology associated with stress. Vythilingam et al. (2011) performed a volumetric analysis of hippocampal volume of 46 clinically depressed and control women using MRI imaging. Of the depressed subjects, 21 had experienced prepubertal abuse (sexual, physical or neglect), and a further eleven had no history of childhood abuse; and a control sample consisted of 14 healthy adults. Depressed subjects with a history of childhood abuse had 18% smaller mean left hippocampal volume than the non-abused depressed subjects, and a 15% smaller mean left hippocampal volume than the healthy subjects.

The authors discuss the association of psychosocial stress with reduced declarative memory, elevated glucocorticoid levels and hippocampal dysfunction. They also draw on previous preclinical research demonstrating chronic psychosocial stress and glucocorticoid administration inhibiting neurogenesis in the dentate gyrus region of the hippocampus (Eriksson et al., 1998), atrophy of hippocampal neurons (Lupien et al., 1998) and remodelling of the apical dendrites of pyramidal neurons of the CA3 hippocampus region (Magarinos et al., 1999). Furthermore, they suggest that earlier research on hippocampal morphology in depressed patients was often inconclusive because it failed to include data on preadolescent abuse.

Stress-induced hippocampal plasticity is also seen in healthy populations. Ganzel et al. (2008) demonstrated reduced hippocampal grey matter volume in adults who lived in close proximity to the World Trade Centers in New York, three years after the 2001 attacks. Relative to other healthy adults, proximity to the stressful event appears to correlate with grey matter volume not only in the hippocampus, but also in parahippocampal cortex and amygdala.

Neuronal atrophy has been demonstrated by Woolley et al. (1990) to occur after exposure to three weeks of stress in otherwise healthy populations. Watanabe et al. (1992) attribute deficits in hippocampal-dependent cognition to the reversible decrease in number and length of apical dendritic branch points mediated by this level of overexposure to glucocorticoids. More sustained levels of stress can lead to permanent loss of hippocampal neurons — neurotoxicity (Sapolsky, 2000a). Experimental exposure of rats to high concentrations of glucocorticoids for approximately 12 hours a day for three months involved a 20% loss of CA3 neurons (Brumelte & Galea, 2010).

Reduction in hippocampal volume is also caused by reduced neurogenesis (Gould & Cameron, 1996). Granule cells in the hippocampal dentate gyrus continue to proliferate into adulthood and neurogenesis is markedly reduced by stress (Mirescu et al., 2004). Maltreatment studies in mammals, including non-human primates, indicates that methylation status — and subsequent expression — of brain-derived neurotrophic factor (BDNF), which functions in cortical and subcortical neurogenesis, is linked with quality of early care and variations in resource allocation (Roth et al., 2009).

The prefrontal cortex (PFC) shows similar trends as the hippocampus in pathophysiology from overexposure to glucocorticoids. The PFC occupies the anterior portion of the frontal lobe and is broadly involved in higher cognitive functions such as executive control and emotional regulation (Wallis, 2007). The hippocampus and PFC function as negative feedback inhibitors of HPA activity, and studies have focused on their structural and functional interconnectedness (Bazzari & Parri, 2019; Howland & Wang, 2008). Cerqueira et al. (2007) discuss how the modulation of synaptic activity between the hippocampus and PFC contributes to synergistic regulation of learning and memory processes alongside stress inhibition. To model the effects of chronic stress on associative learning, they reasoned that stress induced plasticity of the hippocampal-medial PFC axon pathway would reveal deficits in selected learning and memory tasks, alongside specific PFC neural atrophy. In a series of experiments, they examined long-term potentiation in the hippocampal-PFC pathway of stressed versus control rats involved in PFC and hippocampal-dependent tasks.

Analysis of behavioural tasks and stereological brain imaging showed significant differences in stressed and non-stressed animals. Layers I and II of all regions of the medial PFC were significantly smaller in animals exposed to chronic, unpredictable stress. Chronic stress also impaired performance in working memory and reference memory tasks, including behavioural flexibility. The authors concluded that hippocampal - PFC long-term potentiation is dependent on PFC synaptic plasticity and is directly modifiable by environmental stressors.

Arnsten (2009) describes the loss of human dendritic material in PFC layers II and III following exposure to chronic stress. Such loss relates to PFC networks losing dendritic material — dendritic length, branching and spine density. They note that established synaptic connections could be especially vulnerable to stress, and that dendritic changes appear associated with marked PFC dysfunction in areas such as working memory. The authors discuss the susceptibility of the PFC to stress plasticity. While hippocampal plasticity requires weeks of exposure to chronic stress, PFC plasticity can be evident after as little as a single exposure to chronic stress.

The anterior cingulate cortex (ACC) is an evolutionary old cortical system (Allman et al., 2001) and occupies much of the medial wall of the prefrontal cortex. Plasticity of the ACC is notable as dorsal ACC projects to PFC and frontal eye fields (Ridderinkhof et al., 2004) alongside ventral ACC 'emotional' projections to amygdala and hypothalamus. Indeed, subdivisions of the ACC have been described in terms of a dorsal cognitive-motor division, a ventral visceral-motor division, and an intermediate affective division (Bush et al., 2000). A particular subdivision of the ACC, the perigenual ACC, has been linked in neuroimaging and lesion studies to the appraisal of environmental and personal events, the experience of emotional states, and behavioural and autonomic response to stressful and emotional stimuli (Vogt, 2005).

In order to extend animal studies of social hierarchy showing perigenual ACC (pACC) structural plasticity, Gianaros et al. (2007) used voxel-based morphometry to assess homologous regional grey matter volume in human subjects differentiated by subjective accounts of social standing. They used Adler et al.’s (2000) pictorial scale of a 'social ladder' to garner respondents perceived social standing and controlled for confounds including subclinical depressive symptoms and conventional objective measures of socioeconomic status. They report that grey matter volume in the pACC covaried with perceived social standing, emphasising the potential impact of this plasticity on the pACC's role in experiencing emotions and regulating behavioural and physiological reactivity to psychosocial stress. With relevance to research objective 2 (Section 1.5.1), this finding mirrors that of Braveman et al. (2005) and others as described in Section 2.4.2.

Further understanding of ACC morphology and HPA dysfunction emerged from a study by Alasdair et al. (2006) who examined volumes of bilateral anterior cingulate cortex and HPA dysfunction in elderly men. Two groups of ten 65-70 year olds, namely, suppressors and non-suppressors of endogenous glucocorticoid, were formed following administration of the synthetic corticosteroid dexamethasone. Nonsuppressors had significantly smaller left anterior cingulate cortex volumes than suppressors, and the authors suggest that this indicates an important role for the anterior cingulate cortex in suprahypothalamic feedback regulation of the HPA axis. While this study didn't consider stress-induced dysfunction per se, it can reflect depression-like abnormalities of the ACC and HPA dysregulation either accompanying, or compounding, the aging process. Individual differences in respondent ACC morphology can also reflect stress in upbringing.

The amygdala is comprised of several nuclei in the medial anterior temporal lobes which project to numerous corticolimbic regions. It is well known for its role in fear conditioning (Lopez et al., 1999), formation and storage of emotionally salient memories (Kilpatric & Cahill, 2003), and stimulation of the HPA axis (Tsigos & Chrousos, 2002). The amygdala supports the rapid assignment of emotional and behavioural salience to environmental events by integrating multimodal sensory inputs from distributed cortical, thalamic and brainstem afferent relays (LeDoux, 2003), and it possesses glucocorticoid receptors similar to hippocampus and prefrontal cortex (Conrad et al., 2004).

Stress processing occurs between the amygdala's central nucleus and paraventricular hypothalamic nuclei, as well as in prefrontal networks (Herman & Cullinan, 1997). Unlike the hippocampus and PFC, the amygdala shows dendritic growth under chronic stress situations, enhancing amygdala-dependent unlearned fear conditioning. Perhaps not surprisingly, this parallels impairment in hippocampal-dependent cognitive function (Vyas et al., 2002).

Studies of emotion regulation highlight amygdala activation, typically observed in functional magnetic resonance imaging (fMRI) studies involving presentation of hostile, angry or otherwise emotionally salient faces (Batty & Taylor, 2006; Hariri et al., 2003). For example, Taylor et al. (2006) hypothesised that amygdala response in 'risky' children, as assessed by an adapted version of Felitti et al. (1998) Risky Families questionnaire, would be inversely related to activity in the right ventrolateral PFC which is a brain region implicated in emotional regulation, such as in verbalising negative experiences — perhaps as a coping strategy. Using functional magnetic resonance imaging (fMRI), Taylor and colleagues presented a series of emotional stimuli to 30 participants in order to measure haemodynamic response in amygdala and right ventrolateral PFC. The stimuli were a series of negative faces which were either unmarked or accompanied by two alternative emotions printed on the card.

Analysis showed expected amygdala response to faces in non-risky children, along with expected right ventrolateral PFC activation while labelling emotions. As expected, a moderate negative correlation of activity between the two occurred in the two viewing paradigms. By contrast, risky children showed little amygdala activation in the faces-only viewing, and a strong positive correlation between amygdala and right ventrolateral PFC activity in the labelling task. The authors reasoned that amygdala activation to negative emotions can become habituated in risky children, and normal coping strategies involving regions such as right ventrolateral PFC are not recruited. The higher amygdala activity during the labelling task in risky children could reflect an avoidance strategy resulting from impaired right ventrolateral PFC function that is unsuccessful in deactivating the amygdala in non-risky children. This research offers insight into the mechanisms underpinning overreaction to stressful socioemotional stimuli among children in stressful or low SES environments, and the concomitant lack of cognitive regulation of emotions.

Acute and chronic stress modifies glucocorticoid homeostasis by altering amygdala-hippocampal-PFC networks. Arnsten (2009) describes how the effects of acute stress drives cognition towards more ancient brain regions. For example, social stress tests such as the Trier test involving public speaking have been shown to impair cognitive flexibility and working memory which are both PFC-dependent (Alexander et al., 2007), and to drive long-term potentiation of amygdala-ventromedial PFC circuitry (Britton et al., 2011). The altered catecholamine, glucocorticoid and dopamine response by the amygdala under chronic stress induces positive feedback towards ever greater amygdala inhibition of both PFC cognition / regulation and PFC-hippocampal suppression of the HPA stress response (Makino et al., 2002). The way this reorients attention from 'top down' thoughtful regulation by the PFC to 'bottom up' sensory-based information mediated by stress-induced, hypertrophic amygdala projections is important for this study. This represents a hypothetical association of stress mechanisms and allostatic load (Section 2.7.1) with the Field-Dependence / Independence cognitive style dimension identified previously.

This section has outlined mechanisms of hippocampal, PFC and amygdala plasticity in relation to social stress. As seen, these variations constitute a predictive contextual factor and thus form an essential basis of individual development. In isolating the PFC, hippocampus and amygdala as neural hubs involved in receipt and processing of socioemotional stimuli, their role in learning is reviewed in the following section.

2.5 Hippocampal, amygdala, prefrontal and cerebellar-dependent cognition

Pezzulo (2011) proposed that human prefrontal-cerebellar and parietal-cerebellar cortical connectivity underlies executive functions like that of other animals and that goal-directed behavior across species is derived from sensorimotor anticipation. The proposal that executive function is not unique to our species, and that goal-directed action forms the basis of cognition, has implications for multimedia research. Akin to Piaget's developmental theory, though without reference to schema theory as in multimedia learning (see Sections 1,1,2 and 1.7), Pezzulo (2011) proposes that an organism's knowledge and representational ability is derived from sensorimotor action and competence. Accordingly, procedural knowledge is generated through the interplay of behavioural systems. Declarative knowledge, from this perspective, derives from the re-enactment of these situated behaviours and actions via mental simulation. In extension, executive function is the internal manipulation of these functions and processes. Pezzulo (2011) describes this as internalised situated behaviour and stresses the importance of autonomic (visceral) and conscious elements of cognition in this model.

Drawing from this embodied cognitive model to my present study of multimedia learning effects, focus is placed on a functionally adaptive neural architecture in a 'bottom-up' subcortical model. The model assumes the relevance of ecologically valid sensory multimodality and recognises that adolescents are attuned to socially salient stimuli (c.f. Insel & Fernald, 2004 ‘social brain’ model). Goal directed action underlies social interactions and is presumed to motivate attentional processes in accordance with variations in brain development (as reviewed in Sections 2.4). Within this setting, subcortical and cortical regions coordinate to plan and execute motor behaviour via anticipatory cognition and sensory feedback. Therefore, sensorimotor systems interface with significant frontal lobe knowledge and neural processing operates along a continuous feedback process. This contrasts with the established cognitive science view of serial, reconstructive processing of stimuli properties (Gallese, 2003). Instead, neural processing of objects, including relevant ‘what’ and ‘how’ properties, are represented in the same sensory and motor brain circuits that were activated on initial acquisition. Traditionally, sensorimotor and procedural learning systems, memory systems and ‘higher order’ cognition have been compartmentalised (Squire, 2004), although interactions between procedural and declarative memory processes are still not fully understood (Poldrack et al., 2001). Further discussion of the integrated roles of amygdala, hippocampal bodies and prefrontal cortex (PFC) in supporting parallel behavioural and memory processing is provided in Section 2.6.

The amygdala, composed of distinct cell groups, lies adjacent to the hippocampus within the medial anterior temporal lobes (McEwen & Gianaros, 2010). It functions in stressor-related processing that involves the rapid assignment of emotional and behavioural salience to environment events (LeDoux, 2003; Sah et al., 2003). The amygdala supports such processing via integrative multimodal sensory inputs from distributed thalamic, brainstem and cortical relays (Figure 2.8). Sensory input is relayed to the basolateral area via the lateral nucleus, basolateral nucleus and accessory basal nucleus (Amaral & Price, 1984). Motivationally relevant signals are relayed, in turn, from the basolateral nucleus to the central nucleus. In output, the central nucleus signals adaptive behavioural changes and related physiological adjustments via the stria terminalis to lateral and paraventricular hypothalamic nuclei and to periaqueductal, medullary and pre-autonomic nuclei (Amaral & Milner, 1984; McDonald, 1998). Importantly, the central nucleus also networks with cortical areas involved in stressor-related processing. These include areas of the prefrontal cortex, including the anterior cingulate cortex (ACC), ventromedial prefrontal cortex and orbital prefrontal cortex (Morecraft et al., 2007). In stress processing, the amygdala is thus viewed as interrelating cortical processing supporting stress-evoked coordination of behavioural change and peripheral physiological reactivity (McEwen, 2007; Repetti et al., 2002; Taylor et al., 2004).

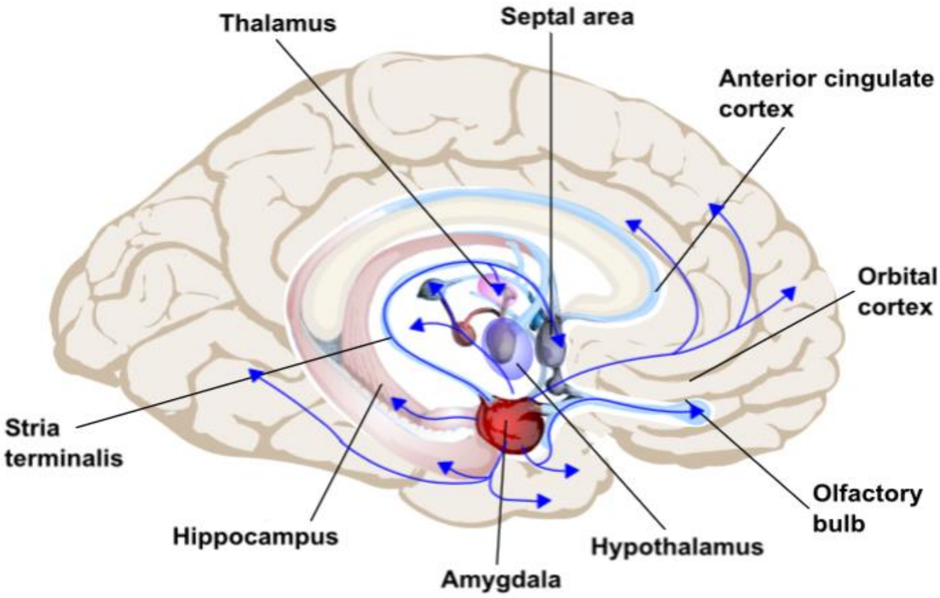

Figure 2.8 Amygdala projections to fore, mid and hind brain (Wright, 2020)

Stress reactivity appears to underlie the amygdala's broader role in social cognition. Phelps (2006) describes the emerging understanding of the amygdala in the modulation of neural systems underlying cognitive and social behaviours in response to emotional cues. Functional imaging studies highlight how the neural circuitry of emotion and cognition interact from early perception to decision making and reasoning, and emerging lines of research demonstrate the role of human amygdala in emotion and cognition.

Emotion has traditionally been linked with episodic memory which, through the amygdala's influence, is understood as three components: encoding, consolidation and the subjective sense of remembering (Phelps, 2006). While other brain regions such as the hippocampal complex are responsible for aspects of episodic memory, the amygdala is considered important in modulating the underlying neural circuitry. Encoding is the initial stage of episodic memory formation, and emotion can influence the regulation of to-be-remembered stimuli through its regulation of attention and perception (Easterbrook, 1959). Brain imaging studies have demonstrated, for example, that activation of the amygdala during encoding is predictive of later recognition or recall for emotional stimuli (Canli et al., 2000; Hamann et al., 1999). Additionally, research involving amygdala damage patients shows memory impairment for details of emotional scenes which are central to the event, with intact memory for more peripheral details (Adolphs et al., 2005).

The primary neural mechanism of episodic encoding appears to be the amygdala's modulation of hippocampal memory consolidation (Knowlton & Fanselow, 1998). Consolidation is the storage process in which memories increase over time in stability, and enhanced consolidation appears to depend on arousal and emotion. Packard and Teather (1998) highlight this effect by showing that manipulation of amygdala after stimulus encoding alters the impact of arousal on episodic memory. A slow consolidation process is assumed by Phelps (2006) to represent an adaptive response in allowing greater emotional reaction to a stimulus, and thus influencing the memory strength. Environmental stressors in authentic ecologies, from this perspective, are less likely to be forgotten. Additionally, the amygdala has direct projections to the anterior portion of the hippocampus (Stefanacci & Amaral, 2002). Dolcos et al. (2004) found that activation of anterior hippocampus and amygdala is correlated with the encoding of later-remembered emotional scenes. Studies indicate that emotion can also influence subjective memory recall in the case of 'flashbulb' memories (e.g. Talarico & Rubin, 2003). Flashbulb memories are often described as especially vivid and detailed and more highly recollected than regular episodic memory, and Schmolck et al. (2000) suggest that emotion, via the amygdala, can have an independent effect in enhancing the subjective sense of remembering.

The relevance of emotion in memory processing is aligned with attention and perceptual processes. Attention and perception are the first two stages of stimulus processing, and factors which influence these early stages have downstream influences on memory and reasoning (Niendenthal & Kitayama, 1994). The emotional significance of stimuli is described in multiple effects such as the *cocktail effect* (Cherry, 1953) for which emotionally salient stimuli focus attention during tasks designed to tax attentional resources. Morris et al. (1988) suggest that the amygdala's facilitation of attention, in the presence of emotional stimuli, is the result of its modulation of sensory cortical regions. Brain imaging research supports this conclusion. Kosslyn et al. (1996) used fMRI to show enhanced primary visual cortex and amygdala response to novel emotional stimuli. Furthermore, the magnitude of this enhanced visual cortex activation is associated with amygdala activation in response to the same stimuli presentations. Vuilleumier et al. (2004) presented subjects with faces with fearful and neutral expressions in a study involving three groups of subjects: normal controls, hippocampus damage patients and patients with both hippocampal and amygdala damage. The results were consistent with previous imaging research as amygdala damage was not associated with visual cortical activation in fear versus neutral facial expressions. These imaging studies suggest a critical role for the amygdala in mediating rapid visual processing for emotional stimuli.

While the amygdala has been researched for perceptual processing in early visual areas, other brain regions such as parietal cortex are often linked with attentional allocation (Corbetta & Shulman 2002). Carrasco (2004) suggested that the observed effects of emotional attention result from the impact of attention on perception. Perceptual enhancement, alongside that of attention, seems likely given the anatomical connectivity between amygdala and visual cortex, and suggests enhanced perception and attention from stimuli leading to amygdala activation (Phelps, 2006). Additionally, the effect of attentional capture relates to differentiated attention towards emotional stimuli, with impaired processing of non-emotional aspects of the stimulus. Pratto and John (1991) review studies that demonstrate emotional capture of attention and suggest that this effect is due to difficulty in disengaging attention from the emotional qualities of a stimulus.

In extension of the role of social stimuli in memory processes, a holistic notion of ecologically valid sensory multimodality involves non-social stimuli. In this respect, and with relevance to an adequate conceptualisation of multimodal learning text design, it is worth asking whether social stimuli are processed in distinct regions, or whether social and mechanical properties are processed as domain-general properties. For example, the fusiform gyrus is often viewed as a specialised region in the recognition of facial features (Kanwisher et al., 1997) though this region has also been studied for its involvement in more general processing such as in identification of individual exemplars from stimuli classes (Tarr & Gauthier, 2000). Other brain regions are known to underpin modality-invariant representational activity, including the bilateral anterior temporal lobes (Pobrix et al., 2016). The anterior temporal lobes, like the superior temporal sulcus (Oba et al., 2020), lack any single dominant motor, sensory, or verbal input/output and are widely connected to other temporal, parietal, and frontal regions (Catani et al., 2008).

In line with this apparent merging of social / non-social processing, Heberlein et al. (2004) replicated the classic experiment of Heider and Simmel (1944) to examine social and non-social processing. Heider and Simmel (1944) showed subjects a film depicting geometric shapes moving around a box. The movements of the shapes were suggestive of social interactions — i.e. goal-directed action — and respondents described them as characters with motives, interacting in complex social situations. Heberlein et al. (2004) showed this video to amygdala damage patients and found that their descriptions emphasised the actual movements of the shapes, divorced from any social or emotional context or motives. Normal controls showed responses consistent with the original study. These results emphasise the salience of emotional content, irrespective of precise perceptual stimuli features. The amygdala can thus be seen as playing a general role in perceiving and interpreting emotion from a wide range of stimuli classes, and preferentially orienting attention towards socially salient information.

As outlined above, Pezzulo (2011) considers anticipatory and simulative mechanisms — adaptations to action-control — as foundational to more advanced cognitive processes. Procedural and declarative forms of knowledge are explained as on-line sensorimotor anticipation and off-line simulations of potential actions, respectively. Stimuli appraisal underlying procedural adaptations occurs in the amygdala and involves the orbitofrontal cortex and whole-body connectivity via endocrine and central and peripheral nervous systems (Damasio, 1994). On the basis of feelings (emotions), established behavioural choices obviate the need for peripheral nervous system feedback. This is because bodily states underlying emotional expression become redundant as frequent associations become centrally represented in the brain. Declarative knowledge subsumes perceptual knowledge, and higher cognition is considered to emerge from interactions from medial prefrontal cortex (mPFC) and hippocampus.

Memory formation and retrieval rely on two kinds of processing in these brain regions. During learning, the brain must initially form a neural representation of the new experience, and this representation must then be consolidated in an organisation that optimises retrieval when cued by a relevant stimulus. Multi-system pathways initially process information about the identity of objects and events, before converging into multimodal association regions (Preston & Eichenbaum, 2013). These are the 'what' streams of information processing. 'Where' streams constitute a distinct stream of pathways that identify where in space an event occurs. Both streams converge in the medial PFC (mPFC) at the level of the hippocampus (see Figure 2.9, next page); highlighting a hippocampal role in forming cohesive memories in the context in which they occurred (Davachi, 2006; Diana et al., 2007). Hippocampal outputs return to cortical areas where the inputs arose via perirhinal, lateral entorhinal, and parahippocampal medial entorhinal cortex, supporting the hippocampus in retrieval of 'what' information in the context of 'where' an event occurred (Eichenbaum et al., 2007; Squire et al., 2007). As a consequence, the hippocampus supports strong recollective memory retrieval based on experience.

The anterior hippocampus also projects to the mPFC. Experimental evidence suggests that mPFC can bias retrieval of event information in the 'what' stream in output to the hippocampus via lateral entorhinal and perirhinal cortex (e.g. Navawongse & Eichenbaum, 2013). Xu and Sudhof (2013) demonstrate how the PFC can also moderate the specificity of memory retrieval directly to the hippocampus, via a subcortical route through the thalamus. Therefore, the PFC and hippocampus can allow creation of contextual representations linking related memory as well as using contextual representations in retrieving appropriate memories within a given context (Preston & Eichenbaum, 2013).

Along with mPFC-hippocampal memory consolidation, experimental evidence suggests that the PFC contributes to memory retrieval through strategic control of other brain regions (see for example, Buckner & Wheeler, 2001; Dobbins et al., 2002). The PFC is comprised of functionally distinct areas which interface in memory processes including, with relevance to the currently accepted cognitive architecture of multimedia learning, memory retrieval in selection of memories relevant to the current context, while suppressing irrelevant memories (Depue, 2012). Dobbins et al. (2002)

liken this interaction between hippocampus and PFC to a railway: the hippocampus lays the tracks while the PFC switches between tracks. In application, the hippocampus forms and retrieves specific memories while the PFC accumulates features of related memories in forming the context of sets of interconnected experiences. When cued to a context, the PFC biases the retrieval of context-appropriate memories in the hippocampus alongside other brain regions. Figure 2.10 displays the functional anatomy of memory systems of the brain. Here, multiple sensory pathways converge at the level of the hippocampus where neural ensembles in dorsal hippocampus encode specific objects and their locations within a context. Ventral hippocampus encoding, by contrast, links and distinguishes events within given contexts, and projects contextual representations to the medial prefrontal cortex (Navawongse & Eichenbaum, 2013).

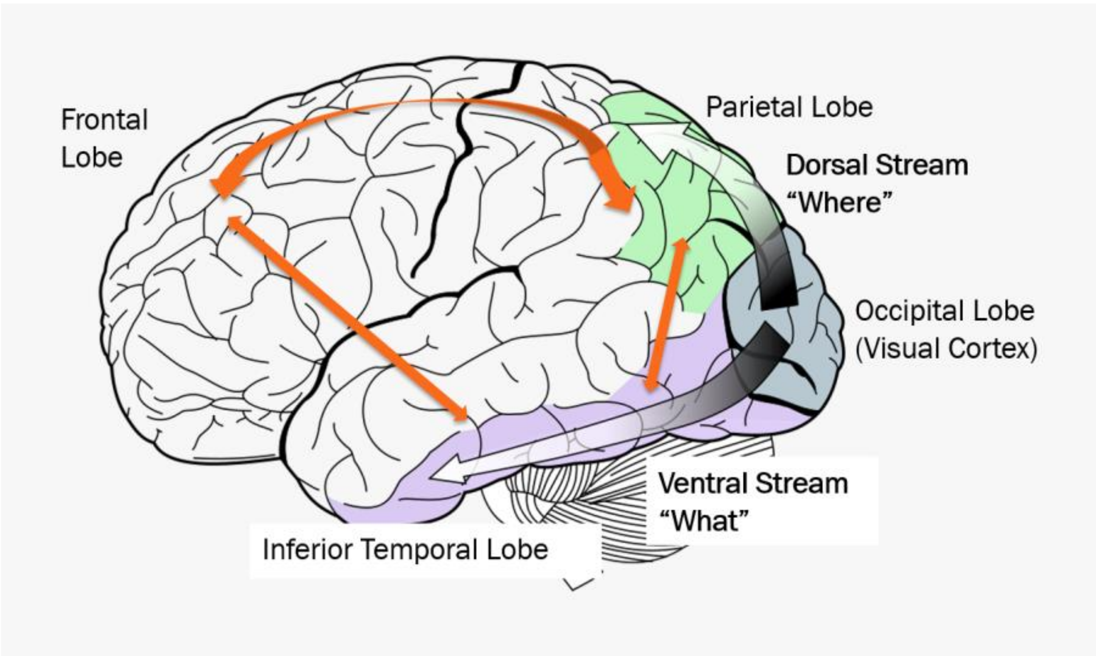

Figure 2.9 Dorsal (‘where’) and ventral (‘what’) streams converge in the PFC (Sheth & Young, 2014)

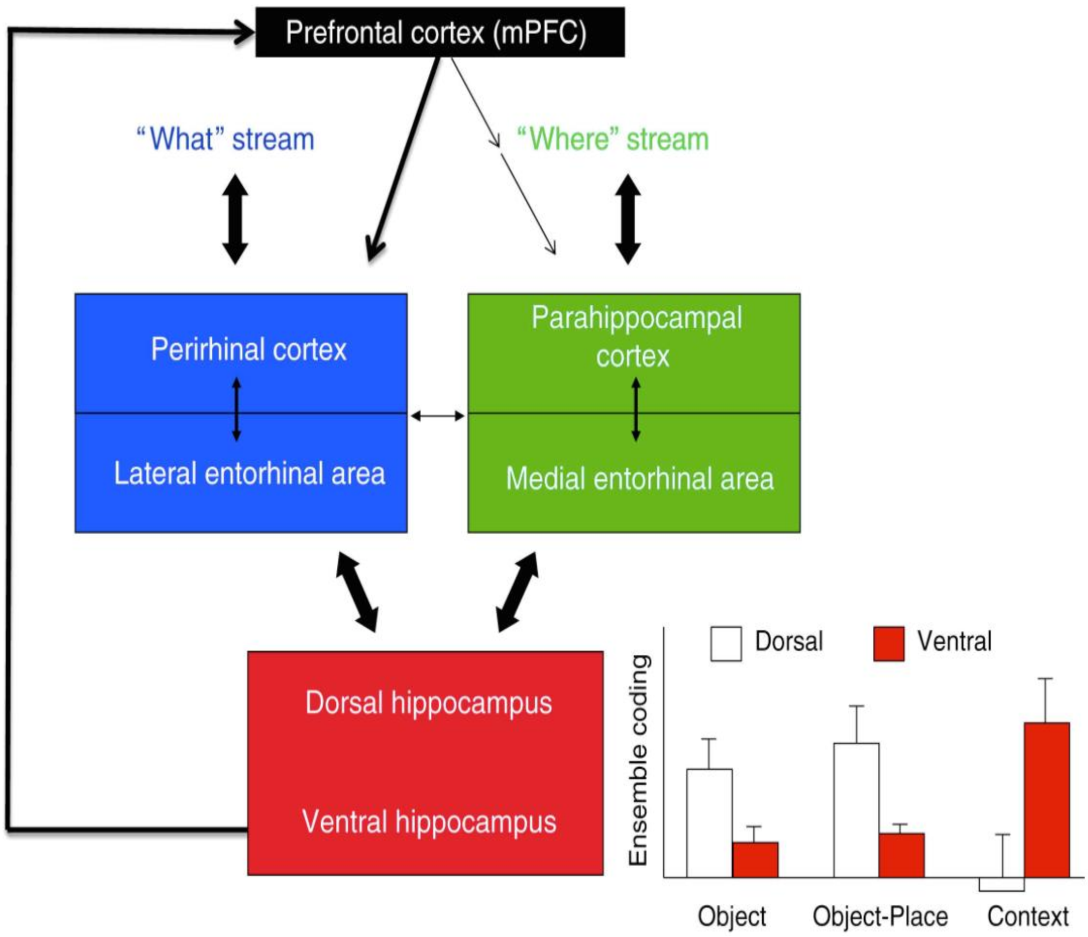

Figure 2.10 Pathways of information flow in between the hippocampus and prefrontal cortex (Preston & Eichenbaum, 2013)

Studies have demonstrated how mPFC damage impairs ability to switch between remembering differing perceptual dimensions in compound stimuli (Birrel & Brown, 2000; Ragozzino et al., 2003). Findings indicate that the mPFC uses the relevant context in resolving conflicting information and plays an active role in the retrieval of related and competing memories. Study on neuronal activity patterns in mPFC is also supportive of the notion that mPFC acquires representations of behavioural contexts in determining appropriate memory retrieval. For example, it has been shown that distinctive neuronal firing occurs in different behavioural contexts (Hyman et al., 2012), reset when faced with uncertainty in changes of contingencies (Karlsson et al., 2012) and, upon changes in contingency, makes sudden transitions between contextual representations (Durstewitz et al., 2010). In addition, when the mPFC is deactivated, dorsal hippocampal neurons have been observed indiscriminately retrieving both appropriate and inappropriate memory representations (Durstewitz et al., 2010).

Executive function within the embodied cognitive framework is framed phylogenetically as an extension of lower animal brain structure and function. Executive function can be roughly conceptualised as an umbrella term encompassing the individual's capacity to adaptively regulate thoughts, emotions, actions and instincts (Posner & Rothbart, 2011). Within embodied cognition, executive function relates to three major activities: shifting, updating and inhibition (Miyake et al., 2000). Updating refers to the ability to refresh or add to information currently held within working memory. Inhibition is a goal-directed suppression of an overriding response pattern and shifting refers to the ability to switch between strategies in changing circumstances. While executive function in frontal regions has often been considered as supporting conscious thought, within embodied cognition, neocortex is considered to function as a co-adaptation supporting intricate motor function. Meeting demands of social functioning and mentalising (see Frith et al., 1991) probably evolved alongside greater cerebro-cerebellar connectivity in the critical role of allowing frontal systems to plan, think ahead and abstract (Koziol et al., 2012). Consequently, as an extension of basic anticipatory control mechanisms, executive function can be assessed from the interplay of dorsal 'where' and ventral 'what' streams of stimuli processing.

Pragmatic representations of action opportunities are processed in the dorsal stream within the parietal cortex and reciprocally connected premotor regions (Cisek, 2007). This system is important in procedural memory for action concepts, and it registers not only an object's location, but also 'how to do something' (Rizzolatti & Luppino, 2001) with that object. The dorsal pathway is transformed into a visual control area for actions, with the parietal cortex focusing on spatial information in establishing parameters of ongoing and potential actions (Cisek & Kalaska, 2010). The ventral processing stream registers 'what' is being perceived along with information about 'what' that object is used for. Buxbaum and Kalenine (2010) consider that the ventral stream operates relatively slowly in comparison with the dorsal stream as the ventral stream doesn't serve an action purpose, although it plays an important role in behavioural patterning. Complementary functioning between streams is permitted given their trans-callosal connectivity (Rousselet et al., 2004) and both streams project to the hippocampal formation for memory storage (Amaral & Lavenex, 2007).

Anticipatory biasing occurs within the ventral pathway on the basis of reward value accorded to preferential action or behavioural selection (Capilla et al., 2014). Behavioural biasing occurs due to information sharing with the basal ganglia reward centres and PFC which predict reward outcomes (Gottlieb, 2007). Decision making can thus be seen as distributed amongst not only PFC, but also within the same sensorimotor circuits employed in sensory processing, associating stimuli with reward value and anticipatory planning.

It is estimated that approximately 95% of an adult human's activity is routine and automatic (Sailing & Phillips, 2007). Because direct cortical sensory feedback processes operate too slowly for generation of effective behaviours, brain regions have evolved that allow the organism to predict sensorimotor feedback (Caligiore et al., 2017). Mechanical-behavioural repertoires allowing for adaptive functioning alternate with episodes of higher-order control, which Wolpert et al. (1998) describe as *internal models* within the cerebellum.

Despite being largely associated with voluntary motor functions, the cerebellum is emerging as a proposed regional coordinator of higher cognitive functions including language processing (Ito, 2008), executive function (Ramnani, 2006) and visuospatial processing (Molinari et al., 2007). As noted above, Wolpert et al. (1998) consider the cerebellum to be the site of associative / predictive internal models given its anatomical features including a 'monotonously repetitive architecture' (Schmahmann, 2000) and connectivity with 'virtually all major subdivisions of the brain' (Argyropoulos, 2016). Cerebro-cerebellar circuitry allows the cerebellum to copy the contents of PFC working memory, which has implications in learning. During the learning of a new task, conscious thought involves neural signals from the primary motor and premotor cortices and the temporoparietal cortex (Ito, 2000). External sensory feedback is required in initial learning but, as learning continues, the PFC acquires 'body' and 'motor' schemas which are copied by parietal cortex and cerebellum (Wolpert & Ghahramani, 2004) in the formation of forward and inverse models. A cerebellar *internal model* contains all sensory and motor features needed for execution of the particular task, and behavioural refinement follows cerebellar detection of predicted performance error and / or imperfection. Therefore, this forward model can predict motor command consequences and allow greater automatisation and removal from conscious awareness (Wolpert & Flanagan, 2001). Moreover, the cerebro-cerebellar circuitry provides feedback to motor cortical areas which allows the storage of representations of efficient behaviours (Jacobson et al., 2008, 2009; Yarom & Cohen, 2002). Koziol et al. (2012) describe the storage of procedural memory within PFC as the PFC having been ‘taught’ by the cerebellum. As can be seen, internal models carry specific implications for the integrated nature of learning and inform the revised cognitive model as presented in Section 5.4.

Returning to the interaction of procedural and declarative knowledge within executive function, the globalised architecture underpinning motor learning can be functionally reliant on regional connectivity. Friston and Frith (1995), for example, relate their *dysconnectivity hypothesis* of executive function impairment to the integrity of fronto-temporal and fronto-parietal white matter circuitry. Harrison (1999) identified developmental abnormalities in the neuropathology of schizophrenia in terms of connective tissue arborisation, synaptogenesis and pruning. Schizotypal impairment in executive function relates to planning, cognitive flexibility, complex problem solving and verbal fluency (Orellana & Slachevsky, 2013). These executive function impairments are similar to, albeit more severe than, those identified as markers of reduced *somatic effort* (introduced in Section 2.4). Moreover, the timing of insult suggests stress hormone involvement by the second trimester, which corresponds with midgestational circulating levels of corticotropin releasing hormone (CRH) and cortisol (Pepe & Albrecht, 2013). Whatever the etiology, motor-system dysfunction has implications for normal memory processes. As the ‘supervised’ or ‘internal’ learning models of the cerebellum are reciprocally connected with motor cortex and with somatic schemas stored in parietal and frontal cortices, this organisational profile ensures parallel processing of the same data. The declarative and episodic ‘unsupervised’ learning modules in the PFC provide a common representational basis of cognition which, theoretically, associates dysconnectivity or other neurological insult with interruption of reinforcement-based motor-learning and, by extension, procedural and declarative memory processes.

This neurological view of executive function can be summarised as a system of goal-directed sensorimotor reinforcement that fractionalizes working memory within a broader neural ensemble including PFC, amygdala and hippocampus and interconnected subregions. Key questions for multimedia research theory are generated from this departure from cognitive psychology models of working memory such as the multicomponent model (see Section 2.3). These include: the nature of sensorimotor integration in learning and recall; the basis of executive function in coordination of cerebro-cerebellar internal models; congruence as a feature of PFC-dependent cognition; and the outsized role of affect in amygdala-dependent attentional and perceptual regulation of cognition.

2.6 Cross-modal cognition

Perception is inherently multimodal. This assumption comes from common experience as well as from neurological (Fregnac & Bathellier, 2015; van Gerven, 2017) and behavioural research findings (Munhall & Vatikiotis-Bateson, 2004; Rosenblum, 2005). With relevance to the phylogenetic basis of cognitive processes in embodied cognition, as currently explored within this literature review, similarities exist in brain activation patterns in humans and non-human primates to species-specific vocalisation. Homologous associational regions within human and primate brains show activation upon bimodal or unimodal calls which Ghazanfar et al. (2005) describe as evidence in multimodal audiovisual (AV) processing for within-species communication versus speech-specific mechanisms. Moreover, supra-additivity in blood-oxygen-level-dependent (BOLD) imaging has been demonstrated in presentation of congruent auditory and visual speech (Calvert et al., 2000) (i.e. a response not present for either modality in isolation). Despite human experience being necessarily multimodal, it is surprising that multimedia research has focused on unisensory information codes. This was raised in Section 2.3 in relation to the discovery of the modality and contiguity effects and was critiqued there in terms of congruency limitations inherent to the multimedia experimental paradigm.

Evidence for supra-additivity in multimodal stimuli processing includes the finding that speech reading in the absence of auditory input activates auditory cortex (Gottleib et al., 2010; Scott et al., 2000). Additionally, this can include activation in core regions of primary auditory cortex (Pekkola et al., 2005). Speechreading has also shown the tendency to generate left-lateralised or bilateral activation (Calvert & Lewis, 2004; Capek et al., 2004) which contrasts with other face actions. Ghazanfar et al. (2005) describe perception of gaze direction and facial expressions, for example, as tending to activate more extensive right-lateralised regions (see also, Adams & Franklin, 2009; Hagen et al., 2009). Also, within the posterior superior temporal sulcus, middle and posterior regions are consistently activated by AV speech and silent speech reading (Callan et al., 2004; Hall et al., 2005). The left posterior superior temporal sulcus can also show differential activation for congruent and incongruent AV speech and supra-additive activation is seen for congruent AV speech compared with unimodal seen or heard speech (Miller & D'Esposito, 2005). Inhibitory AV activation has been observed in other regions of the superior temporal gyrus as compared with unimodal input and for incongruent AV presentations within posterior superior temporal sulcus (Wright et al., 2003). These findings indicate that posterior superior temporal sulcus acts as a primary binding site for AV speech processing.

Cross-modal and cross-temporal AV associations also occur in frontal cortex neurons. The PFC is essential for the temporal integration of behavioural and linguistic arrangements of sensory information (Constantinidis et al., 2002). Acknowledging that encoding of sensory information occurs in more than one modality, Fuster et al. (2000) reasoned that the PFC could associate visual and auditory stimuli across time, and tested tone-colour associations with monkeys. PFC cells responded selectively to tones, and behavioural responses to colours also mostly followed task rules. The authors concluded that the PFC is part of an integrated network representing behaviourally meaningful cross-modal AV associations. Moreover, such networks are crucial for information sharing that underpins behaviour, language and reasoning (Hickok et al., 2013). These findings concord with the integrated perceptual, affective and cognitive socioemotional networks described in Section 2.4.3 and underscore the goal-directed nature of learning as theorised within embodied cognition.

Ecologically meaningful stimuli pairings extend our understanding of cross-modal cognition. For example, Joassin et al. (2011) found that the binding of faces and voices relied on an integrative network involving multiple processes. They used fMRI to measure recognition of previously learned static faces, voices and voice-static face associations. Voice-face associations activated specific multimodal areas in the right hippocampal formation and left angular gyrus, along with unimodal visual and auditory cortices. Furthermore, functional connectivity analysis confirmed the connectivity of the unimodal sensory cortical regions with right hippocampus, suggesting that such multimodal binding relies on a cortico-limbic network in sustaining different aspects of integration including perception, attention and memory. Within a traditional model of stimuli processing, the authors reason that voices alone would elicit bilateral activation of the temporal cortex, and specifically the anterior posterior superior temporal sulcus, while faces alone would show activity in the right fusiform face area. Psychophysiological Interaction (PPI) analysis revealed that the right fusiform face area and superior temporal sulcus were interconnected during the face-voice association, which confirms research of Von Kriegstein and Girraud (2006) who demonstrated joint visual and auditory regional activation, including when an isolated voice from a previously learnt voice-face association was presented. These results appear to confirm that ecological redundancy induces specific multisensory associations and enhanced connectivity between visual and auditory sensory regions. Of additional significance was the observation that the hippocampus remained inactive during unimodal presentations, while supra-additive right hippocampal activation occurred during bimodal processing. General memory processes therefore seem unlikely with unimodal stimuli and, in this context, the authors speculate that the hippocampus could instead be involved in associative recognition of faces and voices per se.

In extension, behavioural enhancement, along with neuroimaging measures, have been observed following multi-modal input that differs from uni-sensory identification (e.g. Hagan et al., 2009; van Wassenhove et al., 2005). Multi-sensory experiments have also revealed behavioural modifications with subsequent uni-sensory presentations, and that more extensive training also alters brain regions involved in AV integration and congruent processing with novel cross-modal associations (Bindemann & Burton, 2008; Naumer et al., 2009). In this context, Butler and James (2011) discuss the *reactivation memory* hypothesis (Wheeler et al., 2000) which considers memory processes as intimately connected with perceptual and motor-related activity. Central to this hypothesis, and similar to embodied cognition, is the idea that regions related to information processing in specific modalities are also involved in later recall and recognition. Important for learning, reactivation is linked to the simulation of perception and the reactivation of cortical activity occurring during initial encoding (Barsalou, 2008).

In support of the reactivation memory hypothesis, Butler and James (2011) show that greater *blood-oxygen-level dependent* contrast imaging activation occurred in primary perceptual areas following a respondent's correct retrieval of within-modal targets given within-modal cues. These results support the *reactivation* hypothesis in that memory retrieval appears to depend on reactivation of perceptual areas elicited during encoding. Moreover, cross-modal and within-modal retrieval of auditory information was associated with activation of left anterior superior temporal gyrus. Cross-modal auditory reactivation also occurred in anterior superior temporal sulcus, prompting several mechanistic explanations. Firstly, hippocampal and greater medial temporal regional activity during cross-modal retrieval appears to show hippocampal contextual modulation. In addition, associative cortical regions such as the superior temporal sulcus can link modality specific activity during learning. Finally, feed-forward connectivity amongst modality specific regions have been found, and these are likely to be involved in cross-modal reactivation (Foxe & Schroeder, 2005). Butler and James (2011) suggest that greater hippocampal activity during cross-modal retrieval is reflective of enhanced demand for relational memory during this type of association and that this finding supports earlier work showing higher hippocampal activity in cross-modal rather than within-modal associations (Gottlieb et al., 2010; Rugg et al., 2008).

As mentioned previously, Sections 2.4 - 2.6 function to bridge established multimedia theory and practice as currently understood amongst multimedia practitioners. As seen from this discussion, individual development can be viewed as a series of life history trade-offs in the utilisation of physical and biological resources, including brain structure and function. Socioeconomic status, in this regard, is a predictive factor of brain development as it represents reliable information on the nature of the physical and social environment. Additive to SES as a contextual factor in development is a cognitive architecture that prioritises socioemotional processing over other information classes and views learning as having a sensorimotor basis. With these details in mind, the following section describes current instructional design principles as forwarded by multimedia theorists.

2.7 Instructional design principles: praxis

The instructional design principles of *spatial contiguity* and *modality* outlined previously in Section 2.3 have been recommended when developing texts to support deep learning (see for example, Mayer, 2005a). These effects come with three assumptions from research in cognitive science — the dual channel assumption, the limited capacity assumption, and the active processing assumption. As discussed above, these architectural constraints are central features of Paivio's (1986) dual-coding theory and Baddeley's (1998a) theory of working memory. Two prominent theories in multimedia learning design informed by cognitive science are cognitive load theory (Chandler & Sweller, 1991; Sweller, 1999) and the cognitive theory of multimedia learning (Mayer, 2005a) and both theories offer similar theoretical explanations for effects of audiovisual modality and contiguity. However, the idea that a lack of contiguity could be responsible for the modality effect, and not an enhancement of cognitive resources as held by cognitive theory of multimedia learning theory, is relevant for this thesis in that it forces a reconsideration of dual coding theory and working memory.

Cognitive load theory (CLT) presents a framework to integrate cognitive science findings in instructional design. In attempting to maximise a learner's performance, the theory holds two established assumptions. One is that we possess an effectively unlimited long-term memory, which holds schemas of varying degrees of automation. The second is that working memory has a limited capacity and is split into sensory-specific subsystems dedicated to visual and auditory information. The central premises of CLT are that the working memory load of instruction should be a primary concern, and that limitations of working memory can be described in terms of a cognitive workload that is dependent on key learner and task characteristics.

Cognitive load theory differentiates between intrinsic and extrinsic cognitive loads. Intrinsic load refers to the context of learning material, with load determined by the interaction between the nature of the material, prior knowledge, expertise and cognitive abilities of the individual. In understanding an instruction, intrinsic cognitive load is the basic amount of processing required and is contrasted with extraneous cognitive load, which is equated with the load of the presentation format. In CLT, extraneous cognitive load interferes with the formation of schemas (Leppink et al., 2013) and can be affected by manipulating instructional design. Germane cognitive load, by contrast, is the loading imposed on a learner through processes that are directly relevant to learning, (i.e. schema construction). Germane cognitive load increases cognitive load, in contrast with extraneous cognitive load, as it contributes to, rather than interferes with, learning.

Cognitive theory of multimedia learning (CTML, Mayer, 2005a) is like cognitive load theory in its basic assumptions and related design guidelines. It differs, however, in how sensory modalities are processed in working memory subsystems. Within cognitive load theory, the visual and auditory subsystems of working memory are closely related to the actual stimuli presented to the sensory modalities. The sensory subsystems in Mayer's theory (2005b) adhere to Paivio's (1986) dual coding theory in that information can be stored verbally or pictorially. As opposed to auditory or visual information being processed in working memory, however, verbal or pictorial representations of information are processed as mental models with differing internal information codes. Text is transformed into a verbal representation, and visualisations transformed into pictorial representations before mental models are built in respective subsystems. This processing implies that spoken and written text are represented in the same verbal system, despite initial processing in different channels. Figure 2.11 shows the integration of working memory content within long term memory stores. Core assumptions of multimedia learning environments are illustrated including active and separate channel processing and the bottlenecking of information processing in long-term memory.

Guidelines for learning follow from the inherent limitations in the verbal and pictorial processing channels. When learners are presented with a text and accompanying visualisation, verbal and pictorial mental models are created, and referential and associative connections are made between subsystems. The picture superiority effect of dual-coding theory (see Section 2.3.1) is used by Mayer as a basis of the multimedia principle: "Students learn better from words and pictures than from words alone"

(Mayer, 2001, p. 63). This follows from the code-additive effect in dual-coding theory in that information stored verbally and pictorially is easier to recall than information stored in one code alone. Multimedia presentations thus reduce cognitive load as it permits the learner to more easily construct a verbal and a pictorial model than if either words or pictures were presented in isolation.

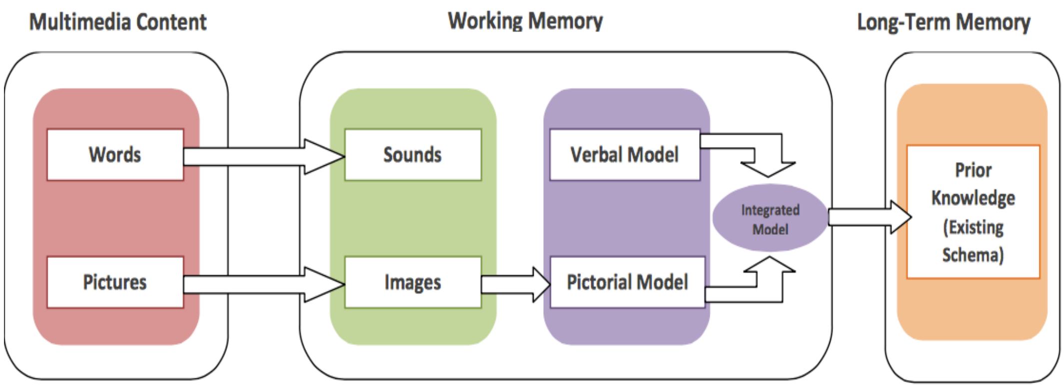

Figure 2.11 Information processing model (Mayer, 2005a)

Mayer (2005c) outlined the modality and spatial contiguity effects amongst five recommendations for presenting text and pictures to learners to support understanding of a topic. The superiority of pictures with auditory text against pictures with visual text has been confirmed in numerous studies, and Mayer (2005c) presents specific delivery and context characteristics in alignment with these design principles (Figure 2.12). Meaningful learning is assumed to occur from adherence to the principles of multimedia learning with learning effects derived from CTML basic principles (see Section 2.7.2 for details of CTML research) and related design and contextual factors.

Superior recall experienced from visuo-auditory compared with visuospatially presented information has been a consistent research focus in multimedia learning. Ginns (2005) provided a meta-analysis of empirical research on the modality effect which used different measurements and topics and reported an overall moderate to large weighted mean effect size. This appears to confirm the significance of the modality effect, although Schueler et al. (2008) state that explanations for the modality effect are still unclear. The spatial contiguity principle, meanwhile, is described by

Mayer as decreasing the need for visual search via the physical proximity of corresponding words and pictures: "When corresponding words and pictures are far from each other on the page or screen learners have to use cognitive resources to visually search the page or screen for corresponding words and pictures. Thus, learners are less likely to be able to hold them both in working memory at the same time" (Mayer, 2001, p. 81).

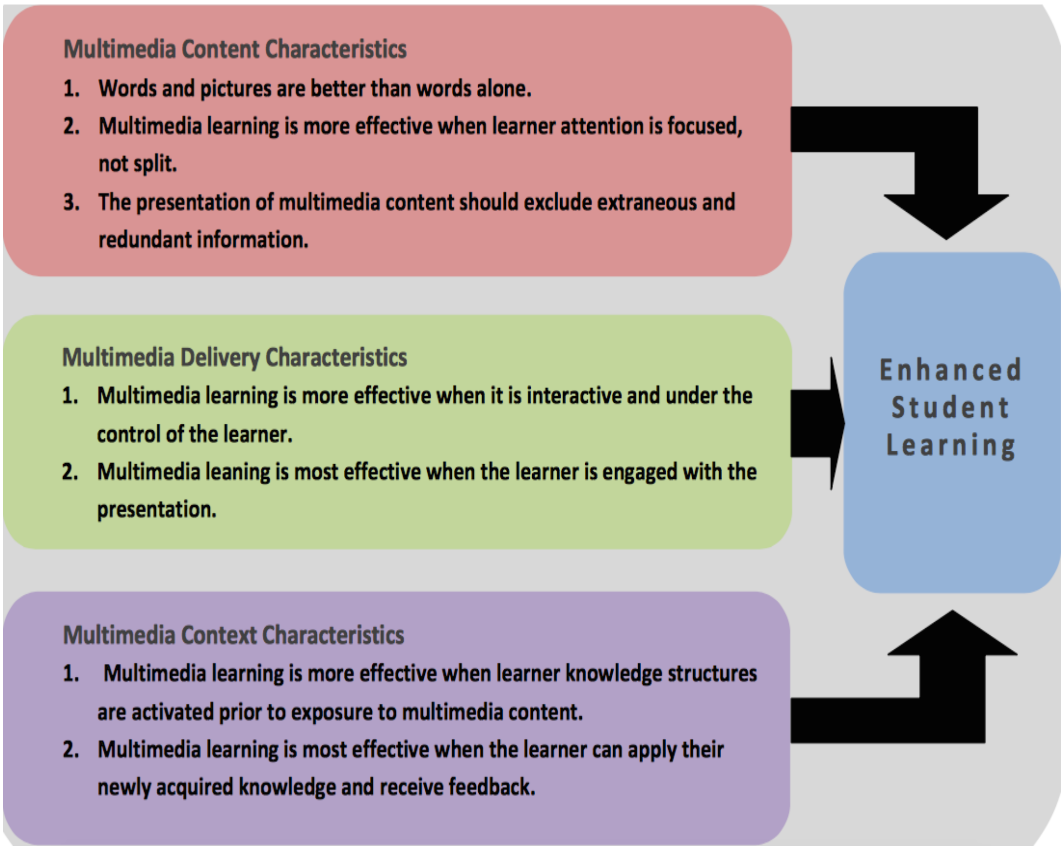

Figure 2.12 Summary of multimedia learning principles (Mayer, 2005c)

Meaningful learning from visualisations with accompanying text, is similar for CLT and cognitive load theory, and relates to verbal and pictorial representations being present in working memory at the same time. The modality effect can be neatly summarised as an augmentation of working memory channels through avoidance of overloading one channel alone —i.e. processing of auditory text reduces the need for processing of extra visual material in the visual channel. Schueler et al. (2008) describe this as the cognitive resources explanation and contrast it with the possibility of a lack of temporal or spatial contiguity inherent in multimedia presentations.

An alternative view of the modality effect is simply that auditory text and visualisations can be perceived simultaneously. In the case of visual text and picture, it is only possible to process one source of information at a time, thus removing contiguity. The spatial and temporal contiguity principles can thus be aligned with Mayer’s (2001) spatial split attention effect, which describes the spatial integration of corresponding visual text and pictures. A spatial contiguity effect is theoretically seen in static texts. Increasing visual search through incomplete textual integration can be assumed to increase extraneous load associated with holding representations in mind, while germane loading is potentially decreased. For congruently presented audio-visual presentations, a temporal contiguity effect could be present in presentations where auditory and visual information are perceived and processed concurrently. Unlike in successive presentations (i.e. system-paced learning), verbal and pictorial constituents are probably held in parallel in working memory, making reconstruction of related information unnecessary.

Spatial and temporal contiguity are not provided in the case of static texts. A learner must switch between sources of information, thus reducing spatial contiguity, and temporal contiguity is impossible given the inability to receive text and visualisations simultaneously. Schueler et al. (2008) tested the cognitive resources explanation of the modality effect by examining how the temporal contiguity of text and picture and the text modality influence learning. Presented with the topic of tornado formation, subjects heard or read relevant content concurrently with, before, or after the corresponding picture. Learning was measured by verbal recall, pictorial recall, and transfer. The authors describe how a pictorial recall modality effect was found with simultaneous but not sequential presentation. This was deemed indicative of a split of attention — a contiguity effect — and not an enhancement of cognitive resources as assumed by a separate-streams hypothesis. The following two subsections (2.4.1 and 2.4.2) provide further discussion of the research approaches of CLT and CTML.

2.7.1 Cognitive load theory research

Cognitive load theory (CLT) originated with John Sweller (Chandler & Sweller, 1991; Sweller, 1994; Sweller, 2016) and was motivated by earlier research on working memory. Given the role of CLT in multimedia learning, Kirschner et al. (2009a) critically reviewed contemporary cognitive load research in terms of positive contributions to the field of learning as well as within CLT more generally. The authors also identify problematic issues such as conflicting results and unresolved explanations and neglect in the accurate identification and measurement of cognitive load. They group current research within three areas: a) learning in complex environments, b) learner control and choice; and c) animated and multimedia instruction. They conclude the analysis with 'good' 'bad' and 'ugly' aspects of research efforts to date.

Kirschner et al. (2009a) commend the work of cognitive load theorists for their focus on emulating the complexity of real-world learning settings. For example, they describe work by Schwonke et al. (2009) who investigated ratios of worked solution steps (high assistance) and to-be-solved problem steps (low assistance). A hypothesised inverse U-shaped relation between high and low ratios of assistance and problem-solving practice is assumed by the authors and, in accordance with previous research (e.g. Kirschner et al., 2006), it was seen that problem solving induced more cognitive load than worked examples. This effect occurred irrespective of the ratio of worked-steps and to-be-solved steps. Kirschner et al. (2009a) also discuss CLT research on the cognitive basis of collaborative learning. Kirschner et al. (2009b), meanwhile, highlight the effect of element interactivity — the measure of intrinsic load — when learning individually or collaboratively. A 'group effect' was found with learning concepts with high element interactivity, thus showing that group work was preferable for learning complex information. This work, which suggested a group "collaborative collective efficacy" (Kirschner et al., 2009a) warrants related research.

Kirschner et al. (2009a) describe how CLT research has mirrored the global movement towards student-centeredness in learning. CLT research has revealed how heavier cognitive load in student self-directed learning can negatively impact on less able or inexperienced learners. For example, research within the expertise reversal paradigm

(Kalyuga, 2007) has shown associations between level of expertise and effectiveness of learner control. When Schwamborn et al. (2010) examined teacher- and student-designed computer illustrations, they found that, contrary to the hypothesis that no significant differences would exist, that teacher-designed illustrations were more effective. The imposition of excessive cognitive load presumably retarded the design process, suggesting that inchoate learner participation could be counterproductive.

Zhang et al (2009) studied cognitive load and group participation in web design in an extension of Kirschner et al. (2009b). They assigned groups of students involved in complex web design either to an open-ended task (group's own choice of web design) or a closed task for which they had no choice but to design a personal web page. Results confirmed a *group* effect, but only for the open-ended task. This finding is notable for its educational authenticity because it incorporated a task as both homework and classwork and it extended earlier group effects in other subject areas, suggesting a cross-disciplinary generality (Kirschner et al., 2009a).

Kirschner et al. (2009a) note the widespread usage of computers in teaching and learning, and the associated increase in animation and multimedia in learning materials. In relation to CLT research, Amadieu et al. (2009) investigated the effect of cuing on animated instructions. A comparison of cued and non-cued hierarchical and network structure conceptual maps on the subject of coranovirus virology involved a dynamic system in which each step was zoomed in on — with irrelevant information hidden — and an identical, non-cued animation. For a related problem-solving task, the cued group demonstrated significant gains over the non-cued group. No differences were found on measures of mental effort, though differences were seen on a combined difficulty scale. The authors concluded that searching and extracting relevant elements from an animation could constitute extraneous cognitive load and enhance learning as cuing represents an additional, helpful, learning task.

Spanjers et al. (2010) investigated segmentation within the context of the expertise reversal effect (Kalyuga et al., 2003). Learners in the segmented condition outperformed learners in the continuous condition, with significant benefits seen in mental effort and efficiency. Whereas students with low prior knowledge benefitted from segmentation, no difference was observed for students with high prior knowledge, for both measures. Kalyuga et al. (2003) suggest that, similar to previous research with instructional animations showing an increase in cognitive load, a compensatory mechanism could be used to reduce cognitive load. However, high prior knowledge learners do not require such strategies - and while test scores do not reveal an expertise reversal effect, measures of efficiency and mental effort were associated with prior subject knowledge.

From this brief review of CLT research, it is seen that 'mental effort' is often used as a measure of 'cognitive load', which itself is typically defined in terms of item interactivity. Also, 'cognitive load' associated with actual learning conditions is defined as extraneous or cognitive load. Furthermore, germane cognitive load, as mentioned in Section 2.7, is defined as a facilitative load associated with the manner of instruction.

Kirschner et al. (2009a) describe positive outcomes in the field of CLT research in terms of experimental rigour, movement towards more realistic educational settings, and the general expansion of CLT. For example, a contrast is made between traditional educational research and CLT in the use of actual learning outcomes versus subjective perceptions or opinions. Randomised controlled studies are regularly used in CLT and have made the attempt to study complex learning environments, including group work, the recognition of expertise gradients, and usage of worked examples. Additionally, progress in CLT research has followed the detection of experimental inconsistencies. For example, Berthold et al. (2009) showed that while explanation prompts can advance learning in some contexts, they can impede learning in others. The group effect (mentioned previously) suggests, for example, that such irregularity could relate to motivational or affective factors. Likewise, learner control and choice appears to moderate the effects of expertise and more realistically relates CLT research to the classroom (Kalyuga, 2007). Finally, research on animation and multimedia also highlights contingencies in learning contexts that are additive to basic CLT theory. Cuing was seen as enhancing problem solving in animations, especially for materials high in element interactivity (Crooks et al., 2012). Additionally, animation research has yielded the finding that segmentation is effective for learners with low prior knowledge, but an expertise reversal effect (Kalyuga et al., 2003) could be present.

In recognition of negative aspects of CLT research, Kirschner et al. (2009a) describe the abundance of unexplainable effects, conflicting measures, and inconclusive and ambiguous findings. Carefully designed follow-up experiments and focus on unresolved issues are suggested for future research. Kirschner and colleagues also discuss the preponderance of 'marginally significant' or 'trend' results. They note that, in the absence of significant results, non-significant findings are reported and used in inappropriate post-hoc analyses. The lack of specific measures of cognitive load — in its intrinsic, extraneous and germane forms — is also a critical aspect facing CLT research. Kirschner et al. (2009a) describe the inconsistencies between performance and load measures and conclude that a circular argument is being made within CLT theory when specific effects are claimed to be caused by cognitive load increases, but in the absence of any independent measures of cognitive load. Improvements have been discerned in subjective measures of load but with little success (Van Gog & Paas, 2008). Notably, discrepancies exist in the wording of cognitive load measures, how and when they are collected, and how efficiently they are used. To this end, it is seen that performance measures often don't correlate with subjective measures, significant effects occur for one measure but not both, or test results are conflicting or otherwise inconsistent with theory (Kirschner et al., 2009b). Finally, while marginal effects have helped to patch up research inconsistencies, no consideration of developmental effects are found within the CLT research literature. This is perhaps best exemplified in the expertise reversal effect, which, as the most prominently reported *individual* effect, relates to prior learning and not to developmental constraints in learning. These proposed deficiencies are addressed in the current study via its focus on measures of individual development, namely socioeconomic status as a nuanced, though universal, influence on brain development.

2.7.2 Cognitive theory of multimedia learning research

Cognitive theory of multimedia learning (CTML) subsumes and extends aspects of cognitive load theory. Mayer (2011) describes CTML as being based on three cognitive science principles, five cognitive processes during learning, and five kinds of learning representations. A CTML research tradition has grown around base forms of learning outcomes (no learning, rote learning and meaningful learning), experimental comparisons of instructional effectiveness and individual differences in learning. Mayer (2011) describes triarchic goals within CTML research including the reduction of extraneous processing, managing essential processing, and fostering generative processing. Additionally, multimedia instructional principles are derived from nearly two decades of CTML research covering nearly 100 studies (Mayer, 2009).

Experimental work in CTML is premised on three underlying assumptions from cognitive science: the dual channel principle; limited capacity principle; and active processing principle. Because these are discussed separately in Section 2.3, they are not considered further here. As mentioned previously, Mayer (2011) considers that five cognitive processes underpin successful learning:

1. Selecting relevant words for processing in verbal working memory
2. Selecting relevant images for processing in visual working memory
3. Organising selected words into a verbal model
4. Organising selected images into a pictorial model
5. Integrating the verbal and pictorial representations with each other and with prior knowledge.

Within working memory, these processes determine attention and selection of information, retrieval and integration of new knowledge with existing structures, and ultimately, long-term memory (Sorden, 2005). Multiple representations are theorised to exist and include the transfer of external representations to sensory copies in sensory memory, sounds and images in working memory and, finally, knowledge within long-term memory (see Figure 2.11). From analysis of prior CTML research, Mayer (2009) identifies 12 multimedia principles which can be assessed within consideration of cognitive load avoidance and management (see Appendix xi for a copy of Mayer's multimedia principles). So-called 'boundary' conditions have been proposed in determining the effectiveness of the principles (see Table 3.2, Ch. 3). These have often been incorporated into CTML as the result of experimental inconsistencies (DeJong, 2010). Mayer (2010) considers that these relate to individual differences, and examples include the *expert reversal* effect and *complexity* and *pacing* conditions. The expert reversal effect holds that some instructional methods could be more effective for low-knowledge learners than high-knowledge learners. This has been explained in CLT terms in that a germane cognitive load for a novice can represent an extraneous cognitive load for an expert (Paas et al., 2004).

Numerous other effects have augmented CTML research. The *collaboration* and *guided-discovery* principles show the beneficial effects of peer or expert assistance, although alongside the *self-explanation* principle, Mayer's (2005c) *advanced* principles can appear somewhat contradictory and suggest that new effects continue to influence the theory.

Experimental evidence on management of cognitive load highlights a range of effect sizes and possible boundary conditions within CTML research. For research aimed at reducing extraneous cognitive load, meta-analyses of spatial and temporal contiguity principles show median effect sizes (Cohen's *d*, 1977) of 1.12 and 1.31 respectively (Ginns, 2006). In five out of five experimental comparisons, Mayer (2005b) reported students showing enhanced learning from integrated dynamic presentations (i.e. words placed near animated graphics). In research involving paper-based lessons on brakes (Mayer, 1989) and lightning (Mayer et al., 1996), better performance on a transfer test was reported when printed descriptions were placed next to the corresponding part of the graphic, as opposed to being printed as a caption or presented away from the graphic. Additionally, Kalyuga (2005b) suggests that the spatial contiguity principle applies most for low-knowledge learners, for difficult content or when the pace of the lesson cannot be controlled by the learner.

Temporal contiguity, as the name suggests, involves corresponding words and pictures being presented simultaneously. Mayer et al. (1996) describe eight out of eight experimental comparisons in which better performance on transfer tests followed simultaneous rather than successive presentations. Experiments were conducted as computer-based multimedia lessons and topics included: how brakes work (Mayer, 1999); how the human respiratory system works (Mayer & Sims, 1994); and how lightning storms develop (Mayer et al., 1999). Identified boundary effects included the use of highlighting, as well as effects of low-level learners and complex materials similar to spatial contiguity findings.

The modality principle, within CTML, is considered from the perspective of intrinsic load associated with to-be-learned material (Gerjets et al., 2004). The inherent difficulty of a topic cannot be altered by an instructor, though schemas can be broken into ‘subschemas’ to be later reintegrated. In 17 out of 17 experimental comparisons reported by Mayer et al. (2001), students performed better on transfer tasks when they learned with animation and accompanying narration rather than with on-screen text (median effect size *d* = 1.02). These comparisons included presentations of fast-paced lessons with unfamiliar content (Mayer & Moreno, 1998); multimedia biology lessons (Harskamp et al., 2007); and virtual reality games in Botany (Moreno & Mayer, 2002). Additionally, Ginns (2005) reported a mean effect size of *d* = 0.80 from meta-analysis of 43 *modality* effect experiments. Effect sizes of surveyed studies ranged between -0.6 and 2.2. All but two studies involved high element interactivity, and all but seven were system paced. Additionally, 25 of the experimental designs involved adults. Ginns (2005) suggests that the modality effect is moderated by the pace of delivery and that it can disappear under self-paced learning.

As such, research pertaining to the *multimedia principle* can be considered as a fundamental aspect of CTML research and emphasises CTML efforts in enhancing germane load in instruction. The multimedia principle is of obvious importance given that it underpins the field of multimedia research. By way of example, Mayer (2005b) reported a median effect size *d* = 1.39 from eleven *multimedia* effect studies. All of these comparative studies showed enhanced learning in transfer tests from students exposed to combinations of words and pictures in instructional material. Relative to isolated narration and animation, narration was associated with higher transfer test scores on how pumps work (Mayer & Anderson, 1992); how lightning works (Moreno & Mayer, 2002); or with an arithmetic simulation game (Moreno & Mayer, 1999). Additionally, with static texts on how brakes work, students performed better on transfer tests following presentation of booklets with printed text and illustrations versus printed text alone (Mayer, 1989). This was also observed with how generators work (Mayer & Gallini, 1990) and how lightning works (Mayer et al., 1996).

Having been presented with a snapshot of CTML research, critiques of CTML suggest theoretical shortcomings. Ballantyne (2008), for example, described the narrowness of CTML research and suggest that CTML principles could be limited in use in educationally realistic settings. For example, Rasch and Schnotz (2009) suggest that the modality principle could lack stability as a learning effect in that improvements in learning from interactive versus non-interactive pictures were not observed in their, or other, study. Furthermore, Gall (2004) suggests that Mayer's research has been too focused on physical and mechanical systems and suggests that Mayer's results could be incompatible with student-centered learning. A more fundamental objection to CTML is offered by Gerjets et al. (2009) who state that CTML is not scientific as its central tenets cannot be tested scientifically. Additionally, CTML's core cognitive principles face increasing pressure to conform with emerging understandings in neuroscience (as discussed in Section 2.3.2.2).

Other conceptual issues surround cognitive theory of multimedia learning, such as the delineation and measurement of the various cognitive loads. De Jong (2010) quotes Paas et al. (2004, p. 3):

> If the load is imposed by mental activities that interfere with the construction or automation of schemas, that is, ineffective or extraneous load, then it will have negative effects on learning. If the load is imposed by relevant mental activities, i.e. effective or germane load, then it will have positive effects on learning.

De Jong suggests that this definition of an extraneous load is tautological (what is good is good; what is bad is bad), and that it broadens extraneous load to potentially include not only aspects of instructional design, but also to any processes that do not lead to schema formation. This leads not only to confusion around definition of extraneous load, but also whether a separate germane load exists. In the same vein, De Jong (2010) questions the rationale of intrinsic load alongside germane load. An ontological difference in CLT exists between the external learning 'object' and the germane 'process' of learning from that object, and the distinction can only be made once learning has commenced. De Jong considers that CTML has insufficiently demarcated these two load forms as they both constitute purely mental forms of load and entirely depend on learner attributes in processing. Rather than discrete forms of cognitive load, De Jong (2010) considers differences between intrinsic and germane loads to be at best matters of degree, and at worst, indistinguishable in research. A related issue exists with the presumed additivity of cognitive loads. Sweller et al. (1998, p. 263) state that: “Intrinsic cognitive load due to element interactivity and extraneous cognitive load due to instructional design are additive.” De Jong (2010) suggests that such additivity could be impossible if definition issues exist between the load types.

Additional to these conceptual concerns, methodological issues in CTML have also been raised. Measuring cognitive load through self-reporting has been critiqued based on its subjectivity and instrument inconsistencies, for example. Questionnaires on mental effort have differed in usage of anchor terms and have been inconsistent in measuring effort versus difficulty (De Jong, 2010). Kester et al. (2006) highlighted this issue in using a 9-point scale in assessing mental effort experienced during learning, and a separate mental effort score for understanding the content matter. Analysis showed an effect of experienced mental effort during learning, but no effect for mental effort associated with understanding. This example, De Jong suggests, is indicative of the potential for conflicting results depending on the specifics of questions asked. Another important methodological implication of self-reported accounts is the limitation of cognitive load as a student-bound characteristic. This is contrary to CTML which suggests that mental effort is a combination of the task, personal characteristics and the interactions between these two factors (Paas et al., 1994). Finally, like that of cognitive load theory, the lack of individual / contextual differences as moderators of learning within CTML is raised as a theoretical and methodological concern. While marginal / boundary effects are proposed in CTML, these appear to represent remedial efforts following experimental inconsistencies rather than genuine attempts to differentiate amongst learners.

2.8 Chapter summary

This literature review has addressed the theoretical and methodological background of multimedia learning and areas of developmental neuroscience that pertain to textual learning. Following this order, key points include:

- Multimedia learning emphasises the importance of perceptual and cognitive processes in learning. Current guidelines in multimedia design are based on a universal account of neural architecture and cognition.

- Key assumptions within multimedia research derive from dual coding theory and Baddeley's model of working memory and include (a) modality-specific subsystems within working memory, (b) limited subsystem processing capacity, (c) active processing of sensory information.
- Mayer's multimedia effect suggests that deeper learning occurs when text and pictures are presented together. Imagery provides deeper referential connections than text alone.
- Learners fail to benefit from multimedia learning when: (a) information is not presented at learner-pace; (b) the text is very rich; (c) redundant auditory information is presented.
- Two prominent design recommendations for static textual design include consideration of modality and spatial contiguity effects.
- Testing for developmental differences has not been attempted within the two most prominent multimedia theories: cognitive load theory and cognitive theory of multimedia learning.
- The modality and spatial contiguity effects can represent experimental artefacts. In the case of static texts, accounts of modality and spatial contiguity effects could represent split-attention and not enhancement of cognitive resources in the case of successful learning.
- Cognitive styles are associated with socioeconomic gradients and show a related degree of cognitive abstraction. Low socioeconomic students perform poorly on executive function and language tasks.
- Perceived social standing could be a better predictor of health issues associated with socioeconomic status than objective SES measures.
- Allostasis provides a mechanistic framework in explaining socioeconomic status and health. Allostatic overload pertains to pathology associated with chronic stress. Allostatic overload is seen disproportionately in environments of low socioeconomic status.
- Emotions are central in behavioural regulation as emotion modulates attention, perception and cognition. The hippocampus, amygdala and prefrontal cortex are interconnected hubs involved in socioemotional information processing.

- Embodied cognition considers cognition to be action oriented and biased towards holistic stimuli.
- The hippocampus and prefrontal cortex show stress-induced dystrophy, while the amygdala shows cellular proliferation under chronic stress.
- Joint hippocampal and prefrontal involvement are involved in successful memory formation and retrieval in context-based processing. Efficient memory processes depend on stimuli congruency in 'what' and 'where' streams.
- 'Abnormal processing' in the context of this thesis involves unimodal or incongruently presented stimuli. Abstract information is devoid of context and falls into this category. Impaired hippocampal-dependent memory processes are associated with unimodal stimuli.
- Supra-additivity in audiovisual stimuli processing shows integrated brain processing, involving attentional, perceptual and cognitive functioning. The reactivation memory hypothesis suggests that better recall occurs when the same perceptual areas are elicited as when originally encoded.
- Multiple components models assume brain modularity with experimental focus on architectural and organisational constraints. Embodied cognitive models, by contrast, assume attentional, perceptual, and cognitive integration. Experimental focus is placed on inherent cognitive limitations that follow from developmental or task-specific constraints.
- A model of embodied cognition suggests that split attention in static texts is better understood as a processing deficit from lack of audiovisual congruency. Audiovisual integration should be understood in terms of ecological congruence.

2.9 Chapter synthesis

Brain structure and function are influenced by a rich combination of genetic and environmental forces. Broadly speaking, individuals adapt phenotypically to an environment which is most profoundly defined by resource allocation. Resource scarcity manifests in SES-gradients of disease incidence and psychiatric dysfunction with flow-on effects for cognitive style and related learning dispositions. This long-acknowledged association has motivated large-scale interventions such as the

Australian National Partnership's *Agreement on Low Socio-economic Status School Communities* (Council of Australian Governments, 2009) and the *Off to a Good Start Program* (Association of Independent Schools NSW, 2010). Multimedia learning research, however, has not taken a correspondingly differentiated approach in application of textual design (John Sweller, personal communication, 2014). As a consequence, successful textual comprehension within the cognitive load theory and cognitive theory of multimedia framework is considered from the perspective of effects inherent to limitations within a neural architecture largely divorced from evolutionary or developmental considerations. An alternative approach is to view learning behaviour in terms of developmental trajectories inherent to our position within the socioeconomic spectrum. This approach necessitates an understanding of brain development and function including an appreciation of the salience of socialised stimuli in memory processes.

The field of multimedia research thus contains an identifiable gap in omission of learner variates pertaining to socioeconomic status. Multimedia design should focus on *normal* and *abnormal* brain function. *Normal* functioning refers to the preference for cross-modal, socialised stimuli. Congruent stimuli preferentially elicit attentional and perceptual biases and related information is readily understood. *Abnormal* functioning is an inability to accurately process information in abstract non-social situations and manifests behaviourally as motivational biasing away from incongruent presentations. This occurs due to inhibitory mechanisms in executive function from altered neuronal processes. Such alterations occur in socioemotional processing hubs, either from neurological disturbance in specific neural ensembles or from impaired connectivity. In either case, disrupted neural processing can be viewed from a framework of allostatic dysregulation involving social standing.

Ontogeny is thus essential when modelling cognitive as well as attentional and perceptual processes. Multimedia learning was critiqued early in the chapter for viewing the cognitive architecture as computationally analogous. This view can be considered monolithic in the sense that individual development is overlooked or viewed as a straightforward series of age-stages, while instructional design is influenced by universal learning effects and principles. In a similar vein, the computational nature of symbolic representation stands at odds with holistic experiential coding in embodied cognition (see Section 6.2.2 for a discussion of semantic processing) which has implications for learning theory and design.

In conclusion, this chapter has analysed and evaluated the theoretical framework currently influencing multimedia learning. Specific inconsistencies motivating the study include a linear, universal account of cognition with related constraints in textual comprehension and, consistent with the cognitivist influence, a poverty of individual learner factors in applied research. The following chapter continues the review of multimedia literature in an exploration of methodology used within the field. Together, these reviews inform the experimental text design (see Appendix ii) that is used to test the research objectives (Section 1.5.1) and study hypotheses (Section 1.5.2).

Chapter 3

SYSTEMATIC REVIEW OF MULTIMEDIA RESEARCH LITERATURE

3.1 Chapter overview and organisation

This chapter builds on the instructional design principles outlined in Chapter 2 and presents an overview of existing research in multimedia learning. Specifically, I review the literature to the extent that multimedia research addresses individual differences, including learner affect, as variables in research. These aspects of multimedia learning relate to the research objectives posed in Chapter 1 (Section 1.5.1), thereby prioritising examination of existing research approaches. In addressing these questions, this chapter is presented as a quantitative review of multimedia learning research. Quantitative reviews, including meta-analyses and systematic reviews, complement narrative reviews as they offer a transparent and explicit summary of research literature and limit bias in the identification, evaluation and synthesis of the research corpus in addressing specific research questions (Valentine et al., 2010).

The current chapter thus presents two quantitative reviews with related analysis and discussion. The rationale for conducting these quantitative reviews, in addition to the narrative review of Chapter 2, was to critically evaluate the methodology of multimedia learning via its research foci and approaches. In extension of above, the first review is a collation of findings from educational meta-reviews examining, amongst other areas, multimedia principles and resources; meanwhile, the second is a systematic review of the literature of the extent and influence of individual and affective factors in multimedia learning. Following this, design principles are reviewed and applied to the development of the intervention text as discussed in Section 4.3. The chapter is structured as follows:

- Review 1: Review of meta-analyses in multimedia learning (Section 3.2)
    - Method (Section 3.2.1)
    - Findings (Section 3.2.2)
        - Established multimedia effects (Section 3.2.2.1)

        - Multimedia resources (Section 3.2.2.2)
        - Reading enhancement (Section 3.2.2.3)
    - Summary of findings from multimedia learning meta-analyses (Section 3.2.3)
- Review 2: Systematic review of multimedia learning (Section 3.3)
    - Method (Section 3.3.1)
    - Definition of multimedia instructional design (Section 3.3.2)
    - Inclusion / exclusion criteria (Section 3.3.3)
    - Data sources and search strategies (Section 3.3.4)
    - Data coding and extraction (Section 3.3.5)
    - Systematic review results and discussion (Section 3.3.6)
        - Research question 1 (Section 3.3.6.1)
        - Research question 2 (Section 3.3.6.2)
- Summary of systematic review of multimedia learning (Section 3.4)
- Chapter conclusion (Section 3.5)

3.2 Review 1: Review of meta-analyses in multimedia learning

Educational research has become increasingly focused on multimedia for delivering meaningful learning outcomes. Indeed, finding the most effective way to engage students and increase student learning outcomes has involved multimedia since at least 1922 when Thomas Edison proclaimed that “the motion picture is destined to revolutionize our educational system,” and that “in a few years it will supplant...the use of textbooks” (Mayer, 2005a, p. 8). Notwithstanding the dramatic rise of multimedia research over the preceding decades, formal education typically still largely follows traditional approaches (Shrand, 2008). Krippel et al. (2010) reason that this could reflect contradictory findings in research on the learning outcomes of using multimedia. Bryant and Hunton (2000) relate these conflicting results to the soundness of the research methodologies, alongside confounding effects of research variables; they also describe how research studies have been formulated on multiple theoretical bases. To explore these issues further and to isolate specific variables of interest in multimedia research, this section presents an overview of meta-analyses sourced from educational databases. In organisation, Sections 3.2.1 describes the method used for this review of multimedia meta-analyses while Section 3.2.3 outlines the findings of the review. Subsections in this section include: (1) established multimedia effects (Section 3.2.2.1), (2) multimedia resources (3.2.2.2) and (3) reading enhancement (3.2.2.3).

3.2.1 Method

Meta-analyses were located from the Curtin University library data base (http://databases.library.curtin.edu.au), with databases filtered by subject (education). Seven databases (ERIC; Informit; JSTOR; Sage Knowledge; Scopus; TROVE; Wiley Online Library) were used alongside Google Scholar to provide good coverage of relevant material.

Inclusion criteria delineated key words relating to study-type; field of research; established effects / principles; and multimedia informing theory.

Key words (separated with Boolean operators [AND; OR]) included: meta-analysis; multimedia; learning; “multimedia research”; “multimedia learn*”; “multimedia instruction”; “instructional visualisation”; “multimedia instruction* principle*”; “instruction* technol*”; “modality effect”; “modality principle”; “spatial contiguity effect”; “spatial contiguity principle”; “temporal contiguity effect”; “temporal contiguity principle”; “multimedia effect”; “multimedia principle”; “personalisation effect”; “personalisation principle”; “cognitive load”; “cognitive load theory”; “cognitive theory of multimedia”; “cognitive theory of multimedia theory”.

Other criteria included:

1. A primary research focus on multimedia (i.e. involving audio-visual presentations)
2. Any age groups encompassed
3. Peer-reviewed (published) study
4. Accessible by educators (i.e. inclusion of Google Scholar)
5. Standardised mean difference (*d*) effect or effect estimate included
6. Clear elucidation of research (influence) variables (e.g. performance / boundary / task variates) alongside stated research hypotheses

7. Published between 2000 - 2016

Features leading to exclusion included:

1. Game based research
2. Primary focus on *pedagogical agents*
3. Second language (L2) focussed
4. Computer-assisted learning (CAL) focussed
5. Online-learning focussed
6. Hypermedia focussed

A total of 14 meta-analyses satisfied inclusion / exclusion criteria and were selected for analysis. A broad coding scheme differentiated the papers into three sets of research: established multimedia effects (6 papers), multimedia resources (5 papers), and reading enhancement (3 papers).

3.2.2 Findings

With few exceptions, the reviewed meta-analyses adhered theoretically and methodologically to the assumptions and research traditions of cognitive theory of multimedia learning (Mayer, 2005a; b) and Cognitive Load Theory (Pass et al., 2004). Moreover, when theoretical discrepancies arose or reported results appeared discordant with established multimedia theory, discussion was mostly framed from the perspective of dual coding theory or related models of cognition. Learning effects, additionally, were often considered as boundary conditions requiring further investigation following experimental uncertainty.

The following sub-sections elaborate on the methods and findings of the included meta-reviews. As mentioned previously, these subsections conform to specific research foci including established multimedia effects (Section 3.2.2.1), multimedia resources (Section 3.2.2.2) and reading enhancement (Section 3.2.2.3). The studies were examined for stated purpose and theoretical framework, influence variables, ages of participants and results. Study results were further analysed for effect size modulation, consistency with previous research, alignment with established multimedia theory, experimental heterogeneity and boundary condition amendment for effects originally modelled as design, outcome or learner variates.

3.2.2.1 Established multimedia effects

Six of 14 multimedia meta-analyses were focused on established learning effects. These effects derive from CTML basic principles (*modality*; *spatial* / *temporal contiguity*; *redundancy*; *signaling*) as well as effects reported in the CLT literature (e.g. the *expertise reversal* effect and management of extraneous / generative processing). Studies included in the meta-analyses were dated between 1967 and 2009, involved 812 independent effect sizes from 328 studies, and included more than 12,000 participants.

Reinwein's (2012) review of the modality effect in multimedia learning builds on Ginns' (2005) meta-analysis of the same topic though widens the range of moderator effects to include dichotomisation of existing measures (e.g. *element interactivity*), addition of new moderators (e.g. *type of visualization*) and other modifications to existing variables (e.g. *performance variate* changed to *type of outcome*). Considering the latter modification, Reinwein (2012) reduced bias identified with Ginns' (2005) usage of priority rules in selecting dependent outcomes from multiple *performance variate* scores alongside identified publication bias. In essence, potential collinearity existing across multiple measures (i.e. recall, pictoverbal matching and transfer tests) was controlled by Ginns (2005) through a rule-based selection of iteratively-chosen dependent measures ranging from *transfer test, to recall*, to *test of subjective appreciation of the cognitive load experienced*. Reinwein (2012) shows that this induces a higher standardised effect-size difference (Hedge's *g*) as subjective measures often showed significance alongside existing, yet non-significant, objective indicators and increased proportionately with the number of dependent measures. Reinwein (2012) used objective indicators only and, with usage of Duval and Tweedie's *Trim and Fill* method for correction of publication bias, Ginns' (2005) overall large effect size (d = .72; 95% CI = .52-.92) reduced considerably to d = .20 (95% CI = .07–.32).

Specific moderator effects reported by Reinwein (2012), such as the significance of *type of visualisation* (*dynamic* vs *static* picture) also shed light on interactions inherent to instructional design. With two exceptions (*age*; *decorative pictures*), all moderators significantly impacted the overall modality effect size. The analysis confirmed the importance of the pace of study, but the inclusion of *type of visualisation* in particular showed a large superiority of *dynamic* over *static* pictures (*static*: d = .23; *dynamic*: d = .82). This result challenges existing theory on the modality effect (e.g. Moreno & Mayer 2007, 2010; Tabbers 2002) because the modality effect relates to text type and not the type of presented visualisation. Reinwein (2012) reasons that confounding variables may explain the variation in effect sizes seen in previous studies of the modality effect (e.g. Mayer et al., d = .93 with all comparisons involving dynamic pictures and system-paced., cf. Tabbers et al., 2001 d = -.24, with all comparisons involving static pictures and self-paced instruction). He concludes that these results are more credible in light of a possible split-attention effect which warrants a theoretical reconsideration of the modality effect.

In the year following his meta-analysis on the modality effect, Ginns (2006) published a subsequent meta-analysis on the spatial / temporal contiguity effects within multimedia research. Hypotheses were derived from CLT and CTML theory and research and predicted that reduction in the need to split attention – both temporally and spatially – across multiple sources of information would enhance learning across topic domains, educational levels, form of testing and form of information presentation. Additionally, a second hypothesis moderated the strength of the effect to the level of element interactivity with a stronger effect predicted for materials with high element interactivity.

The results of Ginns (2006) meta-analysis support prior theorising of extraneous cognitive load with particular regard to negative consequences associated with materials of high element interactivity. Similar to findings in Ginns (2005) systematic review of the modality effect, weighted mean effect sizes for both types of contiguity were large (d = .85; 95% CI = .68-1.02) with a highly significant homogeneity statistic indicating the presence of one or more conditioning moderators. Moreover, there was no significant difference between temporal (d = .78, 95% CI = .63-.92) and spatial (d = .72, 95% CI = .61-0.82) contiguity. Analysis of element interactivity and educational level provided interesting results as they offer mixed support for CLT and previous empirical results. Age, as a proximate measure of educational level, showed a general decrease against contiguity as a learning effect (primary-learner *d* = 1.02; junior high school *d* = .67; senior high school *d* = .79; adult *d* = .73) and suggests that novice learners benefit most from reduced split-attention with experienced learners perhaps showing greater rehearsal ability in decoding textual features. However, the effects for low element interactivity materials were not nearly as large as for high element interactivity materials (high element interactivity *d* = .78; low element interactivity *d* = .28). Ginns (2006) raises the limitation of small samples in the low element interactivity studies (generally n = 10 per condition) reducing the ability to smaller effects in the available studies and also highlights the large confidence intervals for low element interactivity studies (0.03 to 0.58). Following Cohen's (1988) suggestion that a standardised mean difference of 0.5 constitutes a 'moderate' effect, the range of plausible effects ranging from nil effect to moderate or even large effect can be deduced.

The most salient result, according to Ginns (2006), is that novice learners stand to gain significant learning improvement – irrespective of learning material complexity (element interactivity) – when materials are designed with a high degree of spatial and temporal contiguity. This was especially the case with materials of high element-interactivity and, moreover, the studies demonstrate that increasing integration supports learning across a wide variety of educational domains, media and age levels.

In other research examining novice-expertise effects in multimedia comprehension, Gegenfurtner et al. (2011) integrated 296 eye-tracking studies into a meta-analysis. Eye movement and performance data from 819 experts, 187 intermediates and 893 novices were analysed with expert performance defined as "consistently superior performance on a specified set of representative tasks for a domain" (Ericsson & Lehmann, 1996, p. 277). In extension of previous expertise-reversal effect findings, and assuming that eye-fixations reflect processes underlying task performance, Gegenfurtner et al. (2011) hypothesised that experts, who encode and retrieve information quicker than novices, should reflect such information processing with shorter fixation durations. Additionally, experts are likely to fixate more quickly, and longer, on task-relevant areas and, in support of Kundel et al. (2007) *holistic model of image perception*, are likely to have longer saccade length. Additional hypotheses relate to moderators at the visualisation, task and domain levels and reflect Ericsson and Kintsch's (1995) *theory of long-term working memory* and Haider and Frensch's (1999) *information-reduction hypothesis*. Both of these align with Cowan’s (2001) consideration of working memory as a subset of long-term memory, which ostensibly rejects the dominant *separate-streams* model that influenced other reviewed meta-analyses. Smaller differences were hypothesised at the visualisation level upon static, schematic and two-dimensional presentations, use of dual modality and textual annotation. Task level differences (i.e. a smaller moderating effect) were hypothesised for task complexity, time limitations and user-control and, at the domain level, expertise was hypothesised as a function of the professional domain.

Findings offer support for notable expert task efficacy such as that noted for expert radiologists detecting cancer in a mammogram in a split second (Kundel et al., 2007) or grandmasters locating the positions of checking pieces on the chessboard without moving the eye (Reingold et al. 2001). Furthermore, the findings offer support for expert enhanced retrieval structures and task-relevance allocation of attentional resources within an embodied model of cognition. Consistent with Ericsson and Kintsch's (1995) *theory of long-term working memory,* experts had slightly shorter fixation durations than novices ($r = -0.09$). Consistent with the assumptions of the *information-reduction hypothesis,* the expert sample had more fixations on task-relevant areas ($r = .53$) and fewer fixations on task-redundant areas ($r = -0.31$) relative to that of novices. Moderate to strong effect size differences were reported between experts-novice comparisons ($_{r}$relevant = 0.27, $_{\mathrm{r}}$redundant = −0.43), with a general tendency for longer fixation durations on relevant areas and shorter fixation durations on redundant areas with expertise level increases.

Within Reingold and colleagues’ (2001) analysis of moderator effects, second-order sampling bias was controlled for by focusing on variables with the highest sample sizes and number of data sources. This led to inclusion of number of fixations, fixation duration, reaction time and performance accuracy for the expert–novice comparisons. Visualisation characteristics significantly moderated eye movement and performance variables including dynamic / static presentations, with experts tending to employ more fixations ($r = .05$) of shorter duration ($r = -0.12$) for dynamic visualisations. Novices, on the other hand, tended to employ more fixations ($r = -.22$) of shorter duration ($r = 0.04$) for static visualisations. Within levels of realism, experts gradually used more fixations than novices did as the levels of realism increased from schematic ($r = -0.24$) to rather realistic ($r = .01$) and photo-realistic ($r = .02$) visualisations. Expert–novice differences were smaller for photo-realistic than for schematic visualisations regarding response time and performance accuracy and experts tended to employ fewer fixations for two-dimensional and more fixations for three-dimensional visualisations than novices. Modality and text-annotation also showed expert-novice distinctions: smaller expert–novice reaction-time differences for annotated visualisations existed, alongside significant expertise gradient differences in dual-modality, and novices also showed greater accuracy in visualisations with annotated text. In task complexity, all findings confirmed expert efficacy (i.e. greater performance accuracy; shorter response time with growing levels of complexity) although, unexpectedly, user-control moderated accuracy and speed more for experts than novices.

Gegenfurtner et al. (2011) concluded that their primary and secondary (moderator) findings confirm assumptions within the framing theories and suggest that performance is a monotone function of experience. There were perceptual inconsistencies, such as evidence of longer fixation duration for intermediates than for novices, which the authors assumed as representative of an attempt to apply a complex knowledge base that was not yet fully automated. Substantiation of the *information-reduction hypothesis* (Haider & Frensch, 1999) is also claimed because task-relevance resulted in higher numbers of fixations and results also appear to confirm Kundel et al. (2007) *holistic model of image perception* as experts' parafoveal processing showed longer saccades and shorter fixation times on areas of task relevance.

The *redundancy* and *signalling* effects which are basic principles within CTML research (Sorden, 2005), were reviewed in meta-analyses by Adesope and Nesbit (2012) and Richter et al. (2015), respectively. Richter et al. (2015) hypothesised an overall positive effect on comprehension from the presence of signaling between different media modalities. They refer to Schwonke et al. (2008), who claim that 'ecologically valid' (i.e. school-relevant) materials should be employed in testing the robustness of an effect, and they acknowledge that several included studies used learning materials that are unlikely to be used in schooling or had poor control group design. As usual within multimedia meta-analyses, potential moderators of the overall effect size are included to help explain observed variance. In Richter et al. (2015), *domain-specific prior knowledge*, *pacing of materials*, *pictorial format*, *multimedia mapping requirements* and *distinctiveness of signals* were included for subsequent analysis. Alongside stringent inclusion / exclusion criteria, the authors assume high discriminant validity because only independent effect sizes were included; multiple group comparisons were avoided as all studies used between-subjects designs, and control groups were only used once for effect size calculations within a study.

Twenty-seven articles involving k = 45 pair-wise comparisons included the comprehension performance of multimedia learning material with or without multimedia integration signals. Richter et al. (2015) reported that 38 out of 45 comparisons had positive effect sizes (84.4%) which, taken together, suggest a small-to-medium overall signaling effect in favour of signalled compared to non-signalled multimedia learning material (r = .17; 95% CI= .11- .22). Similar to other reviewed papers, the set of effect sizes was overall heterogeneous, resulting in further moderator analyses. Only one of the hypothesised moderator variables — *domain-specific prior knowledge* of the learner — accounted for appreciable variance in this random-effects meta-analysis. As domain-specific prior knowledge was operationalised as a dichotomous variable (low / medium vs. high), the analysis revealed that learners with a low / medium level of domain-specific prior knowledge gained more from signaling than learners with a high level of domain-specific prior knowledge. *System pacing* also showed significant moderation of the overall signaling effect when studied in isolation (i.e. from a seperate meta-analysis). The authors concluded that prior knowledge most significantly moderates the effect of signaling in textual presentations and that multimedia integration signals were more effective when system-paced materials, in contrast to self-paced materials. were used.

Referring to the *ability-as-compensator* hypothesis (Mayer & Sims, 1994), Richter et al. (2015) emphasised the importance of signaling as a means to facilitate integration in low prior knowledge learners. They suggest the likelihood of an *expertise-reversal* effect (Kalyuga et al., 2003) in the interference of pre-existing mental representations in experts upon receipt of additional instructional support, although this discounts the fact that experts could simply ignore distracting cues. Meanwhile, low-prior knowledge learners were found to benefit from reductions in verbal redundancy in

Adesope and Nesbit's (2012) meta-analysis with presentation of auditory and written text. Redundancy arises from the concurrent presentation of text and verbatim speech (Wiebe & Annetta, 2008) and the authors investigated the effects of spoken-only, written-only and spoken–written presentations on learning retention and transfer. Overall, outcomes did not differ between spoken–written and written-only presentations, though spoken–written presentations outperformed spoken-only presentations. Additionally, spoken–written presentations showed advantage for low prior knowledge learners alongside system-paced learning materials and picture-free materials. This is claimed by Adesope and Nesbit (2012) to present important theoretical advances as previous research has not adequately delineated specific boundary conditions - including participant characteristics, contextual factors and outcome constructs.

This concludes the reporting of established multimedia effects within multimedia learning meta-analyses. The following section outlines an additional primary focus of multimedia research, multimedia resources.

3.2.2.2 Multimedia resources

Reviewed meta-analyses, with multimedia resources as the research focus, primarily assessed learning effects from usage of animations and simulations. Three of five located studies involved analysis of animations and / or simulations and included university-aged or adult participants (Gegenfurtner et al., 2014; Lin et al., 2007; Rolfe & Gray, 2011). One study (Yue et al., 2013) examined educational tools – medical animations – involved in medical training, within the CTML theoretical framework. Yue et al. (2013) also assessed young adult / adult learning outcomes. Only one study involved school-aged students (Hoffner & Leutner, 2007) as a sub-set amongst other age groupings and, as in the above studies, age or educational-level did not feature as a learner-characteristic with statistical significance as a learning effect. Overall, the meta-analyses drew from studies published between 1973 and 2010, included 224 independent effect sizes or effect estimates expressed as mean differences with confidence intervals, and involved 9343 participants.

Yue et al. (2013) examined a large sample (p = 430) of medical animations and evaluated learning potential in terms of cognitive load associated with CTML multimedia instructional principles. Within this analysis, the management of essential processing, minimization of extraneous processing and facilitation of generative processing were aligned with eight specific CTML principles and associated interactivity features from a subset of the 430 located animations. As such, no consideration of experimental design or participant characteristics moderated the research approach and, by default, the specific learning resource precludes non tertiary-education aged learners. The authors raise the issue of conflicting findings in CTML research and discuss debate on the exact cognitive mechanisms responsible for the modality effect and other effects. They speculate that for practical purposes, empirical findings outweigh purely theoretical considerations of working memory architecture as confirmatory results have been repeatedly observed under specific conditions. For example, Yue et al. (2013) note that the modality effect is observed when computer-paced lessons are short (i.e. < 10 minutes) or when learners can control the lesson pace. This apparent management of essential processing exists alongside other confirmatory findings such as the experimental manipulation of redundancy of aural and visual modalities (*redundancy* principle; c.f. cognitive load of extraneous processing) and interactivity features of learning materials (*interactivity* principle; c.f. germane cognitive load).

Yue et al. (2013) provide statistics on animations that exhibit multimedia principles, ranging from 7.7% (*pre-training principle*) to 92.4% (*spatial contiguity principle*) and averaging 48.4% across all eight principles. Management of essential processing has the lowest degree of adherence (*pre-training principle* - 7.7%; *modality principle* - 17.4%); mixed results were reported in minimisation of extraneous processing (*coherence principle* - 67.2%; *redundancy principle* - 45.6%; *signaling principle* - 18.9%; *temporal contiguity principle* - 76.5%; *spatial contiguity principle* - 92.4%); and the highest overall percentage is found for generative processing (*interactivity principle* - 61.2%). Findings revealed that the average adherence rate was 4.2 principles per animation; the majority of animations used solely graphic images (94.4%); animations were mainly commercially sourced (79.8%) and animations ran on average for one-and-a-half minutes.

The authors conclude the meta-analysis with discussion of merits and improvements for animations in medical undergraduate training. Because the average animation run-time length was consistent with materials used in multimedia research, core multimedia principles are considered applicable to medical animations. The lowest rate of adherence to multimedia principles was seen from the essential processing construct – *pre-training* and *modality* – which the authors relate to deficits attributable to 10% of animations defining key terms prior to the lesson and < 20% using narration as primary communication of verbal information. Usage of animations as adjunctive to formal training could remove need for pre-training, such as providing definitions, though the modality effect could easily be catered for via inclusion of auditory narration. A danger of cognitive overload through identified lack of coherence or redundancy exists in that more than two-thirds of animations presented at least one design element that could lead to extraneous processing. As these distractions related to easily removed features such as redundant (identical) bullet-points or background music, the authors suggest that their removal could improve learning outcomes. Finally, the embedding of user control features can facilitate generative processing through the implementation of the *interactivity principle*. Overall, animations are assumed by Yue et al. (2013) to provide meaningful learning outcomes even though they are presently designed with some inherent limitations. Additionally, some multimedia learning principles, such as spatial integration of textual / pictorial features, are apparently inbuilt as a design feature irrespective of underlying multimedia effects.

Hoffner and Leutner (2007) reviewed 26 primary studies in an attempt to answer whether instructional animation provides better learning outcomes than static pictures. They discuss CTML (Mayer, 2001, 2005a) in the context of learner as a self-constructor of knowledge. In so doing, they relate three basic assumptions informing CTML – *active processing*; *dual channel processing* and *dual coding*; *limited capacity short-term memory* – to strong empirical evidence in learning from coordinated materials but they also raise the omission in research of static versus animated pictures as examples of a pictorial presentation format. Individual learner differences are hypothesised to influence whether static pictures or animations within a specific domain of knowledge or skills are superior and include *spatial ability* and *prior knowledge*. Alongside animation features (such as being video or computer-based, being representational or decorational or in differentiation of realism) individual differences are nonetheless conflated to *instructional domain* and *type of knowledge* – a decision reflecting poor empirical coverage in the literature. As such, study characteristics, such as educational level, were thus listed, though not included for analysis.

Hoffner and Leutner's (2007) findings, from 76 pair-wise comparisons of dynamic and static visualisations revealed a medium-sized overall advantage of instructional animations over static pictures (d = .37; 95% CI = .25-.49). Furthermore, analysis of weighted effect sizes indicates that effect-size distribution reflects differences in study features. Subsequent moderator analyses revealed more substantial effect sizes with representational animation being superior to decorative animation (d = .40; 95% CI = .26-.53) though decorational animations were not significantly superior to decorational static pictures (d = .05; 95% CI = .37-.27). Additionally, two types of requested knowledge moderated findings in favour of animations: procedural-motor knowledge had the largest mean weighted effect size in favour of animations (d =1.06; 95% CI = .72-1.40), followed by declarative knowledge (d = .44; 95% CI = .27-.57) though problem-solving knowledge showed a reduction in mean effect size (d = .24; 95% CI = .04-.44). The authors note that the latter variable could be influenced by some confounding of type of knowledge with role of animation as all procedural-motor knowledge visualisations were also representational; in contrast, numerous visualisations requiring declarative or problem-solving knowledge were decorational. Other potential confounds existed between type of animation and the role of animation, with 92% of video-based animations used in a representational role versus 48 from 64 computer-based animations used in a representational role. Indeed, effect size differences disappear when examining video-based and computer-based animations in representational roles only. Finally, two significant effect-size differences are seen between the four operationalised levels of realism (level 1 - *schematic* through level 4 - *photo realistic*). Holme-Bonferroni adjusted contrasts between realism levels 3 and 4 and levels 1 and 4 were significant which, along with superiority of animations over static pictures with signaling cues, suggests a clear overall advantage of non-interactive representational animations compared with static pictures or decorative animations.

Rolfe and Gray (2012) extend on Yue and colleagues' (2011) analysis of multimedia learning instruments through examination of learning outcomes in the field of life science. Inclusion of quasi-experimental studies alongside randomised controlled trials satisfied search criteria, although the authors raise the issue of rigour in educational versus medical research. As the primary outcome measure of interest was a knowledge or learning gain and appreciating the less-rigorous nature of many education studies, non-randomised studies were accepted if they were controlled in a matched or longitudinal design with equivalent control or comparison groups. As previously mentioned, studies were excluded if they contained school-aged participants or affective outcomes in the absence of reported learning gains. Unique amongst the selected multimedia meta-analyses, risk of bias was determined solely as a study design feature with no consideration of publication bias. This is contrary to Ferguson (2007) who describes the various measures that researchers commonly use to estimate such bias. Importantly, Torgerson (2005) claims that inherent bias exists against publishing statistically non-significant findings which can result in (a) skewing findings towards more positive mean effect sizes and / or (b) nonsignificant findings not being published or available only in less accessible 'gray literature'.

The 17 publications chosen for analysis involved 9 comparisons (e.g. multimedia instruction *versus* traditional teaching) and learning gain was evaluated from 2290 student participants from 16 sub-groupings. Studies ranged between 1994 and 2008, covered tertiary life science subjects such as human anatomy and DNA replication and involved multimedia variously defined as: graphics; animation; audio; simulation; 2D graphics; 3D models; narrations; images; quiz; PDF text; photos; drag and drop. Outcome measures included achievement post-tests immediately following use of resource, retention tests completed one to several months afterwards and end-of-year examination results.

Overall, Rolfe and Gray (2012) found that use of embedded multimedia was associated with positive outcomes for undergraduate student learning gains in 10 from 16 sub-group comparisons. In replacement of a wet laboratory practical experiment with an online multimedia version (four studies), post-test results indicated knowledge gains (mean difference 23.21; 95% CI = -1.56-47.97). This result was non-significant although significant learning gains were seen in end-of-year examinations. Significant learning gains were demonstrated for multimedia substituted for a traditional lecture (in post-test, but not examinations); multimedia vs text book (post-test); in static vs interactive webpages (post-test); graphic vs animation short view (post-test / repeat view, post-test / retention test, but not post-test) and multimedia vs multimedia + 3D (post-test). Negative effect estimates showed a favourable control approach for multimedia vs blended learning (examination); multimedia + lecture vs tutorial + lecture (post-test), and lecture vs lecture + multimedia (retention test or retention test at 16 months). In conclusion, Rolfe and Gray (2011) note that multimedia could influence short-term understanding as lectures with substituted multimedia resources did not improve examination results. Other long-term retention issues are apparent from the findings, with multimedia resources being associated with improved examination results for multimedia vs practical; multimedia vs blended learning; graphic vs animation, and lecture vs lecture + multimedia conditions only. Finally, brief discussion of multimedia theory (e.g. Mayer, 2005a) and acknowledgement of confirmatory findings as that of Hoffner and Leutner (2007) and Lin et al. (2007) are considered by the authors to add credence to established CTML effects in that well designed resources in multimedia-enhanced learning optimises cognitive load.

Gegenfurtner et al. (2014) present a meta-analysis of digital simulation training, which builds on existing systematic analysis of eye-tracking research from Maastricht University, the Netherlands. The study aimed to correct the size of true score population correlations between transfer and self-efficacy for artifactual variance as well as estimation of moderating effects of specific instructional design characteristics. The study draws on Bandura's (1997) *social cognitive theory* and Mayer's (2009) *cognitive theory of multimedia learning* as useful frameworks in theorising and conceptualising self-efficacy as a motivational disposition in transfer learning. This is unlike Gegenfurtner et al. (2011) who, as discussed above, explore Cowan’s embodied model of cognition with novice-expertise differences influenced by Kundel et al. (2007) *holistic model of image perception.* Influence variables in this study include *social*, *narrative*, *adaptivity*, *multimedia* and *assessment* features as instructional characteristics of digital simulations and are presented as five hypothesised effects in moderating the relationship between self-efficacy and transfer of training in digital simulation-based training environments.

2274 learners with a mean age of 21.40 years (*SD* = 2.84) comprised the 15 independent data sources in the analysis. Simulations involved procedural knowledge and trained psychomotor skills in learning of professional work skills with transfer tests conducted on average one week after training (SD = 2.1 days). In the primary analysis, the uncorrected mean observed correlation *r* between self-efficacy and transfer of learning was .34 and the variance attributable to sampling error and error of measurement was estimated at 99.64%. Social characteristics, as the first proposed moderating construct, were operationalised as number of players and team context. Effect sizes were more positive when the trainee acted in a single-player simulation (*d* = 0.85) and not part of a team (*d* = 0.82) though these moderator effects were not significant. Of the narrative characteristics (*scenario*; *player perspective*; *fantasy*; *timing of the simulation*) only *timing of the simulation* showed statistical significance with self-efficacy, indicating that greater transfer (i.e. enhanced efficacy) occurs with simulated time flow (*d* = 0.90) compared with simulations using real-time (*d* = 0.75). For *difficulty level*, as an adaptivity characteristic (alongside *rule rigidity* and *simulation ending*) there was a significant difference in transfer with higher estimates found for simulation environments with user-controlled difficulty (*d* = 1.07) than for no increase (*d* = 0.85) or system-controlled difficulty level increase (*d* = 0.63). Finally, multimedia characteristics were assessed. Operationalised as modality (*visual only* vs. *visual and auditory modality*), realism (*schematic* vs. *realistic*) and dimensionality (*two dimensional* vs. *three dimensional*), 80% credibility intervals overlapped in all of the tested subgroups, thus indicating no significant moderating effects between multimedia characteristics and self-efficacy and transfer of training.

Conclusions were drawn about the effectiveness of digital simulations in training with instructional characteristics presented schematically as estimates of the positive (ρ = .38) correlation between self-efficacy and transfer of training. The leading four instructional characteristics were *user increase of difficulty level* (ρ = .48), *assessment after the simulation* (ρ = .43), *three-dimensional simulation* (ρ = .42) and *simulated time* (ρ = .41). Interestingly, the alternate dichotomisation with instructional characteristic comprised the bottom four correlation estimates although not in the same order [*system increase of difficulty level* (ρ = .30); *real time* (ρ = .35); *two-dimensional simulation* (ρ = .35); *assessment during the simulation* (ρ = .36)]. Returning to the framing theory, *social cognitive theory* (Bandura, 1997) appears validated given the positive learning transfer upon control of difficulty. This stands in contrast to *cognitive theory of multimedia learning* (Mayer, 2009) as population correlation estimates were largely unaffected by social, narrative or multimedia characteristics. These findings, with the practical suggestion to offer assessment after the simulation, prompt instructors to seek optimal user-control and to provide performance feedback after training.

Lin et al. (2007) discuss the empirical discrepancies in previous animation studies and present a meta-analysis of the instructional effectiveness of different types of enhancement strategies used to complement animated instruction. This analysis is unique amongst those reviewed as its 1124 college-age participants participated in 12 independent experimental studies in which the instructional content and four independent criterion measures were held constant across all studies. Investigation of the effect of varied enhancement strategies (*audio/narration*, *chunking*, *scaffolding*, *advance organizer*, *animation*) employed in the 12 studies examining heart anatomy and physiology were assessed by criterion tests – consisting of 20 items – designed to measure different types of learning objectives. The enhancement strategies conformed broadly to cognitive load and cognitive theory of multimedia learning, such as that of the modality effect and its role in optimising factual recall, in the audio/narration strategy. Other strategies, such as that of the *advance organiser* method adhere to older concepts in cognitive psychology such as Ausubel's (1963) *meaningful learning* and *assimilation theory* as elements of *subsumption theory* which base learning on superordinate, representational and combinatorial cognitive processes.

124 effect sizes were recorded by Lin et al. (2007) for all enhancement strategy criteria and ranged in magnitude between –1.20 and 4.15. Mean effect sizes across criterion tests showed inconsequential or negative moderation (in the case of identification test) by animation regardless of animation feature or enhancement strategy (drawing, d = 0.23; identification, d = –0.04; terminology, d = 0.20; comprehension, d = 0.20; total, d = 0.23; mean d = 0.16). The relative effect of varied enhancement strategies on different learning was estimated in the study. Here, averaged effect sizes indicated that the *advance organizer* method produced the greatest effect size (d = .47), followed by *chunking* strategy (d = .33) and *audio / narration* strategy (d = .04). The other included strategies which were conflated to a single group due to the small number of subjects

or poor experimental design, contributed to an overall negative effect (d = –.02). Discussion of the lack of consistency across animation enhancement features and learning outcomes frame the authors' conclusion. They propose that enhancements used in animations can induce a positive or negative effect depending on the type of enhancement and the type of learning objective to be facilitated. Specifically, in practice, they suggest that distracting animation features, such as concurrent use of audio / narration, could limit a learner's close attention, while use of advance organisers and chunking information can enhance cognitive processing germane to learning.

The following section concludes review 1 in detailing the methodology and findings of meta-reviews on reading enhancement as a subset of multimedia learning research.

3.2.2.3 Reading enhancement

Three meta-analyses located were focused on reading performance and each had hypotheses and variates drawn from CTML (Mayer, 2005a). Takacs et al. (2015) and Pearson et al. (2005) both examined learning effects associated with technology-enhanced reading materials from school-aged or younger students, while Ginns et al. (2013) assessed mainly college-aged or older participants in meta-analysis of textual conversational style and personalisation. In summary, learning outcomes for younger learners using technology-enhanced reading show minor improvement over traditional approaches, though the scarcity of affective and motivational research is a potential validity issue alongside the high degree of observed experimental heterogeneity. On the other hand, textual design employing a conversational rather than formal style was more likely to affect learning outcomes and processes including retention and transfer and factors concerning learner interest. The three meta-analyses discussed in this section draw from 107 journal articles, conference papers or Masters / PhD dissertations, include over 5500 participants and yield 220 effect sizes in estimation of hypothesised learning effects and secondary moderators.

Pearson et al. (2005) describe the growing integration of literacy and technology and the importance of substantive, content-area learning. A lack of related research for middle-school aged learners, though, is considered to hinder development of educational policy as cognitive processing in middle-school students differs from that of other age groups (Nelson et al., 2004). Advanced reading skills, including comprehension, metacognition, strategy use, motivation and engagement, are considered by the authors to be benefited by technology-enhanced reading materials as evidenced in previous work on distance-learning (e.g. Cavanaugh et al., 2004; Shachar & Neumann, 2003), technology-enhanced instruction (Kulik & Kulik, 1991), computer-aided writing skills (Goldberg, 2003) and literacy-acquisition with computer-assisted instruction (Torgerson et al., 2003). Motivated by this research gap, Pearson et al. (2005) designed their meta-analysis to assess strategy-usage, metacognition, reading motivation, engagement and comprehension as influence variables among students in the sixth to eighth grades.

Hedge's '*g*' statistic was used by Pearson et al. (2005) as a weighted effect-size estimate along with two effect-size calculation methods reported from summary statistics. From the five areas of interest, only comprehension featured as a study variate adequate for analysis. Included within an umbrella grouping of reading outcomes, the authors report comprehension as most commonly assessed (65%) and vocabulary as a distant second (10% of outcomes). They mention that intervention emphasis was more evenly distributed with 'mixed' emphases (e.g. multimedia learning environment with access to word meaning, pronunciation, comprehension scaffolds etc.) at around 30% and single emphases as vocabulary (17%), word recognition (15%), independent reading (12%) and comprehension instruction (12%). The weighted mean of all 89 corrected effect sizes was 0.49 (sd = .74).

Further analyses involved comparisons of specific programmatic, assessment and contextual variables. Statistically reliable contextual differences were observed in secondary analysis between undifferentiated middle school students (mean g = 0.52) and targeted populations of students (i.e. struggling readers and those with learning disabilities; mean g = 0.32), though not between meaning-focused and code-focused interventions. Study duration, contrary to expectation, showed a "U-shaped" effect distribution in that effect sizes in medium-length (2-4 weeks; N_{es}=21, g = .55) studies were larger than those lasting less than a week (N_{es}=25, g = 0.48) and much larger than studies lasting five or more weeks (N_{es} =43, g = .34). Sample size was a reliable predictor of effect size (small *n* studies averaged g = .77, large *n* studies averaged g = .38) with test type, although "policy focus" categorisation by primary purpose into (a) *reducing the achievement gap,* (b) i*ncreasing technology use in general*, or (c) *improving a specific educational outcome* such as reading comprehension, did not yield statistically significant differences (Q=1.68, p>0.05). In discussion, the authors reaffirm the positive benefits of technology-enhanced literacy while lamenting the scarcity of existing research in meta-cognition, reading motivation and engagement. They conclude the meta-analysis by calling for more research in digital technologies in improving the five identified areas of literacy acquisition and restate the implications of such research for curricular practice, policy and research.

Takacs et al. (2015) conducted a meta-analysis of the effects of technology-enhanced stories versus listening to stories in young children's literacy development. Studies were included on the basis of narrative stories for children with reported multimedia or interactive features while excluding the effects of device-type or media employed in their delivery. The cognitive theory of multimedia learning (Mayer, 2005a) was presented as an overarching theoretical framework for multimedia design. Several CTML basic principles (e.g. *spatial* / *temporal contiguity*; *modality* effect) are presented with extraneous and intrinsic cognitive load constraints from CLT (Chandler & Sweller, 1991) in the explication of multimedia benefits over traditional media formats and of interactive elements that could present extraneous processing demands. Acknowledgement is made, additionally, of *disadvantaged* children who may lag in language and comprehension skills. Operationalisation of *disadvantaged* learners in Takacs et al. (2015), as discussed in Section 3.1, is an umbrella construct comprising low socioeconomic status (SES) families, immigrant and bilingual families, children with learning problems, children with special needs, children with developmental delays or children with severe language impairments.

Four research questions were considered in the meta-analysis in which orally narrated stories were contrasted with technology-enhanced story presentations. Because oral narration was considered as posing significantly reduced cognitive demands on children compared with reading, oral narration in both traditional and technology-enhanced settings was included. Takacs et al. (2015) primary research question was the overall effect of technology enhancement for at least one outcome measure (e.g.

story comprehension / vocabulary; code-related literacy skills; letter knowledge; general reading skills). The other research questions focused on multimedia versus interactive story features which were broadly hypothesised to conform to CTML *multimedia principle* in fostering generative processing. In short, it was hypothesised that congruent multimedia features can be beneficial while interactive features irrelevant to learning could distract the learner and inhibit comprehension. The final research question involved the moderating effect of disadvantaged versus non-disadvantaged learners, with multimedia features hypothesised to aid learning in disadvantaged groups more than others.

Takacs et al. (2015) mention that as different outcome measures with different scales were compared between conditions, Hedge's *g* functioned as the standardised mean difference for the 57 reported effects from studies between 1980 and 2014. Effect sizes reflected a small, yet significant gain in all outcome measures (story comprehension, $g = .17$; expressive vocabulary, $g = .20$; code-related literacy skills, g = .16; engagement, g = .26) with effect size heterogeneity detected for vocabulary learning [$Q(12) = 25.54$, $p = .01$] and code-related literacy skills [$Q(13) = 23.65$, $p = .03$]. Subsequent analyses revealed outcome differences between disadvantaged and non-disadvantaged learners, with a significant effect for at-risk children with environmental factors such as low parental education, ($g = .35$) in vocabulary learning. Further heterogeneity was found within the disadvantaged group for vocabulary learning although, with insufficient contrasts including samples with developmental delays or learning problems for comparison, analysis of the kind of disadvantage was not possible for this outcome. Heterogeneity within code-related literacy skills outcomes was also detected between disadvantaged and non-disadvantaged groups although significant within- and between-group differences were not detected.

In answering research questions two (i.e. if multimedia-enhanced stories were more beneficial for children's literacy than traditional story presentations) and three (whether interactive features distract learning), observed heterogeneity in story comprehension was assessed by contrasting multimedia-only features with interactive-only features and presentations with both multimedia and interactive features present. Takacs et al. (2015) describe a significant contrast for multimedia-only presentations (g = .39), although this effect was not significant for stories including both multimedia and interactive features. Further analysis in the multimedia condition was conducted between oral text only or oral text plus static illustrations in the control conditions. No effect of illustrations was seen for the comparison conditions and multimedia presentations were seen to be advantageous over both oral-only presented stories (g = .43) and stories presented with static illustrations (g = .36). Moreover, for disadvantaged learners a strong additional effect of multimedia stories was detected (g = .66) as well as larger differences for multimedia versus interactive stories as predicted in research question four (i.e. whether technological additions to stories were more important for disadvantaged than non-disadvantaged groups). However, as with the previous moderator analysis, isolating developmental issues from other effects of poverty was not possible due to inclusion of only a single study featuring developmental delays.

Interestingly, relevance of story features (congruity) was not found by Takacs et al. (2015) to moderate the effect of technology on student outcomes. Inclusion of irrelevant only, or relevant and irrelevant features, did not have a significant effect (g = −0.21); however, stories with only relevant features also failed to show a significant additional effect compared with more traditional stories (g = −0.06). While there were not enough contrasts with multimedia-interactive stories to test the difference between multimedia-only and multimedia-interactive stories, disadvantaged children showed a significant advantage over traditional story materials on expressive word learning (g = .32). As before, further analysis of disadvantaged groups was not possible due to inadequate numbers of contrasts within the study corpus. In conclusion, the authors note the modest gains expected with technology in story comprehension, but suggest that, as an additional effect in augmenting existing benefits, technology is of relevance in literacy development. Moreover, the observed heterogeneity in findings is assumed to underscore different modes of presentation and forms of technology. This, along with a lack of learner engagement, suggests that technology, properly aligned with multimedia principles, can facilitate generative processing as a cognitive though not a motivational attribute.

The final meta-analysis reviewed is concerned with one of Mayer’s (2005a) guiding principles of multimedia design — *personalisation*. The argument that social cues can elicit generative processing in learners through presentation of socially congruent information underpins Ginns et al. (2013) review of multimedia research employing elements of *conversational style*. *Conversational style* is considered as multi-dimensional although it relates mainly to stylistic changes in the personalisation of text such as emphasising first- or second-person forms of address rather than third-person forms (e.g. Mayer et al., 2004), directly addressing the learner (Moreno & Mayer, 2000), author visibility (e.g. Paxton, 2002) or politeness (Wang et al., 2008). As mentioned above in Section 3.1, these textual-features are assumed by Mayer (2005a; b) to involve deeper cognitive processing in a sense-making attempt akin to normal listener cooperation in social discourse. Correspondingly, Ginns et al. (2013) present hypothesised effects of conversational style on learning processes and outcome measures. Hypothesised learning processes of instructional messages imbued with social cues include (a) an activation of social response with perceived friendliness and learning assistance, leading to (b) an increase in active cognitive processing with corresponding increases in (c) quality of learning outcomes. Potential moderators were hypothesised by Ginns et al. (2013) as: publication type; operationalisation of conversational style; educational level; language of instruction; broad field of study; pacing of instruction; length of learning phase and prior knowledge level. A noted absence is acknowledgement of disadvantaged learners, contrasting this with other meta-analyses in this section. This is noteworthy given the assumption of socialised information-modulating schema-acquisition processes that exist within the research-base on established learning effects in deprived environments (e.g. Bradley & Corwin, 2002; Hackman et al., 2010; Sirin, 2005).

Ginns et al. (2013) reported 74 effect sizes from published learning outcomes and / or processes from 3312 students and were included with standardised mean differences between conversational style and non-conversational style conditions included and corrected for bias associated with small sample size. 62 effect sizes were derived from college-aged students (84%), a further eight effect sizes were from research on senior high school students (11%), three studies drew from mixed-aged adults (4%) and one study included junior-high school students (1%). Hypothesis one related to the perceived friendliness of conversational instructional text and showed a positive, moderate effect (d = .46) as indexed by friendliness perceptions. Follow-up analysis of learning process moderators were hampered by small samples though showed small (*language of instruction - English*, *d* = . 03) to moderate-large effect sizes (effective cognitive processing, *d* = .62). The second hypothesised effect of conversational style assistance of instructional materials was small (*d*= .16; 95% CI= −0.19 to 0.52) and was not accepted due to the range of plausible values. Follow-up analyses were not possible, despite a statistically significant homogeneity statistic, due to insufficient variation across study features (such as one category having only one effect).

Ginns et al. (2013) report the second hypothesised effect of conversational style on perception of learning assistance of instructional materials as small (*d* = .16). The large range of possible values (95% CI= −0.19 to .52) and observed heterogeneity suggests that conversational instructional text was moderated either by learning process (c.f. paragraph above) or by learning outcome. In terms of learning outcome, standardised mean differences of moderate or greater size (i.e. $.3 < d < .8$; Ellis, 2010) were detected for retention (*d* = .3); language of instruction (other) (*d* = .55); publication type (journal article) (*d* = .38); operationalisation (politeness) (*d* = .38); operationalisation (l) (*d* = .58); educational level (senior high school) (*d* = .49); form of materials (paper based) (*d* = .50); broad field of study (mathematics / logic, science and engineering) (*d* = .3); pacing of instruction (system-paced) (*d* = .35); and transfer (*d* = .54). Interestingly, prior knowledge level was inconsistent with low (*d* = .6), medium (*d* = -0.11), mixed (*d* = .66), and high (*d* = -0.28) effect sizes showing little agreement with prior multimedia research.

Based on other results, Ginns et al. (2013) dismiss the assumed association between conversational style and learner interest (*d* = .16) but report moderate to large effect sizes which support the hypothesised effects of conversational style and effective cognitive processing (*d* = .62), tests of retention (*d* = .3), and tests of transfer (*d* = .54), respectively. The authors conclude with agreement with Mayer’s (2009) suggestion that learning is inherently social and that an “implied conversation” is evident between instructor and learner. This premise appears supported with the reliable effects reported within retention and transfer tests and with learners’ rating of personalised learning material as being more friendly and promoting more effective cognitive processing.

3.2.3 Summary of findings from multimedia learning meta-analyses

Examination of multimedia meta-reviews reveal specific trends in the literature. An overwhelming consensus of the workings of the cognitive architecture in stimuli processing is represented by CTML (Mayer, 2005a, b) and CLT (Pass et al., 2004). A sole exception is Gegenfurtner et al. (2011) who challenge existing accounts of working memory, specifically disputing the limited subsystem processing capacity assumption and instead invoke aspects of Cowan’s Embedded Cognition model in analysis of expert visualisation comprehension. A theoretical reframing of expertise differences is constructed around rapid information processing and greater selective attention allocation in experts. This, as discussed, was attributable to the superior processing resources of experts in domain-specific material, operationalised as extended visual span and parafoveal processing. It is noted by Gegenfurtner et al. (2011), though, that expert differences, as a subset of learner experience are represented by CTML in the prior knowledge principle (Mayer, 2009) and the expertise reversal effect (Kalyuga et al., 2003) as plausible boundary conditions. Likewise, Gegenfurtner et al. (2014) appear to deviate from the dominant framework theoretically with inclusion of Social Cognitive Theory, alongside CTML, in their review of primary and secondary multimedia learning effects. They note, though, that CTML and Social Cognitive Theory both appear insufficient as causal frameworks, with social, narrative and multimedia textual characteristics failing to modify correlation estimates between self-efficacy and transfer of training.

Appendix 1 provides a summary of findings from the included meta-analyses. Influence variables included in the result summary typically related to multiple hypotheses posed in meta-analysis, with results presented as boundary conditions following detection of heterogeneity in primary analysis. Primary hypotheses in all studies except Yue et al. (2013) included outcome variates directly attributable to CTML or CLT principles and related to established multimedia effects or their derived use in multimedia resources. Moreover, outcome variates are almost exclusively cognitive in nature — with Rolfe and Gray (2012) even removing affective outcomes in the absence of cognitive outcomes. Correspondingly, Ginns et al. (2013) decry the general lack of affective and motivational variates and discuss the inherent validity issues of this decision for multimedia research. Also within the selected meta-analyses, secondary analyses followed the almost universal detection of effect size variance, either as an absolute measure (e.g. using the Q statistic) or as a relative measure of dispersion (e.g. I^2 index). Observed heterogeneity, furthermore, was generally discussed in discernment of confounding variables - either operationalised and contrasted within the same studies - or marked for future research. Finally, all studies highlight at least minor theoretical and / or methodological inconsistencies in application of multimedia learning principles to educational settings.

3.3 Review 2: Systematic review of multimedia learning

Individual differences in multimedia research within the meta-analysis review (Section 3.2.2) broadly conformed to learner expertise (domain knowledge / aptitude), age / stage of learning and race / social background. Furthermore, these distinctions were often found to be regarded as possible confounders of main effects in meta-analyses and are generally presented as boundary conditions requiring follow-up research. The position taken in this thesis is that measures of socioeconomic status exist as covariates of cognitive outcomes which, as discussed in Section 4.10, are variates typically used in health research and not in education. Inclusion of synecdochic SES measures – such as subjective or objective social standing – are thus unlikely in multimedia research and, from examination of multimedia reviews, so too are student attitudinal outcomes. As presented in the previous chapter, however, socioeconomic status is an essential variate given its contextual influence in shaping brain development and learning behaviour. In order to adequately address published findings in multimedia instructional design aligned with the research questions posed by this thesis (Section 1.5.1), and to widen coverage of multimedia research to the present, the following section is presented as a systematic review of the multimedia learning literature. Specifically, two research questions are asked:

1. To what extent is socioeconomic status applied to multimedia instructional design as a moderator of learning outcomes, and how is it operationalised?
2. How are affective outcomes used in evaluation of multimedia instructional design in learning?

3.3.1 Method

This systematic review adopts the approach developed by Uman (2011) through the following steps: defining multimedia instructional design, inclusion / exclusion criteria, data sources / search strategies, data coding / extraction, analysing and interpreting results, and disseminating findings.

3.3.2 Definition of multimedia instructional design

Multimedia instructional design, for the purpose of this systematic review, is defined in the spirit of Mayer (2005a). In accordance with research showing learning gains with a 'visible' author (Clark & Mayer, 2011; Monero & Mayer, 2004), Mayer (2005a) emphasises instructional design involving a multimedia message as "a presentation consisting of words and pictures designed to foster meaningful learning" (p. 128). Also, the personalisation of learning text is important in establishing a communicative connection between teacher and learner (Mayer, 2005b) and is achievable with the presentation of textual features in a socially congruent manner. *Meaningful learning* and *social congruence* are factors reflecting the likely prioritisation of socioemotional stimuli processing over other information classes (see Section 2.3.3). In generalisation to the learning effects and principles presented for analysis in this thesis, these terms are intended to coalesce around motivated attentional, perceptive and cognitive processes that are synonymous with vicarious social learning in an embodied cognition model (Rosenthal & Zimmerman, 2014, p. 59). Specifically, for multimedia instructional design, meaningful outcomes are associated with efficient memory-consolidation and retrieval of content from socialised, multimodal stimuli. Thus, evaluation of multimedia instructional design ideally incorporates:

a) Inclusion of indices of perceived or objective social standing as learner variates
b) Measurement of affective outcome/s alongside cognitive outcome/s
c) Theoretical acknowledgement of developmental factors in assessing cognitive / affective outcomes.

3.3.3 Inclusion / exclusion criteria

To be included in this systematic review, studies had to meet the following criteria:

a) A primary research focus on multimedia (i.e. involving audio-visual presentations)
b) Inclusion of individual effect variate as independent (non-confounding) variable or covariate (interacting variable).
c) Involvement of any age groups
d) Study is peer-reviewed (published) study
e) Accessibility by educators (i.e. inclusion of Google Scholar)
f) Published between 1980 - 2016.

Features leading to exclusion included:

a) Inclusion of individual effect variate as confounding variable / moderator of main effect
b) Game based research
c) Primary focus on *pedagogical agents*
d) Second language (L2) focused
e) Computer-assisted learning (CAL) focused
f) Online-learning focused
g) Hypermedia focused.

3.3.4 Data sources and search strategies

The studies in this review were sourced from the same educational databases as the systematic review in Section 3.2. These include databases that are both researcher and publicly accessible and provide good coverage of multimedia instructional design as an educational topic. Databases included: ERIC; Informit; JSTOR; Sage Knowledge; Scopus; TROVE; Wiley Online Library; and Google scholar.

Key words related to individual characteristics; socioeconomic status; affective outcome; and field of research.

Key words (separated with Boolean operators [AND; OR]) included: individual; "multimedia research"; "learner charact*" "individual effect"; "individual learn*"; socioeconomic; "socioeconomic status"; "social standing"; affect*; "affective outcome"; attitud*; "learner attitud*"; "learner affect*"; multimedia; learning; "multimedia learn*"; "multimedia instruction"; "instructional visualisation"; "multimedia instruction* principle*"; "instruction* technol*"; "instructional design".

3.3.5 Data coding and extraction

A codebook was developed to parsimoniously code multimedia studies. This included a coding scheme to differentiate studies involving *learner characteristics* into (a) low socioeconomic status, (b) race / ethnicity, (c) learning problems / language impairments, (d) second-language learner, (e) expertise-novice gradient, (f) prior knowledge level, (g) attitude, (h) domain knowledge / aptitude, and (i) age / learning stage. Additionally, studies were coded into learner perceptions with *affect as learning process* — (1a) learner interest / enjoyment, (1b) learner motivation, (1c) learner perceived importance of subject, (d) cognitive processing; and *affect measured as outcome* — (2a) sole variable, (2b) additional to other construct/s. All studies were additionally coded for dominant multimedia learning effect / principle: (a) coherence principle, (b) signaling principle, (c) redundancy principle, (d) spatial / temporal contiguity principle, (e) segmenting principle, (f) pre-training principle, (g) modality principle, (h) multimedia principle, (i) personalisation principle, (j) voice principle, and (k) image principle, as well as advanced multimedia learning effect / principle: (a) animation / interactivity principle, (b) cognitive ageing principle, (c) collaboration principle, (d) guided-discovery principle, (e) navigation principles, (f) prior knowledge principle, (g) self-explanation principle, (h) site map principle, and (i) worked-out example principle.

3.3.6 Systematic review results and discussion

Overall, 126 multimedia studies which included learner characteristics as an independent variable were located and included for analysis. These 126 studies were chosen from a total of 406 located publications of which the majority (301) included socioeconomic status (or other measure of social standing) as a background condition that was not included as an experimental variate. The 126 studies included journal articles (88), book chapters (21), technical papers / conference papers (13) or PhD / Masters theses (4).

Research reports which involved perceptions of learning numbered in excess of 500 publications. Four hundred published articles were included as a representative sample of which the majority were articles in professional and academic journals (342), a further 26 were Masters / PhD theses, 12 were books / chapters and the remainder were technical papers / conference papers (20).

3.3.6.1 Research question 1: To what extent is socioeconomic status applied to multimedia instructional design as a moderator of learning outcomes, and how is it operationalised?

While low socioeconomic status was considered important enough to feature as a social determinant of learning and educational advantage (see for example, Dickerson & Kubasco, 2007; Neuman et al., 2011) in over 400 publications, socioeconomic status by itself did not feature as an experimental construct in any reviewed study operationalised either as a perceived or objective measure. When included as an umbrella construct along with one or more other variables (remedial reader; ESL student; disadvantaged / deprived background learner; struggling reader or immigrant learner), it featured as an experimental variable in 32 studies (Figure 3.1). Theory, as determined from observation of the reviewed articles, reveals that a majority of research adheres to the tenets of CTML and its derived principles (see Section 2.4.2). One hundred and eighteen studies directly or indirectly involved established multimedia principles or effects (Figure 3.2). The broad acknowledgement of social background as being correlated negatively with learning outcomes, though presented within a research corpus devoid of any explicit testing of this potential effect, highlights two important conclusions within multimedia research. These include a lack of individual cognitive development as a learning effect and a corresponding omission of socioeconomic status as a contextual variate in multimedia research; both factors are described below.

Individual cognitive development has not emerged as a multimedia effect

Accounting for individual differences in CTML-influenced research has probably emerged from analysis of boundary conditions in explanation of residual variance and unexpected results (De Jong, 2010; Gerjets et al., 2009). Boundary conditions, including *prior knowledge* and *pacing* effects (Mayer, 2009; Schnotz & Bannert, 2003), have been critisised as representing experimental inconsistencies (e.g. De Jong, 2010), although Mayer (2010) suggests that boundary conditions – which have developed around each of the twelve basic principles (see Section 2.2.9) – are suggestive of an evolution of the principles into a more realistic framework. Nonetheless, when individual differences are recognised, simplistic dichotomization of learner attributes, such as low versus high prior knowledge or aptitude, are typically used. Sorden (2012) summarises CTML 'advanced' principles (Table 3.2) which have emerged since the introduction of CTML 'basic' principles (see Section 2.7.2).

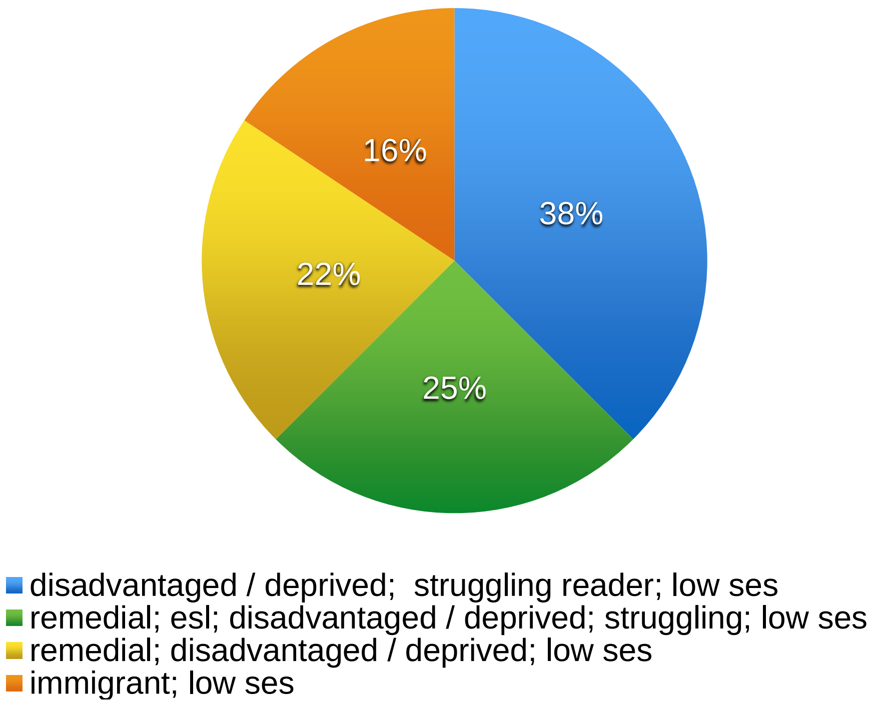

Figure 3.1 Individual factors in multimedia research

Eight from nine of the advanced principles explicitly relate to design or task characteristics, and not individual learner attributes. As a learner characteristic, the *prior knowledge principle* is the most widely applied to research, though usually included as a moderator variable in secondary analysis of the *expertise reversal effect* (e.g. Leutner et al., 2009). The lack of principles pertaining to learner characteristics and the scarcity of individual effects in multimedia research highlight the consensus of CTML principles within the research tradition. Importantly for my research, this underscores the dominant view of cognitive ontogeny as a global, linear process.

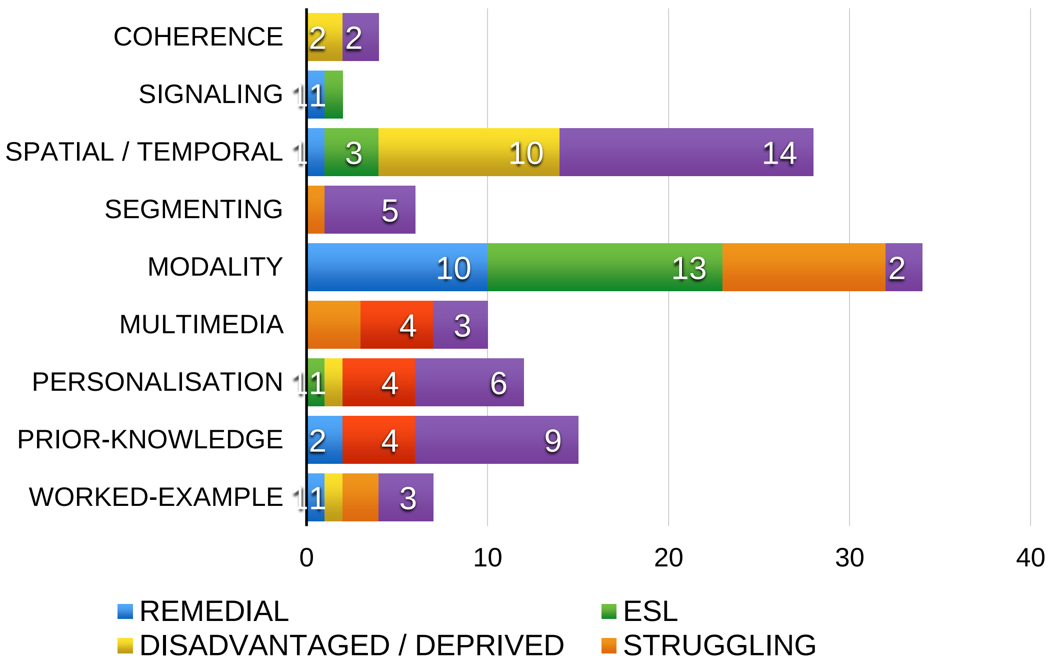

Figure 3.2 Individual factors and established effects / principles in multimedia research

Socioeconomic status resists operationalisation

Low socioeconomic status, despite being coalesced amongst other predictors of disadvantage, stands out as the sole variable in this category present within each study that recognises *disadvantage* as a potential learning effect. This suggests a resistance in operationalisation of socioeconomic status in multimedia research despite its widespread usage in other academic fields such as health and language development (as discussed in Section 2.3). Moving from acknowledgement of socioeconomic status as a moderator of learning, to its direct measurement, is likely to reduce much of the confusion in multimedia research.

3.3.6.2 Research question 2: How are affective outcomes used in evaluation of multimedia instructional designs in learning?

High inference, perceptual measures of the learning environment have accompanied educational research and initiatives since Herbert Walberg's (1968) development of the Learning Environment Inventory (LEI) in an evaluation of the Harvard Project Physics (1962-72). Fraser (2012) describes the ensuing typology of classroom climate measurements, of which qualitative and subjective self-accounts predominate in the multimedia literature. Correspondingly, articles in this analysis utilise either qualitative methods conforming to narrative accounts, with related methods of data collection such as focus group interviews, as well as self-accounts of interest, effectiveness or mental effort. Studies in the latter category generally used mental effort as a surrogate measure of perceived difficulty in using multimedia versus 'regular' instructional material. Together, these approaches were broadly used in two ways: the more common research goal was to assess learner perceptions with instructional material developed to test a given CTML principle or cognitive load.

Such research tested learner perceptions of multimedia presentations versus non-multimedia presentations or, more commonly, involved multimedia presentations developed as non / intermediate / fully complying with the principle being considered. As an example, Lee et al. (2014) compared student perceptions of multimedia instructional material within five treatment groups exposed to low through high degree of visual / verbal cues. Conclusions for multimedia design emphasised the relevance of cues for student learning (understanding, perceived learning and difficulty of content), but not for student affective outcomes (interest, overall satisfaction). Lee et al. (2014) study is indicative of a broader pattern in the literature in that multimedia principles when applied to learning materials do not translate into learner interest nearly as often as enhanced learning for participants. The second general approach was to simply contrast multimedia instructional materials with corresponding non-multimedia materials such as with books, hypermedia (see for example, Liao, 1999) or interactive features as seen with Takacs et al. (2015) in the meta-analysis review (Section 3.4.3). Figure 3.3 shows the organisation and proportion of variates aligned with CTML principles and cognitive load. Two conclusions are drawn from this systematic review and are presented below.

Table 3.1 CTML 'advanced' principles (Sorden, 2012)

Multimedia 'advanced' principle	**Description**
Animation and interactivity principles	People don't necessarily learn better from animation than from static diagrams.
Cognitive aging principle	Instructional design principles that effectively expand the capacity of working memory are particularly helpful for older learners.
Collaboration principle	People learn better when involved in collaborative online learning activities.
Guided-discovery principle	People learn better when guidance is incorporated into discovery-based multimedia environments.
Navigation principles	People learn better in environments where appropriate navigational aids are provided
Prior knowledge principle *	Instructional principles that are effective in increasing multimedia learning for novices may have the opposite effect on more expert learners.
Self-explanation principle	People learn better when they are encouraged to generate self-explanations during learning.
Site map principle	People learn better in an online environment when presented with a map showing where they are in a lesson.
Worked-out example principle	People learn better when worked-out examples are given in initial skill learning.

N.B. (* - learner characteristic)

Affective orientations of multimedia learning track theoretical developments, though not subject-area learning

Perceptual measures typically involved researcher-developed instruments using subjective summative scales of learner interest or perceived effectiveness of learning materials. Ogochukwu (2010), for example, used a 5-point Likert scale to assess 17 statements for which learners were asked to rate their acceptance of a multimodal presentation across multiple constructs including: ease of understanding, visual acuity, attention, emphasis of relevant / important information, organisation and attractiveness. This study is illustrative for its theoretical framework as well as its methodological approach in that results adhered to CTML principles and affect was most commonly measured as a part of the learning process. In the majority of studies, learner perceptions are aligned and measured across CTML basic principles with coherence, signaling, redundancy and contiguity principles predominating. The vast minority of studies lacked preliminary discussion of CTML or CLT and these studies were typically marginal in that they were published in professional journals or were from countries / regions atypical of the research corpus.

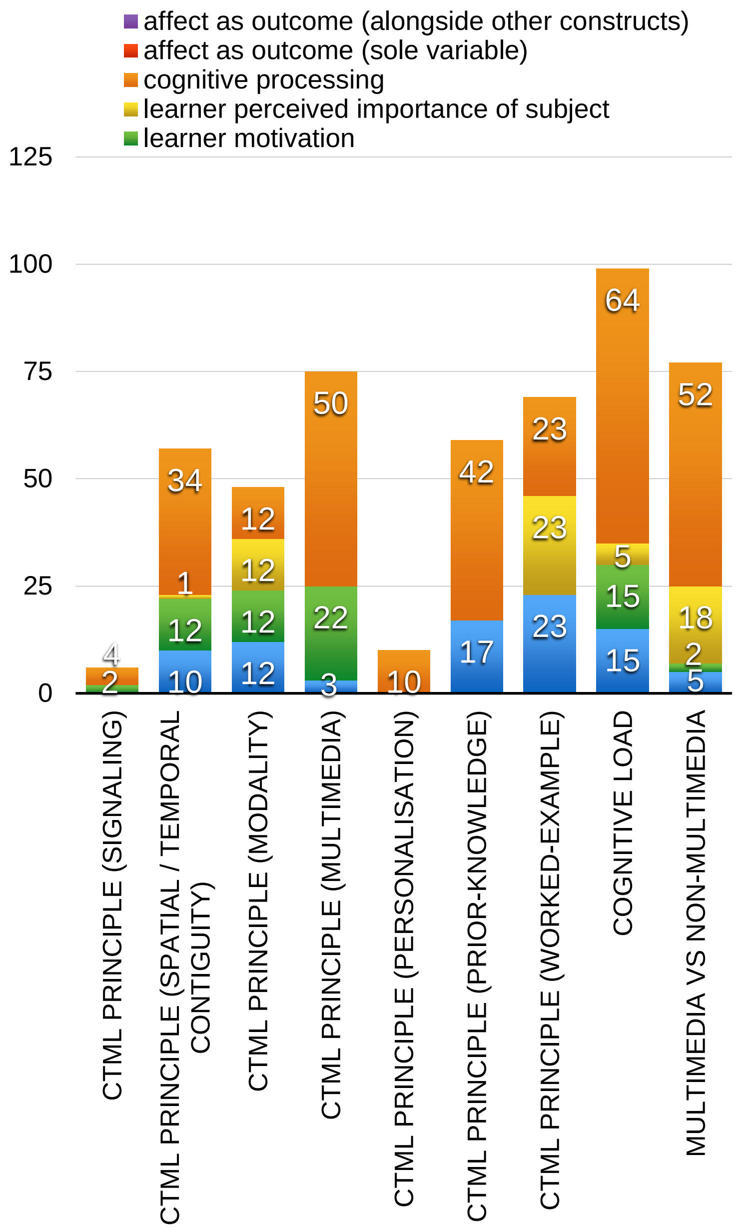

Figure 3.3 Learner perceptions with established multimedia principles / effects

Strikingly, no studies featured perceptual measurement of the domain / content material being presented. This is considered to represent a gap in the literature given that attitudinal measures ideally relate to the instructional content regardless of any theoretical benefits of multimedia presentation. Affect measured as outcome would benefit from inclusion of subject area understanding, interest / enjoyment and importance in widening the scope of multimedia design from underlying principles to relevant learning outcomes.

Multimedia is perceived as beneficial for learning though not interesting

In the reviewed literature, multimedia was rarely associated with learner interest. Only 16 positive accounts of learner interest / enjoyment with multimedia text were recorded along with a further 22 indications of improved learner motivation / satisfaction. Contrasted against the >200 studies showing improvement in learner understanding (comprehension, explanation, context, content), a picture emerges of the apparent cognitive, though not affective, value of multimedia instructional materials for learners.

3.4 Summary

An emergent view of the methodological and theoretical features underpinning multimedia instructional design follows this analysis of a wide variety of published research.

- Multimedia research has been primarily influenced by dual-coding theory, Baddeley's model of working memory, CLT, and CTML.
- Multimedia can be defined as an amalgam of “meaningful learning” and “social congruence” as determined by consideration of CTML basic principles including the *Personalisation Principle.*
- Coalescence of socioeconomic status amongst other indicators of educational disadvantage is common but risks type III error (Schwartz & Carpenter, 1999) because of poor operationalisation.

- Key topics in multimedia meta-analyses include testing established multimedia effects, effectiveness of multimedia instructional material and reading enhancement with multimedia instructional materials.
- Meta-analyses consistently reveal high heterogeneity in primary analyses of established multimedia effects and a lowering / moderation of initially reported effect sizes in replicated, follow-up study.
- Most primary analyses were designed around, and confirmed, aspects of CTML / CLT theory.
- All studies demonstrated at least minor theoretical and / or methodological inconsistencies and in two meta-analyses extend to dismissal of established effects within CTML.
- Questions are posed concerning the way socioeconomic status is applied to multimedia instructional design and concerning the inclusion of affective outcomes in multimedia research in addressing my research questions.
- Findings from the systematic review indicate that socioeconomic status has not been operationalised or tested as an independent variable in research.
- Measures of student perception are common within multimedia research.
- Student perception indices show methodological similarity with the development of classroom climate surveys within educational research. Research instruments are characterised as either measuring student self-reported data on established multimedia effects or in comparison of multimedia with non-multimedia learning materials.
- Perceptual measures are not used in assessing learner affect associated with content-area study materials. Perceptual measures are used in assessment of multimedia features only.
- Perceptual measures are more commonly reported with positive cognitive outcomes than that of affective outcomes in use of multimedia learning materials.

3.5 Chapter conclusion

The computational-representational systems of cognitive science are central to CTML and CLT and are methodologically enacted in applied multimedia research. Mental processes in this dominant framework are considered as virtual representations that are processed in accordance with external cues. Cognitive systems, accordingly, are functionally analogous with computer hardware in processing sensory input and generating learning behaviour on the basis of internal information processing. Not surprisingly from this perspective, mental processing has invoked an architecture and cognition dependent on stimuli properties with limiting architectural and organisational constraints. Related research has involved the determination of efficient stimuli processing in order to enhance essential processing in modality-specific subsystems and in avoidance of extraneous processing demands. From analysis of meta-reviews in multimedia learning (Section 3.2), this is revealed methodologically in the emphasis on design and enhancement variates as a primary research aim and neglect of factors pertaining to contextual or learner characteristics. There, individual learner characteristics were found to be typically presented for secondary analysis and portrayed as minor effects. The dominant framework is also revealed in how perceptual measures are used in evaluation of multimedia. As detailed in the systematic review of multimedia learning (Section 3.3), multimedia properties are assessed for purported learning and affective benefits to the exclusion of depicted subject-area content, suggesting a qualitative separation of design characteristics and learner motivation.

In embodied cognitive models, alternatively, semantic processing is situational with an assumed inseparability of an agent from its context in knowledge accumulation. Applied to multimedia research, this rejection of agent-environment dualism maintains the relevance of multimodality, though raises the issue of effective socialisation of visual and auditory stimuli. An approbative methodology involves a shifting of focus from simple integration of audio-visual features, and the constant extrapolation of moderating effects, to presenting content with appropriately socialised features. The latter approach is consistent with parallel behavioural and memory processing established from neurological research and is modifiable in individual development.

The following chapter outlines the methodology used in addressing the research objectives raised in Section 1.5.1. As detailed in the rationale for study (Section 1.3) and elaborated on in this chapter and the last, multimedia research is impeded in key theoretical and methodological areas relating to cognition and individual variation in cognitive function. Following the method section, Chapter 5 presents additional issues central to multimedia learning and details principles of learning material development. These principles are applied, in that chapter, to the development of the experimental texts used in the intervention.

Chapter 4

RESEARCH METHODS

4.1 Introduction

This chapter details the methods involved in answering the research objectives identified in Chapter 1. The overarching aim of the study was to examine the association between social standing and educational achievement. More specifically, the research examined the effect of social standing on science achievement through analysis of middle-schoolers' recall and transfer of science content, with learning conditions involving texts differentiated by visual and verbal modality. In addition, the study examined student affective trends relating to multimedia learning texts as well as science as a learning area and sought to apply these cognitive and affective findings to a revised model of the cognitive architecture. The research methods described in this chapter are presented using the following headings:

- Research objectives (Section 4.2);
- Study design (Section 4.3);
- Sample (Section 4.4);
- Instruments (Section 4.5);
- Data analyses (Section 4.6);
- Threats to validity (Section 4.7);
- Ethical considerations (Section 4.8); and
- Chapter summary (Section 4.9)

4.2 Research objectives

The principal aim of this research was to examine the effects of social standing and textual verbal-visual modality on learning efficacy and perceptions of learning in middle school science students. An additional objective was to present a revised model of the cognitive architecture that is based on current neuroscience theory and the study results as described in Chapter 5. To gain an understanding of these variables on learning outcomes and to revise the way we comprehend brain functions in stimuli processing, the study addressed four major research objectives. These objectives, introduced in Chapter 1, are reiterated here.

1. To examine how the degree of textual visual-verbal modality affects retention of content in learners differentiated by social standing.
2. To explore whether objective and subjective accounts of social standing covary with retention of content.
3. To investigate how student-held attitudes toward science and science learning materials differ based on degree of textual visual and verbal modality integration.
4. To present a model of cognitive architecture consistent with the study results and existing neurological literature.

4.3 Study design

The study used a cluster randomised trial (CRT) with classrooms as units of random assignment. This was a pragmatic approach which negated the need for random assignment of individuals, which would be disruptive as well as non-representational of normal classroom procedure. Justification for the usage of a CRT design stems from the educational setting of the study. Compared with individual randomised trials, clustering accounts for the natural teaching situation and reduces contamination bias (Pence et al., 2015). Also, while CRTs are associated with greater procedural and analytical complexity (Campbell et al., 2004), ability-stratified groups (see Sections 4.4.1 and 4.7) in the design help to ensure structural equivalence and offers similar levels of statistical comparability between treatment arms.

In opting for a quantitative design, the issue of noise reduction (often informing covariance or blocking designs, Trochim & Donnelly, 2008) versus signal enhancing (factorial) design type was deliberated upon. The method taken in this research values the latter category, factorial design, more highly, and its use follows from the quasi-experimental conditions imposed by the research setting. Despite lacking the randomisation found in true experimental design, this quasi-experimental design has sufficient internal validity due to the assumed heterogeneity between student groups and is appropriate in examining treatment variations such as that conducted here.

A 3^3 factorial-design CRT was used to provide flexibility in exploring textual modality as a learning effect. A CRT randomises at the group level and increases the scale of participation (e.g. classes, geographic regions) assigned as study arms (Vetter & Chou, 2014). Factorial design, meanwhile, allows for study of multiple factors, alongside examination of between-factor interaction effects on independent variables. As the study aimed to distinguish treatment variations in a school setting, CRT factorial design was applicable. Factors in the 3^3 factorial-design included perceived and objective socioeconomic status (both factors presented as: *low* / *mid* / *high* - see Sections 4.5.1.1 and 4.5.1.2), and textual design (*multimodal social* (MS) / *bimodal social* (BS) / *bimodal asocial* (BA). CRT factorial design, as described, is efficient here in that it combined several studies into one and enables the accurate examination of interaction effects. Efficiency is also achieved by exposing each student to each textual design, maximising between-group variability, while also reducing the required sample size (see Section 4.4.3.3). Additionally, the use of pre- and post-program covariates in analysis satisfies important principles of experimental design in controlling within-group error variance. Students were all exposed to each textual condition within the factorial design, and threats to validity are reduced through effective replication, randomisation and local control, all of which are potential contributors to experimental error (McMillan, 2007). Further discussion of validity is provided in Section 4.7.

In addition to measures of science retention relating to science learning texts and socioeconomic status, affective outcomes were sought as per Research Objective 3. Specifically, student-held attitudes toward science and science learning materials were assessed according to degree of textual visual and verbal modality integration. The analysis intended to provide a nuanced account of attitudinal data that reflected this distinction and included additional modelling within the factorial design. Data from two attitudinal instruments (see Section 4.5.2 for details) were explored for variance and factor extraction was used to generate factor scores in determination of significant pre- / post-intervention attitudinal differences. The two attitudinal instruments were also assessed to reveal specific trends in affective measures relating to science as a learning area compared with text-mediated understanding, enjoyment / interest and perceived importance of science.

The study involved ten participating classes (details of their selection are provided in Section 4.4.3) with instruments (described in Section 4.5) administered in a pre-post-test design. The study design is diagrammatically presented below in Figure 4.1, where it is seen that all ten groups received a science achievement pre-test and post-test specific to grade and text-type. Additionally, science enjoyment was measured prior to the first intervention and again as a post-test following the third intervention phase. Attitudinal measures were divided between student perceptions of science learning materials (see Section 4.5.2.3 for details) and science enjoyment per se (see Section 4.5.2.7 for details). Science achievement post-tests followed each phase (i.e. accompanying each of the three rounds of testing) and subjective and objective socioeconomic instruments were administered following the third phase of interventions. In Figure 4.1 the letter 'R' indicates that all classroom groups were randomly assigned interventions (order of text A, B, or C - see independent variables in Section 4.5.1). The various measures and interventions in codified form are provided in Table 4.1.

R:	$O_{\phi}\ O^2_{\gamma}\ X_{1\varphi}\ O_{1\varphi}\ X_{2\varphi}\ O_{2\varphi}\ X_{3\varphi}\ O_{3\varphi}\ O^1\ O^2_{\chi}\ O^3\ O^4$
R:	$O_{\phi}\ O^2_{\gamma}\ X_{2\varphi}\ O_{2\varphi}\ X_{3\varphi}\ O_{3\varphi}\ X_{1\varphi}\ O_{1\varphi}\ O^1\ O^2_{\chi}\ O^3\ O^4$
R:	$O_{\phi}\ O^2_{\gamma}\ X_{1\varphi}\ O_{1\varphi}\ X_{2\varphi}\ O_{2\varphi}\ X_{3\varphi}\ O_{3\varphi}\ O^1\ O^2_{\chi}\ O^3\ O^4$
R:	$O_{\phi}\ O^2_{\gamma}\ X_{3\varphi}\ O_{3\varphi}\ X_{1\varphi}\ O_{1\varphi}\ X_{2\varphi}\ O_{2\varphi}\ O^1\ O^2_{\chi}\ O^3\ O^4$
R:	$O_{\varrho}\ O^2_{\gamma}\ X_{1\varrho}\ O_{1\varrho}\ X_{2\varrho}\ O_{2\varrho}\ X_{3\varrho}\ O_{3\varrho}\ O^1\ O^2_{\chi}\ O^3\ O^4$
R:	$O_{\varrho}\ O^2_{\gamma}\ X_{2\varrho}\ O_{2\varrho}\ X_{3\varrho}\ O_{3\varrho}\ X_{1\varrho}\ O_{1\varrho}\ O^1\ O^2_{\chi}\ O^3\ O^4$
R:	$O_{\varrho}\ O^2_{\gamma}\ X_{3\varrho}\ O_{3\varrho}\ X_{1\varrho}\ O_{1\varrho}\ X_{2\varrho}\ O_{2\varrho}\ O^1\ O^2_{\chi}\ O^3\ O^4$
R:	$O_{\beta}\ O^2_{\gamma}\ X_{1\beta}\ O_{1\beta}\ X_{2\beta}\ O_{2\beta}\ X_{3\beta}\ O_{3\beta}\ O^1\ O^2_{\chi}\ O^3\ O^4$
R:	$O_{\beta}\ O^2_{\gamma}\ X_{3\beta}\ O_{3\beta}\ X_{1\beta}\ O_{1\beta}\ X_{2\beta}\ O_{2\beta}\ O^1\ O^2_{\chi}\ O^3\ O^4$

Figure 4.1 Ten-group pre–post-test research design

To expedite and simplify pre- and post-intervention data collection, regular classroom teachers (see Section 4.4.3) were provided with each instrument to be used in the study. Teachers were briefed on data collection procedures including specific guidelines for students on how to complete the instrument; the need for teachers to present the instruments as per normal class operation; established time limits; comprehension checking; emphasis on actual versus idealised responses, and emphasis on student-own responses. Consistency in instrument delivery was ensured via weekly meetings between myself and participating teachers. Through ongoing communication with participating teachers, it was ascertained that each instrument was delivered to students at the same stage of lesson sequencing and ordered as per the research design (Figure 4.1). All students participated due to the desire to reflect normal school practice, though non-participating students were not included in data analysis. All students were initially named during data collation though later codified for anonymity.

Table 4.1 Experimental instruments and interventions

$O\varphi$- pre-test grade 7 (MSSAT)	$X_{x\ \varphi}$ - intervention grade 7
O_{ϱ} - pre-test grade 8 (MSSAT)	$X_{x\varrho}$ - intervention grade 8
O_{β} - pre-test grade 9 (MSSAT)	$X_{x\beta}$ - intervention grade 9
O^{2}_{γ} - affective measure #1 pre-test (TOSRA)	O^{1} - mental effort instrument
$O_{x\ \varphi}$ - post-test grade 7	O^{2}_{χ} - affective measure #1 post-test (TOSRA)
$O_{x\varrho}$ - post-test grade 8	O^{3} - affective measure #2 (AOS)
$O_{x\beta}$ - post-test grade 9	O4 - perceived social standing instrument

4.4 Sample

This section describes the sample and site selected for the study detailed in this thesis. Key organisational and demographic features are outlined and then related to the desirability of the site in addressing the research objectives as well as in terms of generalisability. An important consideration here is the use of academic streaming which has implications for assumed sample homogeneity in the cluster randomised trial (see Section 4.7). The research site is described in Section 4.4.1 and student body in Section 4.4.2; participant selection details are provided in Section 4.4.3. The latter section also provides characteristics of students and teachers involved in a pilot test conducted to validate two researcher-developed instruments used as dependent variables within the study. Here, class and student details are matched with a sampling protocol inclusive of validity considerations associated with the research design.

4.4.1 Characteristics of the site

The site selected for data collection was an international primary - year twelve (P-12) school located in Sharjah, United Arab Emirates (UAE). The school was selected as a convenience sample (Creswell, 2008, p. 155) as it was the location of my employment during the time of data collection. Although this selection involved a non-probability sample, the consecutive inclusion of all consenting middle-school students (i.e. grades 7 to 9) at the site, within intact class groups, provided a representative sample statistic. Of the students enrolled at the school, 54% of them were assumed to be itinerant (as these were non-local students). Of this non-permanent student population, sizeable ethnic and cultural variation existed, alongside distinctions in socioeconomic status. These variations add confidence to estimates of population parameters relevant for export to middle-school students more generally, including Australian students given that the Australian national curriculum is delivered in this International school setting. It is noted that, while the school is locally owned, and partially incorporates a Sharjah Ministry of Education (MoE) curriculum, the school is operated and staffed by expatriate management and teaching staff, and delivers the Australian syllabus in all key subjects, including science.

The school made a suitable site for the study in terms of both programmatic and organisational features. As indicated, the school runs a dual-curriculum, of which core Australian and UAE Ministry of Education subjects comprise 26 contact hours from a 29-hour week for middle-school students. Students receive the Australian curriculum for core subjects, including the eight learning areas mandated by the Australian National Foundation Grade 10 (F to 10) Curriculum (ACARA, 2015) as well as an Arabic or English language Ministry curriculum set by the UAE Ministry of Education. Ministry subjects are divided between Arabic speaking and non-Arabic speaking students, and include Islamic studies, Arabic language, and culture studies. With relevance to the intervention described in Section 4.3, all textbooks used within the Australian and Ministry subjects conform to what could be described as a 'standard' format - i.e. learning texts dominated by columnar written text with related graphics. Typically, science textbook graphics include scientific figures in the form of graphs, tables and so on, though also include pictures of related objects or processes pertinent to the topic. These factors aid generalisability as they conform broadly to schooling practice in numerous international settings and, by extension, a larger sampling frame of middle-school students.

Characteristics of student grouping of the site are relevant for their effects on limiting variability within experimental groups (as outlined in Section 4.3). Students within the middle (grades 6 to 9) and senior schools (grades 10 to 12) are streamed according to academic ability. Middle-school students are also gender segregated, though only for lower ability classes. Grade point average data from core and Ministry subjects is used in student selection for mixed class inclusion. The mixed class is open to the top ranked students within the grade cohort though reflects an equitable gender balance. Actual numbers fluctuate and reflect a mutable percentage based on enrolment numbers and numbers of classes. At the time of the study, there were three academically streamed mixed classes across 7th, 8th, and 9th grades and an additional non-academically streamed gender-mixed grade seven class due to greater enrolment in this year level. Academic streaming is of relevance due to the consecutive sampling method described above which saw inclusion of each intact class grouping at the site. Further discussion on assumed block homogeneity is provided in Sections 4.4.3.2 and 4.7.

4.4.2 Characteristics of the student body

At the time of study, the school had a total enrolment of some 1207 students of which 323 were middle school students (grades 6 to 9). Middle school students made up 16 separate class groups, from which 10 groups comprising grade 7 to 9 students were available for the current study. Local Emirati students comprised some 46 per cent of the entire school enrolment, with 43 per cent of these students being enrolled in the middle school. Students from the Gulf Cooperation Council (GCC) and other Arab students made up 38 per cent of the total enrolment and 35 per cent of the middle school. South Asian and other Asian students formed around 12 per cent of the middle school, and the remaining 10 per cent of middle school students were mainly of European, Australian / New Zealand, North and South American or Russian origin. Student diversity and itinerancy are reflective of UAE labour law which links residency (and thus school enrolment) to fixed term labour contracts from a multitude of developed and developing nations (Article 13, UAE labour law, 2007). The majority of students were thus English as a Foreign Language (EFL) learners, although all core subjects have English as the instructional medium. Common language usage strengthens the generalisability of study findings as a non-situationally specific site feature; it also mitigates certain methodological implications such as in wording of instruments.

4.4.3 Participants

The following section details the description and selection of the sample. The selection of participants for the pilot and main studies are described and presented as selection of students and teachers involved in the pilot test (Section 4.4.3.1) and main study classes and students (Sections 4.4.3.2 and 4.4.3.2, respectively). As previously described, the study focussed exclusively on middle-school students and all available grade 7 to 9 middle-school students (divided into ten class groups) were invited to participate. Two hundred and fourteen (*n*=214) grade 7, 8, and 9 middle school students and five (*n*=5) middle school teachers consented and participated in this multimedia learning research study. Additionally, a subset of grade 7 to 9 students (*n*=61) and their regular science / mathematics teachers (*n*=5) were selected to pilot test two researcher-developed instruments. The pilot test samples are described first.

4.4.3.1 Selection of participants for the pilot test

The pilot test involved both teachers and students. The teachers involved the five participating middle school teachers (*n*=5) who were also involved in the main study. These teachers formed the expert panel that was used in the validation of instruments within the pilot study (as described in Sections 4.5.2.4 and 4.5.2.6). Teachers were selected as the regular mathematics / science classroom teachers of the experimental groups and thus formed a convenience sample. At the time of study, all participating teachers at the site were employed on a regular three-year employment contract and each had greater than five years teaching experience in respective fields of science and / or mathematics.

A student group (*n*=61) was selected to pilot test two researcher-developed instruments. As discussed in Section 4.5.2.1, parallel forms of the science achievement test were developed and administered to three class groups of students across grades

7-9 (*n*=27 grade 7; *n*=15 grade 8; *n*=19 grade 9). Participants in the pilot test were randomly selected as participating students in the main study (Section 4.4.3.3) with probability samples drawn from stratified groups sorted by grade-level (i.e. grades 7 to 9). In determination of sample size within pilot study, Hertzog (2008) describes estimates of test-retest reliability as requiring evidence of correlations of at least .70 (rising to .80 for established instruments); correspondingly, from tabulated 95% confidence interval limits, a sample size exceeding 35 to 40 with an observed *r* value of .75 would provide confidence that the population value would be .70 or higher. Thus, the sample of *n*=61 was considered to be sufficient for the purpose of checking temporal reliability of the piloted instruments.

Similar numbers of males (*n*=34) and females (*n*=27) participated and were drawn from main study experimental classes (Section 4.4.3.3) as no other comparable grade-level students were available within the study site. Finally, it is noted that all of the piloted instruments were completed satisfactorily with a high response rate (>95%) of all items.

4.4.3.2 Selection of classes for the main study

The sample for the main study involved all grade 7 to 9 classes (12 to 15 years of age) in the middle school level of the site, providing a total of ten classes of students. Moreover, these experimental classes were all permanent groupings (i.e. not subject-specific). Specifically, the sample for the study involved four grade seven classes (two mixed gender classes), three year eight classes (one mixed class) and three year nine class groups (one mixed class) which comprised the entire available middle school cohort (for more details see Section 4.4.1). In all cases, intact classes offered relatively homogenous blocks in terms of stratification by grade point average data, offsetting possible objections to the use of class groups as the unit of randomisation in the study design. As described in Section 4.3 there was no distinction between control and experimental groups as all students were exposed to each learning text (i.e. *Bimodal Asocial* (BA) text as a normal science textbook excerpt was the control condition - see research design in Figure 4.1 and related analyses in Section 4.6).

4.4.3.3 Selection of students for the main study

It was important to include an adequate sample to ensure that a range of considerations were addressed prior to study, such as the sample size in relation to the factorial design. Issues that were important to the selection of the sample included effect size, homogeneity of the sample and the risk of error considered appropriate for the question being studied (Burmeister & Aitken, 2012).

The ten classes from which the students were drawn included four co-educational (mixed gender) classes, and six single-sex (three male / three female) classes (see Table 4.2 for a breakdown of the students involved). This provided a sample of 117 males and 97 females (n=214) with a mean age of 13 years 5 months. Group sizes ranged from 13 to 28 students with a mean size of 21.4 students. Attempts could not reasonably be made to ensure size comparability given the fixed nature of class groupings, although the 214 participants were considered to satisfy total sample size estimation in the 3^3 factorial design. This consideration was premised on existing multimedia research and the usage of factorial design in the current study. In an example of related multimedia research, Ginns' (2005) meta-analysis of the modality effect provides a range of sample sizes from 26 to 128 participants. Consideration of this reported sample range prompted an *a priori* power test to determine estimated sample size for the present study. To correctly reject a false null hypothesis (a Type II Error), median effect size (d = .80) from the 43 studies reported in Ginns' (2005) modality effect meta-analysis was used: d = .80, α = .05, and a power of .80 (β = .20) were selected for a required sample size calculated at 26 per experimental group. As seen in Table 4.2, meanwhile, group sizes in the current study range between 13 and 28, with eight of the ten groups having less than 26 students.

By using a within-subjects 3^3 factorial design in the analysis of cognitive outcomes, it was possible to mitigate concerns of sample size limitations as determined by *a priori* power testing. Using a 3^3 factorial design effectively reduced the required sample size as the subjects of the experimental group were effectively 'recycled' by placing them in every level of each factor (Collins et al., 2010). In this way, so long as the sample size in each group were balanced, orthogonality is maintained so that each effect's estimation and testing can be treated as independent of the other effects. In this way, the factorial design was considered to be more efficient than individual experiments (as described by Collins et al., 2010). For example, in comparison with a 3^3 factorial design, a single factor experiment would require N = (k +1) N/2, where k = number of experimental conditions and N is the factorial design sample size. The previously computed sample size of 26 then becomes n = 260 with ten groups. This reduces the sample size requirement as (k +1) N/2 = 260 in the single factor experiment drops to n=190 to satisfy the factorial design. The 214 participants were considered to be satisfactory, therefore, to test the main hypothesised effects.

From these 10 classes, all 286 grade 7, 8, and 9 middle school students were invited to participate. Of these, 219 students responded, providing a response rate of 74.8 per cent. Of these 219 consenting participants, four had incomplete surveys or were absent during post-testing and one student left the school to return to his country of origin. In each case, the data provided by these non-participating students were removed from the study. This left a total of 214 students. The high response rate could reflect the culture of compliance within the school - with parents regularly being asked for, and providing, consent for numerous school-related activities. Considerations of potential misunderstanding of the nature of the project (as doctoral research) were thus addressed via follow-up group emails to clarify any potential linguistic issues, the significance of the study, as well as potential implications for the student and his / her family. Table 4.3 summarises student participants in terms of gender, ethnicity, and age. As seen, participants ethnicity is divided between Emirati (E) - 41%, Arab (other) (A) - 34%, South Asian (As) - 8%, other Asian (Ao) - 4%, European (Eu) - 5%, and other European (Eo) - 8%.

Section 4.4 has described characteristics of the site as well as selection of participants for the main and pilot studies. As seen, students were purposively sampled as the entire middle school student body at the study site, and a representative subsection of these students were further sampled as participants for pilot study. Programmatic and organisational factors of the site made it suitable for research, in particular due to the academic streaming that reduces variability between intact class groupings. The following section describes the instruments used in the main and pilot studies.

Table 4.2 Group details for each class including gender, age and year level

Class group	*n*	Mixed / non mixed	Gender	Mean Age (y)	Year level
1	22	Non-mixed	♀-22 ♂-0	12y 10m	7
2	21	Non-mixed	♀-0 ♂-21	13y 4m	7
3	22	Mixed	♀-18 ♂-4	13y 2m	7
4	28	Mixed	♀-11 ♂-17	12y 9m	7
5	16	Non-mixed	♀-15 ♂-0	14y	8
6	13	Non-mixed	♀-0 ♂-14	13y 5m	8
7	24	Mixed	♀-13 ♂-11	13y 8m	8
8	26	Non-mixed	♀-26 ♂-0	14y 12m	9
9	17	Non-mixed	♀-0 ♂-17	13y 11m	9
10	25	Mixed	♀-12 ♂-13	14y 6m	9
Total (∑) / Mean ($\bar{x}$)	214	Non-mixed – 6; mixed - 4	♀-117 ♂-97	Mean age (13y 5m)	

Table 4.3 Summary of participant details by year level including ethnicity, gender and mean age

Year level	n	Ethnicity	Gender	Mean age (y)
7	93	Emirati-41; Arab (other)-35; Asian (South)-4; Asian (other)- 4; European-2; European (other)-7	♀- 51 ♂- 42	13y
8	53	Emirati -18; Arab (other) -20; Asian (South) -5; Asian (other)-3; European -4; European (other)-3	♀- 28 ♂- 25	13y 9m
9	68	Emirati -29; Arab (other) -17; Asian (South)-9; Asian (other)-9; European-4; European (other)-7	♀- 38 ♂- 30	14y 5m
Total (∑)		Emirati-88(41%); Arab (other)-72(34%); Asian (South)-18(8%); Asian (other)-9(4%); European-10(5%); European (other)-17(8%)	♀- 117 (55%) ♂- 97 (45%)	

4.5 Instruments

This section details the experimental variables and related instruments. As described in Section 4.3 the instruments were administered at various stages of the research to assess social standing, science achievement, social-related attitudes and perceptions of modified texts. In explication, the instruments were presented according to whether they represented an independent or dependent variable (Table 4.4). The first section (Section 4.5.1) outlines independent variables and describes the instruments used to collect data relating to subjective and objective social standing. Following this discussion of independent variables, Section 4.5.2 defines dependent variables and outlines the specific instruments used to gather related data. As two of the instruments were developed by the researcher, related sections (Sections 4.5.2.3, 4.5.2.4 and 4.5.2.5) describe a pilot test conducted for reliability estimates of these instruments. Section 4.3 outlined administration procedures for instruments in the study.

Table 4.4 Experimental variables

Independent variables	**Dependent variables**
Perceived social standing	Science attitudes
Objective social standing	Mental effort
Textual modality	Science achievement

4.5.1 Independent variables

This section describes the instruments used to assess the independent variables in the study. The two instruments included here are subjective social standing (Section 4.5.1.1) and objective social standing (Section 4.5.1.2). As mentioned previously, the variable of textual modality is addressed in a separate chapter of the thesis in order to concentrate more fully on the theoretical and methodological aspects of the development of graphic novels for the study (Section 5.2).

4.5.1.1 Assessing subjective social standing

To examine objective and subjective social standing, two variants of the same instrument (The MacArthur scale of Subjective Social Standing (MSSS)) were used, one that was administered to parents (objective SES) and another that was administered, in class, solely to students (subjective SES). The treatment variables of objective and subjective social standing, relating to research objectives one and two, were thus assessed using either MSSS Variant A (subjective SES; which was administered to students) or MSSS Variant B (objective SES; which was administered to parents).

The subjective social standing instrument is a measure that aims to parse subjective from objective social standing via identification of an individual's sense of position in society. The MacArthur scale of Subjective Social Standing (MSSS) instrument, developed by Adler & Stewart (2007), is a self-anchoring pictorial scale with respondents asked to mark their family's relative standing at the societal level and their own standing within the school community. Reliability of Adler's self-anchoring scale of subjective social status was reported by Operario et al., (2009). A six-month test-retest was conducted on the ladder's reliability and predictive utility for health status in a large (n = 1294), multiethnic national US study. Spearman rank-order correlations were used in assessing test-retest reliability; additionally, Pearson bivariate correlations examined zero-order associations between all variables and Hierarchical Ordinary Least Squares (OLS) regression examined associations between three SES indicator variables (subjective status, income, and education) with self-rated health. Correlation analyses revealed adequate test-retest reliability ($p = 0.62$ [$p<0.01$]; health and subjective status $r = 0.31$; health with income or education both rs = 0.25). Multivariate regression analysis showed largest beta values for subjective status and health ($\beta = 0.30$; $p < 0.01$) compared with income ($\beta = 0.21$; $p < 0.01$) or education ($\beta = 0.21$; $p < 0.01$). The study controlled for confounding factors such as race and health risk, and as a representative sample, provides evidence for the temporal reliability of this subjective indicator. With this established estimate of reliability, the self-anchoring ladder scale was not included in the pilot study.

The MacArthur scale of Subjective Social Standing (MSSS) instrument was modified for use in the present study with inclusion only of perceived rank social standing graphics (i.e. 'SES' and 'community' ladders) without accompanying socioeconomic questions. The subjective social standing instrument (Variant A) used to assess subjective social standing presents two self-anchoring ladders of social standing (see Appendix 8 for a copy of Variant A of the modified MacArthur scale of Subjective Social Standing (MSSS) instrument). The first ladder (Ladder A) asks respondents to position their family within UAE society, with relative positioning determined by: those who are best off / worst off; best jobs / worst jobs; most money / least money; highest / lowest education. The second ladder (Ladder B) relates to the school environment and asks respondents to rank themselves by: most / least respect; best / worst grades; highest / lowest standing. Scoring was a summation of scores from the two ladders with a range of 2 (extremely low perceived social standing) - 20 (extremely high perceived social standing). An example of a self-anchoring social ladder is presented below (Figure 4.2). Appendix 7 provides a full copy of the self-anchoring social ladder with accompanying text / directions as used in this study.

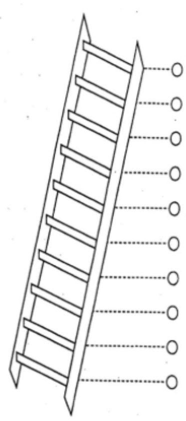

Figure 4.2 Sample self-anchoring social ladder (adapted from Goodman et al., 2001)

4.5.1.2 Assessing objective social standing

For objective measurement of social standing, Variant B of the researcher-modified MacArthur Subjective Social Standing (MSSS) instrument was used. As objective SES data only was sought, the self-anchoring ladder scales were removed and remaining questions covered parental education (i.e. highest grade / year completed), highest degree/qualification earned, main daily activities (i.e. working full time, working part-time, unemployed), nature of employment, earning, home ownership status, total combined assets and debt loading questions (see Appendix 9 for a copy of Variant B of the modified MacArthur scale of Subjective Social Standing (MSSS) instrument).

Scoring objective social standing involved an aggregated raw score from the objective social standing instrument (i.e. Variant B of the MacArthur Subjective Social Standing (MSSS) instrument) and school demographic information (occupation-type / nationality). Occupation type was a nominal score ranging between 4 (professional employment), 3 (non-professional employment), 2 (labour-type employment), 1 (currently unemployed), and nationality was simply Emirati (E) or non-Emirati (nE). Given the enhanced residency and employment status afforded to Emiratis, nationality was scored as 3 for Emiratis and 1 for non-Emiratis. A cumulative raw score of 76 was thus obtained and recorded as objective social status.

Estimates of reliability of the MacArthur Subjective Social Standing (MSSS) instrument were considered prior to its inclusion as a research instrument. As detailed in Section 2.7.2 low objective social standing is linked with multiple disease endpoints as well as schooling success. This is acknowledged by the Australian Council on Educational Research (ACER, 2000) which reports categorical and continuous socioeconomic measures as reliable indicators of cognitive outcomes in schooling. Correspondingly, parental education (both parents), highest parental occupation, and number of home possessions (as approximate measure of family wealth) are variables in the Economic, Social and Cultural Status (ESCS) index which is used as an explanatory factor of student performance within the Organisation for Economic Cooperation and Development (OECD) Programme for International Student Assessment (PISA) testing.

OECD (2009) principal components analysis results revealed similar patterns for these three components (parental education; highest parental occupation; number of home possessions) with factor loadings ranging from .65 to .85. The reliability for ESCS components ranged between .56 and .77 and internal consistency (Cronbach's alpha α) of .69 for the pooled OECD sample coincided with equally weighted country data. A very high stability of socioeconomic measures between cycles was recorded with a correlation (r) of .96 between ESCS 2000 and ESCS 2003 country means (Schultz, 2005). These reliability estimates from established large scale studies provide a measure of confidence in the use of the MacArthur Subjective Social Standing (MSSS) instrument in both of its variants. Given that items in the objective social standing instrument used in this study were scaled to measure parental occupation, income, and household wealth, and with the large literature on links between objective measures of socioeconomic status and health and educational outcomes, further checks for validity and reliability of this instrument were not deemed necessary.

4.5.2 Dependent variables

This section describes the instruments that were used to measure the dependent variables in the study. Dependent variables reflected the need for assessment of student cognitive and affective outcomes and sought to gather attitudinal data related to their science text preferences as well as broader attitudes towards science as a learning area. Related sections include: the development of a suitable science achievement instrument (Section 4.5.2.1); measurement of science attitudes (Sections 4.5.2.2 and 4.5.2.6) and mental effort (Section 4.5.2.7). Sections 4.5.2.3, 4.5.2.4 and 4.5.2.5 detail pilot testing conducted to ascertain reliability and validity of the researcher-developed science achievement and science attitudinal instruments. A brief discussion of control variables (Section 4.5.2.8) concludes this section.

4.5.2.1 Middle School Science Achievement Test – MSSAT

To evaluate the effect of textual modality on student learning, three grade-level specific *Middle School Science Achievement* (MSSAT) tests were developed by the researcher (described in Section 4.5.2.2) and administered as pre-tests to participating students. Additionally, in post-testing, separate science achievement tests were designed for each specific year-level text (i.e. *Multimodal Social* (MS), *Bimodal Social* (BS), and *Bimodal Asocial* (BA) texts - see Sections 4.3 and 5.2 for procedural and theoretical details and Appendices 1 - 4 for grade level / intervention variants of science pre- and post-tests). Two alternate forms of the MSSAT (MSSATa / MSSATb) were developed as suitable pre-tests and then piloted for validity and reliability. The piloted MSSAT variants were developed from science content that was covered in the semester prior to the study's commencement with the final achievement test consisting of thirty multiple choice questions. To ensure continuity between the MSSAT and standard school-developed exams, these 30 questions were divided into three sections comprised of 10 questions each, made up of one section on each of the following:

- Common background knowledge derived from the school-based science curriculum;
- Application of science content; and

- Analysis and evaluation of science content.

Each MSSAT pre-test contained 30 multiple choice questions divided between three sections (*background knowledge of science*, *application of science content*, and *analysis and evaluation of science content*) with 10 questions per section (see pilot testing section for more details - Section 4.5.2.4). These tests were designed to mirror the original *Bimodal Asocial* (BA) control text and featured informationally equivalent questions (see Appendix 5 for grade-level MSSAT instruments). Exact wording in the *Bimodal Social* (BS) and *Bimodal Asocial* (BA) post-tests (see Section 4.3) were modified to maintain equivalent lexical density and social coherence as per the associated learning text (see Biber & Barbieri (2007) who contrast lexical density between spoken and written registers). Questions for learners exposed to the *BA* (control) textual condition received the same questions as other groups due to the informational equivalence. Checking for validity and reliability was considered as unnecessary given that the questions were originally designed for a school textbook and represented normal formative assessment practice in administration.

Appreciation of the forms of scientific literacy that high achieving science students typically demonstrate helped initiate the development of the MSSAT. In consideration of an established test of scientific literacy, and preferably one with well-established estimates of reliability and validity, numerous norm-referenced tests are used for national comparisons in science. A test used at the study site, and applicable to development of the MSSAT, was the Trends in International Mathematics and Science Study (TIMSS).

The TIMSS science and mathematics assessment framework is based on expected factual and procedural knowledge formed from examination of national curricula (Mullis et al., 2003). Chapter Two of the TIMSS assessment framework outlines the scientific literacy requirements of citizens and specifies two organising dimensions as content and cognitive dimensions. Target percentages for cognitive domains differ between two TIMSS test variants (administered to grade four or grade eight) in percentages of questions aligned to knowing, applying, and reasoning skills. Content domains cover life, physical, and earth sciences for the year four version and the year eight test includes biology, chemistry, physics, and earth sciences. The division of physical science into chemistry and physics for the year eight test reflects the diversification of science content domains in middle school national curricula, though the cognitive domains remain the same given the consistency of cognitive processing necessitated by the subject area.

The newly developed MSSAT instruments (see Appendices 1 and 4) were designed to reflect both the content and cognitive domains of the year 8 TIMSS science test. In doing so, an approximation of the content and cognitive domains was reflected in thirty multiple choice questions that were partitioned equally across the three scales of background knowledge of science, application of science content and analysis and evaluation of science content. The content domains for each of the three MSSAT year-level tests were based on topics covered in the preceding school term which included chemistry and physical science topics for grade 7 students, chemistry and physical science topics for grade 8 students, and biology and physical science topics for grade 9 students. Each content domain received an equal allotment of questions and weighting in each year-level MSSAT pre-intervention test and is presented along with the percentage of allocated marks per content domain in Table 4.5.

Table 4.5 Target percentages of the MSSAT pretest content domains

Year level	Content domain	Percentage of test
7	Chemistry	50%
	Physics	50%
8	Chemistry	50%
	Physics	50%
9	Biology	50%
	Physics	50%

The cognitive domains were also aligned with the year 8 TIMSS science test and operationalised as *background knowledge of science*, *application of science content* and *analysis and evaluation of science content*. As per content domains, each cognitive domain received equivalent weighting (i.e. 33%) as a total percentage of each MSSAT test (Table 4.6).

Table 4.6 Target percentages of the MSSAT pretest cognitive domains

Year level	Cognitive domain	Percentage of test
7	Background knowledge of science	33%
	Application of science content	33%
	Analysis and evaluation of science content	33%
8	Background knowledge of science	33%
	Application of science content	33%
	Analysis and evaluation of science content	33%
9	Background knowledge of science	33%
	Application of science content	33%
	Analysis and evaluation of science content	33%

4.5.2.2 Affective Outcomes Scale (AOS)

In addition to measures of science learning and general science attitudes (Section 4.5.2.6), an instrument was developed to assess students' perceptions of modified science texts. This was necessitated by the dearth of existing instruments designed specifically for science textual preferences, and the lack of any instruments which included graphic novels in comparison with other text types. The Affective Outcomes Scale (AOS) was thus developed to specifically target students' responses to the modality-defined worksheets used in this study in terms of their utility in (i) facilitating understanding of the subject matter, (ii) enhancing enjoyment and interest in the subject matter and (iii) emphasising the potential importance of the subject matter (see Appendix 6 for a copy of the AOS instrument). Furthermore, the AOS instrument was developed to provide a sensitive measure of differences between the study conditions as it can be contrasted with general attitudes towards science. As such, the instrument helps to ascertain whether attitudes towards science are independent of textual design and also allows for measurement of degree of textual auditory / visual integration with positive affect.

As described in Section 4.3, the Affective Outcomes Scale (AOS) was developed as a measure of modality-defined science texts as a separate instrument to complement the researcher-modified Test of Science Related Attitudes (TOSRA) instrument in assessing student perceptions of science. The three scales determined as indicative of student perceptions of science were categorised as *understanding*, *enjoyment*, and *importance* of science, and group administration was felt to be applicable given the estimates of internal consistency from the pilot study (described in Section 4.5.2.5). Scoring was determined in line with hypothesised responses. As outlined in Chapter one (Section 1.4.2) it was considered that low SES students would show both cognitive and affective improvements with socialised multimodal text, disproportionate to that of high SES students. As described in Section 1.3.1, this relates to the hypothesised degree of abstraction in cognition of high SES students, and related motivation in reading and comprehending texts of low socialised multimodality. Related distinctions between science *enjoyment / interest* and *importance* sub-scales influenced the design of the AOS, with high SES students hypothesised as less likely to associate graphic novels with either enjoyment or perceived importance of science as a subject.

Students were asked to provide a single response on a five-point frequency scale ranging from never to always. Positive and negative scoring were applied across all 30 responses from the three sub-scales and resulted in a higher score for students of greater abstract reasoning. The scoring followed an irregular pattern (see Appendix 5 for a copy of the AOS scoring key) with sub-scale scores ranging between 10 (extremely low understanding / interest / importance from regular text) to 50 (extremely high understanding / interest / importance from regular text).

Questions were placed in cyclic order to guard against passive responses. The irregular positive and negative scoring reflected the desired use and continuity of positively worded statements in the instrument (e.g. "*scientific information in graphic novels would be easy to understand*"). The irregular scoring also addresses issues associated with student provision of idealised answers that may be prevalent with rating or semantic differential scales (Moors et al., 2014). Though usually apparent from the pattern of answering, validity implications arise when students provide perceived *correct* responses in surveys. The irregular positive / negative scoring format may thus be more sensitive to scrutiny given its less predictable format.

4.5.2.3 Pilot testing the Middle School Science Achievement Test (MSSAT)

As two of the dependent variables had measures obtained using researcher-developed instruments, a pilot study (*n*=61) was carried out to determine instrumental validity and reliability. These instruments, the *Middle School Science Achievement Test* (MSSAT) and the *Affective Outcomes Scale* (AOS) (introduced in Sections 4.5.2.1 and 4.5.2.2, respectively) were designed to measure cognitive and affective outcome data which necessitated estimates of their accuracy and stability prior to inclusion in the main study. As existing instruments with established measures of reliability and validity, the SES measures detailed in Sections 4.5.1.1 and 4.5.1.2 were not included in the pilot study. This section and 4.5.2.4 describe the procedures associated with the piloted MSSAT instrument: Section 4.5.2.5 describes the piloting of the AOS instrument.

The MSSAT achievement test was administered as a test-retest with a four-week interval; the purpose of which was to check for temporal reliability. Based on the pilot study data, the reliability of this instrument was estimated using (a) internal consistency indices within each of the three sub-domains using Cronbach's alpha, and (b) test-retest indices, based on the correlation between scores from the first and second test administrations.

Content validity for the MSSAT achievement test was initially conceived by considering the domains of knowledge, analysis and application of science skills that students with high scientific literacy typically exhibit (Thomson et al., 2010). Two alternate forms of the achievement test were constructed to assess convergent validity, with final design showing equivalence of content and level of difficulty. The second achievement test variant was not used in further pilot analysis for reliability or as an instrument in the main study as the first test was considered valid as means and variances of observed test scores were equal.

In determining cross-cultural validity for this study, group interviews were held with participating teachers to assess whether there were grade-level content irregularities or inappropriately worded questions. Teacher interviews indicated that the content adequately represented the specified *background knowledge*, *application*, or *analysis* domains of the instrument and that grade-level appropriate language was used (for more information on the teacher interview see Section 4.8.1).

A key task of the pilot study was to ensure that the instrument provided reliable data that could be used to assess achievement. To examine whether this was the case, a four-week test-retest pilot study was conducted, during which internal consistency and temporal stability were examined. Inter-observer agreement was not considered as the instrument consisted of multiple-choice questions with no constructed-response items. To examine the validity of the MSSAT, content and convergent validity were examined. Given that reliability is consequent to validity (as a valid instrument is required to be reliable but a reliable instrument is not necessarily valid, Kimberlin & Winterstein, 2008) the MSSAT was initially assessed for its validity prior to reliability. Validity of the TIMSS science test rests on the assumption that as an aggregate of achievement standard descriptors from a variety of national curricula, it provides adequate content and construct validity. By extension, the MSSAT instrument is similarly valid in design. Criticism has been made, though, of the validity of using written test questions in the TIMSS for scientific understanding (Atkin & Black, 1997; Gipps, 1994; Harlen, 1999) yet Harlow and Jones (2004) state that little disagreement exists to suggest that the TIMSS provides valid information on student and educational achievement. Modelling the MSSAT pre-test of student achievement on the TIMSS cognitive and content domains thus appears relatively uncontroversial. Validity of the MSSAT is probably enhanced relative to the TIMMS, additionally, with its exclusion of free response type questions.

To determine whether the MSSAT adequately represented the constructs, an expert panel, made up of classroom teachers involved in the study (the sample for which is described in Section 4.4.3.1) were provided with a copy of the MSSAT pre-tests and asked for feedback. As indicated by Kimberlin and Winterstein (2008), no statistical test exists for content validity; therefore, expert judgement was used to assess whether the MSSAT was sufficiently represents a construct. Teachers were asked to comment on the appropriateness of scientific content and cognitive domains (i.e. *background knowledge*, *application*, and *analysis and evaluation* of science content) and the language that was used. In all cases, the teachers agreed that the items included in the MSSAT provided adequate coverage of the content descriptors. Furthermore, the teachers were all satisfied with the age-appropriateness of the language, although one of the teachers suggested that the number of pages be reduced. This suggestion was not acted on as much of the length (seven to eight pages per test) was used to provide figures for visual reference as well as in providing references for application and analysis / evaluation questions. Also, based on the recommendation of another teacher, the tests were administered electronically via the school Moodle site for seven of the ten participating classes (Classes 1-7; Table 4.2). All students, including the seven groups using the Moodle administered test, answered using the provided answer sheet (see Appendix 1 for a copy of the answer sheet used in the study).

Student responses collected during the pilot test (n=61) were analysed to examine the convergent validity of the test. Participants received one of two versions of the MSSAT (referred to as MSSATa / MSSATb) for both test and retest to allow for checking of equivalence of content as well as level of difficulty. Convergent validity was assessed by examining convergent and discriminant validity measures as subcategories of construct validity (Westen & Rosenthal, 2003). Pearson correlation coefficients (r) were calculated and compared across each MSSAT variant. These correlations were used to examine, jointly, the convergent and discriminant validity of the cognitive domains of science background knowledge, application of science content, and analysis and evaluation of science content. Correlations were calculated by averaging item response scores as answer responses were the same for both MSSAT variants (e.g. the answer for question 1 on MSSATa and question 1 on MSSATb was 'c').

An index of measure correlations, summarised in Table 4.7, was used to provide an indication of the magnitude of the relationship between domain constructs. This analysis provides evidence for discriminant and convergent validity for the cognitive domains with convergent correlations all positive and ranging between .55 and .99 and discriminant coefficients between -.88 and .76. The value of .76 is high for discriminant validity, and there were seven other significant discriminant values (.56 to .72) in the array. Nonetheless, the moderate to high positive domain correlations suggests an adequate domain content; conversely, the highly variable discriminant variables suggest a significant level of unrelatedness between the different scales (based on recommendations by Westen & Rosenthal, 2003).

The level of difficulty was assessed by comparing test and retest scores of each scale in MSSATa and MSSATb using factorial MANOVA for year level groups (as recommended by Tabachnik & Fidell, 2006, Ch. 2). Categorical independent variables included MSSAT variant and scale with scores as dependent variables in the analysis. Checks for normality and outliers were performed prior to multivariate and univariate testing. A low to moderate degree of correlation between dependent variables was observed ($0.23 < r < 0.45$; all Ps < .001). Wilk's Lambda statistic suggests multivariate effects were present but post hoc analyses were not conducted as the analysis only sought univariate effects between scales due to the need for descriptive data only (dependent variables): $\lambda = .358$, F (4, 53) = 4.73, p = .0371. Univariate independent one-way ANOVAs showed no significant main effects for outcomes in respect of science background knowledge: F (3, 58) = 1.55, p = .2113; application of science content: F (3, 58) = 1.932, p = .256; or analysis and evaluation of science content: F (3, 58) = 0.875, p = .523.

Table 4.7 Middle School Science Achievement Test (MSSAT) Discriminant and convergent validity matrix

	Grade 7 (variant a) BK; APP; AN/EVAL			**Grade 8 (variant a)** BK; APP; AN/EVAL			**Grade 9 (variant a)** BK; APP; AN/EVAL		
Grade 7 (variant b)									
BK	**.91**	.43	-.11	**.76**	.25	-.24	**.95**	.76	.05
APP	.12	**.78**	.64	.36	**.78**	.56	.09	**.75**	-.18
AN/EVAL	-.08	.56	**.96**	-.12	-.43	**.89**	-.31	.62	**.63**
Grade 8 (variant b)									
BK	**.69**	.15	-.22	**.67**	.31	.42	**.55**	.66	-.43
APP	.19	**.57**	.43	.55	**.80**	.63	-.88	**.59**	.53
AN/EVAL	-.10	.72	**.93**	.27	.29	**.87**	-.68	.36	**.61**
Grade 9 (variant b)									
BK	**.68**	.54	-.65	**0.99**	-.77	-.19	**.61**	.49	.41
APP	-.87	**.55**	.44	.5	**.69**	.67	.18	**.73**	.08
AN/EVAL	.65	.06	**.75**	-.45	.08	**.75**	-.45	.56	**.81**

(N.B. MSSAT Cognitive domains (BK - background knowledge of science; APP - application of science content; AN/EVAL - analysis and evaluation of science content). Convergent correlations in bold).

These results suggest that, while significant differences may exist between scales, no significance is detected within scales. The findings of the pilot study are similar to the performance of UAE students on the most recent TIMSS (Martin et al., 2012) which indicates similar variation in scale scores across the three cognitive domains with *Knowing* reporting a mean score of 492 (7.6 standard deviation); *Applying* reporting a mean score of 486 (2.7 standard deviation) and *Reasoning* with a mean score of 479 (2.5 standard deviation). Table 4.8 shows mean scale scores for each cognitive domain across both MSSAT variants (MSSATa and MSSATb) for participating pilot study students.

Table 4.8 MSSATa and MSSATb cognitive domain scale scores

MSSATa / MSSATb (year level)	n	Background knowledge of science mean / SD (pre)	Background knowledge of science mean / SD (post)	Application of science content mean / SD (pre)	Application of science content mean / SD (post)	Analysis and evaluation of science content mean / SD (pre)	Analysis and evaluation of science content mean / SD (post)
MSSATa (7)	11	8.13 (1.5)	8.15 (1.7)	6.25 (.9)	5.92 (1.2)	6.16 (.5)	6.95 (.7)
MSSATb (7)	9	8.35 (1.2)	8.23 (1.15)	6.65 (.98)	6.55 (.88)	6.94 (1.51)	7.05 (1.42)
MSSATa (8)	12	7.93 (1.8)	7.73 (1.75)	6.55 (2.1)	6.91 (1.75)	6.15 (1.42)	6.21 (1.38)
MSSATb (8)	9	7.71 (1.35)	7.62 (1.42)	4.85 (.56)	5.96 (1.12)	5.98 (.95)	6.02 (1.12)
MSSATa (9)	8	8.25 (1.45)	8.01 (1.67)	7.0 (1.13)	6.8 (1.27)	6.55 (2.42)	6.52 (2.31)
MSSATb (9)	12	8.02 (1.72)	8.12 (1.95)	7.23 (1.85)	7.2 (1.67)	5.97 (2.21)	6.05 (2.05)
TOTAL (Σ)	61	x̄ - 8.06 (1.5)	x̄ -7.97 (1.61)	x̄ - 6.42 (1.25)	x̄ - 6.55 (1.32)	x̄ - 6.29 1.5)	x̄ - 6.46 (.49)

4.5.2.4 Reliability of the MSSAT

To examine the convergent validity of the MSSATa instrument, the internal consistency reliability was assessed in the test-retest described previously. Measures of internal consistency were calculated using Cronbach’s alpha (*α)* which acts as a function of the number of items, the average covariance between item-pairs and the total score variance in a measure (Tavakol & Dennick, 2011). The indices of internal consistency presented by cognitive domain and calculated separately for the different year levels suggest a high to very high level of reliability for the MSSATa and are presented in Table 4.9: (Grade 7 *background knowledge: α*=0.954; *application: α*=0.931; *analysis and evaluation: α*=0.912; Grade 8 *background knowledge: α*-0.977; *application: α*-0.939; *analysis and evaluation: α*-0.849; Grade 9 *background knowledge: α*-0.881; *application: α*-0.861; *analysis and evaluation: α*-0.902).

Table 4.9 Internal consistency (alpha reliability) and test-retest indices for pilot test: MSSAT instrument

MSSAT scale	**Year level**	**Alpha reliability (*α*)**	***T2* - *T1* mean /(*SD*)**	**Test-retest correlation (*r*)**
Background knowledge of science	7	0.954	+1.2 (2.3)	0.79
	8	0.977	+.87 (1.8)	0.95
	9	0.881	+1.86 (2.1)	0.84
Application of science content	7	0.931	+.65 (1.9)	0.79
	8	0.939	+1.43 (2.6)	0.88
	9	0.861	+2.34 (2.4)	0.94
Analysis and evaluation of science content	7	0.912	+1.23 (2.82)	0.82
	8	0.849	+2.24 (2.45)	0.69
	9	0.902	+.95 (1.65)	0.90

Temporal reliability was sought as a measure of content stability and was evaluated for the instrument via calculation of test-retest indices using Pearson's correlation coefficient (*r*). Correlation coefficients (*r*) ranged between .69 and .95 for the three test domain scales (Table 4.9). To measure potential instrument sensitisation, test-retest mean differences for each content domain of the MSSATa instrument were calculated using the SPSS descriptive statistic function. The positive values (test 2 [*T2*] : test 1 [*T1*]) mean differences ranged between .65 - 2.34 and indicate 'practice effects' may be present. Nonetheless, as no intervention was used in the pilot study, accounting for perceived 'practice effects' with a statistic such as the Reliable Change Index (Jacobson & Truax, 1991) for post-hoc analysis of the direction and magnitude of the change was not considered necessary.

4.5.2.5 Pilot testing the Affective Outcomes Scale - AOS

The Affective Outcomes Scale (AOS) as outlined in Section 4.5.2.2 was developed and administered alongside the modified Test of Science-Related Attitudes (TOSRA) instrument to provide a measure of student perceptions of modality-defined science texts in (i) facilitating understanding of the subject matter; (ii) enhancing enjoyment of the subject matter, and (iii) emphasising the importance of the subject matter. Scoring for the AOS was made in terms of hypothesised responses which involved low SES students being expected to show significant variation between texts, expressed in motivated learning behaviour, and measured in enhanced understanding, enjoyment, and perceived importance of science with socially congruent texts.

Inter-rater reliability was not sought with the AOS instrument given its usage of easily-scored Likert-type scale responses and multiple choice questions. Internal consistency was considered as a potential source of measurement error, meanwhile, given the hypothesised association between the constructs and the traits of scientifically literate learners they purport to quantify. Alongside this, and the validity issues discussed in Sections 4.7 and 6.4 which relate to the usage of social standing as an experimental covariate, the AOS faces possible limitations as an effective measure by its scoring method. For expediency, the scoring of the AOS reflected a hypothesised range of low to high scientific literacy (Section 4.5.2.3), with highly literate learners displaying greater cognitive abstraction. Greater cognitive abstraction was associated with an enhanced motivation to seek, and comprehend, science content in traditional textual format in the AOS design i.e. an association with higher SES. This distinction was designed to provide a distinguishable range of scores which showed, incidentally, a moderate to high degree of correlation with perceived, though not objective, student SES measures in most AOS scales across grades. As shown in Table 4.10, Pearson r correlation values were all positive and moderate to strong (r = .39 - .93) for subjective SES and AOS scores; conversely, objective SES appeared uncorrelated with AOS (r = -0.24 - 0.41). As a measure of predictive validity, SES and AOS scale correlations are significant and conform with the demonstrated association between subjective SES and science learning (for more detail see Section 5.5).

Table 4.10 Correlations between AOS scales and subjective and objective measures of socioeconomic status (SES)

AOS scale	Year level	Correlation with subjective SES	Correlation with objective SES
Understanding of science	7	0.86	0.25
	8	0.56	0.15
	9	0.93	0.015
Enjoyment / interest in science	7	0.76	-0.13
	8	0.72	0.21
	9	0.83	0.41
Importance of science	7	0.89	-0.24
	8	0.45	-0.006
	9	0.39	-0.29

Cronbach's alpha was used to measure item equivalence for each scale in order to provide an estimate of internal consistency. As reported in Table 4.11, alphas ranged from .335 to .876 with the former value a possible outlier given its distance from the mean (α = .643). To augment and further investigate test reliability, an indication of student true scores was obtained from the test score standard deviation and alpha coefficient and used to calculate standard error of measurement (SEm) values. SEm values are inversely related to reliability; thus, as reliability increases, the SEm decreases, and confidence in the observed test score increases (de Vet et al, 2006). Standard error of measurement (SEm) uses the following formula (where S - test standard deviation; $r\varkappa\varkappa$ - test reliability estimate):

$$\mathbf{SEm = S \sqrt{} 1 - r\varkappa\varkappa}$$

As indicated in the variability of scale mean values relative to SEm values in Table 4.11, there is greater consistency in respective estimates of group mean values than that of individual scores. Nonetheless, the relatively high reliability estimates necessitated a decrease in SEm values which indicated less variability existing within student scores than within group effects in measurement. This was taken as an indication of construct validity which was not considered further within the pilot study. Overall, based on the results reported above, reliability and validity of the two researcher-developed instruments - the Middle School Science Achievement Test (MSSATa) and Affective Outcomes Scale (AOS) - are considered to be sound, and were used in the main study as per their piloted format.

Table 4.11 Internal consistency (alpha reliability) for pilot test: AOS instrument (single administration)

AOS scale	Year level	Alpha reliability (α)	Mean (SD / SEmean)	SEmeasurement (SEm)
Understanding of science	7	0.557	25.98 (4.79 /1.07)	3.16
	8	0.876	21.48 (4.10 / 0.92)	1.44
	9	0.355	23.45 (4.14 / 0.93)	3.32
Enjoyment / interest in science	7	0.656	25.81 (5.28 / 1.18)	3.10
	8	0.561	26.82 (3.47 / 0.776)	2.30
	9	0.651	22.93 (5.29 / 1.18)	3.13
Importance of science	7	0.61	23.481 (4.12 / 0.92)	2.57
	8	0.761	22.48 (5.12 / 1.15)	2.50
	9	0.756	23.69 (2.27 / 0.51)	1.12

4.5.2.6 Enjoyment of science as a learning area

A modified version of an existing instrument, the Test of Science-Related Attitudes questionnaire (TOSRA) (Fraser, 1981; Fisher et al., 1995) was used to assess general attitudes towards the key learning area of science. The TOSRA was considered to be a suitable instrument as it has been reported to have high internal consistency reliability. In testing for reliability of the original seven scale TOSRA, Fraser (1981) obtained Cronbach α coefficients ranging from 0.66 to 0.93. The *Enjoyment of Science Lessons* scale had the highest coefficient across all grades tested. Test-retest reliability coefficients were between 0.69 and 0.84 and cross-validation data between the US and Australia showed similarity in internal consistency reliability. This was taken as evidence of the instrument's quality and it was used in the original English wording for this study.

Although the full version of the TOSRA includes items which assess seven distinct facets of science-related attitudes (namely, *Social Implications of Science*, *Normality* *of Scientists*, *Attitude Toward Scientific Inquiry*, *Adoption of Scientific Attitudes*, *Enjoyment of Science Lessons*, *Leisure Interest in Science*, and *Career Interest in Science*) in this study only the *Enjoyment of Science Lessons* scale was used, as this was the only sub-scale deemed to be relevant given the nature of the interventions used. Ten items were used to assess this scale.

The responses for the 10 items were modified from the original guidelines (Fraser, 1981) as the original N (not sure) response was removed given the desire to present more concrete response options to participants. Four instead of five response types were thus scored: allocation of 4, 3, 2, 1 for the responses strongly agree, agree, disagree, strongly disagree for positive (+) items, and reverse scoring for negative (-) items was made as per the original scoring instructions. Positive and negative scoring followed an alternating positive / negative pattern: Q1 (+), Q2 (-), Q3 (+), Q4 (-), Q5 (+), Q6 (-), Q7 (+), Q8 (-), Q9 (+), Q10 (-), and scores for the ten items ranged between 10 (extremely low enjoyment in science class) to 40 (extremely high enjoyment in science class). The modified version of the TOSRA was administered to participating students and is provided in Appendix 7.

4.5.2.7 Mental effort

A measure of mental effort was used as a measure of learning efficacy in the current study alongside the previously described cognitive and affective measures. Self-reported mental effort can be considered as an index of cognitive processing and has been used in studies on cognitive load (e.g. Paas et al., 2005). Paas and van Merriënboer's (1994) formula of learner self-rating of task difficulty can help determine the degree of difficulty of specific tasks (where E = efficiency, P = the test performance z-score (test phase) and R = the mental effort z-score (acquisition phase)):

$$E = |P - R| / \sqrt{2}$$

Following the third round of post-testing, learners were asked to self-rate the difficulty of understanding each text type, giving a score between one (extremely easy) through nine (extremely hard). An independent t-test was used to compare means (mental effort) between groups which provided a descriptive statistic to complement inferential results.

A measure of mental effort was obtained once all students had been exposed to each of the three textual conditions. Three *multimodal social* (MS) / *bimodal social* (BS) / *bimodal asocial* (BA) text excerpts corresponding to an intervention text were presented as examples of science learning texts (see Section 5.2 for details of intervention text development and Appendix 10 for a copy of the mental effort survey). Students were instructed to record ease of understanding on a nine-point scale ranging between *extremely easy to understand* (1) and *extremely difficult to understand* (9). Response 5 was *the text type doesn't make any difference in my understanding* and was intended to represent a neutral score. Scoring was a summing of the three scores giving a score range of 3 - 27.

4.5.2.8 Control variables

Having discussed independent and dependent variables and the instruments used to quantify related constructs, attention is drawn to control variables, that is, those factors kept constant across treatments. Control variables included:

1. Gender composition: approximately equal number of each gender from the site.
2. Curriculum content: same selected topics from grade seven, eight, and nine curriculum documents.
3. Teaching approach: in all interventions, the teaching approach of the regular teacher was not altered. This reduced threats to internal validity in terms of experimental procedure and external treatment validity as the presence of an outsider isn't a common occurrence in classrooms.
4. Number of experimental sessions: Selected students were exposed to modified texts as part of classwork in three regular classes.
5. Timing of tests: Pre-test taken four weeks before the first session to minimise practice effects. Post-test taken two weeks following experimental sessions to mimic normal school practices.

4.6 Data analyses

Having discussed the research objectives (Section 4.2), study design (Section 4.3) sample (Section 4.4) and instrumentation (Section 4.5), attention is now drawn to methods of data analysis. Analyses are presented according to research objectives and include research objectives 1 and 2 (Section 4.6.1) and research objective 3 (Section 4.6.2). As mentioned in Section 4.2, research objective 4 is presented a posteriori in deduction of a conceptual model as befits theory and the current study results. Further discussion of research objective 4 is thus withheld until Section 5.4 which presents a summary of results and related conceptual model. The study hypotheses were presented in Chapter 1 (Section 1.4.2) and were based upon personal experience as well as educational and neurological literature. Study hypotheses are reiterated below and frame further discussion of statistical treatment of gathered data:

H_a1: Students will retain more information from multimodal learning texts.

H_a2: Subjective SES will be associated with enhanced learning from multimodal learning texts.

H_a3: Low SES students will exhibit greater learning from multimodal learning texts than high SES students.

H_a4: Students will benefit most from the highest degree of visual-verbal integration.

H_a5: Multimodal texts are perceived as more engaging than regular learning text.

H_a6: Multimodal texts will enhance student enjoyment of the subject area.

H_a7: Low SES students will perceive greater learning benefits from multimodal learning texts than high SES students.

4.6.1 Social standing and textual visual-verbal modality: cognitive outcomes in science learning

To address research objectives one and two, which sought to discern how socioeconomically-differentiated learners retain science content from learning texts of varying degrees of multimodality, and to explore the potential moderating influence of objective and subjective accounts of social standing on information retention, multivariate analysis of covariance (MANCOVA) was performed. This aimed to determine whether there was a significant difference in the post-test achievement of the experimental and control groups (H_a1). To test null hypotheses regarding interaction between social standing and retention of science content a three (condition: low modality; mid modality; high modality) by three (objective social standing: low; mid; high) by three (subjective social standing: low; mid; high) factorial design was used in the MANCOVA (H_a2; H_a3; H_a4).

The three dependent measures were scores for the three subdomains within MSSAT tests (*background knowledge of science, application of science content*, and *analysis and evaluation of science content*). Pretest scores for the three corresponding subdomains were entered as covariates to consider individual differences on the pretest and to reduce within-condition error variance in the post-test scores. All relevant underlying assumptions, including checks for independence, normality, and variance homogeneity, were tested prior to undertaking the analysis, and all significant MANCOVA outcomes were accompanied by an index of effect size (partial eta^2 statistic) to indicate the percent of variance in scores for which the variation accounts.

4.6.2 *Social standing and textual visual-verbal modality: Affective outcomes in science learning*

Research objective three is related to students' attitudes towards science and science learning materials. As originally described in Section 4.2, attitudinal data was assessed according to degree of textual visual and verbal modality integration with analysis involving the AOS and TOSRA instruments (Sections 4.5.2.2 and 4.5.2.6). To address this objective, first, the TOSRA was administered, as a baseline measure of enjoyment of science, before and after the intervention. t-testing was performed to check for pre- and post-intervention statistics including significant differences between year-level groups. Variation in the AOS instrument was then modelled relative to variation from the TOSRA enjoyment measure and student cognitive outcomes. As the AOS was only delivered as a post-test measure of text-related attitudes (as it is specific to the specially designed worksheets), its scales were assessed for variance using ANOVA and restricted maximum likelihood estimation (REML). Subsequent hypothesis testing aimed to detect significant differences between post-test AOS and pre- and post-test

TOSRA data. To achieve this, factor analysis involving maximum likelihood factor extraction was used to derive factor scores to act as substitute pre-test scores for the AOS. Imputed factor scores were then contrasted with TOSRA data in regression and ANOVA analysis in examination of text-based versus subject-specific attitudinal differences (H_a5). Finally, multivariate analysis of variance (MANOVA) was used to determine if significant differences existed between post-test TOSRA and AOS sub-scale scores of experimental and control groups (H_a6; H_a7) and t-tests were used to examine between-group AOS differences.

4.7 Threats to validity

Potential validity and ethical issues helped shape the experimental design in (a) the avoidance of threats to internal validity from student awareness of the (on-going) experimental process; (b) external validity issues in generalisability from reliance on an atypical teacher-student relationship and (c) avoidance of power imbalance issues. In recognition of internal validity and generalisability of research findings, several potential confounds are acknowledged. Initially, the issue of participant self-awareness and experimenter bias were considered in avoidance of threats to internal validity. As such, randomisation only involved the order in which participants received the intervention texts, with normal clusters - class groups - being exposed to their regular teacher at all times of the experimental process. A true randomised experimental design was considered less expedient than this quasi-experimental design due to the constraints of normal school practice.

This, and the desire to be as non-invasive as possible, led to the decision, after gaining ethical clearance, to have regular teaching staff administer all instruments to their own students. Avoiding an external observer in the classroom was considered to simultaneously avoid procedural sensitisation while downplaying experimenter bias. As a streamed school, high and low ability students could possibly elicit different *external* experimenter procedures, such as greater coaxing or time-given for instrument completion. Clearly, this could also happen with the regular classroom-teacher, perhaps from pride, or fear of appearing less able to instruct students on a given topic. This was raised during early consultation with participating staff who were made aware of these potential internal threats.

The possibility of distorted power-relationships between students and experimenter also influenced the experimental process. Aligned with preservation of the normal classroom setting during the interventions, the avoidance of undermining power-relationships was planned by having the regular classroom-teacher administer instruments as per normal classroom practice. Post ethical-clearance, students were not explicitly made aware of specific interventions which were designed to reflect normal curriculum content. Of the instruments used, the post-tests were also designed to reflect normal school assessment, although questionnaires obviously did not fit this trend. The generalisability of findings thus rests largely on the assumption that the experimental design represented normal school practice.

As an example of causal research, important design, measurement, and analytical considerations must therefore be met in order to draw meaningful associations between independent and dependent variables. In Section 4.3 mention was made of the preference for a *signal enhancing* versus *noise reducing* research design. When considering the signal to noise ratio, a sound research design helps clarify the hypothesised associations while good measurement reduces experimental noise. Factorial design is used as it is often assumed to have greater utility in detecting experimental relationships as it is almost exclusively focused on the setup of the treatment, and major dimensions of its components (Trochim, 2006).

Signal enhancement within this experiment is facilitated by the relatively homogenous blocks. Experimental groups are stratified by ability so potentially offer lower variability within, than between groups. This results in greater statistical significance when estimating treatment effects within the factorial analysis, and more efficient estimates than without blocking, albeit with participants presented as classroom clusters. It is recognised that blocking is typically an analysis and not design strategy and that incorrect assumptions of variability may lead to less significant estimates. Additionally, the use of blocking may follow pre-test only results which was not attempted here. However, from analysis of student data including standardised and regular testing and GPA data, and from personal observation, it is concluded that greater between-group variability exists for student ability within streamed and non-streamed classes, and meets the assumption of block homogeneity.

Identifying confounds that may upset the analysis of covariance will further increase the signal to noise ratio. It was assumed that presenting the experimental texts within the normal classroom setting would decrease variability around experimental procedures including *history* and *experimenter bias* internal validity threats, though perhaps other confounds exist. Most physical / situational and researcher variables would, therefore, be removed through the experimental procedure, though student attributes such as IQ, cognitive style, or levels of interest in specific science topics may influence the treatment variables. IQ is likely associated with streamed / non-streamed class inclusion status and though no school IQ data exists, it is ruled out as an extraneous variable. Cognitive style was discussed in Chapter 2 (Section 2.3) as being associated with social status, which as a covariate in this study, makes this factor more likely to be a covariate than a confound.

Personal interest, however, is likely to lead to differences in motivation when learning about specific topics. Personal learning biases, such as my own interest in biological science, cannot be discounted as a confounding variable especially in the context of middle school learners. In defence, the topics used in learning texts within the study all conformed to the current units of study, which limited the possibility of presented topics. Procedurally, this downplayed experimenter bias by avoiding particular topics conforming to the designer's self-interest. Topic selection also enhanced the normality of the experimental proceedings and aligned with established curriculum learning objectives.

While the analysis of covariance reduces noise by removing pre- and post-test variance associated with student cognitive ability, another issue exists within the designation of social standing as an experimental covariate. The analysis divides students into three levels of subjective and objective groupings: high, mid, and low SES. This raises a measurement issue as subjective SES is normally associated with health status in the literature, and not cognitive ability. Cognitive ability is linked with socio-economic status, though usually measured by normative indicators of objective SES. Additionally, to my knowledge, studies on perceived SES as a measure of health have only been conducted in Western countries. These factors raise the issue of whether Adler's ladder of subjective social standing is adequate (a) in defining subjective SES in the UAE and (b) associating it with cognitive ability. Nonetheless, the decision to collapse the design to a 3 by 3 design upon detection of no interaction effects involving objective / subjective social standing helps strengthen the association between learning and social standing per se due to the design having one less factor for replication.

Determining social standing in terms of covariance or confounding influence in the study also requires discussion. As a purported explanatory variable, aspects of social standing may also be seen as predictive of learning outcomes that possibly confound analysis. For example, students of higher social standing may show greater diligence in finishing exam papers regardless of knowing answers or not, may possess greater language skills equipping them with greater communicative competence in answering written questions, or may show a preference for all forms of texts. Furthermore, students of higher social standing are possibly more conducive to educational interventions and may provide favourable answers on instruments regardless of true feelings. Conversely, overly negative answers may be more likely from students of lower social standing, regardless of true feelings, due to factors not discernible in the experimental design. Aspects of social standing are therefore possibly associated with both the dependent and independent variables and are raised again in Chapter six (Section 6.5) alongside other experimental limitations.

4.8 Ethical considerations

This section begins with a brief overview of ethical values and then provides details of adherence to specific ethical considerations. As a first step, ethical clearance for the current study was applied for and granted by Curtin University's Human Research Ethics Office on 30th April 2015 (approval number RDSE-15-15. See Appendix 11 for a copy of the approval letter). In reference to an ethical framework, the opening lines of the National Statement on Ethical Conduct in Human Research (NHMRC, 2015) state: "The relationship between researchers and research participants is the ground on which human research is conducted." Research merit, justice, beneficence, and respect are key values of the statement, and provide guidelines in navigating the almost inevitable dilemmas arising within research. Given the esteemed position that teachers hold within the traditional setting of the UAE, special consideration was given to establishing and maintaining respectful partnerships with all parties involved. In accordance with NHMRC key values, consideration of research ethics within this study included informed consent and the voluntary nature of participation (Section 4.8.1); anonymity, multiple roles and power imbalance (Section 4.8.2), and intellectual integrity (Section 4.8.3).

4.8.1 Informed consent / voluntary nature of participation

In gaining ethical clearance, all participating teachers, students and students' parents were provided with information about the nature of their participation and the purpose of the study. Written permission was obtained from the principal and heads of department at the school site, and four meetings took place prior to commencement of the study: one between the head of department, head of school, and myself; one between the principal and myself; a meeting between myself, the principal and a parent involved in the study, and a formal meeting between participating teachers and myself. It is noted that no data was collected during these interviews.

The initial meeting with teachers followed a semi-structured interview format with topics defined as:

- The nature of educational research
- Benefits of educational research
- Current research on multimedia learning
- This research

The meeting lasted approximately thirty minutes in which time we covered the topics in depth. Most time was spent on the fourth point with discussion focused on the role of the teachers; specific guidelines associated with intervention materials / instruments; and key dates / deadlines. Informal, ongoing support was given as needed, and easily facilitated given that all middle school science teachers share the same staffroom at the study site.

Written consent was obtained from teachers and the parents of participating students and consent forms were accompanied by information letters (see Appendix 12 for copies of information letters and consent forms). Information letters presented details pertinent to the child's and parent's involvement in the research, and outlined in clear language: (a) the intent of the research project; (b) that permission was being sought; (c) expected procedures for participants; (d) the nature of voluntary participation and the option to leave the project at any time with no consequences; and (e) formal procedures regarding the storage and treatment of data. Following data collection, a letter and corresponding email were delivered to give thanks to participating students and their families. In this correspondence the offer to receive a copy of the finished thesis was made contingent on successful completion.

4.8.2 Anonymity / multiple roles / power imbalance

In order to protect identification and to provide access to the quantitative data, a coding system was used at all times. No reference to individuals was made at any time, either in feedback to the schools, or in the reporting of the results. Additionally, post-ethical clearance, no identification of participating versus non-participating individuals was made in the distribution of instruments during the various stages of the experimental design. This decision maintained the normality of proceedings in order to safeguard specific threats to internal validity and may have also helped prevent issues related to pre-existing teacher-student relationships. Students represent a potentially over-researched population and it is recognised that perceived peer or teacher pressure may cause or exacerbate fractious relationships. This is recognised as especially relevant given the nature of this unequal relationship defined by authority and subservience. Differentiating students by participation status could potentially lead to feelings of exclusion and was thus avoided.

4.8.3 Intellectual integrity

Potential conflicts of interest between all parties were considered prior to the study and controlled for. While no financial incentives existed within the research setting (such as increased enrolment or funding for the school) other potential conflicts of interest were possible. Perhaps the greatest sources of unethical behaviour in this regard included academic and interpersonal sources of conflict. Academic findings could easily be doctored to provide confirmatory research findings, or to show outstanding student results from a particular teacher. The school, as a business entity, could perhaps also benefit in terms of prestige and associated benefits. These threats to ethical conduct were avoided through adherence to predetermined procedure, coding of participants and teachers alike, and making no explicit mention of the school name. Additionally, participating teachers were not made aware of student cognitive or affective outcomes at any stage of the experiment. Doing so may have affected future participation in the experiment due to personal disappointment of student results or feelings or from perceived discrepancies between classes.

4.9 Chapter summary

This chapter presented, and justified, the experimental design for the study. Rationale for this quantitative study comes from limitations identified in multimedia learning literature, including but not limited to, the role of individual differences in learning. Purported individual learning effects such as the *expertise reversal* effect identified in Chapter three have been presented as *a posteriori* justifications in multimedia learning research. Identifying and experimentally testing developmental variables may present better associations with learning, though, and limits the need to interpret marginal effects as task-related constructs. By situating the individual learner within an identifiable gradient of social status, specific research objectives and hypotheses were posed: will students of different social background show variability in learning from salient, socially congruent learning texts? Does social status, measured objectively or subjectively, covary with retention of content? Will student attitudes towards science vary with the form of science text they use?

The inclusion of specific research objectives coupled with the intent to generalise findings to a greater population of middle school science learners marks this as quantitative study. Following consideration of the organisational constraints of the school site and potential validity and ethical issues associated with true experimental designs, the decision to use a quasi-experimental cluster randomised trial was made. In discussion of the research design, the distinction between noise reducing and signal enhancing design types was presented as a justification for the design and analyses used. In determining statistical power, the sample size (n=214) was assessed as having adequate sensitivity in identifying the existence and magnitude of interaction effects in factorial design, and signal enhancement within the factorial design is assumed by the relatively homogeneous blocking of students. Experimental groups have low within-group variance in ability given that all students within the middle school are streamed by academic ability. Furthermore, the use of factorial design is efficient in that the rotation of students through every level of each factor simultaneously reduces the required sample size, while enhancing the statistical power.

Participants were consenting students from ten intact middle school classes at the site, with n=214 grade seven, eight, and nine students and parents consenting to participate in the study. Consent also extended to participating teachers (n=5) whose classes formed eight out of the ten experimental blocks and were involved in the distribution of instruments to students as per normal classroom procedure. Of the five instruments used, two were modified versions of existing instruments, one was unmodified, and the remaining instruments were developed by the researcher. The Middle School Science Achievement Test (MSSAT) and the Affective Outcomes Scale (AOS) were designed to measure student cognitive and affective responses and were involved in pilot study prior to the first intervention. The pilot study began in the second week of term 3 at the site and involved sixty-one (n=61) grade 7, 8, and 9 students. These students formed part of the original consenting cohort, though given the lack of other comparable grade-level students, it was felt appropriate to use this data in analysis of instrument reliability and validity.

Within the pilot study, the internal consistency and stability of the MSSAT and AOS instruments were assessed over a four-week period. Reliability estimates are used to estimate measurement stability across time and in evaluation of the equivalence of sets of items either from retesting or as a measure of inter-rater consistency. Validity, in terms of instrumentation, refers to the ability of an instrument to actually measure what it was designed for. Estimation of internal consistency involved calculation of Cronbach’s alpha for each MSSAT subdomain and AOS scale items, while temporal reliability of the MSSAT was provided with test-retest indices of correlation between scores. Additionally, content and convergent validity of the MSSAT were checked prior to using this instrument in study. This involved the consideration of specific domains of knowledge, analysis, and application of scientific content exhibited by high-functioning students, and convergence was checked with the final MSSAT design showing equivalence of content and level of difficulty.

Following establishment of the research design, and the piloting of the two researcher-developed instruments, the interventions and measurements followed three phases of pre- and post-testing determined by learning pace of individual classes over an eleven-week period. Data analyses addressing research question one and two involved multivariate analysis of covariance (MANCOVA) in which pre- and post-test cognitive scores were compared, alongside controlling for subjective and objective social standing which were operationalised as low, mid, or high. Research objective three involved pre- and post-test comparison of the TOSRA instrument of science attitudes. The AOS instrument is specific to the interventions - in comparison of researcher-developed learning texts - so no before and after correlation analysis was possible. Instead, maximum likelihood estimation was used in the calculation of subset correlations and confidence intervals. Multivariate analysis of variance (MANOVA) was then used to detect significant differences between post-test TOSRA and AOS sub-scale scores for experimental and control groups.

Internal and external threats to validity were raised and framed in terms of research design, measurement, and analytical procedures. Firstly, it was noted that experimental associations and causal relationships are distinguishable, and as an isolated example of educational research, the study findings face multiple validity issues which influence generalisation. Within educational research, for example, major threats to internal validity may occur from manipulation of the normal classroom setting. The decision to involve the regular classroom teachers in the study may have helped reduce variability associated with *physical* and *procedural* aspects of experimentation. *History* and *experimenter bias* effects are also presumably decreased in having the regular classroom teacher administer all intervention and measurement instruments, though the *student* variable of personal learning biases, including content-specific motivation, is harder to control for. This is flagged as a potential threat to validity alongside the more fundamental issue of inclusion of social standing as an experimental covariate. In consideration of this variable as predictive of student outcomes, the possibility of aspects of social standing confounding results is raised. In short, behavioural traits associated with social standing may interact with dependent and treatment variables and lead to confused results despite presumed orthogonality in the design. Further commentary is provided in Chapter 6 (Section 6.4).

A discussion of ethical considerations ended the chapter. Key values established by the National Statement on Ethical Conduct in Human Research (NHMRC, 2015) were outlined and related to efforts made by the researcher in terms of permission, privacy and confidentiality, respect and consideration. As a school situated within the United Arab Emirates, a traditional region in which relationships are respected and valued, a proactive attempt was made to establish and maintain respectful communication with all parties involved. Alongside adherence to procedural and analytical aspects of the ethical clearance procedure, showing respect to participants was a central motivation in conducting ethical research.

The next chapter details the findings of the study.

Chapter 5

RESULTS

5.1 Introduction

This chapter provides details of the research analyses and findings related to the influence of social standing and socialised text within multimedia learning. The research design, as outlined in Chapter 4 (Section 4.3), involved a quasi-experimental pre-post design with middle school science learners as participants. The research objectives (as detailed in Section 4.2) were drawn from research inconsistencies in the field of multimedia learning and focused on social background as a developmental influence in textual comprehension. Specifically, research objectives 1 and 2 sought to ascertain whether the degree of textual visual-verbal modality affected retention of science content in students differentiated by objective and subjective socioeconomic status. Additional to these cognitive outcomes, research objective 3 sought to examine whether student attitudinal outcomes are associated with socially congruent learning texts and the subject area itself. Finally, as a deductive process following analysis of research objectives 1 to 3, research objective 4 aimed to relate these cognitive and affective findings to a conceptual model of stimuli processing. The results described in this chapter are organised according to the following headings:

- Social standing and textual verbal-visual modality: Cognitive outcomes in science learning (Section 5.2);
- Social standing and textual visual-verbal modality: Affective outcomes in science learning (Section 5.3);
- Conceptual model: A synthesis of neuroscience theory and study findings (Section 5.4);
- Chapter summary (Section 5.5).

5.2 Social standing and textual verbal-visual modality: Cognitive outcomes in science learning

To evaluate the retention of science content between students differentiated by social standing, learning texts were designed and administered to 214 middle school students in the three conditions described in the study design (Section 4.3): i.e. involving *Bimodal Asocial* (BA) (control text), *Bimodal Social* (BS) and *Multimodal Social* (MS) text. As described in Section 4.3, class-grouped students received the three text variants in random order and were pre- and post-tested for achievement. Post-test achievement was measured as recall and transfer of learning, with post-tests developed specifically for each intervention round per class grouping.

Specific research objectives were developed according to identified deficits and inconsistencies within multimedia research (see Section 1.5.1). The first two of these were related to textual design and cognitive outcomes and involved the influence of social standing:

1. To examine how the degree of textual visual-verbal modality affects retention of content in learners differentiated by social standing;
2. To explore whether objective and subjective accounts of social standing covary with retention of content.

Research objectives 1 and 2 examined whether researcher-developed science learning texts differentiated according to students' perceived and objective measures of socioeconomic status. Specific hypotheses, presented in Section 1.5.2, were developed for the research objectives. For the two objectives, it was hypothesised that students of low social standing would show greatest variability in science achievement. This effect was posited to occur due to preference for cross-modal, socialised stimuli and the limitations of abstraction outlined in Chapter 2 (Section 2.9) as *normal* and *abnormal* brain function. Students of high social standing were hypothesised to show less variability in cognitive results given their ability for greater abstraction in the absence of integrated text (with associated attentional and perceptual processes). Research hypotheses pertinent to research objectives 1 and 2 are reiterated below:

- **H_a1**: Students will retain more information from multimodal learning texts.
- **H_a2**: Subjective SES will be associated with enhanced learning from multimodal learning texts.
- **H_a3**: Low SES students will exhibit greater learning from multimodal learning texts than high SES students.
- **H_a4**: Students will benefit from the highest degree of visual-verbal integration (i.e. *Multimodal Social* [MS] text type).

As seen in research hypotheses 2 and 3, directional predictions for the effects of socioeconomic status on science learning from appropriately designed multimodal texts were made. Related statistical tests were inclusive of objective and subjective SES as covariates, and were modelled to directly test research objectives 1 and 2. Less specific predictions of enhanced learning (H_a1 / H_a4) are also included as baseline indicators of learning effects within science learning texts for wider analysis of the same two research objectives.

Pursuant to research hypothesis 1, that students would retain more science content from appropriately designed multimedia texts, the following section (Section 5.2.1) details findings of cognitive outcomes prior to inclusion of socioeconomic status as a covariate. Section 5.2.2 then addresses research hypotheses 2, 3 and 4 which detail the modelling of objective and subjective socioeconomic status in multimedia learning.

5.2.1 Textual design and science learning

Inspection of student achievement following the final round of Middle School Science Achievement Test administration (MSSAT - see Section 4.5.2.1 for details of instrument development) showed a pattern of overall higher achievement for Multimodal Social (*MS*) and Bimodal Social (*BS*) text variants. Table 5.1 (next page) provides a summary index of post-test *Middle School Science Achievement* test (MSSAT) results across the three grade levels (grades 7 to 9), and Figure 5.1 compares group post-test science achievement mean between the three multimodality-defined text variants (i.e. *Multimodal Social* [MS], *Bimodal Social* [BS], *Bimodal Asocial* [BA] texts) in each year level.

One-way ANOVA was used to test the null hypothesis that no significant differences existed between observed text raw score means (*MS - Multimodal Social*; *BS - Bimodal Social*; *BA - Bimodal Asocial*). Prior to testing for within-sample variance, checks for independence, normality and variance homogeneity were performed within SPSS with no violations detected. ANOVA analysis revealed significant achievement differences between text type for grade 8 students' results ($F(2,102) = 3.599$; $p = .031$) and grade 9 students' results ($F(2,198) = 15.623$; $p < .001$) though not grade 7 students' results. In reference to year 7 results, for whom the differences were not significant ($F(2, 144) = 1.5$, ns), as an omnibus test statistic, it is recognised that one-way ANOVA cannot reliably discern statistically significant differences in the presence of latent independent variables (Kline, 2004) such as the as-yet unexplored MSSAT cognitive domain values. Additionally, in reference to grade 8 and 9 results, Kao & Green (2008) state that one-way ANOVA is inadequate to detect significant effects between groups prior to post-hoc testing.

Table 5.1 Descriptive statistics of student group post-test achievement (MSSAT data)

Learning text	**Grade**	**Mean (SD, SEmean)**
Multimodal Social	7	7.421 (3.365, .347)
	8	8.118 (3.064, .429)
	9	5.806 (3.019, .369)
Bimodal Social	7	7.624 (3.252, .335)
	8	8.745 (3.108, .435)
	9	5.806 (3.163, .386)
Bimodal Asocial	7	7.086 (3.308, .341)
	8	6.706 (3.492, .489)
	9	4.343 (2.598, .317)

In post hoc analysis, Tukey's honest significant difference (HSD) statistic was adapted to the unequal sample sizes and was considered appropriate for ANOVA analysis given its maintenance of a correct alpha statistic despite computation of multiple comparisons where a sum or product of individual levels of significance is inadequate (Stevens, 1999, p. 68). In testing, HSD values are set at commensurable *Q*.01 or Q.05 significance levels, which are computed as following:

$$Q = \frac{ML—MS}{\text{sqrt}\,[MSwg / Np/s]}$$

[Where *MSwg* is the within-groups MS obtained in the original analysis and *Np/s* is the number of values of Xi per sample ("*p*/*s*"=per sample)].

The studentized range statistic (Q) was then compared with table alpha level values with corresponding degrees of freedom and treatment number. Q values were obtained for alphas at .05 and mean differences were compared with the HSD statistic (grade 8: $Q_{.05} = 3.36$; Grade 9: $Q_{.05} = 3.34$). For grade 8, significant differences existed for student achievement between *Bimodal Social* (BS) and *Bimodal Asocial* (BA) texts at $HSD_{.05,}$ while for grade 9 significant differences were seen between *Multimodal Social* (MS) and *Bimodal Asocial* (BA) texts ($HSD_{.01}$ and $HSD_{.05}$) and *Bimodal Social* (BS) and *Bimodal Asocial* (BA) texts ($HSD_{.01}$ and $HSD_{.05}$). Figure 5.2 displays significant values at a family error rate of 0.05. As mentioned previously, significant mean differences are adjusted in Tukey post-hoc analysis, and family error rate was set equivalent to a 95% simultaneous confidence level (confidence intervals that contain zero indicate no difference). Post hoc testing thus revealed a conservative estimate of within-group cognitive gains for two of the three grade-levels (grade 8 and 9) involved in the main study.

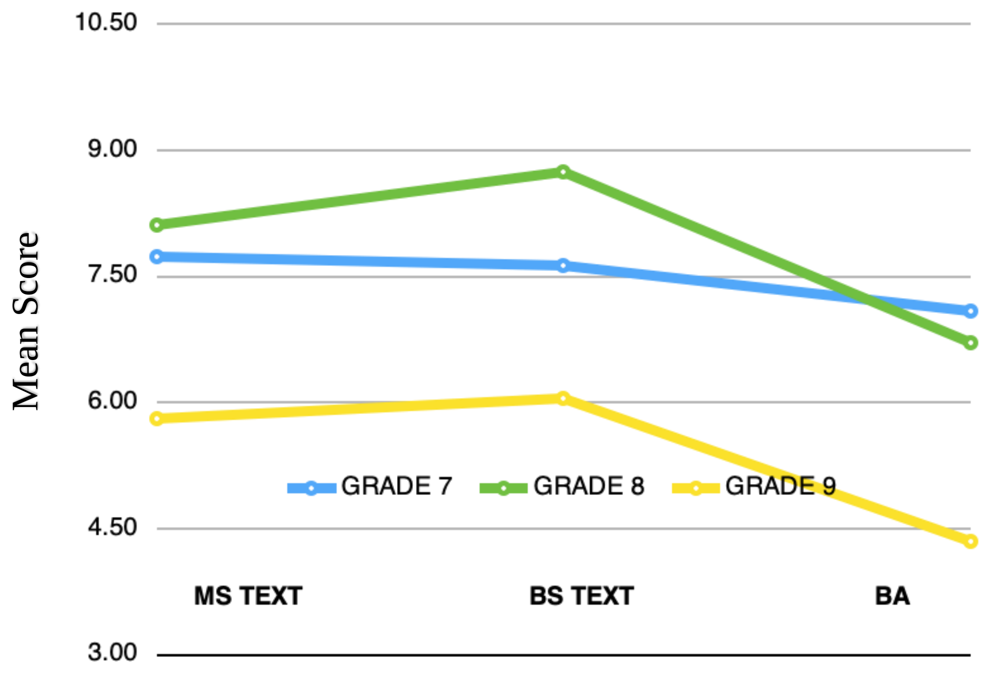

Figure 5.1 Group post-test science achievement mean scores for text type (Grades 7, 8, and 9). (N.B. MS - Multimodal Social text; BS - Bimodal Social text; BA- Bimodal Asocial (control text))

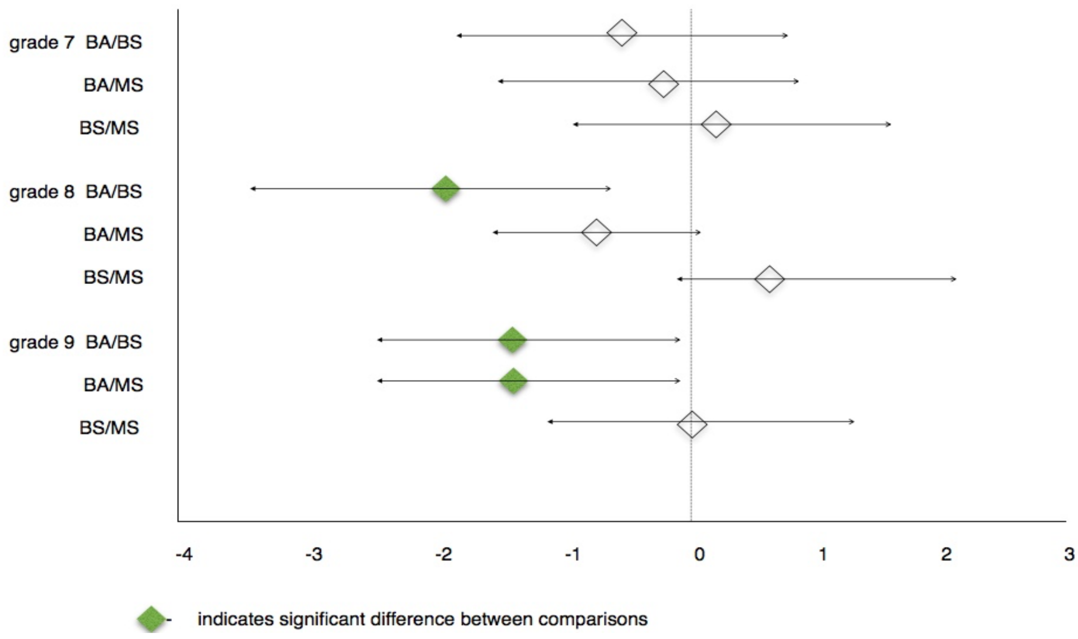

Figure 5.2 Pairwise differences between treatments (Tukey 95% simultaneous confidence intervals). (N.B. BA – Bimodal Asocial (control text); BS – Bimodal Social text; MS – Multimodal Social text)

As indicated, grade 7 science achievement results did not show significant differences between textual variants. This could be reflected in the relatively high grade level variance; for example, when a paired samples *t*-test was used (in lieu of a post-ANOVA comparison) to compare achievement means, significance was detected between *Multimodal Social* (MS) and *Bimodal Asocial* (BA) texts: t (93) = 2.169, p = .033. Taken together, socialised texts were associated with enhanced science cognitive outcomes across the three grade levels although there was no clear distinction between *Multimodal Social* (MS) and *Bimodal Social* (BS) text variants. Inclusion of socioeconomic status as a covariate was then modelled to explore these trends in greater detail, see below.

5.2.2 Social standing and science learning

Additional to the influence of textual design, research objectives 1 and 2 sought to quantify the influence of social standing as a covariate in textual comprehension. Multivariate analysis of covariance (MANCOVA) was used to assess statistical differences across multiple continuous dependent variables with an independent grouping variable. Additionally, covariates were included to enhance the signal-to-noise ratio within factorial analysis. As introduced in Section 2.4, and elaborated on in Section 3.8, the influence of social standing as a covariate in this research stems from its association with cognitive style. Within this analysis, dependent variables included the Middle School Science Achievement Test (MSSAT) post-test and science achievement scores. Text variants were used as a categorical independent variable and covariates included subjective and objective SES measures, and MSSAT pretests to reduce variance associated with individual student science scores on the MSSAT instruments.

Multivariate and covariate outcomes were measured from cross-products and cross-product partitions within MANCOVA, while univariate outcomes were found from partitioning variance into the relevant sum of squares (Flora, 2017, p. 114). Statistical significance in MANCOVA is represented by F ratios which test specific hypotheses. Within this analysis, the following hypotheses were presented:

- **$H_0$1:** mean (μ) Science achievement MS text = μScience achievement BS text = μScience achievement BA text (adjusted for objective SES)
- **H_a:** mean (μ) Science achievement MS text ≠ μScience achievement BS text ≠ μScience achievement BA text (adjusted for objective SES)
- **$H_0$2:** mean (μ) Science achievement MS text = μScience achievement BS text = μScience achievement BA text (adjusted for subjective SES)
- **H_b:** mean (μ) Science achievement MS text ≠ μScience achievement BS text ≠ μScience achievement BA text (adjusted for subjective SES)

Inferential analysis of variance requires certain assumptions to be met prior to modelling. Additional to tests for linearity and the absence of multivariate outliers and multicollinearity are specific requirements of variance and covariance homogeneity (Davis, 2003). Prior tests for assumptions and restrictions were thus run, commencing with analysis of correlation between the covariates and dependent variables. Observed coefficients of correlation ranged between .422 and .916 for all dependent variables, representing reasonable correlation between the dependent groups across the treatment conditions (Evans, 1996). Correlations between covariates and dependent variables also satisfied inclusion given their assumed collinearity and ability to reduce the magnitude of the error term in the design (Keppel & Wickens, 2004, p. 311): ($.547 < r < .865$) except for objective SES ($-.019 < r < .077$). Objective SES appeared weakly associated with the other variables and was subjected to independence checking to determine its suitability as a covariate with textual design.

One-way ANOVA was used to evaluate whether the covariates differed significantly across text variants; subjective SES demonstrated no significant difference with respect to text $F(2,211) = 1.6$, $p = .2043$. This result was similar for other covariates except for objective SES: MSSAT pretest *Knowledge / Understanding* — $F(2,211) = 2.4$, $p = .0932$; MSSAT pretest *Application* — $F(2,211) = 1.22$, $p = .2973$; MSSAT pretest *Analysis / Evaluation* — $F(2,211) = 2.96$, $p = .054$; objective SES — $F(2,211) = 4.97$, $p = .0078$. No post hoc tests were required as only main outcomes were sought. Objective SES was removed from the factorial design following this analysis, and the study was collapsed from a 3^3 to a 2^3 factorial design**.** This satisfied subsequent testing via focus on subjective social standing as a more effective covariate and enhanced overall statistical power in lowering the degrees of freedom and thus the complexity of the model.

A two-sample Kolmogorov-Smirnov test for dependent variable distribution (MSSAT post-test and science achievement scores) was used as a test of normality and was considered appropriate within the context of the study's design given that greater than 50 subjects exist within each group (Ghasemi & Zahediasl, 2012). Estimates of normal distribution appeared to be satisfied as all significance values exceeded .05.

Finally, prior to running MANCOVA, a test for homogeneity of regression was conducted between the remaining covariates and dependent variables. The variables showed no significant interactions: text-type and subjective SES and text-type / MSSAT 1, 2, and 3 had p values ranging between .097 and .855. Having satisfied this final MANCOVA assumption and proceeding without objective SES as a study covariate, MANCOVA was used to examine multivariate and univariate outcomes.

In initial MANCOVA analysis, MANOVA was used to ascertain effects of dependent variables with the text-type treatment variable. Significant multivariate outcome was detected in respect to text type and Middle School Science Achievement Test (MSSAT - see Section 4.5.2.1 for details on instrument development) results across the categorical independent variable (IV) groups: $\lambda = .877$, $F\ (8, 416) = 3.52$, $p = .001$. Significant univariate outcomes were also seen for science achievement - [$F\ (2,206) = 3.11$, $p = .0467$]; MSSAT post-test *Knowledge / Understanding* (K/U) [$F\ (2,206) = 4.57$, $p = .0114$]; and MSSAT post-test *Application* [$F\ (2,206) = 3.68$, $p = .0269$] but not MSSAT post-test *Analysis / Evaluation* [$F\ (2,206) = 2.56$, $p = .0798$] across text-type categories. Initially, then, significant learning effects appeared to be associated with multimodal learning texts in cognitive domains of science understanding and science application, though not necessarily analysis and evaluation of scientific concepts.

Subsequent MANCOVA analysis sought covariate effects and a Bonferroni post-hoc test was included to modulate overall error rate given that it accounts for each statistical hypothesis in overall attribution of significance. This compensatory effect is achieved by testing individual hypotheses with a significance level of α/m (with α

being the desired overall alpha level and *m* being the number of hypotheses, Barton et al, 2016). The Bonferroni test lacks power, though, due to possible overcorrection for type I error in the assumption of test orthogonality / consistency with prior research (Armstrong, 2014). Nonetheless, type II error rates were considered as non-significant within this analysis for individual tests given the removal of the objective SES covariate and assumed block homogeneity in the within-subjects factorial design (as described in Sections 4.4.3.2 and 4.7).

Levene's test was used as a homogeneity check in interpreting output, and significance values exceeded .05 in each case. Box's test for homogeneity of variance-covariance matrices also indicated that the correlation between dependent groups did not differ between text-type. After applying covariates to the analysis, both multivariate and univariate effects were evident from inclusion of subjective SES. Multivariate testing showed a decrease in error variance: $\lambda = .896$, $F\ (8, 416) = 2.879$, $p < .001$ (compared with $\lambda = .877$, $F\ (8, 416) = 3.52$, $p = .001$ prior to covariate inclusion). Marginal means showed a concomitant decrease with subjective SES and MSSAT pre-tests included. Univariate outcomes for all four dependent variables showed significance, and the three dependent variables which showed significance prior to covariate inclusion became stronger after applying covariates: *Science achievement* - [F (2,211) = 3.331, $p = .038$]; MSSAT post-test *Knowledge / Understanding* [F (2,211) = 7.347, $p = .001$]; MSSAT post-test *Application* [F (2,211) = 7.084, $p = .001$]; MSSAT post-test *Analysis / Evaluation* [F (2,211) = 11.135, $p < .001$]. As mentioned above, prior to inclusion of subjective SES, *Analysis and Evaluation* results did not exhibit significance as a multivariate outcome. Covariate modelling may thus provide an improved estimate of cognitive outcomes in this study.

Post-hoc Bonferroni analyses demonstrated that, adjusted for subjective SES and MSSAT pre-tests, *Multimodal Social* (MS) (p - .006) and *Bimodal Social* (BS) (p - <.001) text types were associated with greater learning for science achievement; *Multimodal Social* (MS) (p - .001) and *Bimodal Social* (BS) (p - .004) text with outcomes in MSSAT post testing for knowledge and understanding and *Multimodal Social* (MS) text (p - 0.043) with MSSAT post testing for application of science content. In analysis, these findings highlighted cognitive benefits of multimedia text for learners differentiated by subjective SES, although raised uncertainty surrounding the degree of textual audiovisual modality in efficient learning. Uncertainty also existed in the broader benefits of multimedia text in transfer learning for analysis / evaluation type problems.

In summary, multimedia texts enhanced student learning (H_a1). Cognitive outcomes, measured in recall and transfer of scientific content matter, were significantly improved using both multimodal text variants (*Multimodal Social* [MS] and *Bimodal Social* [BS] text). Inclusion of perceived social standing as a study covariate further refined this finding, with the observation that subjective SES is significantly associated with knowledge / understanding and application cognitive outcomes (H_a2). In analysis of interaction effects inclusive of independent variable variance, the predictive association of subjective SES with enhanced science learning is seen to benefit low SES students (H_a3). However, the relative importance of degree of socialisation of learning text is called into question as *Multimodal Social* (MS) and *Bimodal Social* (BS) texts were almost equally associated with knowledge / understanding outcomes, and strongest association with application of science content for *Multimodal Social* (MS) text (H_a4). A summation of analyses for each research objective and related commentary is given in Section 5.5.

5.3 Social standing and textual verbal-visual modality: Affective outcomes in science learning

Research objective 3 sought to quantify student-held attitudes toward science learning materials which differ in degree of integrated textual visual-verbal modality. The rationale for use of a perceptual measure of student affect, alongside cognitive outcomes, stems from systematic review findings of multimedia learning literature (Chapter 3). In questioning how affective outcomes are used in evaluation of multimedia instructional design in learning, publications reviewed in Section 3.8 typically involved measurement of affective orientations against theoretical developments including cognitive load theory (CLT, Chandler & Sweller, 1991) and cognitive theory of multimedia learning (CTML, Mayer, 2001). An additional finding from systematic review was that multimedia is perceived as beneficial for learning, though not necessarily interesting. Importantly, reviewed studies offered no perceptual measurement of specific domain / content material, which narrows interpretation of student affect as an outcome variate. As discussed in Section 3.8.2, the inclusion of subject area understanding, interest / enjoyment, and importance as affective outcomes widens the scope of multimedia research from underlying design principles to learning outcomes more generally.

The hypotheses pertaining to research objective 3, presented in Chapter 1 (Section 1.5.2), are reiterated here:

- **H_a5:** Multimodal texts are perceived as more engaging than regular learning text.
- **H_a6:** Multimodal texts will enhance student enjoyment of the subject area.
- **H_a7:** Low SES students will perceive greater learning benefits from multimodal learning texts than high SES students.

Like the hypotheses generated for research objectives 1 and 2, hypotheses for research objective 3 vary in specificity. Baseline measures of learner affect were aligned with multimodal text as well as measurement of affective domains representing science as a subject area (H_a5, H_a6). Learner affect was also modelled with the subjective SES variate (H_a7) to further explore the association between social standing and engagement with science learning materials.

Participants responded to the modified Test of Science-Related Attitudes (TOSRA) instrument before and after the interventions allowing for correlation analysis. Additional to this measure of enjoyment of science, the novel Affective Outcomes Scale (AOS) instrument (see Section 4.5.2.2) was administered following final achievement post-testing to measure affective response towards textual form. Given that no pre-intervention AOS instrument was used, estimates of variance were obtained to assess scale effects and to test hypotheses regarding the variance components of the two affective measures. Because of the relatively high internal reliability and estimated construct validity seen in the piloted AOS (Section 4.5.2.5), the decision to not seek exploratory or confirmatory factor analysis was made, although factor plots and factor scores were developed for subsequent regression analysis. Post-test TOSRA and AOS results were compared using MANOVA in determining whether differences existed between these measures, and a final analysis examined post-test and proxy pre-test AOS scores.

Initial examination of pre- and post-intervention statistics for the TOSRA instrument show a high degree of correlation and minor grade-level variance (Table 5.2 shows pre-post intervention mean scores and Pearson correlation coefficients [*r*]). No significant pre-post differences were seen within year level groups using paired *t*-tests: year 7 [t (93) = .061, p = 1.99]; year 8 [t (51) = .73, p = 2.01]; year 9 [t (67) = 1.48, p = 2.0]. This within-group consistency led to the decision to cease further exploration of between-group TOSRA variation.

Estimates of variance associated with the scales of the AOS instrument were obtained using ANOVA and restricted maximum likelihood estimation (REML) within SPSS variance components analyses. Factors and covariates included *science achievement* and *science enjoyment* (post-intervention TOSRA data) as main effects and AOS scales as interaction terms within the model. The variance associated with the AOS sub-scales was therefore calculated relative to variation from the TOSRA enjoyment measure and student cognitive outcomes.

Table 5.2 Pre- and post-intervention science related attitudes (TOSRA) data

Year	**Scale items**	**N**	**Pre-intervention mean (SD)**	**Post-intervention mean (SD)**	**Pre-post correlation (r)**
7	10	96	28.245 (6.32)	28.191 (5.76)	0.895
8	10	51	29.535 (5.43)	30.288 (4.94)	0.864
9	10	67	28.176 (5.63)	29.515 (4.85)	0.879
Total / average		214	28.652 (5.79)	29.33 (5.18)	0.879

In the initial ANOVA estimate, the AOS *understanding* scale accounted for 14.3% of random variation; AOS *enjoyment* — 35.6%; AOS *importance* — 22.7%. In this initial estimate, therefore, variance attributable to chance error alone accounted for 27.4%, while AOS science enjoyment accounted for the largest single variance proportion. Subsequent REML using the same variables saw stability after five iterations in the maximisation of the likelihood function's natural logarithm. REML variance estimates attribute slightly greater variation to the AOS sub-scales; AOS *understanding* scale — 17.8% of random variation; AOS *enjoyment* — 38.2%; AOS *importance* — 23.2%. As seen, the estimate of chance error drops marginally to slightly above 20%, and AOS *enjoyment* sub-scale variance retains the greatest share of variation (understood as subject to effects of treatment or individual differences, Oehlert, 2012). Moreover, estimates of variance are conservative following REML manipulation of the model parameters. In summary, this indicates that enjoyment of science is a construct requiring further analysis given its plasticity as a treatment effect. It is also of interest given its consistency as seen in the AOS *enjoyment* scale and TOSRA (*science enjoyment* / *interest* scale) pre- and post-testing.

In hypothesis testing, confidence intervals can be calculated from the asymptotic variance-covariance matrix which is generated as a by-product of the REML iteration process. 95% asymptotic confidence intervals were calculated for AOS scale variance and were used to test the null hypothesis that variances for AOS science *enjoyment* and pre- and post-test TOSRA scores are equal:

- H_{01}: $_{\text{variance}}\ (\sigma^2)_{\text{ AOS(enjoyment)}} = \sigma^2_{\text{TOSRA(pretest)}}$
- H_a: $_{\text{variance}}\ (\sigma^2)_{\text{ AOS(enjoyment)}} \neq \sigma^2_{\text{TOSRA(pretest)}}$
- H_{02}: $_{\text{variance}}\ (\sigma^2)_{\text{ AOS(enjoyment)}} = \sigma^2_{\text{TOSRA(posttest)}}$
- H_a: $_{\text{variance}}\ (\sigma^2)_{\text{ AOS(enjoyment)}} \neq \sigma^2_{\text{TOSRA(posttest)}}$

The purpose of this procedure was to establish a measure of continuity of student enjoyment of science for subsequent comparison with student attitudes towards learning texts. A two-tailed F test was used with test statistic $F = s^2_1/s^2_2$, critical regions defined as: F < or > F 1-α/2, N1-1, N2-1 and a significance level $\alpha = 0.05$. Testing revealed evidence to reject both null hypotheses as critical values H_{01} (.607) and H_{02} (.679) both fell outside the statistic's critical range (H_{01} / H_{02}: $F < .764$ or $F > 1.31$; H_{02}:

F < .764 or *F* > 1.31). These results further strengthen the apparent collinearity of the two measures of science enjoyment, suggesting that learning enjoyment operates as a consequence of multimedia text, independent of subject area interest. No variance comparisons were conducted for the other two AOS sub-scales as no assumptions of correlation between these scales was assumed.

As mentioned above, factor analysis was used to derive factor plots as an indicator of factor loadings, and factor scores for subsequent analysis of AOS and TOSRA data. In short, this testing was conducted to establish a measure of similarity between post-test TOSRA and AOS sub-scales, prior to establishing a proxy pre-intervention AOS enjoyment sub-scale for comparison with TOSRA data. TOSRA and AOS data were subjected to factor analysis using Maximum Likelihood factor extraction as a confirmatory analysis given the prior establishment of instrument validity and reliability.

Factors were rotated orthogonally and obliquely using varimax and promax rotation methods, respectively, to counter the expectation that TOSRA and AOS *enjoyment* scales would be correlated. All Kaiser-Meyer-Olkin (KMO) values for the individual items (> .90) were above .5 and the KMO measure was .715 suggesting that data was suitable for exploratory factor analysis should this be sought. A Bartlett's test of sphericity $\varkappa^2$ (6) = 306.26, *p* < .0001 indicated the presence of patterned relationships between items, and with an eigenvalue cut-off of 1.0, two factors (i.e AOS sub-scales and TOSRA data) emerged which explained a cumulative variance of 54.5%. As less than three factors emerged during analysis, a factor plot is appropriate in demonstrating factor loadings geometrically. Figure 5.3 shows rotated factors from the varimax rotation with Kaiser normalisation; no differences existed between orthogonal or oblique rotations.

While no further analysis was sought, the results of confirmatory analysis helped define the content of factors, as well as quantify the number of latent constructs. In qualitative extension of prior checks for validity and reliability, this analysis of variation amongst condensed items provided confidence that the AOS and TOSRA instruments discern between ostensibly similar constructs (i.e. general attitudes towards science scale - TOSRA, contrasted with enjoyment, understanding and importance of science attributable to science learning texts – AOS instrument. For more see Sections 4.5.2.2 and 4.5.2.6).

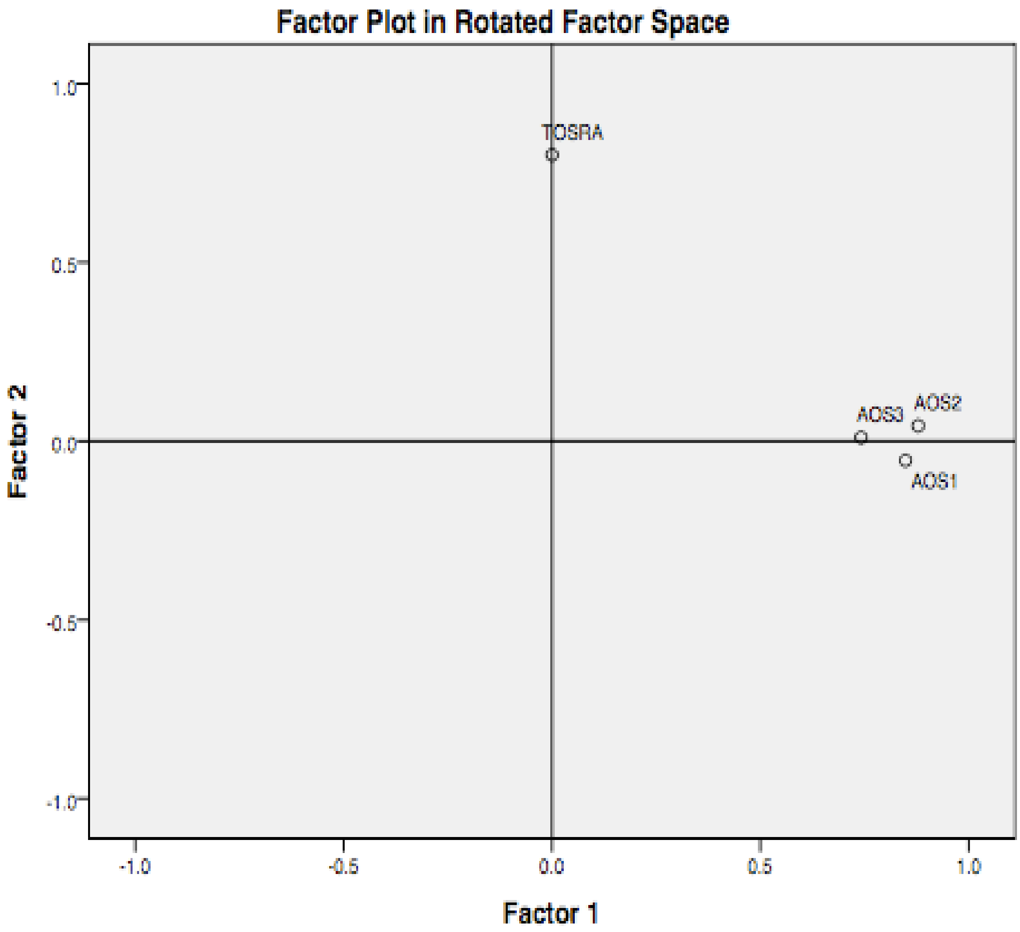

Figure 5.3 Factor plot showing two factors. (N.B. AOS sub-scales: AOS 1 - *science understanding;* AOS 2 - *science enjoyment; AOS 3 - importance of science* / TOSRA data) in rotated factor space (SPSS output)

Unlike factor loadings which represent the extent that a factor explains a variable, factor scores are estimates of factor values. As such, they can be used in subsequent analyses, including regression and comparison of means (Yong & Pearce, 2013). In this analysis, factor scores were saved as a variable in SPSS, and derived using both *Bartlett* and *Anderson-Rubin* methods. The desired use of factor scores in this instance was to compare pre- and post-test AOS *enjoyment of science* data to assess aptitudinal patterns across the intervention specific to the usage of multimedia text. Included for analysis were objective and subjective SES data to establish whether low SES students perceive greater learning benefits from multimodal learning texts than their high SES counterparts.

The *Bartlett method* uses a regression approach to produce unbiased scores which are correlated only with their own factor; *Anderson-Rubin* scores are uncorrelated and standardised. This distinction allowed for meaningful regression analysis and analysis of variance tests using factor scores while avoiding issues of multicollinearity (Skrondal & Laake, 2001). Following checks for linear relationships between independent and dependent variables and multivariate normality in the model, multiple linear regression analysis was performed. In brief, this procedure was undertaken to ascertain whether TOSRA data (science attitudes) reliably associates with AOS (perceptions of science learning material) post-test data.

The role of factor scores satisfied the need for a proxy measure of pre-test AOS scores within the model. Independent variables were jointly entered into the model, and the linear regression was found to explain 38.3% of data variance. In testing the linear regression F-test null hypothesis of no linear relationship, a highly significant result [F (2,213) = 24.844; p = <.0001] indicated that a linear relationship existed for TOSRA data and the AOS *enjoyment* scale. Similar results were seen for the AOS *understanding* scale: 27.5% of variance [F (2,213) = 8.608; p = <.0001], though not AOS *importance of science*: .008% of variance [F (2,213) = .187; p = .830] or either of the SES measures: Perceived SES .005% of variance [F (2,213) = .334; p = .574]; Objective SES .022% of variance [F (2,213) = .432; p = .78].

These results suggest that enjoyment is aligned with understanding of science, which as related constructs could be interpreted as a multimedia effect. This could also reflect elevated student interest coinciding with subject matter comprehension due to the effect of appropriately socialised text (see Section 3.8.2.2). Importance of science, by contrast, is likely to be more influenced by underlying attitudes towards science as a learning area, and less affected by design variates including multimedia principles. The lack of association with either measure of SES is also noteworthy given the significant relationship between subjective SES and science outcomes described in Section 5.2.2.

Finally, paired sample *t*-tests were used to check for significant differences between observed means of pre- and post-test AOS results using *Anderson-Rubin* factor scores as substitutes for AOS pre-test data. Analysis of variance was not conducted given the lack of a categorical independent variable in this case. Significant differences were seen between pre- and post-test AOS results: AOS *understanding* [t (213) = 77.29, p = <.0001]; AOS *enjoyment / interest* [t (214) = 69.59, p = <.0001]; AOS *importance* [t (214) = 80.12, p = <.0001]. No effect size (e.g. Cohen's d or partial eta-squared) could be calculated given that *Anderson-Rubin* scores are standardised scores. Estimation of AOS pre-intervention mean scores of *Anderson-Rubin* factor scores was performed by averaging standardised scores across grades. Table 5.3 shows *Anderson-Rubin* factor scores as proxy pre-intervention and actual post-intervention AOS sub-scale scores, alongside pre- / post-intervention mean TOSRA data.

In summary, two conclusions were reached inferentially from the constructs operationalised in the Affective Outcomes Scale (AOS) and Test of Science Related Attitudes (TOSRA) instruments: students engaged more with multimedia texts than regular texts (Ha5); and participants also engaged with multimedia texts disproportionately to their interest in science (Ha_6). The TOSRA is specific to enjoyment of science as a content area while the AOS presents its scales of understanding, enjoyment / interest, and importance of science as specific to student attitudes from use of intervention (i.e. modality-defined) texts. With no discernible pre / post differences existing in the subject-area measure, or between the AOS enjoyment scale and TOSRA, while appreciable pre / post differences exist in the modality-defined text measure (AOS), it was concluded that multimedia mediates not only attitudinal gains but also improved cognitive outcomes in terms of perceived understanding and importance of science. Finally, no effects of socioeconomic status were observed in regression analysis examining influences of student affect. This is surprising given the significant role subjective social status played as a cognitive influence in learning from multimedia text.

Table 5.3 Student affective data (TOSRA and AOS sub-scales)

Year	Scale	Pre-intervention mean (SD)	Post-intervention mean (SD)
7	AOS understanding	* 27.87	28.191 (5.76)
	AOS enjoyment / interest	* 30.01	30.288 (4.94)
	AOS importance	* 29.24	29.515 (4.85)
	TOSRA	28.245 (6.32)	28.191 (5.76)
8	AOS understanding	* 26.84	26.07 (4.52)
	AOS enjoyment / interest	* 26.90	25.94 (5.61)
	AOS importance	* 28.99	27.96 (5.99)
	TOSRA	29.54 (5.43)	30.29 (4.94)
9	AOS understanding	* 25.35	25.599 (4.74)
	AOS enjoyment / interest	* 25.17	25.47 (5.74)
	AOS importance	* 26.99	28.47 (4.63)
	TOSRA	28.18 (5.63)	29.515 (4.852)

* Pre-test estimate from standardised factor score (no SD)

5.4 Conceptual model: A synthesis of neuroscience theory and study findings

Research objective 4 sought to conflate the results described for research objectives 1 to 3 with aspects of neuroscience theory. As such, this research objective offers no specific hypotheses; instead, the research findings are related to the theoretical background that was developed in Chapter 2 and generalised as a conceptual model (Figure 5.4). This has the additional aim of revising other models of stimuli processing in the field of multimedia learning (reviewed in Section 2.3) and helps to complete the transition from conceptual framework to formalised interpretation of study results. Surveying the conceptual framework presented in the literature review indicates that stimuli processing occurs within integrated brain networks biased toward goal-directed behaviour in natural ecologies. Consequently, normal stimuli processing is characterised by embodied and supra-additive multimodal processing involving attentional, affective and cognitive functioning. The study results are concordant with these basic premises and highlight the relative contributions of socioeconomic status and cortico-cerebellar interactivity in effective learning. The following areas of discussion thus relate normal and abnormal processing to the results presented in Sections 5.2. and 5.3. Specifically, a recap of the integrated nature of passive and active processing (Section 5.4.1) precedes discussion of stimuli integration and student performance in cognitive-regulatory tasks involving multimodal learning texts. This latter analysis is dichotomised according to integrated (Section 5.4.2) and non-integrated textual (Section 5.4.3) processing.

5.4.1 Brain networks involved in stimuli processing.

Linear as well as supra-additive non-linear processing is observed in the same neural networks depending on the task-immediacy and relevance of observed stimuli. The passive (default) mode network (Buckner et al., 2008) that underpins embodied cognition (outlined in Section 2.5) thus forms the corticolimbic basis of passive as well as active information processing, respectively. As seen in Chapter 2, this network is defined by its perceptual, cognitive, homeostatic and behavioural roles and can be subdivided into its basic cognitive-regulatory, perceptual and affective components (c.f. Nelson et al., 2004). This simplified network is presented as graphic 'A' in the conceptual model (Figure 5.4). The nodes process social stimuli in a sequential manner (i.e. affective and cognitive processes are contingent on perception) though are assumed to interact as a distributed network. Accordingly, a social stimulus imbued with affective significance generates feedback from the affective network on the perception network for further perceptual processing.

Importantly, this network's structural integrity and the limitations of hippocampal, amygdala and prefrontal-dependent cognition, as outlined in Sections 2.5 and 2.6, are contingent on patterns of glucocorticoid expression and related inhibitory dysfunction. Given that a key mediator of glucocorticoid response is socioeconomic status (see for example, McEwen & Gianaros, 2010; Nusslock & Miller, 2016), the conceptual model in Figure 5.4 takes as an assumption the influence of individual development as indicative of impaired passive and active processing at both structural and functional levels of analysis. Meanwhile, Sections 2.3.2.2 and 2.6. detailed the role of joint cortical and cerebellar processes involved in formation of automated *internal models* linked with higher-order control. Accordingly, involvement of prefrontal-cerebellar and parietal-cerebellar processes hypothetically bridge the gap between passive and active processing and form the basis of learning differences between learners of differing social background.

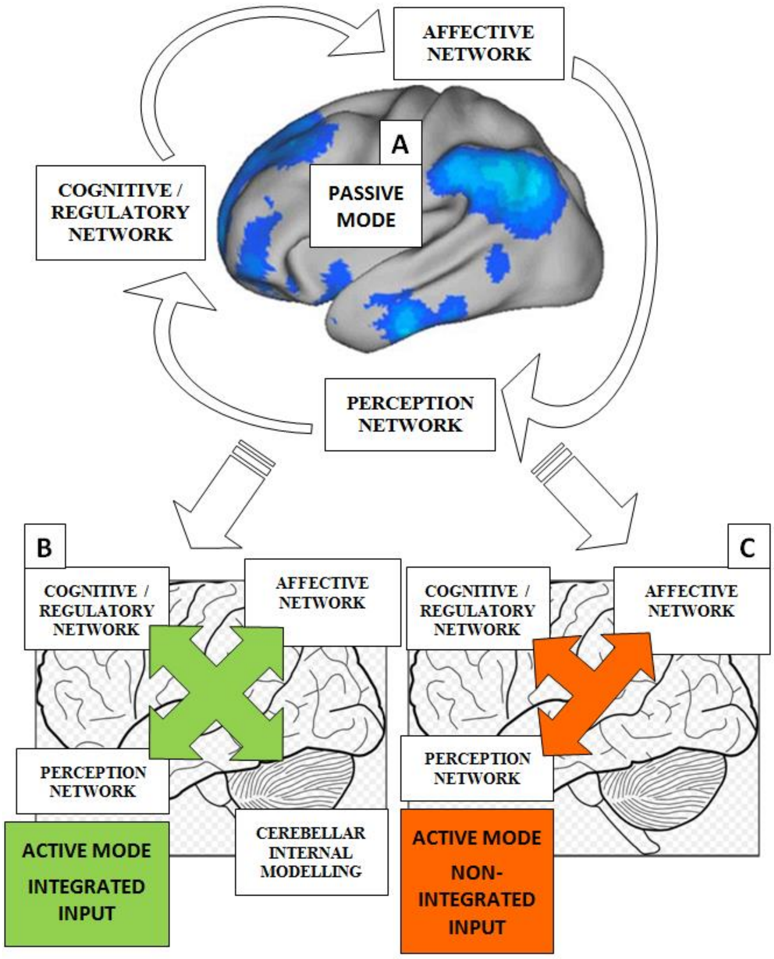

Figure 5.4 Conceptual model of normal and abnormal processing with and without stimuli integration

5.4.2 Integrated processing: Union of passive and active nodes

In the conceptual model, passive and active mode processes are distinguishable by inverse levels of activity during periods of rest compared with externally oriented cognitive tasks. In Figure 5.4, Graphic 'B' indicates normal active processing with integrated stimuli. As outlined in Section 2.5, the basis of active processing (i.e. normal learning) is a specific cooperation between the passive mode network and the cerebellum. Cognitive-regulatory, affective and perceptual networks involved in default 'resting' passive mode processes are suppressed during higher-order active mode control; subsequent processing within reciprocal cerebro-cerebellar regions involves duplication of working memory content as cortical ‘body’ and ‘motor’ schemas by the cerebellum.

This is necessary for model formation in the cerebellum and declarative off-line learning and emphasises the normal behavioural refinement mediated by intentionality and motor affordance encountered in ecologically realistic learning. Successful schema formation with integrated input involves iterative modification ('updating') of internal models with conscious awareness eventually disappearing following storage of efficient behaviours in motor cortex. In short, declarative learning culminates as the uncoupling of over-learnt sensorimotor procedural and semantic properties and their purposive application in voluntary learning.

Within the conceptual model, limited as it is to the analyses undertaken in the project, learning patterns are conceptualised in terms of two features. Learning gains for students of high socioeconomic status with socialised learning text are due to normal suppression of passive mode networks and cerebellar involvement in model formation. Integrated text model formation is facilitated by the normal interplay of dorsal ‘where’ and ventral ‘what’ streams in stimuli processing (Section 2.5). Meanwhile, with control text (i.e. non-integrated stimuli presentation), model formation in high SES students occurs via motor abstraction and simulation in the absence of pragmatic action opportunity representations. This occurs due to the higher level of abstractive ability afforded by typical, non-aberrant maturational patterns in higher SES individuals (Section 2.4.3). Conversely, learning gains for low socioeconomic students with either of the socialised texts, though not the *Bimodal Asocial* (BA) control text, are attributable to an overriding of passive mode network hyperactivity and / or dysfunctional cerebro-cerebellar connectivity (for details of individual neural development see Section 2.4.2). These inhibitory pathways represent an imbalance between cognitive-regulatory top-down processing and off-line mentalising and help explain the affective-reactive response to socialised stimuli of low SES students.

The conceptual model assumes subjective social standing as an appropriate measurement of socioeconomic status. Specifically, parsing SES by objective and perceived measures in the study design revealed the association of subjective social standing with cognitive outcomes, including recall, transfer and analysis and evaluation of science content. By extension, robust directionality in analysis emphasised the likely mechanisms of cerebro-cerebellar dysfunction in low SES learners mentioned above. Putatively, integrated learning text facilitates cerebellar internal modelling of content in learners self-identifying as low SES. In such learners, efficient PFC modelling of motor and body schemas is hypothetically enabled via the congruent 'narrative' of the multimodal graphic novel which grounds information to a derived social setting (Tabachnick, 2009).

In reference to suitably contextualised information (integrated input), the research findings suggest that social congruency overshadows effects of stimulus mode interaction and dominance in multimodal presentations. Within the conceptual model, integrated input (Figure 5.4, Graphic 'B') is defined according to ecological congruency in depicting the co-deployment and co-contextualisation of semiotic resources presented as a wide range of communicative sensory aspects. In reference to previous multimedia research on stimuli integration (surveyed in Sections 2.7.1 and 2.7.2), as neither auditory mode variant in socialised text (i.e. speech bubble compared with columnar text) better predicted learning in low SES students, 'integrated' input is presented simply as social integration of stimuli irrespective of auditory modality (see Appendix XX for a copy of researcher-developed texts used in this study). Indeed, it can be considered that multimodal perception emerges as a feature of its context rather than any dominant visual or auditory modality. Mechanistically, integrated stimuli approximate ecological congruency in audiovisual processing and align procedural representations of to-be-learnt material with 'on board' motor cortex behavioural models. Derived declarative knowledge is contingent on cerebro-cerebellar simulation of these situated behaviours and actions and when measuring output as successful recall and transfer of content, executive function in learners using integrated text involves the successful internal manipulation of these embodied functions and processes.

5.4.3 Non-integrated processing: Disrupted cognitive-regulatory processing

Graphic 'C' in Figure 5.4 highlights disrupted processing in the absence of integrated stimuli input. In this condition, non-integrated text fails to activate normal cerebro-cerebellar connectivity and non-linear memory processing. As supported by the study findings, implications of non-integrated text for learning are contingent on individual SES differences and relate to disrupted cerebro-cerebellar model formation and the influence of affective network processes. In the conceptual model, disrupted model formation thus prioritises affective network dysfunction as a primary mediator with flow-on effects for perceptual and cognitive-regulatory networks. As mentioned earlier, a directional sequence of stimuli processing occurs between the perceptual, affective and cognitive-regulatory networks. Nonetheless, this directionality is interactive, in that a social stimulus imbued with affective significance will elicit feedback back to the perceptual network for further affective and cognitive-regulatory processing. Importantly, in normal learning with integrated audiovisual input, cortico-limbic 'executive' processes assert strategic control over other passive mode brain regions and involve cerebellar modelling in memory consolidation. By contrast, incongruent stimuli leave the learner susceptible to affective network influence in the integration of external and internal stimuli as an influence of individual experience and perception. Self-referential mentalising (see for example, Amodio & Frith, 2006) in the affective network attributes meaning to personal experience, which in the case of low SES students broadly equates science as a content area with negative affect. This affective- / perceptual-cognitive imbalance was seen in the study results in the experimental contrasting of students' perceptions of integrated science learning text and enjoyment of science as a learning area. As seen, integrated learning text was associated with perceived science understanding, enjoyment and importance despite (a) low SES student understanding with non-integrated text, and (b) consistently poor low SES student attitudes towards science as a learning area.

The affective system underlies embodied cognition as it mirrors the observed actions and intentions of social entities and generates the basis of action understanding (Wang et al., 2017). As discussed, this brain network develops early in childhood and influences cognition as a result of environmental influences in its developmental trajectory. With low SES learners, affective system dysfunction (see Section 2.4.3 for discussion of amygdala inhibitory / excitatory regulation of hippocampus and prefrontal cortex) presents as hyperactivity of passive mode brain networks with a physiology manifesting in threat detection and preparative energy regulation. When considering cognitive outcomes within the study, these functional observations equate to impaired action understanding when learning involves non-socialised text; attitudinal findings, correspondingly, emphasise the low engagement of low SES students with such text. Learning for low SES students in this context fails to generate normal interactions between perceptual, affective and cognitive-regulatory networks; affective network hyperactivity also poses a likely inhibitory factor. Within the constraints on the currently described research design, the normal sequence of procedural-declarative knowledge generation is thus delayed by a lack of motivationally relevant signals and stimuli incongruency is further compounded in processing by possible cerebro-cerebellar disconnectivity and / or hyperactivity in resting state affective mode processes. In sum, within the context of the currently described conceptual model, low SES learners are likely to lack the cognitive resources necessary to disengage passive state processing and employ normal cerebro-cerebellar model formation with non-integrated text. This may manifest behaviorally as low interest in science as a learning area; though, as discussed in Section 5.4.4.2, low engagement can be reversed with appropriately designed learning text.

5.5 Chapter summary

This section summarises the results of the study as detailed in this chapter. In so doing, key findings are organised according to the research objectives and related study hypotheses; summaries of research objectives 1-4 are thus presented sequentially as Sections 5.5.1 – 5.5.4.

5.5.1 Research objective 1

Research objective 1 asked:

> *How does the degree of textual modality affect retention of content in learners differentiated by social standing?*

Related research hypotheses were:

- **H_a1:** Students will retain more information from multimodal learning texts.
- **H_a4:** Students will benefit from the highest degree of visual-verbal integration (MS text type).

Research objective 1 sought descriptive and inferential accounts of the effect of textual visual-verbal modality on retention of science content in socioeconomic-differentiated middle school students. In initial analysis, prior to inclusion of objective and subjective socioeconomic status as study covariates, the hypothesised benefits of multimodal learning text for enhanced learning across the student body was observed with use of multimedia texts in both variants, *Multimodal Social* (MS) and *Bimodal Social* (BS). Observed cognitive gains satisfied acceptance of research hypothesis 1 as student improvements occurred with both variants of multimedia intervention texts and were inclusive of each grade level. Also, notwithstanding the unexpected variance in grade 7 science achievement, cognitive gains in retention and recall map well to the assumptions of block homogeneity established in Chapter 4 (Sections 4.4.3.2 and 4.7). This preliminary finding supports the use of multimodal text in science learning, irrespective of personal factors including social standing as well as design factors such as distinctions in auditory mode. Meanwhile, study hypothesis 4, itself closely associated with study hypothesis 1, conflates the degree of visual-verbal integration to cognitive / memory processing. Greatest retention and transfer of science content was predicted for the *Multimodal Social* (MS) text which presents the highest degree of social congruence and salient multimodality. Nonetheless, enhanced recall and transfer of science content appears less sensitive to auditory mode (i.e. relating to the 'aural proxy' mode of *Multimodal Social* [MS] text versus the 'linguistic mode' of *Bimodal Social* [BS] text) than to multimodality per se as evidenced with the apparent superiority of *Bimodal Social* (BS) text in two grade levels (grades 8 and 9 - Figure 5.1). Given the hypothesised multimodal congruency and saliency benefits of the *Multimodal Social* (MS) text, the apparent equivalency of MS / BS text for learning is unexpected though interpretable in light of cross-modality in multimodal audiovisual processing (Section 2.6 provides details of neural mechanisms in processing congruent and incongruent audiovisual presentations). In sum, study hypothesis 4 (H_a4), that students will benefit from the highest degree of visual-verbal integration, is accepted with reservations surrounding the appropriate definition and representation of auditory mode in learning text design.

5.5.2 Research objective 2

Research objective 2 sought to:

> *Explore whether objective and subjective accounts of social standing covary with retention of content.*

The related research hypotheses were:

- **H_a2:** Subjective SES will be associated with enhanced learning from multimodal learning texts.
- **H_a3:** Low SES students will exhibit greater learning from multimodal learning texts than high SES students.

Research hypothesis 2 aimed to examine the association of subjective socioeconomic status and student cognitive gains from use of multimodal learning text. Research hypothesis 3, meanwhile, sought to discern the relative benefit of multimedia learning text, appropriately socialised, for low SES students. Following the decision to remove objective SES from the factorial design due to its lack of predictive impact on the response variable of science learning, only subjective SES remained as a covariate. This appears to confirm research hypothesis 2 given that objective SES failed to significantly correlate with the dependent variables. It also strengthens the hypothesised benefits of multimedia text per se when viewing the consistency and directionality of MANOVA and MANCOVA effects (i.e. text type / science outcomes before and after covariate inclusion). In analysis of SES as a predictor of cognitive outcomes, subjective social standing effectively reduced noise between each dependent variable with enhanced student learning in the cognitive domains of science achievement, knowledge and understanding and application of science content. Student gains, moreover, were observed for post-test *Analysis / Evaluation* results, which represented a finding otherwise undetected in analysis prior to inclusion of subjective SES as a study covariate. In conclusion, modelling subjective SES helped control extraneous variance and highlights the association of subjective social standing with multimodal text and enhanced science retention and recall in middle school students.

5.5.3 Research objective 3

Research objective 3 aimed:

> *To investigate how student-held attitudes toward science and science learning materials differ based on degree of textual visual and verbal modality integration.*

The related research hypotheses were:

- **H_a5:** Multimodal texts are perceived as more engaging than regular learning text.
- **H_a6:** Multimodal texts will enhance student enjoyment of the subject area.
- **H_a7:** Low SES students will perceive greater learning benefits from multimodal learning texts than high SES students.

Research objective three sought to measure student attitudinal data relating to science as a learning area as well as science learning materials. As described in Section 6.2.2, this was considered essential as while multimodal text could be associated with enhanced science learning, such text may facilitate learning as a result of greater engagement with text type rather than the subject area itself. Indeed, from analysis of perceptual data, it is suggested that multimedia texts may enhance learner enjoyment and understanding, though not subject-area interest.

From initial analysis of enjoyment of science, no significant between or within-group differences were observed in pre- or post-test Test of Science Related Attitudes (TOSRA) data. Additionally, prior to linear regression analysis, no differences existed between the Affective Outcomes Scale (*AOS*) *enjoyment* scale and TOSRA post-test. The latter finding was expected, though the former was evidence for limited student enjoyment of science as a subject area regardless of text-type. Also expected was the finding from multiple regression analysis that TOSRA data share a linear association with AOS *enjoyment*; however, the strong correlation between TOSRA *enjoyment of science* and AOS *understanding* initially appears to upset the general trend of low learner interest. It is noted, moreover, that the discordant association of multimedia text between (a) learner enjoyment and understanding and (b) the perceived importance of science, appears to operate independently of student social background. Taken together, this suggests confirmation of research hypothesis 5 though rejection of research hypothesis 6. The findings also colour interpretation of research hypothesis 7 which holds that low SES learners will disproportionately engage with multimedia learning texts and perceive enhanced learning benefits from such text. As related analyses showed improvement in perceived learning across each Affective Outcomes Scale (*AOS*) scale, with AOS *enjoyment* and *understanding* strongly correlated with TOSRA data, the conclusion is drawn that multimedia itself generates learner interest and learning outcomes separately from the content being presented and separate of socioeconomic status. In conclusion, research hypothesis 7 is rejected and it is suggested that attitudinal gains from use of multimedia learning materials are enhanced irrespective of social background.

5.5.4 Research objective 4

Research objective 4 aimed:

> *To present a model of cognitive architecture consistent with the study results and existing neurological literature.*

Research objective 4 was presented a posteriori in deduction of a conceptual model consistent with neuroscience theory and the study results presented in Sections 5.2 and 5.3. In line with research objectives 1 and 2, the conceptual model (Figure 5.4) is primarily focused on multimodal stimuli processing for SES-differentiated middle school students. In incorporating research objective 3, the conceptual model also involves student attitudinal findings in the attempt to build a holistic view of multimedia learning. Implications for multimedia learning are captured by the conceptual model in the interaction between passive (default) mode and active mode brain networks and their relationship to internal model formation and declarative learning. In learning from non-integrated stimuli in paper text, low SES learners appear to lack the cognitive resources to override passive mode hyperactivity and / or benefit from cerebro-cerebellar integration in the absence of congruent textual features. Conversely, positive feedback between the affective and perceptual / cognitive-regulatory networks appears to be supra-additive in that low SES learners engage more with socialised stimuli, regardless of personal feelings towards the subject. Learning gains in the latter condition are explained in the conceptual model in terms of efficient cerebro-cerebellar internal model building and simulation of internal models in subsequent learning. As such, these processes are described in the conceptual model as a consequence of cortico-cerebellar integration and mirror basic procedural-declarative learning processes. When examining high SES students, for whom learning gains did not differ significantly between control and experimental texts used in the study, learning gains in socialised text is explained as for low SES students – i.e. in suppression of passive mode networks. The additional assumption of non-aberrant abstractive ability in high SES learners helps explain learning gains for this group with non-integrated (i.e. control) text. Taken together, the conceptual model positions SES as a central contextual variable in multimedia research and prioritises socialised text for efficient learning.

The following chapter further discusses these experimental findings and presents conclusions for the field of multimedia learning.

Chapter 6

DISCUSSION AND CONCLUSIONS

6.1 Introduction

This study investigated the suitable design of science learning materials as a multimedia learning research project. The study involved 214 middle school students within a quasi-experimental design; as outlined in Chapter 4 (Section 4.3), cognitive and attitudinal outcomes associated with textual design were assessed using ten intact groups of science students in a cluster randomised trial lasting for one school term. Also, socioeconomic status was included in both objective and subjective forms to better understand the relationship between multimedia text design and student socioemotional processing and cognition. In this chapter, the findings from Chapter 5 are summarised and discussed; to situate the findings within the field of multimedia learning, conclusions relating to each of the research objectives are integrated with existing multimedia research (Section 6.2). Theoretical and practical implications of the research for multimedia learning and educational practice are then outlined in Section 6.3 where specific administrative, design and pedagogical recommendations are identified. Additionally, limitations of the research are discussed (Section 6.4) and a summary of recommendations is provided (Section 6.5). Finally, significance of the study is given (Sections 6.6) and future research directions are outlined in the concluding remarks (Section 6.7).

6.2 Summary and Discussion of Major Findings

The following section outlines study findings and juxtaposes them against developments within the multimedia learning literature. In so doing, an evaluative account is provided to contextually ground, and theoretically relate, the findings to established principles of multimedia learning. Study findings are categorised according to research objectives (see Section 1.4.1) and related hypotheses. As such, Section 6.2.1 describes key findings for research objectives 1 and 2, while Sections 6.2.2 and 6.2.3 present key findings for research objectives 3 and 4, respectively.

6.2.1 Research Objectives 1 and 2

Research objective 1 sought to examine how textual modality would affect retention of science content for middle school learners. Textual modality was defined in the study as either socialised or non-socialised in its display and integration of linguistic and graphical depictions. To this end, key assumptions guiding the effectiveness of learning text design in promoting the recall and transfer of scientific content was multisensory congruency and the attribution of animacy to science content. Socialised text, in this regard, included personalisation and personification of textual elements and presented to-be-learnt concepts within social contexts. In the design of intervention texts, socialised text thus aimed to present learners with scientific concepts and content constructed to represent real world settings. From review of the literature on accompanying text in multimodal presentations, including eye-tracking study, it was considered that a graphic novel format would best suit these design requirements and, hence, suit the study. Non-socialised text, by contrast, was conceptualised as an incongruent presentation of pictorial and verbal information. Following the definition of congruence offered above, non-socialised text was one which presented words and pictures in contextual isolation i.e. devoid of deliberate multimodality. Within the study, the regular science textbook used at the site represented a suitably incongruent display of audiovisual features, and thus acted as the control text.

Socialised text, moreover, was designed to represent a continuum between ‘full’ and ‘intermediate’ socialised formats. Addressing the ‘full socialisation’ of text, Multimodal Social (*MS*) text, was designed by the researcher to mimic a graphic novel format and presented auditory stimuli as speech bubbles; meanwhile, the Bimodal Social (*BS*) text used the same visual referents as the *MS* design though presented accompanying text in columnar format. Hypothetically, the socialised text variants corresponded to a differentiated auditory mode: congruent auditory components in the *MS* text were ‘multimodal’ as they were socially congruent (i.e. received and processed in an ‘expected’ integrated manner) while the *BS* text was ‘bimodal’ as it presented auditory stimuli separate to their corresponding visual elements. Relative to the *MS* text, stimuli processing in this condition was hypothesised to present a potentially unexpected ‘splitting’ of audiovisual modality like that of asocial text.

Research objective 2, in turn, sought to better understand the connection between student social standing and science learning. Here, hypothesised associations between multimodality in textual design and retention of science content for learners, differentiated by socioeconomic status were tested. The study design involved separate measures of social standing; this involved collection of objective SES data as aggregated family survey scores including educational, occupational and financial measures as well as a subjective measure gained directly from students. The latter measure involved two self-anchoring scales of perceived social standing and was included to provide a richer measure of SES in response to research examining subjective social standing as a causal factor in social epidemiology, including variations in cognitive development.

Research hypotheses relating to Research Objectives 1 and 2 were:

- H_a1: Students will retain more information from multimodal learning texts.
- H_a2: Students will benefit from the highest degree of visual-verbal integration (i.e. multimodal social (*MS*) text type).
- H_a3: Low SES students will exhibit greater learning from multimodal learning texts than high SES students.
- H_a4: Subjective SES will be associated with enhanced learning from multimodal learning texts.

A summation of the results presented in Chapter 5 concerning Research Objectives 1 and 2 are presented according to the relevant research hypotheses:

a) Socialised multimodal text enhances subject-area cognitive outcomes (H_a1);
b) Auditory mode may be less important than social congruence in learning texts (H_a2); and
c) Subjective socioeconomic status covaries with student learning (H_a3; H_a4).

A brief extension of these summary points precedes further discussion.

- Socialised multimodal text enhances subject-area cognitive outcomes (H_a1)

  - The study results showed a pattern of higher achievement for socialised intervention text in both conditions (i.e. for Multimodal Social [*MS*] and Bimodal Social [*BS*] text variants) when compared with asocial control text (i.e. the Bimodal Asocial [*BA*] text variant).
  - The observation of improved science raw scores across each grade, albeit with marginally higher error variance for grade 7 students relative to grades 8 and 9, suggested acceptance of research hypothesis 1.
  - The effect of socialised text on learning appeared to be limited to cognitive gains in the domains of science knowledge / understanding and application of science content only, without similar improvements in analysis and evaluation. In short, this satisfied the assumption that socialised text would benefit learners in recall and transfer, though as seen, cognitive improvements were not evident for higher order cognitive demands.

In sum, multimodal learning texts enhanced science learning in this study. Cognitive gains were similar for the two researcher-developed texts (i.e. Multimodal Social [*MS*] and Bimodal Social [*BS*] texts) and included significant gains for students in the cognitive domains of knowledge / understanding and application, though not analysis and evaluation.

- Auditory mode may be less important than social congruence in learning texts (Ha2)
  - Prior to modelling social status as a covariate in MANCOVA analysis, learning gains were approximately equal across both variants of socialised text (i.e. Multimodal Social [*MS*] and bimodal social [*BS*] texts) which differed only in auditory mode. This raised questions regarding the nature of auditory mode dominance.
  - Following the inclusion of social status as a covariate in MANCOVA analysis (described for H_a3; H_a4 below), cognitive gains were seen for the *MS* text in analysis and evaluation without similar gains for the *BS* text. Nonetheless, questions of auditory mode dominance persisted given the lack of correspondingly significant differences in ‘lower order’

cognitive gains (i.e. knowledge / understanding and analysis cognitive domains) for the *MS* text relative to the *BS* text.

Analysis of research hypothesis 2 suggests that in contrast with established multimedia principles, textual multimodality appears to moderate learning due to social congruency rather than any inherent effect of auditory modality. This effect may disappear, however, for higher order cognitive domains that involve evaluation and reasoning of science concepts. To enhance higher order reasoning, in other words, it may be necessary to fully integrate auditory and visual elements of learning texts.

- Subjective socioeconomic status covaries with student learning (H_a3; H_a4)
    - The beneficial learning effect of socialised text survived inclusion of socioeconomic status in MANCOVA analysis where the modelling of subjective social standing strengthened the association between science cognitive outcomes and socialised text for both text variants (i.e. Multimodal Social [*MS*] and bimodal social [*BS*] texts).
    - Objective SES, meanwhile, was removed as a study variable following its failure to satisfy essential assumptions within preliminary MANCOVA analysis.
    - In multivariate analysis, subjective SES not only emphasised the positive association between text design and improved recall and transfer of science content (i.e. gains in knowledge / understanding and application questions) but also included improvements for students in the analysis and evaluation of science content.
    - Dissimilar to preliminary ANOVA analysis (discussed in relation to H_a2 above), the *MS* text was solely associated with improvements in the analysis and evaluation of science content in MANCOVA, thus reinforcing subjective SES as a significant predictor of cognitive outcomes in multimedia learning.
    - Modelling subjective social standing as a covariate in MANCOVA also indicated that low SES learners benefited the most from use of socialised learning text. Cognitive gains for such learners included recall and transfer of science content across each cognitive domain tested.

In summary, multimodal text is predictive of enhanced learning across the socioeconomic gradient. Additionally, while multimodal socialised text benefitted learners irrespective of social background, socialised text disproportionately benefitted learners who position themselves lowest in social rank.

These results present both corroboratory and conflicting findings within multimedia learning research (see for example, Gegenfurtner et al., 2011; Reinwein, 2012; Richter et al., 2015). In analysis, the current findings are contextualised according to cognitive theory of multimedia learning (CTML) principles and learning effects given the centrality of this research paradigm in the field of multimedia learning. With relevance to the current findings, CTML research is typified by cognitive science precepts and derived principles of instructional design (see Section 3.2.2). Three such design principles which frame multimedia learning research theory and colour CTML findings are the modality, spatial and temporal contiguity principles (see for example, Schuler et al., 2012). A fourth principle, the multimedia principle, is generative of, and umbrellas, these and other core principles (see Section 2.4.2). As seen, the results presented in Chapter 4 accord with reported findings of the efficacy of the multimedia principle in promoting learning and are consistent with other surveyed research (see Section 3.2.2). Nonetheless, the study results contradict reported findings for the modality and spatial / temporal contiguity principles. These findings are elaborated on further below where the cognitive architecture of CTML is critiqued for its reliance on separate streams of processing.

The results in the current study accord with research findings examining the multimedia principle (e.g. Mayer & Moreno, 2003; Mayer & Johnson, 2008; Sorden, 2005). Here, consistency with multimedia research examining the utility of concurrent versus serial presentation of visual-verbal stimuli is seen in the enhanced recall and transfer of science content for learners presented with text and accompanying images. Such a result is unsurprising, though, given the task-immediacy and relevance of congruently presented audio-visual stimuli (see conceptual model, Section 5.4). Correspondingly, at this level of analysis, dual coding theory is perhaps adequate in explaining learning gains from combining text with visual referents (although c.f. Stanovich, 2009, p. 55). Nonetheless, from further analysis of research objectives 1 and 2, mechanistic shortcomings of dual coding theory can be theorised from research inconsistencies in the modality and temporal / spatial contiguity principles. With respect to the modality principle, CTML theory holds that cognitive processes are enhanced when new information is presented as audio narration rather than via on-screen text (Hasler et al., 2007). This assumption is undermined in the current study by the demonstration of enhanced learning occurring as a result of stimuli integration with static text. Correspondingly, limiting the pace of learning to student-paced learning, as a methodological consequence of static learning text, further erodes confidence in CTML's explanation of spatial and temporal contiguity effects in learning. In short, the results reported in this thesis bring into question the assumed auditory dominance of narration (see Ginns, 2005; Mayer 2001, 2005b; although c.f. Schuler et al., 2011) and highlight the importance of defining spatial contiguity as a feature of socialised multimedia text.

The demonstration that auditory mode distinctions appear to be less important for learning than social congruence, with respect to text design, could cast doubt of the nature of the CTML cognitive architecture as regards stimuli processing (see Sweller et al., 1998). The results reported in this thesis, alongside those of Schueler et al. (2008) and others using static learning resources in multimedia format (see for example, Mayer, 1989; Mayer & Gallini, 1990; Mayer et al., 1996) suggest that a more accurate picture of cognition might involve perceptual and memory processes that are attenuated by stimuli congruency rather than dominance in any given modality. The assumption of auditory dominance, nonetheless, underlies the Modality Principle within CTML (see Section 2.4.2) and follows from the assumption of visual and auditory sub-system processing (Baddeley, 1986, 1999; Chandler & Sweller, 1991) and the assumed enhancement of cognitive resources with audio narration (Schueler et al., 2008). Regardless, these fundamental assumptions of CTML would appear to be questionable following the observation of enhanced learning in research involving integrated audio-visual content presented in paper-based texts or when auditory text accompanies visual graphics at user pace. Such discrepancies have been described both in the current research as well as the multimedia literature (see Sections 2.4.1 and 2.4.2). For example, Schueler et al.'s (2008) findings indicate that system-paced presentations emphasise spatial, though not temporal, incongruence in system-paced presentations. As described in Section 2.4, learning gains in that study were equivalent for learners presented with information in either auditory or visual form, provided that verbal and non-verbal information was processed simultaneously. The authors caution that, despite the typical utilisation of technological innovations such as computer-assisted learning (CAL) in research related to CTML (see for example, Crooks et al., 2012 and Kalyuga, 2005b), auditory text presents no advantage to visual text when the learner is free to control the lesson pace. Also notable is Reinwein's (2012) finding that, alongside lesson pacing and learner age, a 'picture realistic' visualization condition was superior to either 'static' or 'decorative' pictures in promoting learning. Controlling these variables also significantly reduced effect size estimates as reported in previous Modality Principle research. Adding weight to the importance of photo-realism was Gegenfurtner et al.'s (2011) eye-tracking meta-review where expert–novice differences were smaller for photo-realistic than for schematic visualisations. These findings are significant as modality principle research relates to stimuli modality and not the type of presented visualization. The current findings parallel these developments and strengthen the notion of socialised texts eliciting positive learning; they also hold implications for a redefinition of the Modality Principle, on the basis of socialised stimuli congruency.

Discrepancies in Multimedia Research results also emphasise the importance of spatial congruence relative to its temporal analogue. This finding, relevant to research hypothesis 2 in terms of visual-verbal integration, mainly relates to inconsistencies in the results of studies that have examined static versus dynamic multimedia presentations and where lesson pacing is modified. Specifically, learner-paced presentations often present significant spatial contiguity effects where learning involves non-static learning texts and vice versa (e.g. Moreno & Mayer, 2002; Hegarty, 2004; Schroeder & Cenkci, 2018) and where spatial contiguity has been moderated as a design feature to include variations in (relative) timing of auditory and visual components of text (e.g. Florax & Ploetzner, 2010; Kalyuga, 2005b, Mayer et al., 1995). Nonetheless, research also reveals that positive learning accompanies narrated text and animation / graphics in either paper-based or computer assisted learning conditions (Mayer et al., 2003; Moreno & Mayer, 1999). In common with the commentary above, though, no studies demonstrate consistent learning gains for system-paced presentations regardless of variations in spatial contiguity. Of importance, also, is the observation that no such equivalence is reported in studies with temporal contiguity measured as either a primary or secondary learning effect (e.g.

Brünken et al., 2004; Gyselinck et al., 2008; Rummer et al., 2010). This is of relevance as such studies reveal that learners perform equally well in recall and transfer tasks regardless of auditory modality provided that spatial contiguity (i.e. audiovisual congruency) is maintained.

In consideration of the above, the findings reported in this thesis help to confirm the relevance of the multimedia effect (that is, positive learning accompanies material presented as text and pictures) whilst also identify a crucial splitting of attention present within incongruous multimedia displays. Unlike traditional research related to multimedia learning, the findings reported in this thesis involved a splitting of attention that was operationalised in text design rather than a feature of distinct aural or visual modes or their relative timing in presentation. That is, as a feature of socialised audiovisual alignment. This finding, and its theoretical implication, is discussed further in Section 6.3.1 in the context of modal redundancy and holistic stimuli integration.

In addition to socialised text, socioeconomic status (SES) was identified in the study as an important variable in learning. Nonetheless, SES, whether objectively or subjectively defined, has not featured in multimedia research as a primary influence variable (see Sections 4.5.1.1 and 4.5.1.2 for further details). This omission is consistent with a view, within the field, of cognitive development as a broadly linear process (see for example, Reed, 2006; Sorden, 2012). Indeed, cognitive development and learning appear to be considered in multimedia research as occurring in tandem; correspondingly, content knowledge is acquired and stored as schema with increasing sophistication (c.f. Piaget, 1936, 1957). Long-term memory, accordingly, differs between individuals on the basis of referential and associational links between schema (see Section 2.3.2.1). Perhaps due to this prioritisation of distinctions, including prior knowledge and level of expertise which are theoretically amendable by experience on the part of the learner, reviewed studies did not involve individual determinants such as SES or other environmental influences on cognitive development. Thus, situating the current study within multimedia learning research is limited to analysis of socioeconomic status as a secondary influence variable or as an influence in hypothesised boundary conditions.

In examination of established multimedia effects, narrative and systemic reviews reveal the tendency of research related to CTML to prioritise design variates while downplaying learner characteristics. This trend persists even when facing theoretical and methodological discrepancies. For example, Reinwein (2012) expressed doubt on the notion of working memory resources as a basis of the modality effect and elicited specific moderator effects in place of dual coding accounts of stimuli processing. This followed his correction of Ginns' (2005) overall mean effect size in *modality principle* meta-analysis from d = .72 to d = .2, a discrepancy which highlights the likely contribution of developmental factors such as socioeconomic status in stimuli processing. Nonetheless, in explication, Reinwein (2012) invoked design variates such as system pacing despite acknowledging the importance of learner characteristics, including the role of SES, as moderators of learning. Moreover, where learner characteristics are used in secondary analysis, it is noted that such studies arbitrarily demarcate learner characteristics including that of novice / expertise gradients (e.g. Korbach et al., 2016; Rey & Buchwald, 2011; Seufert et al., 2009) despite the threat that such distinctions could inadvertently operationalise socioeconomic status. Corresponding to the likelihood of unexpected SES influences, in meta-analysis of reported spatial and temporal contiguity effects, Ginns (2006) found that novice learners stood to gain significant improvements in learning upon spatial and temporal integration of textual elements. This effect, as discussed above, is nonetheless reversed when presentations are user- versus system-paced. Additionally, Mayer (2010) describes the *expert reversal* effect and *complexity* and *pacing* conditions, where learning gains are highest for 'low-knowledge' learners. As described in Section 2.4.2, this is explained in cognitive load theory (CLT) terms as a germane cognitive load for a novice representing an unintended extraneous cognitive load for an expert (Paas et al., 2004). However, given the immutability of temporal contiguity (discussed above) and the possibility that 'novice' status may reflect low socioeconomic status, this effect may better represent the influence of individual development including SES.

The results described in this thesis help to establish the role of subjective social status in educational research. This is despite its more typical use as a study variable in health research, such as the ongoing longitudinal Whitehall II study (Marmot et al., 1991). Specifically, modelling subjective SES strengthened the predictive role of social standing in the determination of successful learning using multimodal text and offers methodological and theoretical refinements for further research. To this end, it extends the notion of subjectivity beyond social standing to a consideration of the situated perspective of the learner more generally. By way of example, Construal Level Theory (e.g. Trope & Liberman, 2010) has been used to understand the interaction of students and the physical learning environment in multimedia learning (e.g. Paas et al., 2014). Here, psychological construals are theorised as reflective of spatial, temporal and social distance. In terms of the learner, the smaller the distance between the learner and the object of thought, the more concretely to-be-learnt material will be considered. The current study builds on this premise via analysis of social and affective distance as features of socialized text in graphic novel format. Methodologically, the study also builds on work such as Braveman et al. (2011) in eliciting sociobiological determinants of learning by providing an accurate approximation of social standing afforded by student self-referential social positioning. Utilizing a self-anchoring scale of subjective social standing possibly corresponds to a smaller 'distance' between the survey question/s and intended SES construct. By contrast, while CLT and CTML research has also considered the effect of learner 'distance' this has been limited to design or task variate status. In CLT, considerations of spatial arrangement have prompted amendment to physical learning spaces (e.g. Choi et al., 2014) while considerations of social distance have been addressed in CTML research via the effect of 'personal address' (e.g. Beege et al., 2017) and self-led study (e.g. Karalis & Vorvilas, 2011). In all reviewed studies, cognitive outcomes were enhanced where 'distance' between the learner and the instructor or learning material is reduced (e.g. Henderson et al., 2011; Snefjella & Kuperman, 2015). The implications of appropriately socialised multimedia and including subjective SES as a multimedia design variate are taken up again in Sections 6.3.2 and 6.3.3 respectively.

6.2.2 Research Objective 3

Research objective 3 sought to measure student-held attitudes towards science learning materials, defined, as for research objective 1, in terms of multimodality and social realism. Lacking an existing survey instrument capable of assessing student feelings towards regular and socialised text of the kind explored in this thesis, a novel instrument, the Affective Outcome Scale (AOS) was developed by the researcher. In addition to gaining a measure of student engagement with multimodal text compared with regular text, the AOS instrument was designed to differentiate students based on social standing. As a multidimensional tool, the survey constructs of science enjoyment, understanding and importance thus required equal and consistent focus on text type as well as the hypothesised associations between socioeconomic status (SES) and abstractive ability. These associations, as outlined in other areas of the thesis (see Sections 2.7 and 2.7.2), assumed a greater abstractive ability in learners with increasing SES due to the greater opportunities in such individuals for prolonged frontal and language development. In high SES students, the corresponding social, cognitive and neurobiological refinement was posited to translate behaviourally within an aptitudinal orientation in favour of science and / or traditional learning texts. While it is recognised that aptitude does not necessarily associate longitudinally with attitude or achievement in science education (see for example, Potvin & Hasni, 2014) a greater tolerance for traditional learning text was assumed for such learners irrespective of personal feelings towards the subject. Conversely, lower ranked SES learners were assumed to hold unfavourable affective and motivational dispositions towards science, a bias that could manifest in an aversion to traditional science texts and a corresponding preference for graphic novel style learning materials.

In addition, student attitudes towards science as a learning area were gained in order to better determine the utility of multimedia text in subject areas for which students lack an aptitude or motivation to learn from. As detailed in Section 5.3, the rationale for including a subject-area attitudinal measure alongside a design-oriented measure was motivated by the absence of corresponding measures in research programs as reported in the multimedia learning literature. As described in Section 3.8.1, a systematic review of the field revealed that affective orientations rarely feature as primary variables in research, and when attitudinal information from learners is sought, it typically relates to design features and not the content area being taught. Such omissions limit research findings given the possibility of overlooking interactions between a given treatment and the full range of attitudinal or aptitudinal data available.

Research hypotheses relating to Research Objective 3 were:

- H_a5: Multimodal texts are perceived as more engaging than regular learning text.
- H_a6: Multimodal texts will enhance student enjoyment of the subject area.
- H_a7: Low SES students will perceive greater learning benefits from multimodal learning texts than high SES students.

The analyses as presented in Chapter 5 relating to Research Objective 3, and the above hypotheses, are summarised as follows:

a) Multimodal text is perceived as more engaging than regular learning text (H_a5);
b) Multimodal text is associated with cognitive gains though does not facilitate greater student interest in science as a subject area (H_a6); and
c) Graphic novels are not disproportionately beneficial for low SES students (H_a7).

A brief extension of these summary points is given prior to further commentary.

- *Multimodal text is perceived as more engaging than regular learning text (H_a5)*
    - Factor and regression analysis revealed that the AOS and TOSRA instruments reliably discerned between measurement of science attitudes relating to text design versus science as a subject area, respectively, and that subject area attitudes did not vary significantly over the course of the intervention.
    - Meanwhile, with exposure to multimedia text during the intervention phases, attitudes towards multimedia text improved significantly though only for enjoyment and understanding of science. Perceived importance of science, conversely, did not show a corresponding increase yet still accounted for a large degree of experimental variance prior to establishment of pre-test AOS factor scores. Confirming this, a posteriori parameter estimation indicated that the importance of science was not influenced by multimodal text though appeared to be closely aligned with existing views of science given its consistency and similarity to TOSRA general attitudes towards science.

The learning gains demonstrated for Research Objective 1 and 2 can be interpreted as a learning effect whereby positive feelings for multimedia / socialised learning text corresponds to improvements in understanding via enhanced affective engagement. Enhanced engagement, in this context, does not appear to include corresponding improvements in the perceived importance of science. In other words, the perceived importance of science is not apparently predictive of student engagement or comprehension of science content. These preliminary results led to acceptance of H_a5 and suggest that enjoyment of science is a pathway to increased understanding of science content.

- *Multimodal text is associated with cognitive gains though does not facilitate greater student interest in science as a subject area (H_a6)*
    - In the analysis presented in Chapter 5 it was determined that, while multimodal text is associated with enhanced science learning, such text may facilitate learning due to greater engagement with text type rather than the subject area itself. Provision of an affective psychometric measure was thus important in delineating the design of effective multimedia learning materials given that any intervention is unlikely to alter fundamental attitudinal orientations toward the learning area.
    - The analyses reported in Chapter 5 indicated that students engaged more with multimedia texts than regular texts and that this engagement was not influenced by enjoyment of science as a content area. This was reached inferentially from the constructs operationalised in the Affective Outcomes Scale (AOS) and Test of Science Related Attitudes (TOSRA) instruments. As described in Section 4.5.2.6, the TOSRA is specific to enjoyment of science as a content area while the AOS presents its scales of understanding, enjoyment / interest, and importance of science as specific to student affect from modality-defined texts (Section 4.5.2.7). That no discernible pre / post differences exist in the subject-area measure, or between the post-test AOS enjoyment scale and TOSRA, while appreciable pre / post differences exist in the modality-defined text measure (AOS) led to the conclusion that multimedia mediates not only affective gains, but also cognitive outcomes in terms of perceived understanding and importance of science.

- In explication of AOS pre / post differences, the AOS *importance of science* scale was not associated with pre / post trends in AOS *enjoyment / interest* or *understanding* yet still accounted for a significant degree of experimental variance (i.e. the perceived importance of science is a meaningful explanatory variable). Further to that, described above for H_a5, the *importance of science* construct as one of three random effects (alongside science enjoyment and understanding), reliably described the observed subject area (TOSRA) affective findings – a finding that emerged in regression analysis involving maximum likelihood estimation (MLE). This suggests that while the *importance of science* is a nuisance variable in not associating with the other AOS scales, it is predictive of underlying subject area attitudes.

These results suggest that learners view learning materials separately to the learning area they represent. With increased familiarity with multimedia text, learners demonstrated greater engagement (enjoyment / interest) with it, and importantly, perceived a greater understanding of science content from using such text. Subject area perceptions, meanwhile, did not vary significantly over the course of the intervention and it was found that perceptions of the importance of science may be a reliable predictor of subject area interest. Collectively, these findings suggested acceptance of research hypothesis 6.

- *Graphic novels are not disproportionately beneficial for low SES students (H_a7).*
  - Dissimilar to the cognitive benefits reported above for Research Objective 1, there was no discernible attitudinal benefit of multimedia text for low SES learners. This finding emerged from multiple linear regression analysis in which neither objective nor subjective SES, modelled as independent variables, displayed linearity with student affective data from either the AOS or TOSRA instruments. Additionally, both SES measures accounted for negligible estimates of variance in the model, contrasting with the established predictive quality of subjective SES in recall and transfer learning with multimedia text.

The results suggest that multimedia texts are more appealing than a traditional textual format regardless of social standing. Research hypothesis 7 is thus rejected and it is concluded that while multimedia content may elicit disproportionate attention amongst lower SES learners (and subsequent learning) it is perceived as engaging amongst learners more generally. Controlling for SES in hierarchical rather than multi-level regression modelling, as conducted in this research, could shed further light on this phenomenon by examining perceptions of learning text in stratified SES groups.

As seen in the current analysis of student attitudes, differentiating between science and science learning material helps discern the cognitive benefits of multimedia learning text in supporting learning, including in less than favourable subject areas. This was apparent from the observation of simultaneous improvements in subject matter comprehension and engagement with multimedia learning material despite no apparent gains in subject-area interest. Accordingly, this forms a potential multimedia effect which can be considered as an exploitation of socialised text in aligning the perceptual, cognitive-regulatory and affective brain networks as developed in Section 5.4.4. This effect is further addressed in Section 6.2.3 in the context of a redefined Modality Principle. Importantly for multimedia learning research, affective network involvement exerts a hypothetical influence on memory and perceptual processes including normal cerebrocerebellar model formation and development. Nonetheless, despite attempts at better understanding the relationship between positive affect and enhanced learning in work such as Park et al. (2015) and Plass et al., (2014), multimedia learning research prioritises cognitive to affective outcomes in research (Ginns & Leppink, 2019). This is detrimental to research validity according to Ginns et al. (2013) who describe the lack of affective and motivational factors as primary outcome variables in multimedia learning. In extension, methodological confusion, including poor export of findings from one learning context to another, necessitates the theorizing of new boundary conditions in multimedia research (see Section 3.2.2.4).

The approach taken in this thesis contrasts with established multimedia research by fractionalising affective outcomes by domain / content as well as material design. Despite the finding that multimedia elicits underlying emotional experience in being perceived as beneficial though not interesting by learners (Section 3.8.2.2), meta-analysis of multimedia research publications reveals that where such research employs perceptual measures, these assess cognitive rather than affective outcomes (Section 3.8). For example, Lee et al. (2014) contrasted research arms by low through high degree of visual / verbal cues and recorded perceptual outcomes as student understanding, perceived learning and difficulty of content. Cognitive load, correspondingly, accompanied other cognitive measures as a primary measure of student affect in that study as well as others within the multimedia literature (e.g. Ginns, 2006; Mayer et al., 1999). This is understandable as Cognitive Load Theory (CLT) suggests that cognitive load differences alone influence subject area understanding, and related perceptions of the learning material. Cognitive load, moreover, is externalised to the conditions of learning and thus linked with the reduction of extraneous load, such as simplifying element interactivity (e.g. Paas et al., 2004; Sweller, 2010) or in cuing multimedia elements (e.g. Tabbers et al., 2004; Yung & Paas, 2015).

Correspondingly, absent from reviewed studies were measures of student interest or satisfaction with using multimedia texts (although c.f. Gegenfurtner et al., 2014 who dispute CTML's cognitive architecture as a basis of individual perceptual differences). Additionally, subject-area measures were absent in reviewed research; as seen, this omission accords with CTML theory in the assumption that processing constraints differ quantitatively across learners in terms of schema assimilation (see Section 2.4).

This demonstrated failure to identify positive and negative emotions, whether attributable to multimedia text or from the subject area, was viewed in the current study as a threat to validity given the integrated nature of affective and cognitive processes in stimuli processing. Importantly, positive affect helps align perceptual and cognitive-regulatory networks (Section 5.4.4) which aids comprehensibility of textual information. Corresponding differences in affect will therefore accompany differences in abstractive ability when dealing with informationally- and lexically-dense learning material. As represented in the conceptual model (Figure 5.4), abnormal processing occurs with incongruent stimuli presentations and is likely exacerbated by passive network dysfunction in low SES learners (see Sections 2.7. and 5.4). Related motivational dispositions influence cognition and have been described as high and low field dependence as strategies for dealing with degrees of abstraction (Section 2.7).

Accordingly, in this study, multimodal text was associated with enhanced understanding and enjoyment of science in low SES students and multimodal text disproportionately enhanced learning for this group. Nonetheless, the cohort-wide perception of science as relatively unimportant helped discern two underlying affective trends involved in cognition. Firstly, in accordance with meta-reviewed study (presented in Section 3.8), multimedia is perceived as beneficial for learning though not inherently interesting (e.g. Frisby et al., 2013). While this represents a source of effect size heterogeneity in reviewed studies (see for example, Merchant et al., 2013), it more likely represents an artefact in misconstruing the medium for the message (i.e. in confusing perceptions of multimedia text for feelings of the subject-area itself). This relates methodologically to future research and is discussed further in Section 6.6. Secondly, the results help affirm the importance of affective-network development and involvement in learning. In contrast to Moreno's (2007, 2009) motivational, metacognitive and prior knowledge underpinnings of individual 'affective' differences, accurate modelling of student affect requires a fresh look at affective network anatomy and adaptive physiology. This concern is addressed in the following section.

6.2.3 Research Objective 4

Research objective 4 aimed to provide a provisional sketch of an embodied cognitive architecture as informed by the findings of the current study. As no hypotheses were tested and no data analysed, this research objective exists as an exploratory addendum to the descriptive and inferential findings of research objectives 1 to 3. Despite its theoretical nature, the described model (depicted in Figure 5.4) has the potential to circumvent ambiguous boundary conditions that feature in multimedia research (see for e.g. Hoffler & Leutner, 2007; Schüler, et al., 2019). Specifically, the conceptual model removes the need for theorising learner constraints external and contradictory to CTML design principles (Ayres, 2015; Schueler et al., 2008) via its focus on social standing as a universal, though unequal, influence in development and by adopting a connectionist view of brain structure and function. As such, the model provides a holistic cognitive model that potentially avoids the mechanistic pitfalls associated with dual-coding theory (DCT) (Paivio, 1982) which as seen in Section 2.3.1 informs the dominant view of cognition within multimedia research. The 'computationalism' of cognitivist inspired multimedia research is taken up again in Section 6.3 where 'embodied' connectionism is contrasted with modularity in multimedia learning.

The conceptual model presented in Section 5.4 is premised on the observed cognitive and affective outcomes described for research objectives 1 to 3, and in extension, attempts to provide an account of normal and abnormal processes in stimuli processing. As defined in Section 2.10, normal processing refers to the cognitive and behavioural ramifications of information processing for learners undisturbed by stimuli incongruency. Key influences informing the conceptual model include the observed affective involvement afforded by socialised multimedia text for learners, unlike that of regular learning text, and the disproportionate learning gains for low SES learners in science in the current study. Affective involvement is thus considered central for textual learning; this feature of the model complements the essential role of socioemotional processing described in cognitive-regulatory processes (Peralta-Carcelen e t al., 2018) including memory processes (Sokolov et al., 2017). Additional to this affective basis are assumptions of brain anatomy and physiology central to embodied cognition including Raichle's (2015) 'default mode network' and Wolpert et al.'s (1998) conception of cerebellar 'internal models' as coordinators of motor-effector processes. Developmental mechanisms, moreover, include the allostatic and SES-mediated developmental influences that were detailed in Sections 2.7.1 and 2.7.2. Taken together, these features of the conceptual model presented in Section 5.4 are a novelty in multimedia research which prioritises a 'computationalist' cognitive architecture (Einhauser & Konig, 2010).

Key details of the conceptual model as presented in Chapter 5 are summarised as follows:

a) Stimuli imbued with socioemotional salience align perception and cognition irrespective of stimulus mode interaction or dominance; and
b) Suppression of passive mode processes is achieved in low SES learners via contextual grounding of scientific content.

A brief extension of these summary points precedes further discussion.

- *Stimuli imbued with socioemotional salience align perception and cognition irrespective of stimulus mode interaction or dominance.*
  - The study results concord with basic embodied cognition principles which hold that brain networks are preferentially attuned to goal-directed and ecologically-congruent stimuli presentations. This was seen in the comparable improvements in student learning with either socialised text variant (i.e. Multimodal Social [*MS*] or Bimodal Social [*BS*] text) compared with the control text. As the socialised intervention texts differed in auditory mode only, the most parsimonious explanation for the observed learning gains is that ecological congruency serves as a necessary conduit for normal cerebro-cerebellar simulation of behavioural stimuli and that modality configurations are at best incidental to learning.

Enhancement in recall and transfer learning as an effect of multimedia learning text can be viewed in terms of the propositional logic of social interactivity. This position is reached by considering the way that socially integrated input mimics the semiotic resources normally present in our environments, including that of goal-directed social interactions. By presenting science content in a personalized and personified manner, learners are motivated to invest in a narrative unimpeded by disrupted cognitive-regulatory processing accompanying non-integrated stimuli.

- *Suppression of passive mode processes is achieved in low SES learners via contextual grounding of scientific content.*
  - As detailed in Section 5.4, non-integrated processing is considered to involve non-linear memory processes and disrupted model formation owing to inhibitory affective network involvement. In this context, the affective network acts as a gatekeeper to wider brain involvement given its role in stimulus appraisal. The corollary of this view is that passive mode suppression, of which the affective network is a key constituent, is facilitated by stimuli congruency and is a concomitant requirement of learning. In the current research, student cognitive and attitudinal results help confirm the requirements of passive mode suppression necessary for cerebro-cerebellar model formation in two ways. Firstly, cohort-wide

> attitudinal data showing enhanced engagement with science learning materials, despite an unchanging interest in the subject area, highlights the interface of appropriately designed material and positive affective network engagement. That this effect did not differ by student social standing is testament to the universality of affective involvement in an area as fundamental as subject area interest. Secondly, disproportionate cognitive gains for low SES students using socialised text helps support the notion that passive mode suppression is achieved via contextual grounding of science content. In terms of the conceptual model (Section 5.4) these findings can be attributed to normal cerebro-cerebellar connectivity and model formation via (a) affective engagement with learning material, (b) subsequent encoding and consolidation of memory trace and (c) ongoing attentional allocation and corticolimbic communication relevant to memory processes including model refinement in procedural learning.

The contextual grounding of scientific content in the two intervention text conditions was primarily social. As discussed in Section 3.3 socialised content was defined by its co-deployment and co-contextualisation of semiotic resources which are naturally present within informal communication. These resources are considered to underlie normal meaning making in linguistic exchange, and thus recruit affective network processing. As semantics and semiotics interface in meaning making (see Section 3.3.1), the suppression of passive mode processes is a necessary union of affect and cognition in learning.

Cognitive models reflect the attempt to reduce complex neural processes to a formalised structure. As such, a competent cognitive model must account for the range of neural processes that underly learning behaviour including perception, motor control and emotion. These processes are biological in nature and have been shaped by evolutionary pressures as well as proximate developmental forces. Nonetheless, cognitive psychology has been influenced by a computationalism that, in rejecting the black-box environmentalism of behaviourism, modularises and internalises mental processes in accordance with developments in computer science (see for example, Chemero, 2013; Kersten, 2017; Zlatev, 2015). This cognitive architecture provides an economical account of perception (van der Helm, 2012) and memory (Raja, 2018) though is subject to multiple inconsistencies in applied research (Skulmowski & Rey, 2017). With reference to the cognitive architecture developed in Section 5.4, these inconsistencies stem from two sources: the influence of dual coding theory with its spatial and categorical separation of verbal and nonverbal symbolic systems and the developmental linearity associated with Piagetian schema theory.

Dual Coding Theory (DCT) (Clark & Paivio, 1991) treats verbal and non-verbal stimuli as discrete entities. In this scheme, linguistic information is processed sequentially while imaginal representations are processed in a holistic, parallel manner (Paivio, 1979; 1986). As such, verbal representations are amodal (symbolic) and require an additional stage in processing when compared with holistic imagery. This additional acoustic-phonemic decoding step is the assumed basis of the picture superiority effect in paired associate learning (Paivio & Yarmey, 1966), free recall (e.g. Gillund & Shiffrin, 1981; Kaplan et al., 1968; Paivio & Csapo, 1969) and semantic memory tasks (Pellegrino et al., 1977). Conversely, the conceptual model presented in Section 5.4, treats all stimulus modalities as modal (i.e. non-symbolic) and suggests, like Damasio and colleagues (Damasio, 1994; Meyer & Damasio, 2009), that stimuli are stored and integrated in convergence zones that form networks of behaviourally meaningful cross-modal AV associations. In appreciation of actual learning behaviour, the notion that working memory is neither modularised nor centralised is supported by the findings described for research objectives 1 and 2. Here, improvements in learning from socialised multimodal text equivalent in graphic design, though differing in auditory modality, suspends the need to theorise cognitive load associated with centralised verbal relative to non-verbal processing. Instead, working memory is decentralised in its role of attendance and control of actively maintained representations within primary and unimodal association regions (D'Esposito, 2007). While the conceptual model described in Section 5.4 accepts the dominance of images to words, the superiority of imagery likely has a basis in imitative learning, mediated via the mirror neuron system, and is not due to any inherent feature/s of visual stimuli. In addition to the apparent lack of modality dominance in audition, this view is reached from the findings described for Research Objective 3 in that socialised multimedia text is regarded as more engaging than regular text regardless of individual development or of attitudes towards science as a learning area.

This perspective, simply, positions vision as the dominant modality due to the gestural basis of spoken language and the conflation of gestural and verbal language in language processing and production (see for example, Wilcox. 2012; Iverson & Braddock, 2011; Williams-Pierce et al., 2017).

In this context, heteromodal / ecologically congruent stimuli associations form a kind of positive feedback with respect to upstream memory and executive functions. In encoding, bimodal or multimodal cues are associated with supra-additive activation in heteromodal cortical areas, and in recall, with enhanced reactivation in primary sensory cortex. Conversely, unimodal (or otherwise ecologically incongruent) presentations are linked with reduced association cortex interconnectedness, deficits in hippocampal / pre-frontal cortex (PFC) involvement in memory consolidation and corresponding reactivation failure in memory. The low recall and transfer of science content for learners using regular science textbooks (described for research objective 1) reinforces this view. The conceptual model thus ascribes lower rates of learning to a lack of external goal-orientation of tasks attributable to a standard science textbook, including content capable of generating regular modes of social reasoning. The influence of social cognition emphasises the role of the default mode network (DMN), as social reasoning, including episodic memory and story comprehension, is demonstrably linked with positive DMN / cognitive-regulatory connectivity and improvements in executive function (Spreng, 2012). Conversely, with its realistic depictions of social interactions, the graphic novel format used for the intervention texts appeared to facilitate memory encoding and reactivation. As discussed in Section 2.8.1, feed-forward connectivity amongst modality specific regions is enhanced in cross-modal versus within-modal stimuli associations, while reactivation is enhanced via eliciting the same perceptual areas as occurring during initial encoding. With reference to dual coding theory, distinguishing visual and verbal stimuli, respectively, as amodal (symbolic) or modal (non-symbolic) elements is problematic for two main reasons: symbolic referents lack a physicality otherwise afforded by sensorimotor grounding (as in embodied cognition) and, as discrete entities, lack a holism required for contextual reactivation in brain regions independent of hippocampal-dependent memory processing (i.e. as forward or inverse models – Pickering & Clark, 2014). This latter point is especially pertinent given the largely automated nature of cerebrocerebellar model simulatory reactivation in recall (Koziol et al., 2012).

As detailed in Section 5.4, the cognitive architecture of the conceptual model differs from the established CTML model in the relations between stimuli and perceptual and motor systems. Sensory processing, in traditional cognitive psychology, modularises working memory subsystems (Baddeley, 2017) and does not involve sensorimotor processes; instead, information is encoded - ‘transduced’ - within separate audio-visual channels and cached amodally in working memory subsystems (Hasson et al., 2015). As detailed in Section 2.4, this informs text design, likely including that of the science textbook used as the control text in this study. In concession, visualising the embodiment of sensorimotor analogues has influenced multimedia research, though appears to be limited to consideration of abstract and concrete word forms (e.g. Paivio, 2010; Rofes et al., 2019). For example, researchers such as Geary (1995) have drawn on ideas in evolutionary psychology (including the massive modularity thesis of Tooby & Cosmides, 1998) in theorising primary and secondary mental modules in the processing of concrete and abstract classes of information (c.f. the ‘picture superiority effect’ in Section 2.3.1). Nonetheless, the conceptual model in Section 5.4 is less speculative from a functional perspective as it explains the concreteness of visual stimuli, for example, as an amalgamation of biological and mechanical information classes contextualised within a socioemotional framework (c.f. grounded cognition, Barsalou, 2008). Sensorimotor influences on memory formation and retrieval, in this framework, interface in the development of forward models (see Section 2.8) which act with increasing sophistication in repeated learning. Abnormal processing interferes with model formation and learning, meanwhile, via disruptions to pragmatic representational activity in the dorsal stream (Cisek, 2007) which theoretically disrupts the production of procedural and declarative knowledge forms. Thus, the model summarises stimuli processing and successful learning as a coordination between perceptual, affective and cognitive-regulatory activity in which recollective memory is strongly influenced by the cohesiveness of presented information.

Additional to providing a mechanistic basis of stimuli processing, the conceptual model in Chapter 5 (Figure 5.4) provides an account of individual development that is parsimonious in its assumed phylogeny of neural structure and function. As such, it meshes ontogeny with phylogeny and provides biobehavioural insights into adaptive behaviour across the socioeconomic spectrum. In reference to cognitive abstraction and its association across a hypothesised continuum of normal and abnormal stimuli processing, the model reflects current neurological thinking in adaptive ontogeny (Pollitt et al., 2005; Tamayo et al., 2010) including the influence of hypothalamic-pituitary-adrenal axis (HPA) dysfunction in memory processes (van Bodegom et al., 2017; Cerqueira et al., 2007; McGowan et al., 2009). This contrasts with the standard view of cognition (see for example, Paas et al., 2004) which maps cognitive development according to the accommodative and assimilative properties of schema development (c.f. Piaget, 1923). Schema theory influences dual coding theory, which as seen, suffers from issues of symbolic grounding (Harnad, 1990) and treats stimuli modalities as discrete entities prior to establishment of arbitrary referential associations in modular memory. Individual differences, from this perspective, stem from biological maturation and environmental interaction and discount the role of affect or other socioemotional influences (Roby-Brami & Goasdoué, 2010). Developmental linearity thus provides a basis of comparison amongst learners in CTML research, and as a cognitive construction, can be measured according to learner expertise (Leppink et al., 2013) or age (Kalyuga et al. (2003).

Cognitive development, however, is viewed as an aggregate of personal, behavioural and environmental influences in the conceptual model under discussion. For over a century, pioneers in the field of affective neuroscience have appreciated that emotion processing works in parallel with other subcortical and cortical processes (see for example, Brosch et al., 2013; Schulkin, 2003). Correspondingly, as reported for research objective 3, the supra-additive influence of emotional engagement was apparent from the relative gains in socialised versus non-socialised texts amongst learners in the current study. This was interpreted in research objective 4 as an emotional enhancement of perceptual, attentional, and memory processing, and informed the conceptual model as such. Textual sociality, meanwhile, differs in its impact amongst individuals given that while low SES students alone showed significant learning gains with socialised texts, students collectively engaged with socialised multimedia more so than with traditional science texts (see Section 6.2.2). This pattern of differential learning across SES is informed by life history patterns in development (Section 2.7). In this context, allostatic load (McEwen, 2001) exerts its ‘wear and tear’ on physiological systems in proportion to the expression of key neuroendocrinological markers of stress, all associated with low SES (see Section 2.7.1). Importantly for stimuli processing, stress-mediated plasticity represents an important influence for key brain networks including hippocampus, amygdala and prefrontal cortices (see Section 2.7.2), with flow-on effects for perceptual and emotional processing. Central to the conceptual model, correspondingly, is the proposition that abstractive ability, itself plastic as a result of inhibitory amygdala activity due to chronic stress in development, intersects with stimuli processing.

In extension of its developmental basis, the conceptual model is mindful not only of individual development but of broader trajectories including the relative maturation and integrity of cognitive, perceptual and affective networks (Leppänen & Nelson, 2009) across SES-defined populations. As such, the model adds to multimedia theory in its assumption that social congruency, as a feature of multimodal presentation, can be expected to disproportionately elicit activation of memory processes and later reactivation in learners differentiated by social standing or not (i.e. as students within regular age / stage groupings). This assumption of the model, as described previously, was informed by the statistically significant gains in recall and transfer learning in low SES students using socialised multimedia text; it is attenuated, though, by the general (i.e. cohort-wide) appreciation of graphic novels as beneficial for learning as well as in actual improvements in learning outcomes. Nonetheless, viewing SES as a primary developmental influence contrasts with the standard cognitive architecture of multimedia learning in its assumption that cognitive development is mediated via schema development (Paas et al., 2004) which introduces an imprecise and misleading measure in multimedia research.

As informed by the research findings presented in research objectives 1-3, the conceptual model differs from other cognitive models within multimedia learning research. Specifically, functional and developmental distinctions pertain to stimuli processing, while non-modularity, as a structural consideration, reflects the model's rejection of domain specificity in perceptual and memory processes. With implications for science learning, the conceptual model presented in Chapter 5 (Figure 5.4) holds that stimuli imbued with socioemotional salience align perception and cognition within interconnected and functionally interdependent neural networks. In turn, memory integration and processing are enhanced by integrated audio-visual content as it is ecologically valid and involves cerebellar involvement in model formation (see for example, Nguyen et al., 2018). Successful model formation thus necessitates affective network involvement and memory processes, including reactivation, are contextually moderated and strongly linked to the modalities of presentation (Butler & James, 2011). Also, as outlined in Section 5.4, cerebrocerebellar model formation is necessary for automation and behavioural refinement and culminates in declarative learning. However, incongruencies in stimuli presentation cause disruptions between ‘supervised’ and ‘unsupervised’ learning modalities and this outcome is possibly exacerbated by affective network dysfunction in low SES learners. Explanations for successful science learning with socially congruent text in the presented model therefore differ from traditional models; in the former, cognitive limitations stem from developmental constraints, while in the latter, architectural and / or organisational constraints explain learning outcomes (see for example, Paas et al., 2010; Sweller et al., 1998; Paas & Sweller, 2012).

6.3 Implications of the study

This research has been primarily motivated by multimedia theory, which in turn has been informed by cognitive psychology in its application to education. Central to the research objectives and hypothesised learning effects presented in this thesis, meanwhile, is a cognitive model not familiar to multimedia research. Within this model, disrupted cognitive-regulatory processing was found to associate with incongruent audio-visual textual input. Affective network dysfunction and its role in holistic memory processes was offered as a likely mechanism to explain this phenomenon and socioeconomic status was used as a secondary variable in analysis given its role in allostatic pathophysiology (Section 2.7.1). Implications of the findings extend to multimedia theory and educational practice and influence future research. Related administrative (A), design (D) and pedagogical (P) recommendations are drawn from this commentary and are indicated in the following subsections. In defining relevant parameters of discussion, while multiple aspects of multimedia learning theory have been discussed in the literature review chapters, the intervention featured only a limited subset of learner and design variates. This section, accordingly, will relate experimental findings to multimedia learning from static texts with characteristics of the learner limited to social background. Specifically, implications relevant to multimedia theory include:

- adopting an appropriately connectionist view of cognitive architecture within multimedia learning theory;
- subsumption of Cognitive Theory of multimedia learning (CTML) basic principles within an appropriately socialized textual multimodality; and
- inclusion of perceived socioeconomic background as a multimedia instructional principle.

6.3.1 Connectionism versus modularity in multimedia learning

As demonstrated in the conceptual model (Section 5.4), a deeply integrated neural network is involved in stimuli detection and related affective and cognitive processing. Moreover, stimuli properties maintain holistic and enduring links with their material referents. Nonetheless, cognitive psychology largely relies on symbolic, localist representations of memory. In that field, sensory and perceptual modes are viewed as computationally autonomous ‘vertical’ faculties which operate via domain-specific input systems, input analysers, and interface systems. Cognitive processes are analogous to computers in the input and processing of symbolic information packages, functioning to relay amodal data to the domain-general ‘central processors’ of memory, imagination, reasoning and so on. As seen in Sections 2.3.2.1 and 2.3.2.2, important considerations within this symbolic paradigm of cognitive science are the encapsulation of information, fast and mandatory stimuli processing, and limited auxiliary access to different levels of representation (Penney, 1989; Tulving, 2002). In this hierarchical system of content-specific components interfacing autonomously with the central executive, we see a clear link with the postulates of multimedia learning - i.e. (a) modality-specific subsystems within working memory; (b) limited subsystem processing capacity, and (c) active processing of sensory information. This view persists despite the emergence of connectionist models within applied neurology.

A connectionist model of the cognitive architecture is theorised within the field of embodied cognition (see for example, Shapiro, 2011). This view has emerged as an alternative to the symbolic application of cognition and is less constrained by the traditional computer analogy as it argues against a symbolic, localist representation of memory, assuming instead that distributed representations are not resident in any single neural element but are instead represented by an activational pattern over a set of neural ensembles. This model espouses a different computer analogy as its highly interconnected excitatory and inhibitory nodes are unconstrained by stored rules or symbols, with knowledge largely or wholly reliant on experience. As described for the current study (Section 6.2), student cognitive data supports this view given the differential patterns of focussed mental activity in learners using socialised and non-socialised text. A social context thus appears to provide a suitable heuristic for situating and comprehending non-social phenomena and, in turn, modulates architectonic patterns in memory including cognitive-regulatory involvement where it may not otherwise exist. As described within the conceptual model (Section 5.4), a social context can be provided quite simply in text via inclusion of recognisable social interactions and / or narrativization of audio-visual elements. Task relevance, once perceived by the learner, determines the execution of stored goals and behavioural repertoires via various corticolimbic pathways. In consideration of higher order cognition, such anticipatory and simulative adaptations to action control are understood to underpin declarative and procedural forms of knowledge, as well as more complex tasks. This latter point is reflected in the significant learning gains in higher-order cognitive skills (i.e. application and evaluation) reported for previously low-scoring students when exposed to socialised multimedia learning texts (see Section 6.2.1) compared with regular learning text.

Task relevance, as discussed in Section 2.2.6, directs attention and perception and modulates memory processes. Memory is thus reliant on contextual cues and is highly resistant to incongruous presentations as these would be unlikely within normal ecologies. Specifically, in the context of the conceptual model (Figure 5.4), incongruity is analogous to default mode network activation as a systemic response-irrelevant mechanism in behavioural flexibility (Ferguson et al., 2017). Correspondingly, a hierarchy of task relevance within an appropriate connectionist model would consider the likely social and non-social demands faced by the individual, which have served as an ecological shaper of cognitive processes. An important implication of this view is the distinction between contextual task-rules and stimulus properties. In constructing the conceptual model (Section 5.4), cognitive control was theorised as a balancing act between a currently presented task rule dictated by a learning text and the learner’s ability to select and execute a relevant response. Flexibility in configuring information processing to support goal-directed behaviour, in turn, was enhanced by the socialised text, which as discussed above (Section 6.2.3), appears to enhance normal memory processes. To reiterate, this refers to enhanced reactivation in primary sensory cortex, which in the context of multimodal stimuli processing, necessitates social congruency as an optimal basis of supra-additive hippocampal and PFC activation as per normal memory activation (Section 2.8.1). In terms of material design, it follows that learning resources should feature socially salient stimuli with clear referential cues between text and visual entity (*Recommendation D1*).

Meanwhile, within the symbol processing approach of traditional cognitive science, predicate logic and propositional and computational formalisms have provided a means to define and separate psychological processes. Nonetheless, this system of representation violates semantic cognition in establishment of consistent and singular reference to external percepts. This violation proceeds from emphasis on cognitive processes in a system devoid of content (symbols are purely symbolic). Semantic representation of words as symbols, in this system, maintains that processing and relatedness between internal verbal and nonverbal representational units override importance of compositional and external referential connections. This symbolic approach, correspondingly, was evident in the science learning text used as the control text within the study design (see Section 4.3). To be manipulated, external information must be transformed (‘transduced') to a qualitatively different format than that received, and in the process of applying symbolic labels for concepts and semantic units loses any designation to the external entity. However, as cognitive symbols must maintain consistent and singular reference to maintain causal links between cognitive function and referent, and as the transduction process itself is poorly understood (Shapiro & Stoltz, 2018), internal manipulation of symbols is inadequate in accurately representing the world and establishing meaning. This issue with symbolic cognition is consistent with that of cognitivism, more broadly, an approach that focuses more on internal systems of representation than ongoing experiential encoding of external input. In short, lacking the capacity for context-independent representation and formal symbolism renders semantics impossible in this system.

By contrast, embodied cognition assumes a limited or even non-existent representationist system as it rejects the need of internal representations. Instead, sensorimotor interaction with the environment underpins adaptive behaviour in the formation and reinforcement of internal models of knowledge. Koziol et al. (2012) propose that human prefrontal-cerebellar and parietal-cerebellar cortical connectivity underlies executive functions similar to that of non-human animals and that goal-directed behaviour across species is derived from sensorimotor anticipation. That executive function is not unique to our species, with movement and goal-directed action as the basis of cognition, has phylogenetic as well as developmental and educational implications. The neurological contender for site of executive function is the lateral prefrontal cortex, which functions in a diverse, nonlinear and concurrent array of tasks (Owen et al., 1990, 1995, 1996). Observed peripheral feedback redundancies in behaviour owing to central consolidation and multi-sensory mediated encoding and retrieval speak to the ability of this brain region, in concert with the limbic and hind-brain, to differentiate between encapsulated packets of sensory information in order to apply whole-or-nothing contingent responses to familiar or novel experience (Hagan et al., 2009). When viewed in isolation, however, stimulus properties are devoid of greater task-relevance. A corollary of this view and informed by the research findings described in Section 6.2.1, is the necessary emphasis on appropriate contextualisation of abstract scientific information. Thus, it is recommended that in verbal presentation, historical and social frameworks including biological and non-biological agents are presented to learners (*Recommendation P1*).

By contrast, the discreteness of visual or verbal representations in Mayer's (2005a) Information Processing Model follows from the assumed separateness of the domains themselves and divorces content from meaning until the final stages of processing where representations, stored as nodes, can be assimilated with experience. This is wholly expected in a rationalist, modulated system though is both evolutionarily and ontogenically inconsistent. These inconsistencies are highlighted in the observed discrepancy between grade-differentiated student science learning prior to and following instances of science learning administered as per the term-long intervention of the currently described study (Section 4.3). If associative networks comprising the brain’s conceptual system follow a generally linear development, then the structure and content of higher cognitive processes including inference, categorisation and memory would be expected to show baseline, if not overall, improvements with older, more experienced, students. As seen in Section 5.2.1, this wasn’t the case as grade 9 students, the oldest student grouping (see Table 4.3), performed poorest in science testing, regardless of text type exposure. By contrast, as seen in research objective 3 (Section 6.2.2) differentiating students by socioeconomic status acted as a valid predictor of learning behaviour, also regardless of text type. In explication, conceptual processing involving embodied simulatory activity is imbued with, and modulated by, emotional and sensorimotor processing as primary influences. As described in Section 2.7.2, regional plasticity associated with SES influences perception, attentional control and higher cognition and therefore better predicts learning outcomes than age / stage learner attributes (Section 6.2.1). The conceptual model qualitatively differs from the associational simulations of CTML in that successful recall and transfer is influenced by conceptual salience and congruency as modal-dependent recreations of experience and as such is influenced by the emotional competence of the individual.

Regional plasticity associated with SES, as described in Section 2.7.2, is involved in perception, attentional control and higher cognition, and as determined in this research, perceived SES can reliably predict learning outcomes (Section 6.2.1).

Social and mechanical processing, moreover, likely involve the same attentional, affective and perceptual processes, thus involving normal limbic, paralimbic and cortical modulation of information storage. Emotional regulation within connectionist networks logically extends to all information classes and necessitates a preferential inclusion of concurrently presented social and mechanical forms of information. This effect was evident in the learning gains described for the socialised learning text used in the study; in explanation, the intervention text design involved the attribution of agency and animacy to both social and non-social agents in order to personalise and personify textual elements (see Sections 6.2.1 and 4.2). Also, in reference to the previous discussion of task relevance and stimuli congruency, the obvious salience of socioemotional cues likely modulates task-relevance in neural networks preferentially oriented toward such processing as determined by their role in emotional conditioning such as in hypothalamic-pituitary-adrenal (HPA) stress feedback. Also, in accordance with Section 2.8, the inadvisability of separating social or mechanical agents from their normal contexts was confirmed experimentally in observed difficulties in processing incongruent sensory information in the control text (Section 6.2.1). Pedagogically, it follows that in maximising situational semantic processing, assessment of learning should involve materials which recreate the same features and learning context as presented in initial learning (*Recommendation P2*). In contrast, while multimedia learning principles have been uncovered in research and linked to discrete modality processors these may simply reflect inadvertent ‘socialisation’ of audiovisual (AV) signals. Socialised text, it is remembered, is methodologically synonymous with audiovisual congruency in this thesis due to the situational nature of knowledge creation.

6.3.2 Subsumption of CTML basic principles within an appropriately socialised textual multimodality

The experimental determination of enhanced learning from contextualised, static text in this thesis relates to, and concords with, the central postulate of multimedia learning - the Multimedia Principle. Indeed, examination of the basic *Cognitive Theory of multimedia learning* (CTML) principles (Figure 2.12) shows that except for the image principle, most principles can be applied to non-dynamic displays if the personalisation principle is applied to printed text in the appropriate *conversationalisation* of the printed word. Additionally, the principles can be umbrellaed within a redefined modality principle given that specific contextualisation, including auditory and visual features, is present. For example, concerns about modal redundancy are alleviated with printed text that is appropriately linked with graphical referents such as that of the graphic novel speech bubble. Likewise, congruency and signaling concerns are mitigated by the temporal and spatial segmentation afforded by normal cartoon presentation. By extension, the Multimedia Principle can be redefined from:

> *People learn better from graphics and narration than from graphics and printed text.*

to:

> *People learn better from socially congruent graphics and text than from graphics and text in contextual isolation.*

Perhaps the biggest conceptual hurdle facing this redefined modality principle is that of the established superiority of narrated versus printed text with graphics. Two defences are presented that relate to existing multimedia methodology and from the current study and research in cross-modal cognition. Firstly, as described in Section 2.2.7, instructional design principles may have been unduly influenced by multimedia findings on the apparent enhancement of learning with narrated audio and graphics. This learning effect, reversible with experience and self-paced learning, was deemed indicative of a split attention effect rather than an enhancement of cognitive resources - an experimental artefact masquerading as a learning effect - and misdirected in terms of dual coding cognitive processes. The current findings (presented above in Section 6.2.1) support an apparent splitting of attention afforded by stimuli incongruity in that learning was enhanced upon stimuli congruency, and also that auditory mode made little difference in learning outcomes when learning from socialised text. Nonetheless, given the supposed discreteness of modularised sensory systems and the existence and widespread use of audio-visual input / output devices with computers, it may be seen that the conditions influencing the assumptions of the modality effect would emerge regardless of any experimental approach. This is as much due to the computational paradigm of cognitive psychology and its applied disciplines as it is to the widespread usage of computers in education.

Secondly, research on cross-modal cognition has examined the supra-additivity of audiovisual (AV) integration in heteromodal cortex and shows the joint involvement of perceptual, attentional, and memory processing in multimodal cognition (Miller & D’Esposito, 2005). Of relevance to the current discussion is the finding that speech reading in the absence of auditory input activates auditory cortex, traditionally viewed as a primary phonological site, and that phonological, lexical, and semantic aspects of language are heteromodally processed in left inferotemporal cortex (ITC) an area normally associated with visual processing as part of the ventral stream (see Section 2.8.1). Multiple other ‘higher’ and ‘lower’ order brain regions, including associational cortex, have likewise been observed to operate heteromodally in feedback and feedforward processing of visuospatial information. In relation to connectionist networks in embodied cognition, including that of the conceptual model presented in Section 5.4, task-relevance appears to underlie sensory and memory processes with AV congruency modulating hippocampal and amygdala connectivity with the PFC -

situationally priming the brain for efficient encoding and recoding of contextualised information. This is seen in AV speech processing and with voice-face associations, and in the case of this thesis, with contextualised scientific concepts. From these observations and strengthened by the study's primary findings, it is recommended that language usage, whether written or spoken, should feature an unplanned, familiar communicative style (*Recommendation D2*). Sense making, in this context, is motivated via the portrayal of locutionary and extra-locutionary factors as normal communicative strategies in productive and receptive communication. In addition, learning should involve self-paced learning (*Recommendation P3*); this suggestion is expedient, moreover, given the costs and resources required for computer-assisted learning and related teacher training.

Returning to the original topic, an appropriately socialised textual multimodality is defined simply as one that integrates biological and non-biological environmental features as a means of providing context. Multimodality was earlier described as a collection of semiotic resources (Section 3.12), including multiple sensory aspects of communication. To this, multimedia theorists would be well-advised to add an environmental context to imbue concepts with motivational task relevancy. The subsumption of *Cognitive Theory of multimedia learning* (CTML) principles to a core principle defined by presence or absence of context raises design questions relating to the attribution of *social congruence* in educational learning materials. These were partially addressed via description of textual features and guidelines for text construction in Section 3.8. Drawing from these guidelines, educators should be mindful to use scientific language featuring informational density at commensurate grade level (*Recommendation D3*). Nonetheless, in keeping with the need to appropriately portray *social congruence*, lexical density should be restricted in line with the semiotic strategies of personification / personalisation (see for example, Zlatev, 2012 and c.f. 'narrativization' – Kissas, 2013). In extension of this design recommendation, a related funding requirement exists for the creation and provision of multimedia learning texts (*Recommendation A1*).

6.3.3 Inclusion of perceived socioeconomic background as a multimedia instructional principle

Acknowledgement of socioeconomic status (SES) gradients in pre- and post-compulsory educational attainment, including vocational training, features in Australian educational policy. This was initiated with Australian Bureau of Statistics (Australian Bureau of Statistics, 2006) mapping of educational social determinants including social participation and material access to student academic achievement within its 2006 census collection districts. A subset of the derived ABS Socio-economic Indexes for Areas (SEIFA) measure is used in production of the Index of Relative Socio-economic Disadvantage (IRSD) which is predictive of the 50 - 60% of year 12 graduation in lowest quintile SEIFA regions. The Index of Community Socio-educational advantage (ICSEA, ACARA, 2011) is a related School-based performance indicator associated with goals of the Coalition of Australian Governments National Education Agreement (COAG, 2009) in providing a richer individual-based measure alongside existing area-based measures. ICSEA data are used in reporting National Assessment Program – Literacy and Numeracy (NAPLAN) results, using composite family and community measures, in provision of national comparisons of expected literacy and numeracy outcomes. It is noted, though, that no causal mechanisms underlying the observed SES gradients of educational attainment are presented within this legislative framework. This includes key documents such as the Strategic Cross-sectoral Data committee (SCDC) report presented to the Australian Curriculum and Reporting Authority (ACARA, 2012) or within its cited literature.

Recognition of educational disadvantage with low social standing is thus made in Australian educational policy though lacks specific effects attributable to development. This coincides with the observed resistance to operationalise SES as a learning effect in multimedia research (see Section 3.8.1.2) despite frequent inclusion as a composite contextual measure alongside other social factors. This is discordant with the recognised importance of SES - emphasised as a measure of disadvantage in often being the sole variate in multimedia studies including measures of disadvantage (Section 3.6.1.2). It may be concluded that social standing is currently viewed as experimentally unquantifiable or perhaps represents a construct more appropriately studied outside of education.

Understanding of hypothalamic-pituitary-adrenal (HPA) feedback processes in response to SES-mediated stress provides a causative and mechanistic model applicable to multimedia research. The observed U-shaped activation of glucocorticoid in inhibitory and stimulatory modulation of forebrain and limbic systems indicates an adaptive range of permissive, suppressive, stimulatory, and preparative actions (Joëls, 2011). Short, sharp exposure to stress is beneficial in the permissive and suppressive roles, while prolonged / extreme stress exposure induces HPA axis hyperactivity and contributes to lifelong vulnerability to stress. Enhanced responsiveness to stress is accompanied by amygdala hypertrophy, hippocampal / PFC neural atrophy and neurotoxicity and fronto-temporal and fronto-parietal white matter circuitry dysfunction (Schulkin, 2003). Correspondingly, life history traits conceptualised as *somatic* and *reproductive* effort are adaptive and relate to early care, and likely orient offspring to environments of varying degrees of resource availability. Within the allostasis literature, the adaptiveness of HPA morphology is viewable as a system of trade-offs in life history traits **(**Eyer & Sterling, 1977). Biobehavioural ‘decisions’ such as enhanced fecundity and adolescent birth rates accompany stress-induced plasticity and increase fitness in unpredictable environments though are susceptible to allostatic state and multiple pathophysiological pathways of allostatic overload (Sisk & Zehr, 2005). As such, resource availability conforms to social standing, albeit nuanced by relative versus absolute measurement (Section 6.2.3), and as experimentally determined within the current study (Section 6.2.1), positions learners within a definable pattern of learning behaviour as per individual cognitive development.

In informing multimedia research, social standing is thus an indispensable tool in isolating trajectories of brain development. Hypothesised developmental patterns are considered in this study to result from a plastic cognitive architecture and relate, at least in part, to abstraction. Experimental conformation of differences in abstractive ability, correspondingly, were seen in the specific cognitive and affective learning behaviours evidenced within the study (Sections 6.2.1, 6.2.2 and 6.2.3) which in turn informed the conceptual model presented in Section 5.4 (and summarised in Section 6.2.4). In explanation, chronic stress in low SES environments induces an over-expression of amygdala-dependent cognition such as in observed long-term potentiation of amygdala-ventromedial PFC circuitry. This is associated with a lack of cognitive emotional regulation, and impairment to hippocampal and PFC-dependant cognition. Regulatory cognition - executive control - is determined by amygdala integrity with amygdala processing acting as a downstream modulator of memory encoding including episodic memory trace as well as semantic consolidation. In export to educational contexts, awareness of SES-mediated brain plasticity, and educational interventions including early interventions amongst low SES learners, should feature in school leadership programs (*Recommendation A2*). Additionally, related in-service opportunities should be made available for teaching staff to promote their understanding, use, and design of contextualised multimedia resources (*Recommendation A3*).

As mentioned, abstraction is an essential element of regulatory cognition which involves executive functioning in the shifting, updating, and inhibition of novel and stored internal models (Section 2.3.4). Abstractive ability, moreover, is characterised by (i) initial memory encoding via the amygdala and (ii) the efficacy of complementary functioning between ventral and dorsal streams. Abstraction will be more defined in brain networks unmodified by stress due to enhanced ability in conscious refreshing of information, goal-directed suppression of overriding response patterns, and contingent response to change. Meanwhile, abstraction will be poorly executed in a cognitive network characterised by dysfunctional stress, with resultant modifications to PFC, hippocampal, and amygdala morphology and related cognition. These assumptions of the conceptual model were informed by the SES differences in observed learning behaviour in the current study, including the link between affective involvement and cognitive gains for low SES students (Section 6.2.2). A possible reason for such modified cognition in low SES students is in the holistic nature of emotionally charged stimuli. Enhanced emotional capture in the stress-modified amygdala likely impairs processing of non-emotional stimulus aspects given the whole-or-nothing characteristics of emotional stimuli. Difficulty in disengaging attention from emotional qualities inherent to the learning context may inhibit abstraction, i.e. in the necessary derivation of general rules and concepts from a given concrete entity or process. A related pedagogical intervention with relevance to abstract reasoning is the need to deconstruct complex concepts into constituent elements. Therefore, educators are advised to employ situational contexts where concepts are structured to avoid complex parts-to-whole inductive reasoning

(*Recommendation P2*). In addition, it is worth noting that while inductive abstraction likely exists as a cognitive typology, such as being a necessity in language production although potentially absent in concrete, crystallised representation, it may be present in degrees in various cognitive domains such as those informing science learning design and its testing in the current context (Section 4.5.2). Nonetheless, regardless of how abstraction is defined, given the centrality of attitudinal orientations to learning, attitudinal measures should be designed to monitor ongoing student engagement with textual modality-defined subject area learning resources (*Recommendation A4*).

The comparison of subjective and objective SES as predictors of abstractive function was assessed in extension of social standing as a learner variate. The observation that subjective social standing is highly correlated with science achievement and predictive of science outcomes alongside variations in textual modality stands in apparent contrast to the influence of objective social status. As discussed in Section 3.2, the distinction between objective and subjective social status likely suffers from confounding effects present at the study site. Nonetheless, this measure of social rank offers a nuanced measure that may otherwise escape detection. A probable reason for the greater correlation between cognitive outcomes and subjective SES in the current study (Section 5.2.2) is the self-anchoring it affords. By contrast, normative scales used in objective measurement of SES generally show poor interrelationship despite each indicator correlating with the social gradient (Adler et al, 1994; Adler et al, 2008). An individual's own positioning on the social ladder allows consideration of multiple dimensions of socioeconomic status and social position, allowing for its greater predictive ability in health, and as demonstrated here, education. Subjective social status may be a “value added" given the individual's evaluation of their own status amid the implications of objective indicators. The findings of this thesis corroborate existing health research and give the researcher utility in identification and analysis of nuanced data. The findings also suggest the need to implement rich measures of contextual and subjective socioeconomic status for individual student identification and tracking (*Recommendation A5*). It is recognised, finally, that the sole use of an objective SES instrument in this project would have led to different interpretations of research objectives 1 and 2. This is addressed in the following section (Section 6.4), which outlines study limitations, as a site effect inherent to demographic and social factors within the United Arab Emirates.

This section (Section 6.3) has outlined implications of the study's results and has proposed a series of related administrative, design and pedagogical recommendations. The following section (Section 6.4) details limitations arising from the current study and provides recommendations relating to further research designated as R1 – R3.

6.4 Limitations of the research

"Man prefers to believe what he prefers to be true" (Francis Bacon).

Limitations present in this thesis relate to methodological and theoretical issues that have a potential impact on the ability to answer research questions as well as on the quality of findings. Emphasis here is placed on the greatest potential moderators of research quality to distinguish such threats to validity from more inherent issues within educational research. A critique typical to educational research, for example, is the use of non-probability sampling, borne out here with use of in situ experimental groups. This was defended as expedient and representative of normal educational practice, and discussion of this and other validity issues were presented as commentary in the thesis. Reported issues here, thus, relate to more fundamental limitations, and include the operationalisation of socioeconomic status as a covariate, the design of the Affective Outcomes Scale (AOS) instrument, and the generalisability of findings.

Socioeconomic status, in its operationalisation and presumed developmental link with cognitive ability, presents a multidimensional quality to this study. Deliberation of whether social status acts as a confound or covariate regarding learning from modality-defined texts centred around its hypothesised association with field dependence (a measure of preference for global versus local processing) as a recognised psychometric of abstractive ability (see Section 2.7). Abstraction has been viewed as a centrepiece of general intelligence since Spearman developed his two-factor theory of intelligence (Tucker-Drob, 2009). However, specific temporal and geographical trends in general intelligence ('g'), and thus abstraction, have emerged with the discovery of intergenerational IQ increases - the "Flynn effect' (Flynn, 2007) - and geographical IQ patterns (Hassall & Sherratt, 2011). These trends suggest a mutable underlying cognition, in a construct likely to represent external validity issues when applied to geographically distinct student populations. Whatever underlies observed patterns of

IQ / abstraction, the question remains of its validity in terms of measurement and application to multimedia learning. In short, answers are likely found in the subjective measurement of socioeconomic status as this may resist temporal and spatial distortions. That subjective social standing was closely associated with scientific learning in this project, while the objective SES measure was uncorrelated with cognitive outcomes, simultaneously confirms this view while acknowledging the need for ongoing, corroborative research and educational practice (*Recommendation R1*). Thus, the need for longitudinal tracking of learner SES is acknowledged; related recommendations (i.e. A1 – A5) were given in the previous section (Section 6.3) in line with developmental alterations attributable to SES. Future research should also incorporate both objective and subjective SES measures as primary influence variables to assess their relative association with abstractive ability. Remedial efforts could then accompany identified SES gradients, and within Multimedia Research, could involve targeted variation in text design as per the redefined Multimedia Principle (Section 6.3). Such research could use the conceptual model presented in this thesis as a theoretical framework and explore it from either a biomechanistic or biobehavioural basis.

The Affective Outcomes Scale (AOS) instrument presents specific limitations in its design validity. While it was found to be reliable in terms of internal consistency, its validity as a measure of student affect from modality-defined texts is questionable given the link between degree of cognitive abstraction with SES and motivation to engage with modality-defined learning materials. This assumption is predicated on the purported attributes of the low SES learner, in preferentially engaging with the socialised multimodal text. That high SES students will show equal engagement with any learning text is also an hypothesised association, and perhaps inconsistent with established principles in multimedia theory unless high SES students can be compared with experienced learners in a novice-expert gradient. Scoring of the instrument is likewise problematic in involving a difficult scoring key in line with hypothesised responses that resisted a simpler approach. The decision to use the instrument in its current form was based on its piloted reliability and the absence of a similar modifiable instrument. Future study on student affect and modality-defined texts should therefore include the design of pre / post measures to provide comparable data and reduce the number of hypothesised textual features i.e. in measuring constructs of perceived understanding, enjoyment and importance of science (*Recommendation R2*). This will help limit potential content and criterion validity issues while raising confidence that the construct of interest is accurately represented. In associating student learning motivation with abstractive ability, further research would ideally involve separating these constructs and verifying them in isolation prior to subsequent attempts to combine them as described here. Additionally, future research would ideally involve objective and subjective SES as primary variables in longitudinal analysis. Together, these suggestions accord with the processing constraints described for non-integrated processing in Section 5.4 as well as the ongoing assessment of perceptual data for science learning materials as per Recommendation A4 (Section 6.3).

Also, generalisability in this study is limited in its export from the non-randomly sampled, predominantly Arab sample. The study site features a range of nationalities, though in line with UAE visa restrictions, only a limited subset of a normal socioeconomic spectrum is present within the study site. This is despite Emiratis making up some 41% of the sample, given the extremely high rate of public sector employment for Emirati nationals. Homogenous social factors in this traditional country, including relatively high incomes and standards of living as objective measures of social standing, are also non-representative when applied to Australia. The use of a subjective scale of social standing confers some protection in this regard as it offers a relative account of social standing and is applicable as a qualitative scale of comparison. Generalisability of the findings to other contexts or countries is thus made with caution; future studies of this kind are suggested to involve an inclusive sample capturing a greater range of social backgrounds (*Recommendation R3*).

6.5 Summary of recommendations

This section provides a summary of the recommendations identified within Sections 6.3 and 6.4. These recommendations are categorised by those relevant for future research (Section 6.5.1), for administrative purposes (Section 6.5.2), material design (Section 6.5.3) and pedagogy (Section 6.5.4).

6.5.1 Recommendations for future research

R1: Ongoing, corroborative research should be undertaken to examine the role of subjective SES on brain development, including abstraction as a product of development including affective brain network involvement. Research projects should involve cognitive and affective measures as outcomes and should occur in authentic learning environments.

R2: Study on student affect should incorporate subject-area, as well as design-focussed, measures of student engagement. Such measures should feature pre- and post-intervention measures to provide a rich account of student attitudes in response to multimedia research interventions.

R3: Multimedia learning research should be inclusive of participants representing a wide range of social backgrounds. Social background should be defined to include objective and subjective socioeconomic status, and as a representative sample, should include a wide range of ethnicities and other student groupings to enhance the generalisability of findings.

6.5.2 Recommendations for administrative purposes

A1: Funding should be directed towards the creation of multimedia learning texts, such as graphic novels. These resources should be implemented in schools regardless of sector or location.

A2: Awareness of SES-mediated brain plasticity, and educational interventions, should be implemented in school leadership. Early intervention for low SES students in strengthening leadership to drive school improvement should also be promoted in order to circumvent poor educational outcomes in later years of schooling.

A3: In-service professional development opportunities should be provided for teachers to develop their understanding, use and design of contextualised multimedia resources.

A4: Attitudinal measures, designed to monitor ongoing student engagement with textual modality-defined subject area learning resources, should be implemented.

A5: Rich measures of contextual and subjective socioeconomic status for individual student identification and tracking should be implemented.

6.5.3 Recommendations for material design

D1: Paper-based learning resources featuring socially salient stimuli with clear referential cues between text and visual entity should inform science learning text design. Science learning text should ideally be presented in graphic novel format.

D2: Language usage in science learning texts should feature an unplanned / familiar communicative style. Sense-making should be accounted for in such text via the appropriate design and incorporation of locutionary and extra-locutionary factors in the accurate portrayal of normal communicative strategies.

D3: Scientific language should feature informational density at a commensurate grade-level difficulty, though with restricted degree of lexical density.

6.5.4 Recommendations for pedagogy

P1: In spoken or written presentation of scientific concepts, educators should emphasise the appropriate contextualisation of abstract information. Appropriate contextualisation includes historical and social frameworks including biological and non-biological agents where applicable.

P2: Assessment / revision or follow-up / auxiliary material should present the original context as initially presented during learning to exploit situational semantic processing.

P3: Learning materials should be used as student-paced resources (i.e. educators should avoid system-paced lessons if / when using computer-integrated or computer-assisted learning).

P4: Educators should deconstruct complex concepts into constituent elements. This involves devising situational contexts to reconstruct concepts in the avoidance of complex parts-to-whole inductive reasoning. This is in reference of the need to engage deductive reasoning in students with contextualised multimedia material as per the scientific method.

6.6 Significance of the study

This study provides a theoretical and methodological framework relevant for multimedia theorists and educational practitioners alike. The dominant model of cognition within multimedia learning with its characteristic architecture and physiology has been found inadequate to account for developmental as well as evolutionary processes and constraints. An alternative model, premised on embodied cognition and developmental plasticity, is favourable in its provision of a more holistic etiology and export to the entire population. This causal framework presents a joint synchronic and diachronic perspective in offering proximate functional and ultimate evolutionary answers to questions of learning behaviour. This thesis is novel in multimedia learning in being the first to explicitly link development with brain architecture, and in establishing subjective socioeconomic status as a reliable and valid predictor of cognitive patterns. Specifically, this thesis offers four main areas of significance:

1. Inclusion of an evolutionary component to an otherwise static view of cognitive processing;
2. Provision of a mechanistic model of cognition accounting for individual cognitive styles;
3. Identification of socioeconomic status as moderator of individual differences;
4. Guidelines for enhanced science learning in application of the derived conceptual model of cognition.

The following sections describe specific theoretical (Section 6.6.1), methodological (Section 6.6.2) and practical (Section 6.6.3) contributions of the study.

6.6.1 Theoretical contributions.

The research adopts a transdisciplinary approach in merging aspects of education with neuroscience. This accords with work by Usha Goswami and colleagues (Goswami, 2006; Goswami, 2008; Howard-Jones., et al, 2016) in cognitive developmental neuroscience and others in science education (e.g. Anderson et al., 2014; Petitto, 2009). Perhaps the most original transdisciplinary contribution this research offers is its identification of the learner as central to learning design. This is transdisciplinary in the sense that it involves a bidirectional relationship between the classroom and the laboratory in the identification and measurement of variables and data not normally present in either approach. For neuroscience, the derived conceptual model is enriched with important behavioural findings; for education, the conceptual model offers a terminology and methodology that transcends existing cognitive models. The reliance on an evolutionary / developmental approach, moreover, offers a parsimonious account of stimuli processing that precludes the need for ever more contrived learning effects in explaining experimental inconsistency. From a methodological perspective, this is common within multimedia learning, despite the obvious criticism that facts are simply being made to fit theory. Instead, stimuli processing can avoid the arbitrariness of computationalism via focus on developmental constraints that underlie cognitive limitations, of which social standing is a universal and persistent force. Multimedia learning has been critiqued in this thesis for its ever-growing cache of learning effects; the redefined Multimedia Principle in Section 6.3 stands as a possible unifying principle within the field. Success in this endeavour requires explicit delineation of social congruence and how this principle supersedes established principles currently associated with learning effects. Future approaches are advised to operationalise textual social congruence and apply this to learning materials. In risking an attitude of conceit, it is possible that following experimentation, established multimedia effects will be relegated to subsets of the redefined Multimedia Principle.

6.6.2 Methodological contributions.

With adoption of an embodied cognitive model such as that presented in this thesis, Multimedia Research findings are predicted to show less ambiguity. Postulation of contrived learning effects upon experimental heterogeneity may become redundant and larger effect sizes are assumed upon presentation of socialised learning materials. This reduction of methodological uncertainty will accompany appropriate focus on the learner's social background due to the strong association between this element of developmental plasticity and cognitive style. Conversely, experimental focus on design, task and outcome variates, as per current practice, are likely to contribute to a continuing state of confusion surrounding CTML learning principles. The other major methodological contribution this thesis makes is the importance of attitudinal data regarding the learning area in addition to design / task conditions as per multimedia learning research. This is of methodological significance given the essential role of the affective network in bridging perceptual and cognitive-regulatory processes. This factor is central to the conceptual model of this thesis and was thus presented as a primary recommendation for educational practice.

6.6.3 Practical contributions.

Significance of the study extends to guidelines for educators. Recommendations map to instructional design principles and are informed by theoretical explanations applicable to multimedia research as well as the classroom. Immediate school-level adoption of principles detailed in this thesis include identification of socioeconomic status and appropriate design and use of graphic novels in science education. This may reorient students towards science as a learning area where overt abstraction may otherwise limit meaningful engagement. In so doing, the thesis offers significance in potentially arresting the decline of Australian secondary students enrolling in senior science and other technical subjects.

6.7 Concluding Remarks

This research project has constructed and tested a model of cognition that has hitherto been lacking in the multimedia learning research literature. Moreover, it has situated its causal framework within an enduring feature of all societies - socioeconomic status. The importance of social standing is recognised within Australian legislation as a shaper of educational outcomes, a ‘socioeconomic achievement gap’ requiring targeted funding for equitable outcomes. This acknowledgement offers a timely reminder of the need to address the needs of low SES students and features as a key driver of this research. This final section offers a brief synopsis of the findings and recommendations for future research in the field of multimedia learning.

Middle school science learners showed gains in recall and transfer of complex scientific concepts when using multimedia learning resources. These resources were socialised to reflect congruent presentations of information, that is, biological and non-biological agents embedded within realistic environments. This was done to test the hypothesised association between cognitive style – and related abstractive ability – with degree of audio-visual integration. Audio-visual integration was defined as a continuum between completely de-socialised presentations featuring abstract textual and pictorial features, and highly socialised graphic novel presentations featuring text as speech-bubbles. Objective and subjective measure of socioeconomic status were added as covariates to test the assumption that social standing shapes cognitive style in abstractive ability. Abstraction was hypothesised to represent motivated learning conforming to globalised or localised processing, though susceptible to inhibitory dysfunction associated with hypothalamic-pituitary-adrenal (HPA) stress dysregulation. Subjective social standing emerged as a consistent and statistically significant covariate of science learning, though objective SES was excluded from the model. Overall, learning with socialised multimodal text was most beneficial for factual recall (knowledge and understanding) and transfer (application) type problems, though extends to evaluation type problems given observed statistical relationships in the analysis. Finally, it was observed from attitudinal data that students showed reliable gains in understanding, enjoyment and perceived importance of science as a result of using socialised texts, although such affective response may not extend to the learning area itself.

Suggestions for future research include (i) extension of embodied cognition in informing multimedia theory and (ii) modification to existing multimedia theory. In applying embodied cognition to multimedia theory, it is suggested that action representations be taught with appropriate situational cues to enhance memory consolidation and retrieval of abstract scientific concepts. This includes careful preparation of science concepts in learning material design. In short, holistic presentation of social and (inanimate) mechanical actors are essential for learner clarification of goal-directed actions in priming memory systems for efficient recall and transfer. Pertinent also to an appropriate transdisciplinary approach, is the use of functional imaging with use of educationally relevant material in determining multimodal neural processing. The conceptual model presented in this thesis could inform perceptual dysfunction in such a research approach. Another future research theme emerging from Section 2.3.4 is that of the dysconnectivity hypothesis explored in relation to chronic stress hormone insult. Executive function impairments inherent to connectivity between cerebellum and corticolimbic bodies may underlie cognitive styles hinted at though not explored fully in this thesis.

Within multimedia learning, the redefined Multimedia Principle is a provocation that deserves ongoing research. Grand unifying theories feature in the physical sciences and are probably equally attractive to social science researchers. Offering a unified multimedia principle suggests an equally omnipresent learning effect may be waiting detection. As stated, this is provocative though deserves attention given the ubiquity of social standing as a determinant of physical and mental development. Subsequent research should gauge the efficacy of socialised texts for learners, tested against all the programmatic, assessment, and contextual influence variables that have been used in multimedia research. This will either strengthen the claims made here or relegate them to a footnote in educational research

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APPENDIX 1

SUMMARISED FINDINGS OF MULTIMEDIA META-ANALYSES

Study	Ages / Education level	Purpose	Influence Variables	Framing Theory	Results
Reinwein (2012)	Senior primary school; junior high school; senior high school; technical institute; adult	**(A) Established multimedia effect.** Reassess modality effect via replication of Ginns (2005) study; widens scope of moderator variables	• Modality effect • Design variate (*pace of presentation*; *text length*; *verbal labelling*; *type of visualisation*; *decorative pictures*) • Learner variate (*age*) • Outcome variate (*transfer test; similar test; time on transfer test; subjective cognitive loading test*).	• Cognitive Load Theory • Cognitive Theory of Multimedia Learning	Results show a significant lowering of earlier estimates of effect size. Age and decorative pictures did not impact overall effect size. Confounding variables on Modality effect (e.g. Type of visualisation; Pace of presentation; Research group) identified in earlier research. Forces a reconsideration of the modality effect. Results from *Type of visualisation* and *Verbal labels* more easily interpreted as a split-attention effect.
Ginns (2006)	Junior primary school; senior primary school; junior high school; senior high school; technical institute; adult	**(A) Established multimedia effect.** To generalise previous results on split attention (spatial / temporal contiguity) across differing design, learner, and outcome characteristi cs.	• Spatial / temporal contiguity • Design variate (*element interactivity*; *type of information presentation*) • Outcome variate (*similar test; transfer test; both similar test and transfer test; time on transfer test)* • Broad field of study (*mathematics*; *science*; *engineering / technical*) • Learner variate (*Educational level*)	• Cognitive Load Theory • Cognitive Theory of Multimedia Learning	Results generally conform to existing research on reduction of extraneous cognitive load. Low element interactivity items showed lower than expected effect size compared with high element interactivity items.

Study	Ages/ Education level	Purpose	Influence Variables	Framing Theory	Results
Gegenfurtner et al. (2011)	Experts (x̄ = 26.54 years; SD = 7.38) Intermediates (x̄ = 23.65; SD = 7.27) Novices (x̄ = 22.99; SD = 3.95)	**(A) Established multimedia effect.** To test theory of long-term working memory, eye fixation patterns hypothesised to show expertise effects.	• Expertise fixation duration • Visualisation variate (static / dynamic; schematic; two-dimensional; dual-modality; text annotation) • Task variate (complexity; time-limited; user-control) • Domain variate (professional)	• Theory of long-term working memory. • Information-reduction hypothesis. • Holistic model of image perception. • Embedded cognition model.	Experts had shorter fixation durations, and enhanced fixation on task-relevant areas. Findings appear to discredit the limited capacity of working memory assumption of CTML and CLT, although are represented within the prior knowledge principle (Mayer, 2009) and expertise reversal effect (Sweller et al., 2011) as boundary conditions. Instructional implications include expert modelling for novices, procedural insights, and affective / cognitive improvements in mapping expert attentional resources in learning visual information.
Richter et al. (2015)	Primary / middle school; high school; university; vocational training.	**(A) Established multimedia effect.** To determine effectiveness of signalling between textual components, as well as identification of potential boundary conditions.	• Signals cueing visual and textual correspondence • Outcome variate (*transfer; far transfer; comprehension; problem solving*) • Hypothesised boundary conditions (*Domain-specific prior knowledge; material pacing; pictorial format; mapping requirements; signal distinctiveness*).	• Cognitive Theory of Multimedia Learning • Cognitive Load Theory	Debate over strength of signalling as an effect following small to medium overall effect. Degree of prior knowledge showed a significant difference in favour of low / medium prior knowledge learners. This was the sole included moderator found to exert an effect on textual signalling.

Study	Ages/ Education level	Purpose	Influence Variables	Framing Theory	Results
Adesope & Nesbit (2012)	K-3; 1-2; 2-6; 7; 8-9; 10; 8-12; Post-secondary	**(A) Established multimedia effect.** Assess verbal redundancy as feature of auditory and visual congruency. Examine potential learner / material characteristics as moderating variables.	• Concurrent spoken-written, spoken-only, and spoken-written presentations • Outcome variate (*transfer; recall, response time*) • Learner variate (*education level*; *reading fluency*; *prior domain knowledge*) • Design variate (*presentation pacing*; *degree of audio and textual congruence*; *presence of images*)	• Cognitive Load Theory • Dual processing Theory of Multimedia Learning (DPTML) - Cognitive Theory of Multimedia Learning	Small effect with large heterogeneity found for the investigated effect. Spoken–written presentations outperformed spoken-only presentations, while outcomes did not differ between spoken–written and written-only presentations. Spoken–written presentations showed advantage for low prior knowledge learners, system-paced learning materials, and picture-free materials.
Ginns (2005)	Junior primary school; senior primary school; junior high school; senior high school; adult; technical institute	**(A) Established multimedia effect.** To establish effectivenes s of visual / auditory presentation of instructional material.	• Modality effect • Design variate (*level of element interactivity; pacing of presentation; form of multiple modality presentation*) • Outcome variate (*similar test; transfer test; dual task performance; time to solution on transfer test; subjective rating of cognitive load)* • Learner variate (*age group*) • Broad field of study (*mathematics / logic*; *science*; *engineering, social science; English comprehension*) • Type of testing (*individual / >1*)	• Separate streams hypothesis • Cognitive Load Theory • Cognitive Theory of Multimedia Learning	Overall moderate to large effect size for modality effect. All major hypotheses supported (i.e. design, outcome, learner variates) with overall modality effect moderated by element interactivity (with larger effects for low rather than high element interactivity). Pacing of presentation likewise moderated the modality effect, with larger effects for the system-paced condition.

Study	Ages/ Education level	Purpose	Influence Variables	Framing Theory	Results
Yue et al. (2013)	No participants	**(B) Multimedia resources** To assess the design of multimedia resources in medical training adhering to CTML principles.	• Multimedia learning principles (managing essential processing; minimising extraneous processing; facilitating generative processing)	• Cognitive Theory of Multimedia Learning	Animations in medical training average 48.4% across all eight CTML principles, and range between 7.7% (*pre-training principle*) to 92.4% (*spatial contiguity principle*).
Hoffner & Leutner (2007)	Student; undergraduate; recruit; adult.	**(B) Multimedia resources** To assess whether instructional animation provides better learning outcomes than static pictures.	• Dynamic / static visualisation • -Design variate *(video / computer based; realism; representational / decorational; annotated with coherent text; signaling cues*) • Outcome variate (*instructional domain; knowledge-type; time on task*) • Learner variate (*educational level*) • Other (*year of publication; sample size*)	• Cognitive Theory of Multimedia Learning	The findings reveal a medium-sized overall advantage of instructional animations versus static pictures. Representational animation was superior to decorative animation, although decorational visualisations did not differ. Animations were found to significantly moderate requested knowledge in procedural-motor knowledge, declarative knowledge, and to a lesser extent, transfer knowledge.

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Study	Ages/ educational level	Purpose	Influence variables	Framing theory	Results
Rolfe & Gray (2012)	Year 1, 2, 3 undergraduate; pre-clinical medicine; pharmacy / nursing	**(B) Multimedia resources** Evaluation of effectiveness of multimedia resources in life science education.	• Outcome variate (drawing test; identification test; terminology test; comprehension test) • Enhancement variate (audio / narration; chunking strategy; scaffolding; advance organiser)	• Cognitive Theory of Multimedia Learning • Dual coding theory	Generally positive, though unequal, results of embedded multimedia in 10 from 16 comparisons. Significant post-test results dominated the findings, while long-term retention generally favoured control conditions in all conditions except graphic vs animation short view. Conclusions drawn for Cognitive Theory of Multimedia Learning in terms of specific outcomes and interactions between learner and animation.
Gegenfurtner et al. (2014)	Professional employees (mean age 21.40 years old; SD = 2.84)	**(B) Multimedia resources** Evaluation of digital simulation design characteristics in aiding transfer and self-efficacy amongst learners.	• Self efficacy / learning transfer • Design variate (*scenario; player perspective; fantasy; timing of the simulation; modality; realism; dimensionality*) • Learner variate (*number of players; team context*) • Outcome variate (*timing of assessment; level of assessment; safety of assessment*) • Adaptivity variate (increase of difficulty level; rule rigidity; possibilities to end the simulation)	• Social cognitive theory • Cognitive Theory of Multimedia Learning	Moderate relationship between self-efficacy and learning transfer, although high heterogeneity indicative of three major moderating effects. These include task-related efficacy beliefs: user-control of difficulty; immediate feedback; and thirdly, self-efficacy and transfer population correlation estimates were unaffected by social, narrative or multimedia characteristics. Results suggest a tentative validation of social cognitive theory, while CTML principles are questioned for their validity in digital simulation design.

Study	Ages/ educational level	Purpose	Influence variables	Framing theory	Results
Lin et al. (2007)	Exclusively college-aged participants.	**(B) Multimedia resources** Evaluation of enhancement strategies used with animated instruction.	• Outcome variate (20-item criterion test: Drawing Test; Identification Test; Terminology Test; Comprehension Test) • Enhancement variate (audio /narration; chunking strategy; scaffolding; advance organiser)	• Cognitive Theory of Multimedia Learning • Cognitive load theory • Meaningful learning • Assimilation theory	Results showed inconsequential or negative moderation across outcome tests, irrespective of the enhancement strategy or animation feature/s. Suggestions for enhancement strategy usage aligned with cognitive resource principles of CLT / CTML.
Pearson et al. (2005)	6th, 7th, 8th grade learners	**(C) Reading enhancement** To assess the usage of digital technologies in aquisition of advanced reading strategies.	• Outcome variate (reading comprehension) • Programmatic variate (meaning-focussed / code-focussed) • Assessment variate • Contextual variate (student undifferentiated / differentiated; study-size; study-duration; policy-focus)	• Cognitive Theory of Multimedia Learning	Moderate to strong effect of digital technology usage on comprehension (only one of five original reading variates coded for analysis). Contextual differences observed between undifferentiated middle school students versus struggling readers. Short study duration was associated with greater comprehension gains, although policy focus did not moderate results.

Study	Ages/ educational level	Purpose	Influence variables	Framing theory	Results
Takacs et al. (2015)	Pre-school aged learner; elementary-aged learner.	**(C) Reading enhancement** Evaluation of technology-enhanced stories versus auditory stories for young learners.	• Multimedia-only; Interactive-multimedia; Interactive-only • Outcome variate (*Story comprehension; Vocabulary learning; Code-related literacy skills; Child engagement and communication during reading*) • Design variate (*congruent features; interactive features*) • Learner variate (*overall; disadvantaged; non-disadvantaged*)	• Cognitive Theory of Multimedia Learning	Small to moderate gains with usage of technology-enhanced stories in all outcome variates. Additional differences detected between disadvantaged and non-disadvantaged children, although no further analysis possible. Multimedia-only presentations were found to be beneficial in comparison with both multimedia-interactive, and interactive-only presentations. Disadvantaged learners saw even greater benefits with multimedia-only presentations, and an enhanced distinction between multimedia versus interactive stories.
Ginns et al. (2013)	Junior high school; senior high school; college; mixed levels of adult education.	**(C) Reading enhancement** Assessment of personalisation principle in instructional material design.	• Outcome variate (retention; friendliness; transfer; effective processing) • Design variate (conversational style; computer / paper based) • Contextual variate (publication type; language of instruction; pacing of instruction; length of learning phase; broad field of study) • Learner variate (educational level; prior knowledge levels)	• Cognitive Theory of Multimedia Learning • Cognitive Load Theory	Use of conversational style results in moderate, positive effect size in outcome and perception of friendliness. Learning assistance and learner interest was not statistically associated with this perception of friendliness, however, unlike that of most other operationalisations. Nonetheless, the ‘implied conversation’ of personalised learning materials is felt to offer cognitive processing benefits irrespective of learner interest.

APPENDIX 2

MSSAT PRE-TEST INSTRUMENT – YEAR 7

SCIENCE REVIEW QUIZ **YEAR 7** **chemistry and physics**

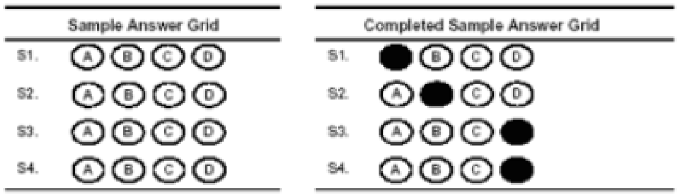
NAME: ______________________

CLASS: ______________________

TEACHER: ______________________

DIRECTIONS: ANSWER ON THE PROVIDED ***ANSWER SHEET***:

— Pick the appropriate answer and shade it in as below —



PART A) SCIENCE KNOWLEDGE AND UNDERSTANDING:

KU 1) Weight is a force and is measured in:

a) newtons

b) kilograms

c) joules

d) metres

KU 2) Where would you feel heaviest?

a) floating in space

b) the moon

c) the earth

d) all would feel the same

KU 3) If gravity pulls you towards the centre of the Earth, why don't you fall through the ground?

a) gravity stops as soon as it hits the surface of the earth

b) the ground exerts an equal and opposite force to gravity

c) gravity cannot travel through solid objects

d) gravity doesn't have enough energy to pull you through the ground

KU 4) Which is not a force:

a) friction

b) weight

c) height

d) magnetism

SCIENCE REVIEW QUIZ **YEAR 7** **chemistry and physics**

KU 5) When an object is at rest/stationary:

a) There is just one force acting on it, gravity

b) There are no forces acting on it

c) There are forces acting on it but these forces are balanced

d) There is just one force acting on it, air resistance

KU 6) Sugar is added to water:

a) Water is the **solvent**; sugar is the **solute**; together they form a **solution**

b) Water is the **solute**; sugar is the **solution**; together they form a **solvent**

c) Water is the **solution**; sugar is the **solute**; together they form a **solvent**

d) Water is the **solvent**; sugar is the **solution**; together they form a **solute**

KU 7) In a mixture containing water, salt, and iron:

a) in this order: you would separate the components with **filtration**; **magnetism**; **evaporation**

b) in this order: you would separate the components with **magnetism**; **filtration**; **evaporation**

c) in this order: you would separate the components with **evaporation**; **filtration; magnetism**

d) in this order: you would separate the components with **filtration**; **evaporation; magnetism**

KU 8) In a solution which do you typically have more of?

a) the solute

b) the solvent

c) neither of these

d) equal amounts

KU 9) What is solubility?

a) The ability of a given substance (solute) to dissolve into a solvent.

b) The ability of a given substance (solvent) to dissolve into a solute.

c) The ability of a mixture to be separated

d) The tendency of a mixture to remain as a mixture

KU 10) How does temperature affect solubility?

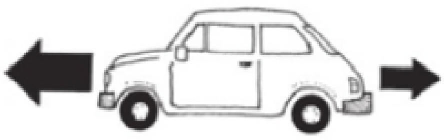
a) Solubility is not affected by temperature.

b) Solubility decreases with an increase in temperature.

c) Solubility cannot be affected by temperature as is a physical property

d) Solubility increases with an increase in temperature.

PART B) SCIENCE APPLICATION



SA 1) Look at the forces acting on the car

a) The car will slow down

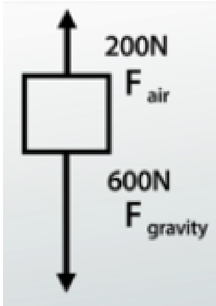
b) The car will continue to travel at the same speed

c) The car will speed up

d) The car will stop

SCIENCE REVIEW QUIZ **YEAR 7** **chemistry and physics**

SA 2) What is the NET FORCE acting on this object:



a) 800 N

b) 200 N

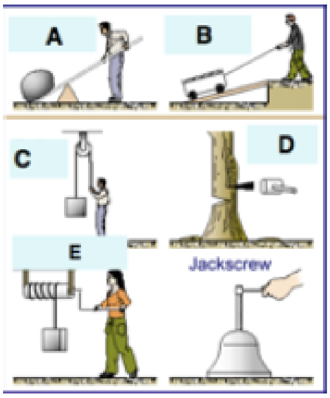
c) -400 N

d) 400 N

SA 3) name the simple machines (diagram below):

a) A - PULLEY; B - LEVER; C - WEDGE D - INCLINE PLANE

b) A - LEVER; B - INCLINE PLANE; C - PULLEY: D - WEDGE



c) A - INCLINE PLANE; B - LEVER; C - WEDGE D - PULLEY

d) A - LEVER; B - WEDGE; C - INCLINE PLANE D - PULLEY

SA 4) A man of 90kg exerts approximately:

a) 900 N

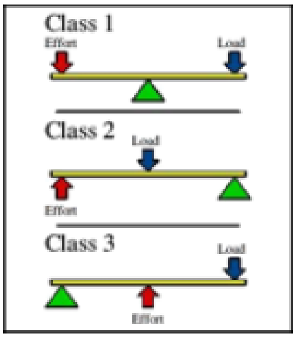
b) 900 N

c) 90 N

d) 9000 N

SA 5) A wheelbarrow:

wheelbarrow

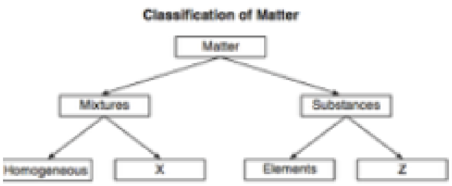


a) is an example of a class 1 lever

b) is an example of a class 2 lever

c) is an example of a class 3 lever

d) is a combination of a class 2 and 3 lever



SA 6) Classification of matter

a) X - heterogenous; Z - molecule

b) X - heterogenous ; Z - colloid

c) X - heterogenous ; Z - atom

d) X - heterogenous; Z - compound

SA 7) What is the easiest way to separate sand and water?

a) Filtration

b) Distillation

c) Chromatography

d) Boiling point

SA 8) Cookies and cream ice cream would be classified as

a) A homogenous mixture

b) A heterogenous mixture

c) An element

d) A compound

SA 9) Helium would be classified as

a) A homogenous mixture

b) A heterogenous mixture

c) An element

d) A compound

SA 10) Two elements chemically combined defines

a) A homogenous mixture

b) A heterogenous mixture

c) An element

d) A compound

PART C) SCIENCE ANALYSIS AND EVALUATION

SAE 1) In an experiment:

a) the independent variable is the input variable; the dependent variable is the output variable you measure; the control variables are variables that you keep the same in a fair test.

b) the dependent variable is the input variable; the independent variable is the output variable you measure; the control variables are variables that you keep the same in a fair test.

c) the independent variable is the input variable; the control variable is the output variable you measure; the dependent variables are variables that you keep the same in a fair test.

d) the control variable is the input variable; the dependent variable is the output variable you measure; the independent variables are variables that you keep the same in a fair test.

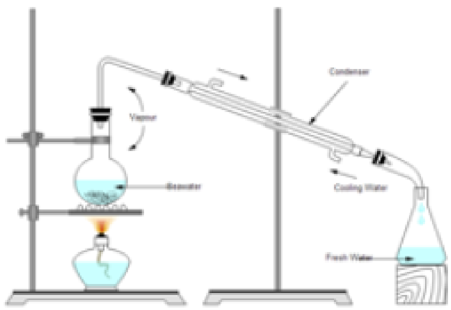
SAE 2) desalination is:

a) the adding of a solute to a solution

b) the removal of a solute from a solution

c) the mixing of two solutions

d) the adding of a solvent to a heterogenous mixture



SAE 3) Limitations of desalination as an alternative water-supply source include all of the following except:

a) higher energy costs

b) creates a wastewater disposal problem

c) seawater is not abundant on planet Earth

d) desalination processes are not very cost-effective

QUESTIONS 4,5,6 REFER TO THE DIAGRAMS BELOW:

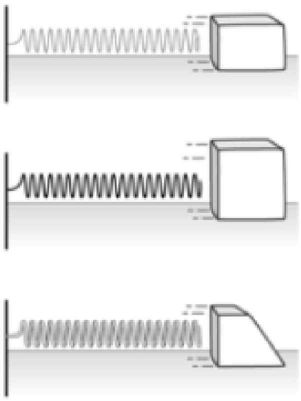


Table: Results of spring launch experiment	
Thickness of Spring	Average Distance of launched block.
thin spring	20 cm
medium spring	24 cm
thick spring	31 cm

SAE 4) A class was going to build a device that launched blocks by using a spring. They wanted to find out which spring of the three available would launch a block the furthest. They had three different shaped blocks they were testing, each with the same footprint. They kept the distance the spring was compressed the same. The blocks were launched on the same surface.

a) This experiment is a fair test because all variables were carefully measured.

b) This experiment is a fair test because the spring was pulled back the same amount each time.

c) This experiment is not a fair test because the launched blocks traveled different distances.

d) This experiment is not a fair test because different shaped blocks were used.

SAE 5) A fair test is:

a) an experiment in which only the independent and dependent variables are allowed to change and all other variables and conditions are kept the same.

b) a statement based on past experience that can be proved or disproved by experimental or observational evidence.

c) a question about what happens when the independent variable changes

d) an experiment in which many variables are tested and involves a question, collection of data, and repeated trials.

SAE 6) Evidence collected in an experiment is:

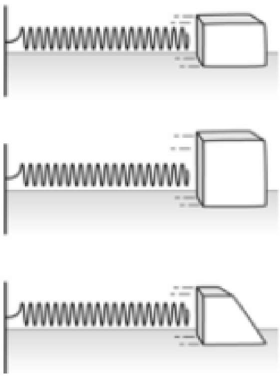
a) the data collected by the investigator

b) an experiment in which only one variable is tested at a time

c) a statement based on past experience that can be proved or disproved by experimental or observational evidence.

d) a question about what happens when the independent variable changes.

QUESTIONS 7 and 8 REFER TO THE DIAGRAM BELOW:



A class is building a device that uses a spring to launch blocks. They have three different shaped blocks. They needed to choose one block to use in their device. They wanted the block that would slide the farthest. The students designed an experiment to measure how the block shape affected the distance the block traveled after it was launched. They conducted a fair test and obtained the following data.

SAE 7) What is the independent variable?

a) The distance the spring is pulled back

b) The spring thickness

c) The block shape

d) The distance the launched block travels

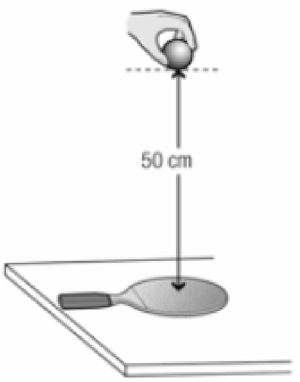
SAE 8) What is the dependent variable?

a) The block shape

b) The distance the spring is pulled back

c) The distance the launched block travels

d) The spring and the block shape



QUESTIONS 9 and 10 REFER TO THE DIAGRAM BELOW:

Antonia is a ping-pong player. She wants to find out which brand of ping-pong ball is the best to use. She has three different brands of ping-pong balls. She devises an experiment in which she drops each ball from a height of 50 cm above her paddle, which is resting on the ping-pong table. She then measures the height of the bounce. The higher the bounced ball reaches, the better the ball. Below is her data.

SAE 9) What is the dependent variable in Antonia's experiment?

a) height from which the ping pong ball is dropped

b) the height the ping pong ball bounces after being dropped

c) the size of the ping pong bat

d) the brand of ping pong ball

SAE 10) What is the independent variable in Antonia's experiment?

a) height from which the ping pong ball is dropped

b) the height the ping pong ball bounces after being dropped

c) the size of the ping pong bat

d) the brand of ping pong ball

APPENDIX 2 (cont.)

MSSAT PRE-TEST INSTRUMENT – YEAR 8

SCIENCE REVIEW QUIZ **<u>YEAR 8</u>** **TERM 2: CHEMISTRY / PHYSICS**

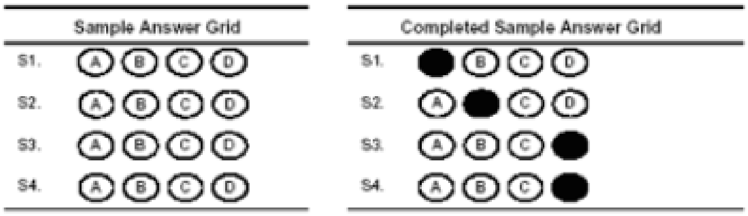
NAME: ______________________

CLASS: ______________________

TEACHER: ____________________

DIRECTIONS: ANSWER ON THE PROVIDED ***<u>ANSWER SHEET</u>***:

— Pick the appropriate answer and shade it in as below —



PART A) SCIENCE KNOWLEDGE AND UNDERSTANDING:

KU 1: The particle theory of matter:

a) demonstrates the importance of chemistry

b) explains the properties of the states of matter

c) shows how most objects are made of tiny particles

d) demonstrates how particles slow down when exposed to heat

KU 2) Three major safety hazards in the laboratory are:

a) chemical; cuts / burns; biological

b) acids / bases; chemical; breakage

c) physical; chemical; heat

d) biological; physical; chemical

KU 3) three examples of physical properties of materials are:

a) pH; melting point; boiling point

b) colour; mass; volume

c) rusting; pressure; tension

d) flammability; density; hardness

KU 4) Chemical changes:

a) are always reversible and involve phase changes

b) involve chemical reactions in matter and help scientists classify materials

c) are the basis of separating mixtures

d) only occur in metals

KU 5) Physical properties can be observed and measured without changing the substance's:

a) appearance

b) composition

c) state

d) mass

KU 6) Two major forms of energy are:

a) potential and kinetic

b) mechanical and kinetic

c) potential and nuclear

d) chemical and physical

KU 7) Three examples of kinetic energy include:

a) radio waves; sound waves reaching your ear; a rock held above your head

b) light; wind; a bullet fired from a gun

c) a coiled spring; a charged battery; energy in a dead animal's flesh

d) feeling the warmth from a fire on your face; fruit falling from a tree; static electricity

KU 8) Simple machines:

a) change the direction or size of a force; an example is a bicycle

b) change the direction or size of a force; an example is a lever

c) increase the amount of force required to do work; an example is a pair of scissors

d) are never found by themselves; an example is a car

KU 9) An energy transfer:

a) occurs when one form of energy changes into another form of energy

b) occurs when energy moves between two objects and increases the total amount of energy

c) occurs when energy passes from one system to another and includes heating and movement

d) occurs all around us such as when sunlight is converted to sugars in plants

KU 10) An energy transformation:

a) occurs when one form of energy changes into another form of energy

b) occurs when energy moves between two objects and increases the total amount of energy

c) occurs when energy passes from one system to another and includes heating and movement

d) occurs all around us such as when a moving object hits another object and moves it

PART B) SCIENCE APPLICATION

SA 1) A scientist wants to measure the space between water particles. Rank in order from smallest to largest:

a) Gases, liquids, solids

b) Solids, liquids, gases

c) Liquids, gases, solids

d) Solids, gases, liquids

SA 2) The burn we receive from H_2O will be most severe:

a) if we come into contact with water as a hot liquid as the particles are moving the fastest

b) if we come into contact with water as a hot gas as the particles are moving the fastest

c) if we come into contact with water as a solid as the particles are moving the fastest

d) if we come into contact with water as a hot liquid as the particles are moving the slowest

SA 3) A student wants to prepare a scientific experiment as an example of a chemical change. Pick the appropriate experiment.

a) melting an ice cube containing red food dye

b) sublimating dry ice

c) iron and oxygen forming rust

d) dissolving sugar and water

SA 4) An example of three energy transfers is:

a) heat from fire —> heated pot handle —> burn to hand

b) sunlight to plant —> sugar in plant forms fossil fuel—> fossil fuel powers car

c) stored energy in battery —> battery powers radio —> radio waves travel to your ear

d) a hair dryer blows wind —> wind moves hair —> hair heats up

SA 5) Joules are units of ______ and are equal to: ___________

a) velocity; 1 kg $\times$ m $\div$ s

b) energy; 1 kg $\times$ m^2 $\div$ s^2

c) force; 1 kg $\times$ m $\div$ s^2

d) direction; 1 kg $\times$ m^2

SA 6) Calculate the approximate amount of energy in joules and kilojoules if a rock weighing 50kg sits 100 metres above the ground (gravity = approximately 10m/s^2)

a) 500 J / 5 kJ

b) 50,000 J / 500 kJ

c) 5000 J / 50 kJ

d) 50,000 J / 50 kJ

SA 7) A box has a mass of 9 kg. The box is lifted from the garage floor and placed on a shelf. If the box gains 180 J of Potential Energy, how high is the shelf? (gravity = approximately 10m/s^2)

a) 6m

b) 2m

c) 2.4m

d) 20cm

SA 8) A man climbs on to a wall that is 4.6m high and gains 4232J of potential energy. What is the man's mass? (gravity = approximately 10m/s^2)

a) 92kg

b) 85kg

c) 9.2kg

d) 78kg

SA 9) A skateboarder has a mass of 55kg, and a velocity of 45km/h.

a) Kinetic energy of the skateboarder given by MV^2 = 111.38 kJ

b) Kinetic energy of the skateboarder given by $2MV^2$ = 222.75 kJ

c) Kinetic energy of the skateboarder given by 1/2 MV^2 = 55.69 kJ

d) Kinetic energy of the skateboarder given by 1/2 M^2V = 3062.8 kJ

SA 10) A car has 470,020 kJ of energy and weighs 950 kg. What is the velocity?

a) 120 m/h

b) 240 km/h

c) 120 km/h

d) 7200 km/h

PART C) SCIENCE ANALYSIS AND EVALUATION

SAE 1) A container of olive oil was placed in the refrigerator and became solid:

a) This occurred due to the bonds between molecules becoming more excited and breaking apart

b) This occurred due to the bonds between molecules becoming more excited and forming stronger bonds

c) This occurred due to the bonds between molecules becoming less excited and breaking apart

d) This occurred due to the bonds between molecules becoming less excited and forming stronger bonds

SAE 2) The following graph shows newly discovered elements:

	Element	Melting Point (ºC)	Boiling Point (ºC)	Solid? Liquid? Gas?
a	Xyggium	-189	-186	
b	Zrttord	714	1640	
c	YYrtesium	-39	357	
d	Caetriol	44	280	

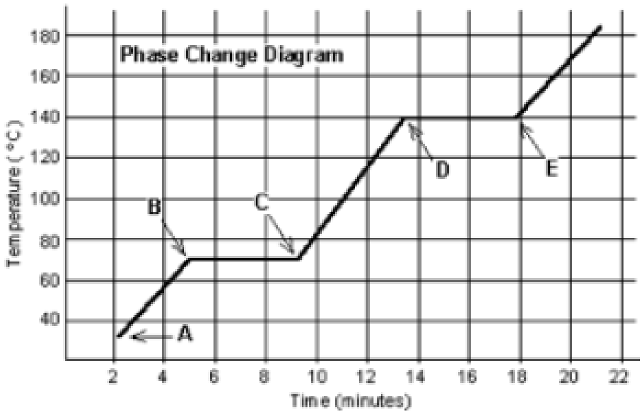
a) at room temperature: Xyggium is a gas; Zrttord is a solid; YYrtesium is a gas; Caetriol is a solid

b) at room temperature: Xyggium is a gas; Zrttord is a solid; YYrtesium is a liquid; Caetriol is a solid

c) at room temperature: Xyggium is a solid; Zrttord is a solid; YYrtesium is a gas; Caetriol is a solid

d) at room temperature: Xyggium is a gas; Zrttord is a solid; YYrtesium is a gas; Caetriol is a solid

SAE 3) A student draws a graph in the laboratory: Choose the correct response.



a) between Points A and B the substance is a liquid

b) beyond point E the substance is a liquid

c) The substance's boiling point is 140 degrees °C

d) The substance is most likely water

SAE 4) A student wants to conduct an experiment on energy efficiency of a light bulb. Which are the correct variables?

a) Independent variable/s: **Time** Dependent variable/s: **temperature of light bulb**; Control variable/s: **colour of bulb; type of bulb**

b) Independent variable/s: **colour of bulb; type of bulb;** Dependent variable: **Time**; Control variables: **temperature of light bulb**;

c) Independent variable/s: **Time** Dependent variable/s: **colour of bulb; type of bulb**; Control variable/s: **temperature of light bulb**

d) Independent variable/s: **temperature of light bulb** Dependent variable/s: **colour of bulb; type of bulb**; Control variable/s: **Time**

SAE 5) What happens to the viscosity of a liquid when its temperature is raised?:

a) The viscosity of the liquid increases.

b) The viscosity of the liquid stays the same

c) The viscosity of the liquid decreases

d) The temperature of a liquid does NOT raise

SAE 6) In an experiment on rate of diffusion two students disagree about the experiment's design. Choose the appropriate variables:

a) Independent variable/s: **temperature of substance;** Dependent variable/s: **amount of substance**; Control variable/s: **rate of diffusion**

b) Independent variable/s: **rate of diffusion;** Dependent variable/s: **amount of substance**; Control variable/s: **temperature of substance**

c) Independent variable/s: **rate of diffusion;** Dependent variable/s: **temperature of substance**; Control variable/s: **amount of substance**

d) Independent variable/s: **temperature of substance**; Dependent variable/s: **rate of diffusion**; Control variable/s: **amount of substance**

SAE 7) In a diagram on a RUBE GOLDBERG machine a student wants to show the following changes of energy: AA BATTERY —> TOY CAR MOVING —> TURNING ON STEREO. Choose the correct energy types:

a) chemical kinetic energy —> mechanical kinetic energy —> sound kinetic energy

b) chemical potential energy —> mechanical potential energy —> sound potential energy

c) chemical potential energy —> kinetic potential energy —> sound kinetic energy

d) chemical potential energy —> mechanical kinetic energy —> sound kinetic energy

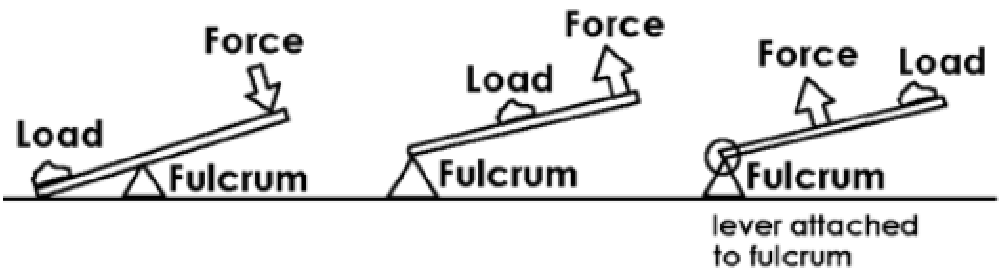
SAE 8) A student wants to demonstrate types of levers with a poster:

a) lever 1 = **first class lever**; lever 2 = **third class lever**; lever 3 = **second class lever**

b) lever 1 = **first class lever**; lever 2 = **second class lever;** lever 3 = **third class lever**

c) lever 1 = **third class lever;** lever 2 = **second class lever;** lever 3 = **first class lever**

d) lever 1 = **second class lever;** lever 2 = **first class lever**; lever 3 = **third class lever**



lever 1 lever 2 lever 3

SAE 9) Chemical potential energy in food can be directly measured:

a) With a bomb calorimeter which measures the temperature change of water

b) By measuring the mass of food and eating it

c) By conducting electricity through food and measuring the conductivity

d) By using an acid to determine how strong the chemical bonds in the food are

SAE 10) In an experiment calculating the efficiency of chemical potential energy between herbivores and carnivores, it was noted that most available energy was lost. Where did it go? Choose the most appropriate answer.

a) it was mostly lost in digestion

b) it was mostly lost in respiration

c) it was mostly lost as heat

d) it was mostly lost as kinetic energy in movement

APPENDIX 2 (cont.)

MSSAT PRE-TEST INSTRUMENT – YEAR 9

SCIENCE REVIEW QUIZ **YEAR 9** **TERM 2: BIOLOGY / PHYSICS**

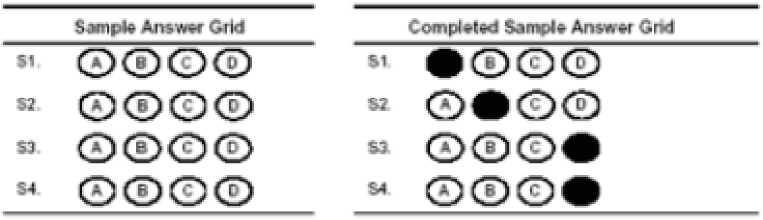
NAME: ______________________

CLASS: ______________________

TEACHER: ______________________

DIRECTIONS: ANSWER ON THE PROVIDED *ANSWER SHEET*:

— Pick the appropriate answer and shade it in as below —



PART A) SCIENCE KNOWLEDGE AND UNDERSTANDING:

KU 1: Choose the correct order of magnitude (Size)

a) Cells, tissue, organs, organ systems, organism, population, community, ecosystem

b) Cells, tissue, organs, organ systems, organism, community, population, ecosystem

c) Tissue, cells, organs, organ systems, ecosystem, organism, population, community

d) Cells, organs, tissue, organ systems, organism, population, community, ecosystem

KU 2) Homeostasis:

a) refers to the body's ability to digest nutrients and assimilate macronutrients into cells

b) refers to the body's ability to fight disease

c) refers to growth, survival and reproduction

d) refers to the body's ability to maintain stability

KU 3) What are the missing body systems:

MURDERS LINC: muscular, urinary, reproductive, _________, _________, respiratory, lymphatic, integumentary, nervous, _________

a) digestive, endothermic, circulatory

b) digestive, endocrine, circulatory

c) digestive, endonatrium, circadian

d) sensory, exocrine, immune

KU 4) Negative feedback loops:

a) help return the body to normal by reducing the magnitude (size) of a particular variable

b) help return the body to normal by increasing the magnitude (size) of a particular variable

c) are harmful as they reduce our capacity to fight high temperatures or high blood sugar levels

d) are harmful to the body compared with positive feedback loops

KU 5) Thermoregulation in homeostasis:

a) receptor organ/s: **hypothalamus;** effector organ/s: **sweat glands / skin blood vessels**; **Thermoregulation is an example of negative feedback**

b) receptor organ/s: **pancreas;** effector organ/s: **hypothalamus**; **Thermoregulation is an example of positive feedback**

c) receptor organ/s: **hypothalamus;** effector organ/s: **kidneys, brain**; **Thermoregulation is an example of negative feedback**

d) receptor organ/s: **liver**; effector organ/s: **muscles; blood vessels; Thermoregulation is an example of positive feedback**

KU 6) Heat can be transferred in three ways:

a) Chemical reactions; nuclear decay; physical changes

b) radiation; sunlight; nuclear decay

c) radiation; insulation; convection;

d) radiation; conduction; convection

KU 7) What is the term for the amount of reflected light from a surface?

a) albedo

b) refraction

c) absorbance

d) insulation

KU 8) In houses:

a) Series circuits are used as they maximise energy flow to devices

b) Series circuits are used as they are not affected by gaps in circuits

c) Parallel circuits are used as they are not affected by gaps in circuits

d) Parallel circuits are used as they maximise energy flow to devices

KU 9) Volts, current, and resistance

a) Voltage are measured in **volts:** current in **ohms;** resistance in **amps**.

b) Voltage are measured in **volts:** current in **amps**: resistance in **ohms**.

c) Voltage are measured in **amps**: current in **ohms**: resistance in **volts**.

d) Voltage are measured in **ohms**: current in **volts**: resistance in **amps**.

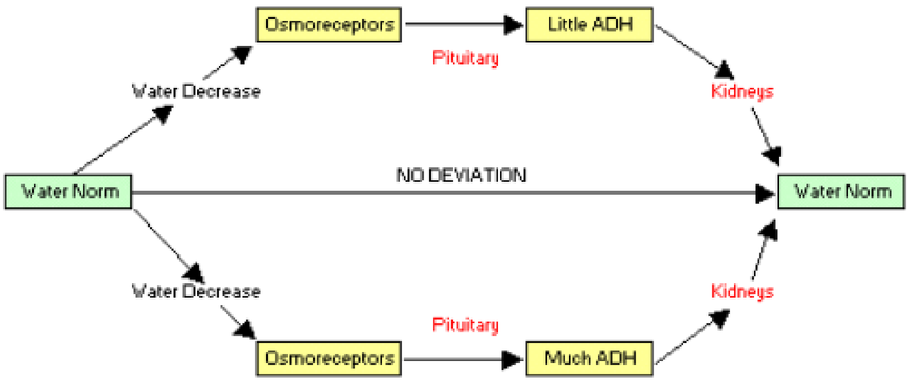
KU 10) Electrical power is measured in watts. In an electrical system power (P) is equal to the ______ multiplied by the ______.

a) current; voltage

b) voltage; current

c) resistance; current

d) voltage; ohms



PART B) SCIENCE APPLICATION

SA 1) Look at the diagram above: ADH is anti-diuretic hormone

a) When water levels are too low **more ADH decreases the absorption of water** in the kidneys

b) When water levels are too low **less ADH increases the absorption of water** in the kidneys

c) When water levels are too high **more ADH increases the absorption of water** in the kidneys

d) When water levels are too high **less ADH decreases the absorption of water** in the kidneys

SA 2) With high temperatures and high humidity:

a) Hyperthermia can occur due to the body's inability to produce sweat

b) Hyperthermia can occur due to the body's inability to cool by evaporative cooling

c) Hyperthermia can occur due to the inability of the kidneys to produce enough ADH

d) Hyperthermia can occur due to the inability of the pancreas to release insulin

SA 3) You are stuck on a desert island and want to keep your food cool. You find some materials and want to test them for their ability to insulate food items. Choose the most appropriate experimental variables:

a) Independent variable/s: **time left in sun** ; dependent variable/s: **temperature of water**; control variable/s: **time of day; weather**

b) Independent variable/s: **time left in sun**; dependent variable/s: **time of day; weather**; control variable/s: **temperature of water**

c) Independent variable/s: **temperature of water** ; dependent variable/s: **time left in sun**; control variable/s: **time of day; weather**

d) Independent variable/s: **time of day; weather**; dependent variable/s: **temperature of water**; control variable/s: **time left in sun**

SA 4) You have been asked to describe glucoregulation in simple terms. The best response would be:

a) glucoregulation is the **control of body temperature**; the **hypothalamus** detects the temperature of the blood; **muscles contract (shiver) if temperatures are too low** and **blood vessels dilate if temperatures are too high**

b) glucoregulation is the **control of blood sugar**; the **hypothalamus** detects the pressure of water in the blood; **vasopressin is released if the pressure is too low** and **ADH is released if the pressure is too high**

c) glucoregulation is the **control of blood sugar**; the **hypothalamus** detects the amount of blood sugar; **insulin is released if too much sugar is present** and **glucagon is released when too little blood sugar is present**

d) glucoregulation is the **control of blood sugar**; the **hypothalamus** detects the amount of blood sugar; **insulin is released if too little sugar is present** and **glucagon is released when too much blood sugar is present**

SA 5) Control variables

a) can potentially become dependent variables and are controlled by removing them from the study

b) can potentially become independent variables and are controlled by removing them from the study

c) can potentially become dependent variables and are controlled by including them in the study

d) can potentially become independent variables and are controlled by including them in the study

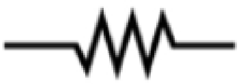
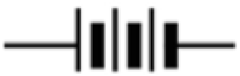
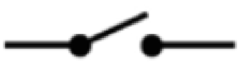
SA 6) Look at the symbols below:

a) symbol A) **NAME**: resistor **DESCRIPTION**: increases current flow

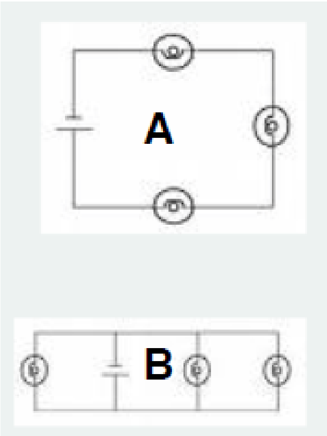
b) symbol B) **NAME**: Ammeter **DESCRIPTION**: Measures electric current

c) symbol C) **NAME**: Inductor **DESCRIPTION**: Generates constant voltage

d) symbol D) **NAME**: Switch **DESCRIPTION**: A/C voltage source

Symbol	Name	Description
	A	
	B	
	C	
	D	

SA 7) Look at the circuits to the right:



a) circuit A is a series circuit and has three cells; circuit B is a parallel circuit and has three cells

b) circuit A is a parallel circuit and has three light bulbs; circuit B is a series circuit and has three light bulbs

c) circuit A is a series circuit and has three light bulbs; circuit B is a parallel circuit and has three light bulbs

d) circuit A is a parallel circuit and has three cells; circuit B is a series circuit and has three cells

SA 8) A 1200 Watt hair dryer is plugged into a 120 volt circuit. What is the current drawn by the hair dryer?

a) 10 amps

b) 10 newtons

c) 10 ohms

d) 10 volts

SA 9) Type 2 diabetics have cells which are resistant to the hormone insulin

a) this results in low blood sugar levels as insulin functions to absorb glucose from the blood

b) this results in high blood sugar levels as insulin functions to release glucose into the blood

c) this results in low blood sugar as insulin functions to release glucose into the blood

d) this results in high blood sugar levels as insulin functions to absorb glucose from the blood

SA 10) Effector organs in thermoregulation

a) directly help reduce or increase heat levels; includes hypothalamus / pituitary gland

b) regulate other organs to help reduce or increase heat levels; includes hypothalamus / pituitary gland

c) directly help reduce or increase heat levels; includes organs of the skeletal and circulatory systems

d) regulate other organs to help reduce or increase heat levels; includes organs of the skeletal and circulatory systems

PART C) SCIENCE ANALYSIS AND EVALUATION

SAE 1) Muscle cramping can occur as an early stage of hyperthermia:

a) due to rapid muscle contraction and relaxation in thermoregulation

b) due to electrolyte loss during excessive sweating

c) due to blood vessel dilation associated with thermoregulation

d) due to the inability to produce sweat

SCIENCE REVIEW QUIZ **YEAR 9** TERM 2: BIOLOGY / PHYSICS

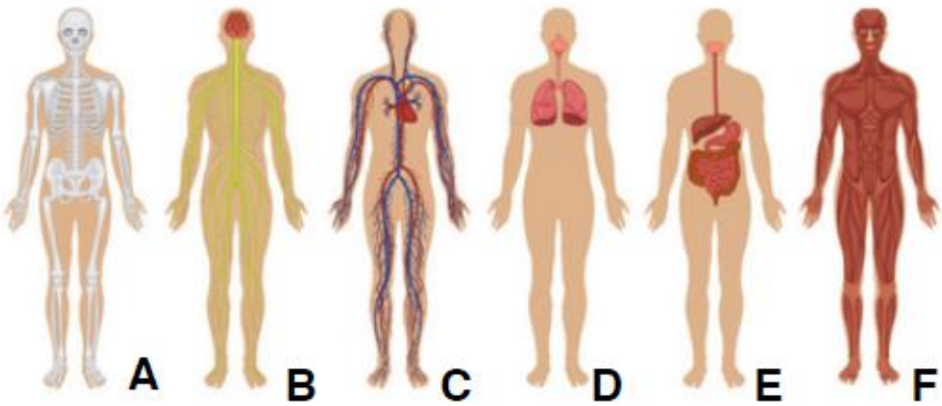
SAE 2) Look at these diagrams of body systems:

a) body system B contains receptor organs in thermoregulation; body systems C and F contain effector organs in thermoregulation

b) body system D contains receptor organs in thermoregulation; body systems C and F contain effector organs in thermoregulation

c) body system A contains receptor organs in thermoregulation; body systems B and F contain effector organs in thermoregulation

d) body system E contains receptor organs in thermoregulation; body systems A and B contain effector organs in thermoregulation



QUESTIONS 3-6 REFER TO THE TABLE BELOW. AIM OF EXPERIMENT: choose a material to keep food cool

Material	Amount	Temp. increase (^{0}C)	Time of day when conducted	Duration of exposure (Min.)
Aluminium	Foil 30cm square	5	9:00 am	46
Wood	300 mm thick logs,	1	8:00 am	34
Bubble Wrap	2 layers 30 cm square	7	12:00 noon	60
Steel	1 sheet	0	6:00 am	3
Palm leaves	5	2	6:00 pm	48
Blanket	1	2	7:00 am	5

SAE 3) You want to test the insulating ability of several materials (from table above).

a) The dependent variable is the material type

b) The dependent variable is the amount of material

c) The dependent variable is the temperature increase

d) The dependent variable is the duration of exposure

SAE 4) The independent variable is (from table above):

a) the material type

b) the amount of material

c) the temperature increase

d) the duration of exposure

SAE 5) Is this a fair test? (from table above)

a) Yes, as all control variables are kept equal (controlled)

b) Yes, as all control variables are deliberately kept different from each other

c) No, as control variables are not kept equal (not controlled)

d) No, as there is no independent variable included

SAE 6) From these results, it was concluded that bubble wrap was the poorest insulator (from table above):

a) This is a valid conclusion as all variables were tested fairly

b) This is a poor conclusion as the control variables were present but the dependent variable was not included in the results

c) This is a valid conclusion as the independent and dependent variables were clearly labelled

d) This is a poor conclusion as the control variables were not properly controlled

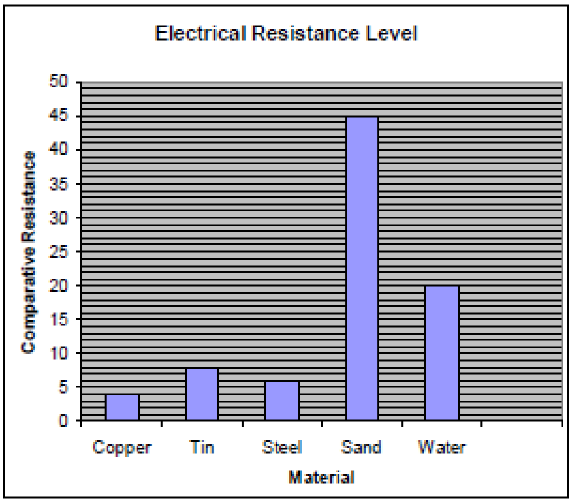
SAE 7) Look at the graph below:

a) Copper would be the best material to use as a conductor of electricity

b) Copper would be the best material to use as an insulator of electricity

c) Sand would be the best material to use as a conductor of electricity

d) Steel would be the worst electrical insulator of the metals



SCIENCE REVIEW QUIZ **YEAR 9** **TERM 2: BIOLOGY / PHYSICS**

SAE 8) Humans use _________ found in the ________ for osmoregulation and excretion.

a) nephron; liver

b) nephron; kidney

c) capillaries; circulatory system

d) airways; lungs

SAE 9) The ascending limb of the loop of Henle is permeable to _____ but impermeable to ______.

a) salt; water

b) water; salt

c) blood; amino acids

d) water; ADH

SAE 10) Urea, uric acid and ammonia are the waste products of:

a) reptiles / birds, mammals, aquatic (water) species

b) reptiles / birds, mammals, aquatic (water) species

c) aquatic (water) species, reptiles / birds, mammals

d) mammals, reptiles / birds, aquatic (water) species

APPENDIX 2 (cont.)

MSSAT ANSWER SHEET (all grades)

SCIENCE REVIEW QUIZ **ANSWER SHEET**

NAME: ______________________________
CLASS: ______________________________
GRADE: ______________________________

ANSWER SHEET

PART A) SCIENCE KNOWLEDGE AND UNDERSTANDING:

KU 1: Ⓐ Ⓑ Ⓒ Ⓓ
KU 2: Ⓐ Ⓑ Ⓒ Ⓓ
KU 3: Ⓐ Ⓑ Ⓒ Ⓓ
KU 4: Ⓐ Ⓑ Ⓒ Ⓓ
KU 5: Ⓐ Ⓑ Ⓒ Ⓓ
KU 6: Ⓐ Ⓑ Ⓒ Ⓓ
KU 7: Ⓐ Ⓑ Ⓒ Ⓓ
KU 8: Ⓐ Ⓑ Ⓒ Ⓓ
KU 9: Ⓐ Ⓑ Ⓒ Ⓓ
KU 10: Ⓐ Ⓑ Ⓒ Ⓓ

PART B) SCIENCE APPLICATION

SA 1) Ⓐ Ⓑ Ⓒ Ⓓ
SA 2) Ⓐ Ⓑ Ⓒ Ⓓ
SA 3) Ⓐ Ⓑ Ⓒ Ⓓ
SA 4) Ⓐ Ⓑ Ⓒ Ⓓ
SA 5) Ⓐ Ⓑ Ⓒ Ⓓ
SA 6) Ⓐ Ⓑ Ⓒ Ⓓ
SA 7) Ⓐ Ⓑ Ⓒ Ⓓ
SA 8) Ⓐ Ⓑ Ⓒ Ⓓ
SA 9) Ⓐ Ⓑ Ⓒ Ⓓ
SA 10) Ⓐ Ⓑ Ⓒ Ⓓ

PART C) SCIENCE ANALYSIS AND EVALUATION

SAE 1) Ⓐ Ⓑ Ⓒ Ⓓ
SAE 2) Ⓐ Ⓑ Ⓒ Ⓓ
SAE 3) Ⓐ Ⓑ Ⓒ Ⓓ
SAE 4) Ⓐ Ⓑ Ⓒ Ⓓ
SAE 5) Ⓐ Ⓑ Ⓒ Ⓓ
SAE 6) Ⓐ Ⓑ Ⓒ Ⓓ
SAE 7) Ⓐ Ⓑ Ⓒ Ⓓ
SAE 8) Ⓐ Ⓑ Ⓒ Ⓓ
SAE 9) Ⓐ Ⓑ Ⓒ Ⓓ
SAE 10) Ⓐ Ⓑ Ⓒ Ⓓ

APPENDIX 3

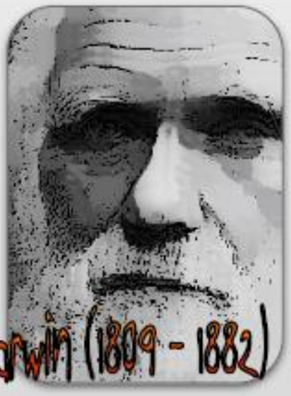
GRADE 7 WORKSHEETS (WORKSHEET 1 BIMODAL SOCIAL)

ATTEMPTS TO CLASSIFY LIVING THINGS DATE BACK TO THE 1700S.

CARL LINNAEUS MADE THE FIRST COMPREHENSIVE CLASSIFICATION SYSTEM OF LIVING THINGS.

THE SCIENCE OF CLASSIFICATION IS CALLED TAXONOMY. TAXONOMY ALLOWS NATURALISTS TO CLASSIFY ALL KNOWN LIVING THINGS. LINNAEUS' SYSTEM USED KINGDOM, PHYLUM, CLASS, ORDER, FAMILY, GENUS AND SPECIES TO CLASSIFY LIVING THINGS.

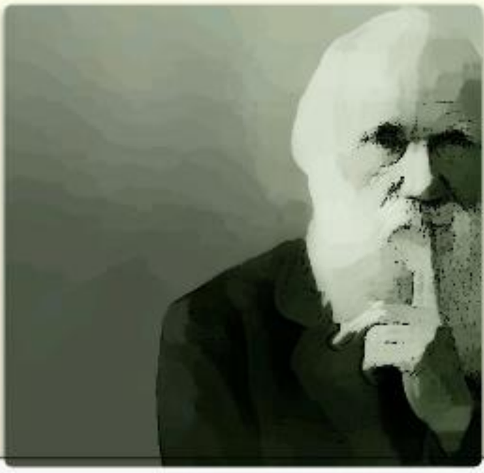
carl linnaeus (1707 - 1778)

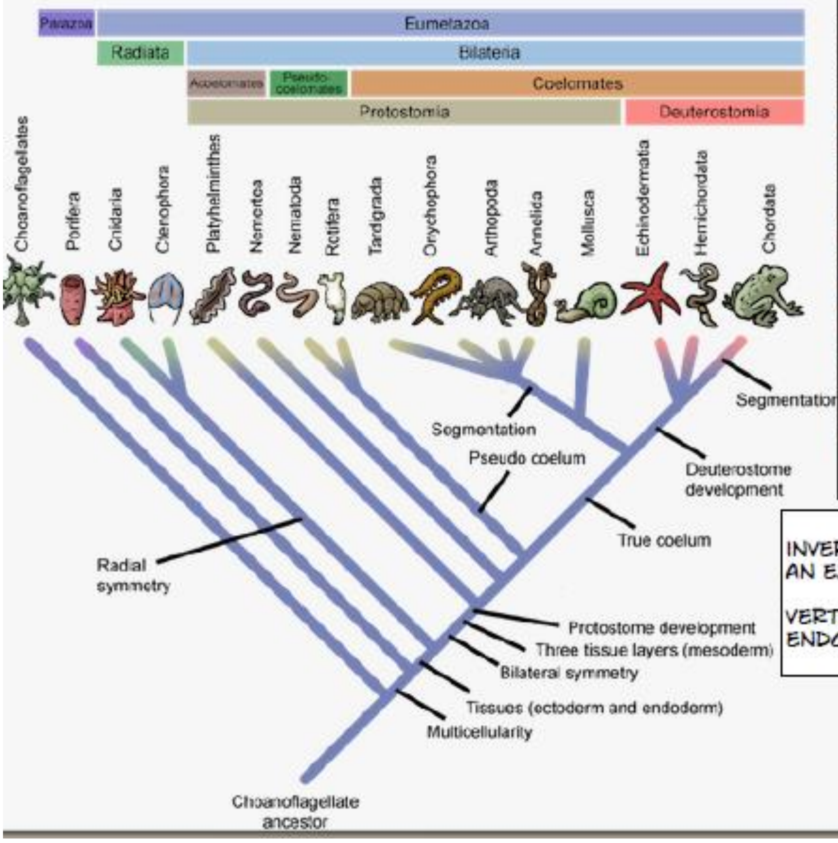


Charles darwin (1809 - 1882)

FOR EXAMPLE, NATURALISTS USE LINNAEUS' SYSTEM TO NAME THE GRIZZLY BEAR – URSUS ARCTOS

LIFE - NOW IN 5 KINGDOMS!!

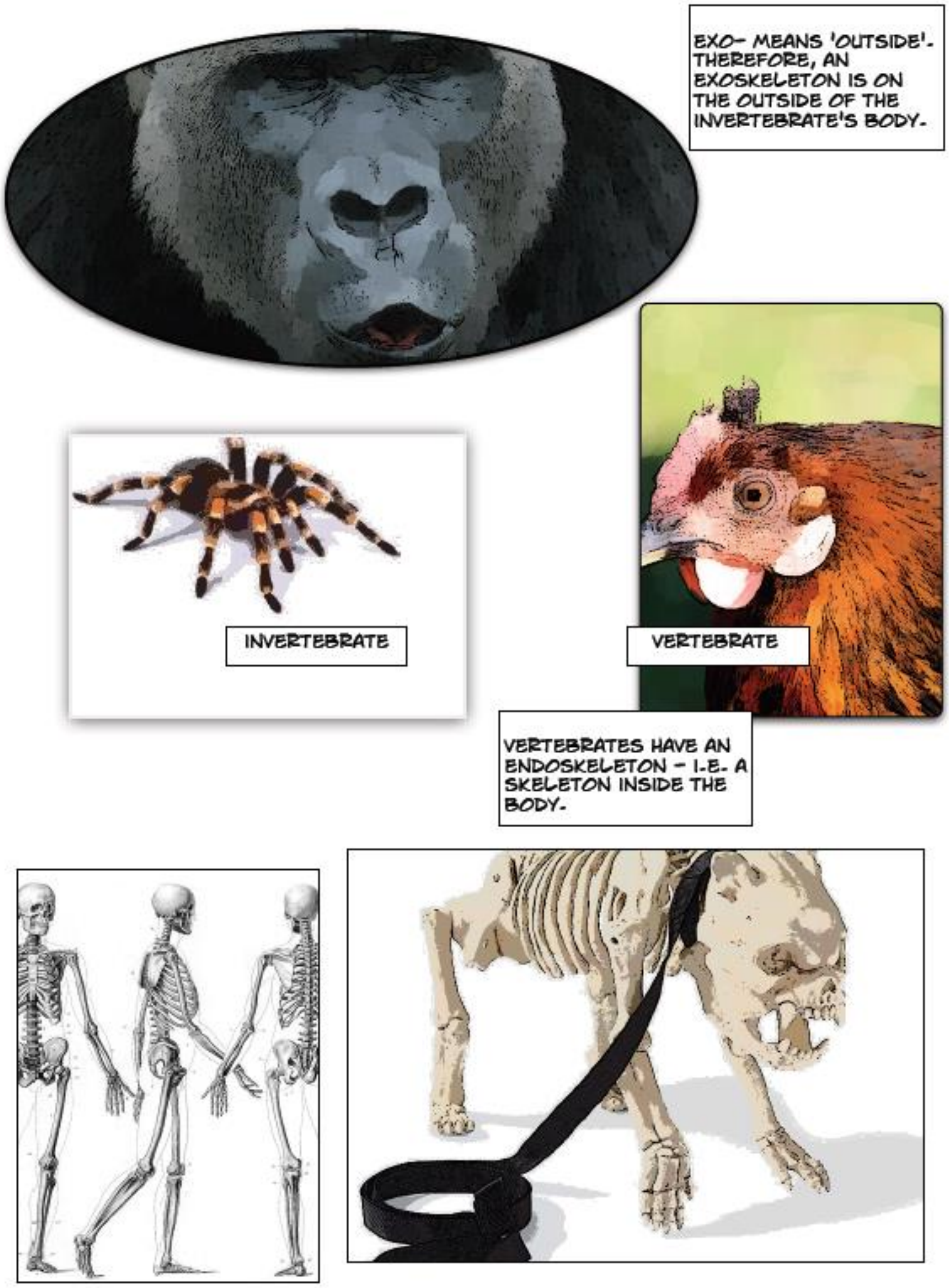




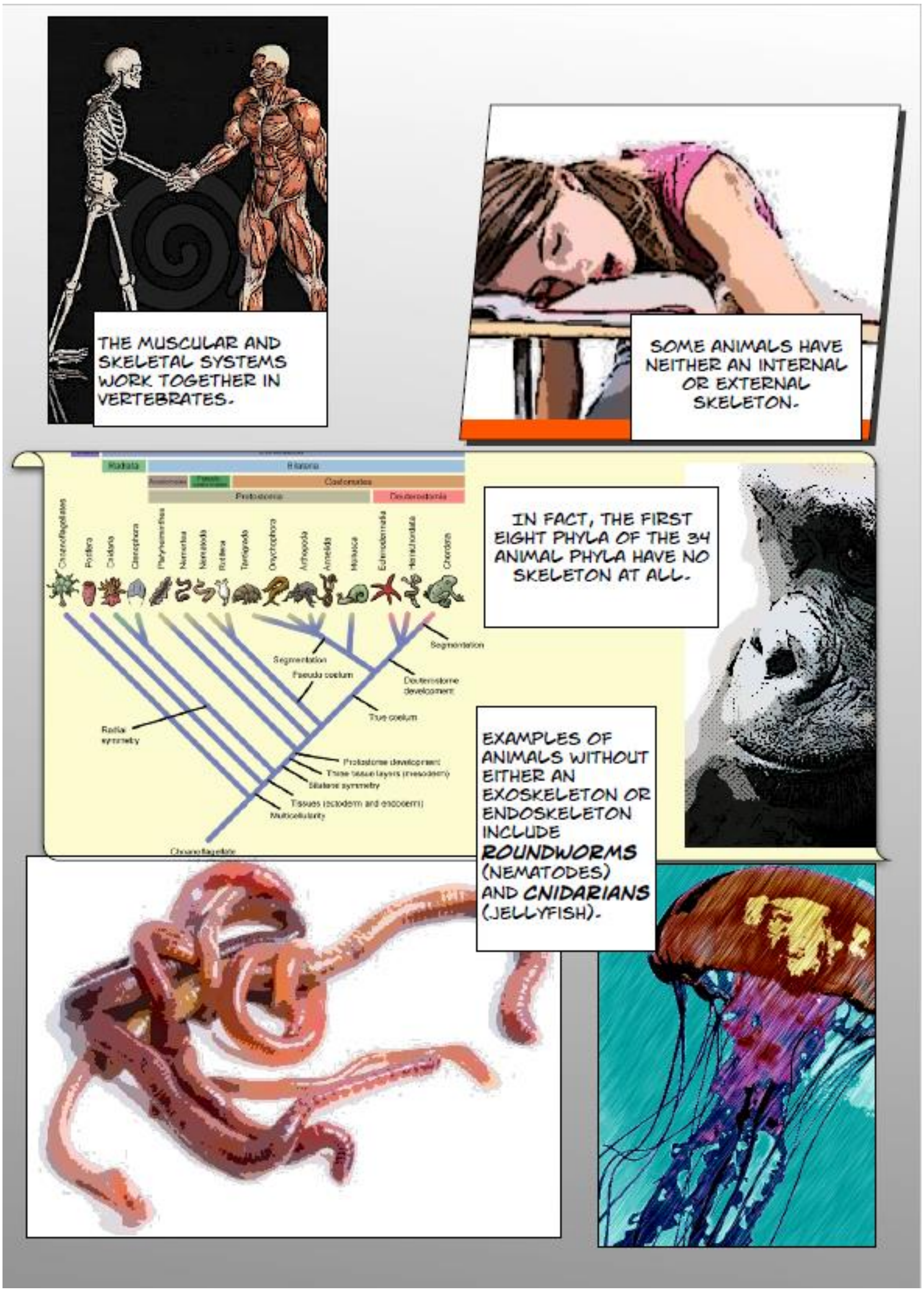
OF ALL THE ANIMAL ***PHYLA*** ONLY ONE OUT OF 34 HAVE A SKELETON. INDEED, ONLY ABOUT 4% OF ALL ANIMALS HAVE A SKELETON. THESE ANIMALS WITH A BACKBONE ARE CALLED VERTEBRATES, WHILE THOSE WITHOUT BACKBONES (ABOUT 96% OF ANIMALS) ARE CALLED INVERTEBRATES.

INVERTEBRATES HAVE AN EXOSKELETON.

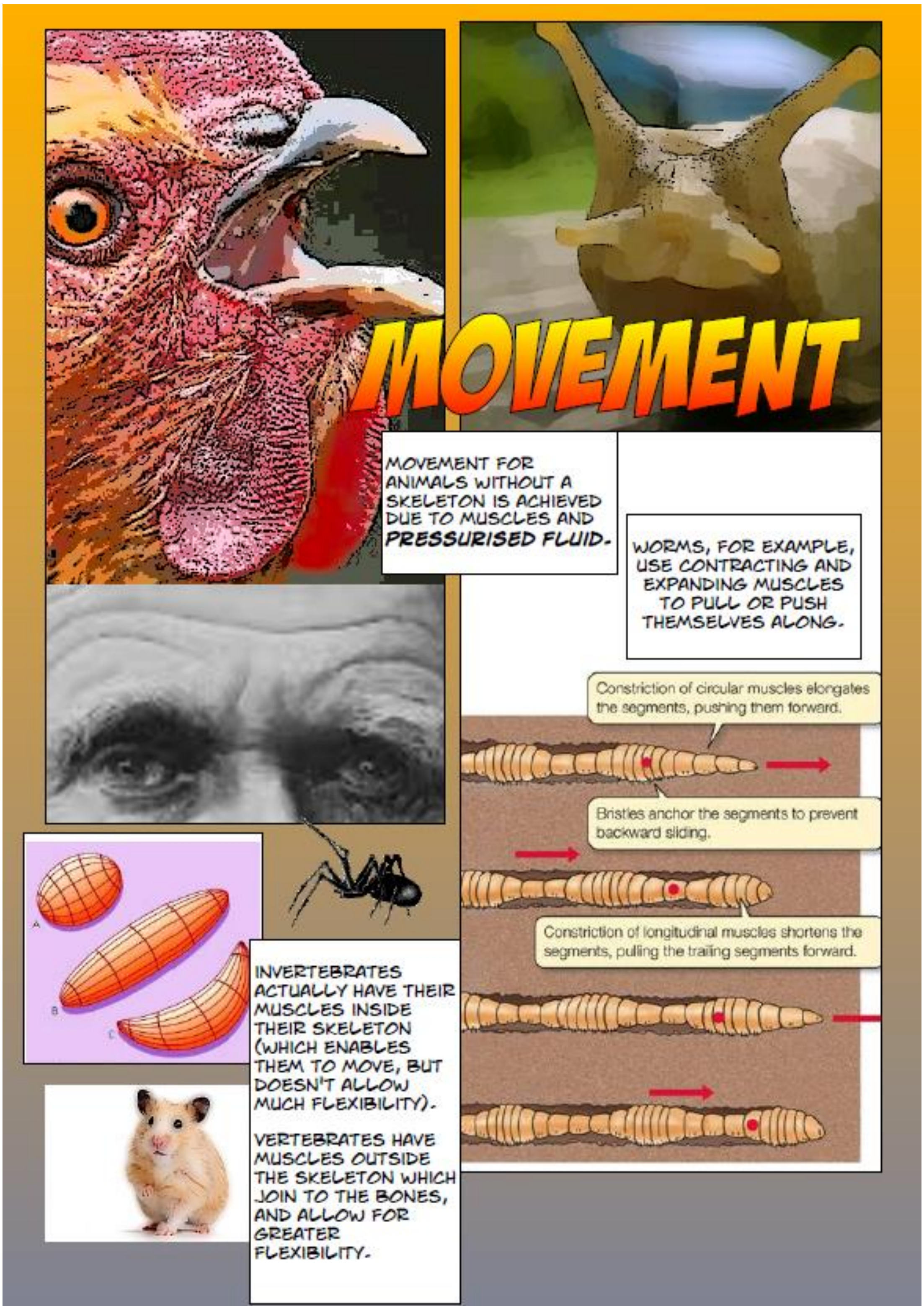
VERTEBRATES HAVE AN ENDOSKELETON.



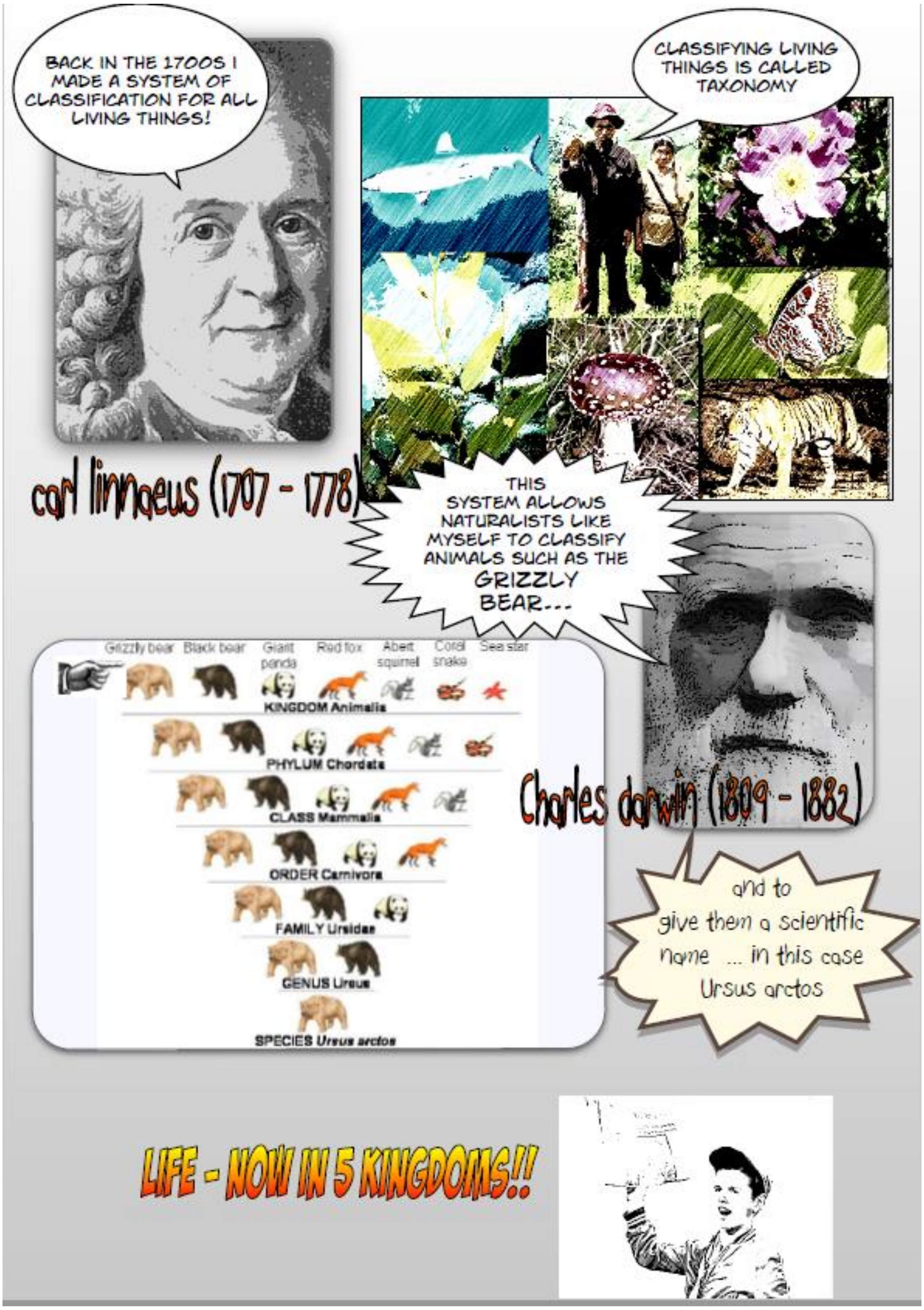
endoskeletons allow animals to be more flexible

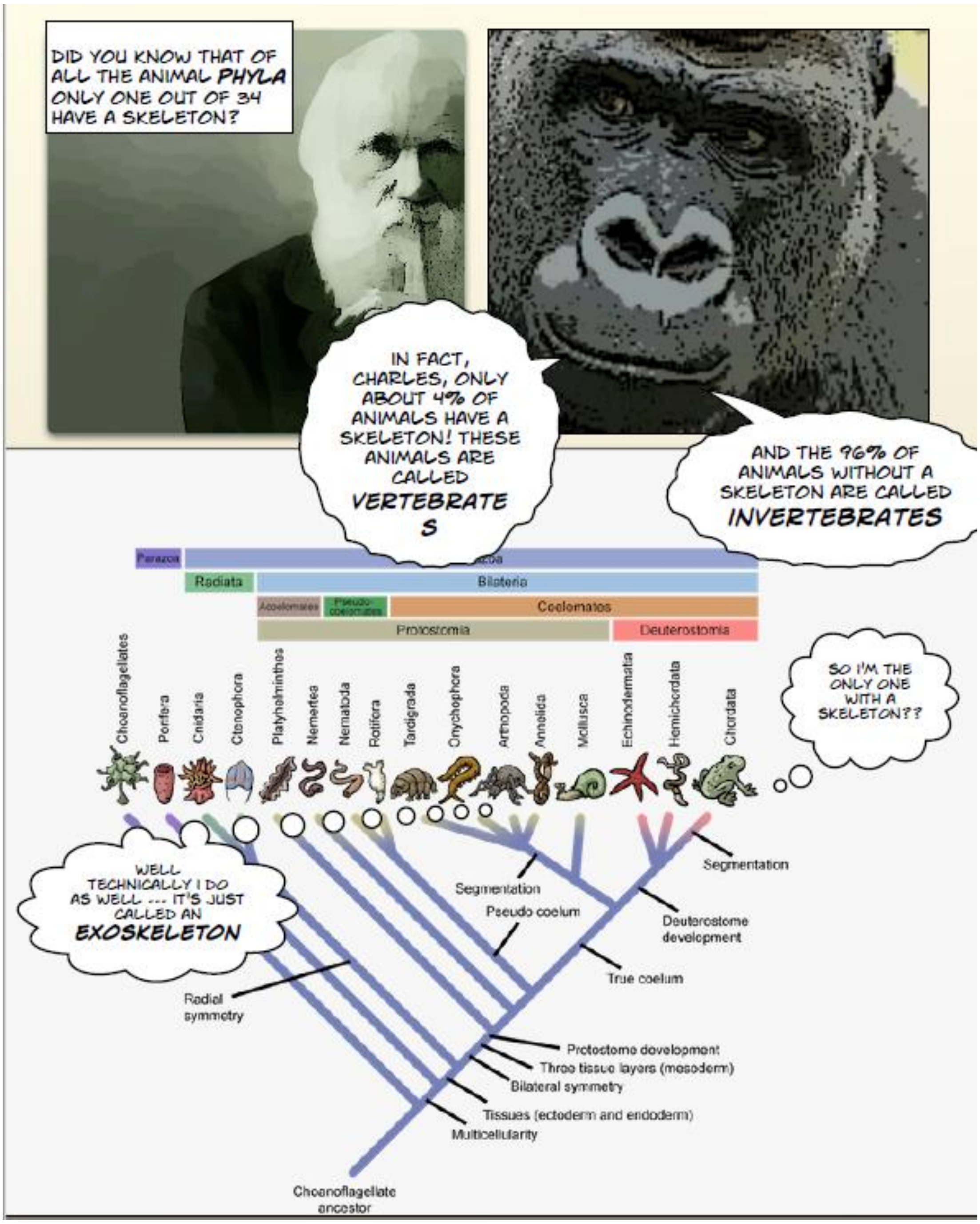


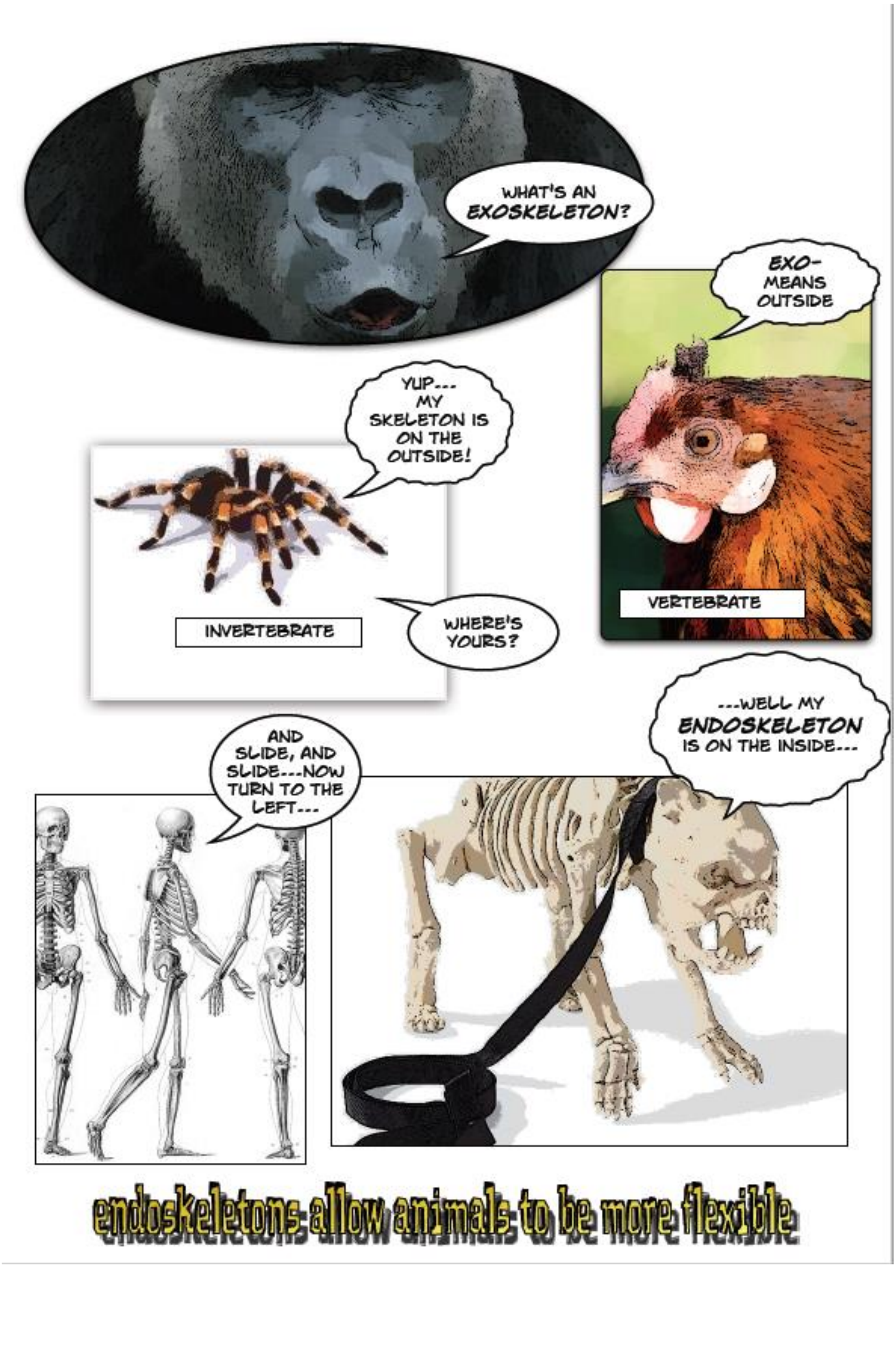
THE MUSCULAR AND SKELETAL SYSTEMS WORK TOGETHER IN VERTEBRATES.
SOME ANIMALS HAVE NEITHER AN INTERNAL OR EXTERNAL SKELETON.
IN FACT, THE FIRST EIGHT PHYLA OF THE 34 ANIMAL PHYLA HAVE NO SKELETON AT ALL.
EXAMPLES OF ANIMALS WITHOUT EITHER AN EXOSKELETON OR ENDOSKELETON INCLUDE **ROUNDWORMS** (NEMATODES) AND **CNIDARIANS** (JELLYFISH).


MOVEMENT
MOVEMENT FOR ANIMALS WITHOUT A SKELETON IS ACHIEVED DUE TO MUSCLES AND PRESSURISED FLUID.
WORMS, FOR EXAMPLE, USE CONTRACTING AND EXPANDING MUSCLES TO PULL OR PUSH THEMSELVES ALONG.
Constriction of circular muscles elongates the segments, pushing them forward.
Bristles anchor the segments to prevent backward sliding.
Constriction of longitudinal muscles shortens the segments, pulling the trailing segments forward.
INVERTEBRATES ACTUALLY HAVE THEIR MUSCLES INSIDE THEIR SKELETON (WHICH ENABLES THEM TO MOVE, BUT DOESN'T ALLOW MUCH FLEXIBILITY).
VERTEBRATES HAVE MUSCLES OUTSIDE THE SKELETON WHICH JOIN TO THE BONES, AND ALLOW FOR GREATER FLEXIBILITY.

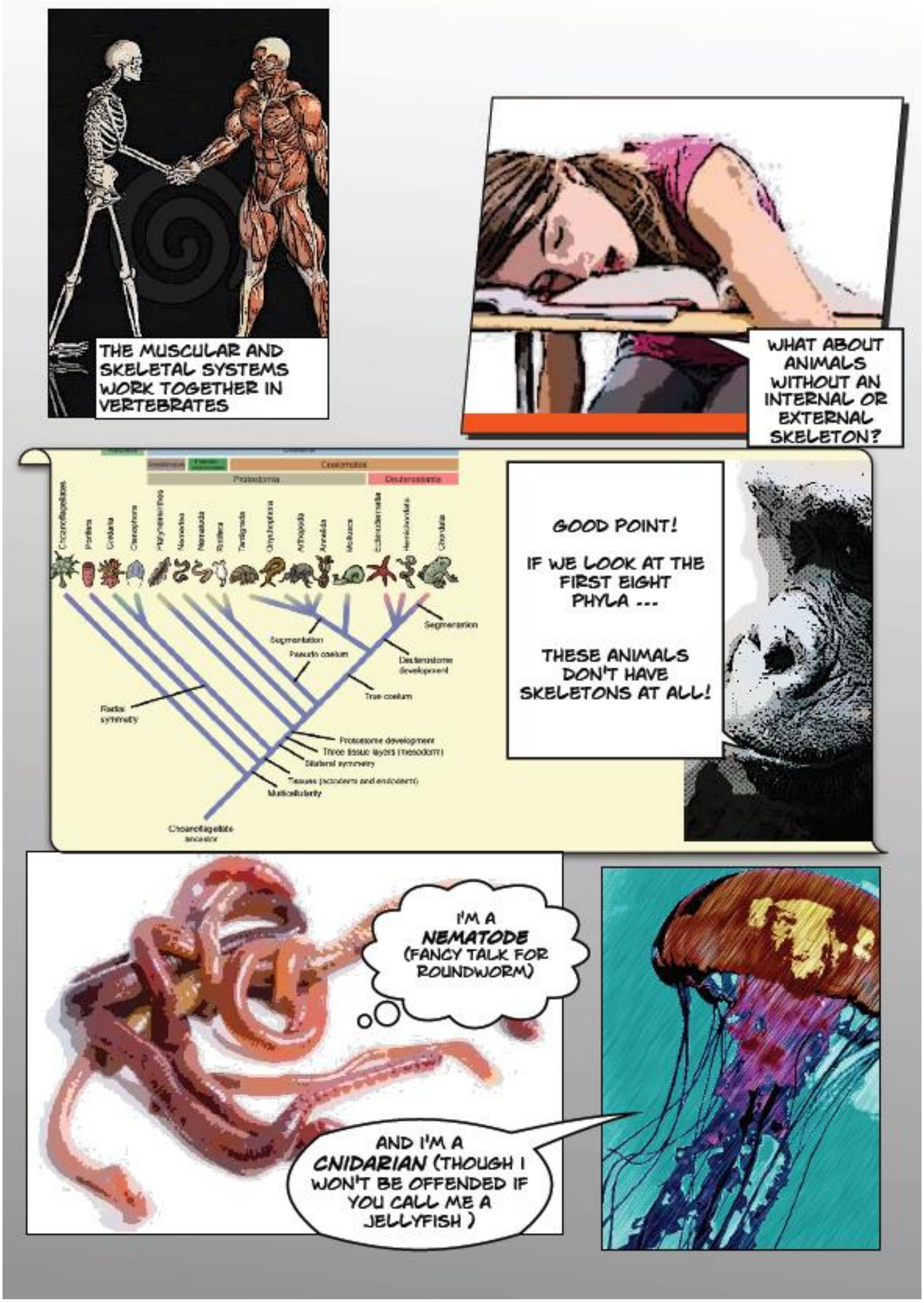
GRADE 7 WORKSHEETS (WORKSHEET 1 MULTIMODAL SOCIAL)

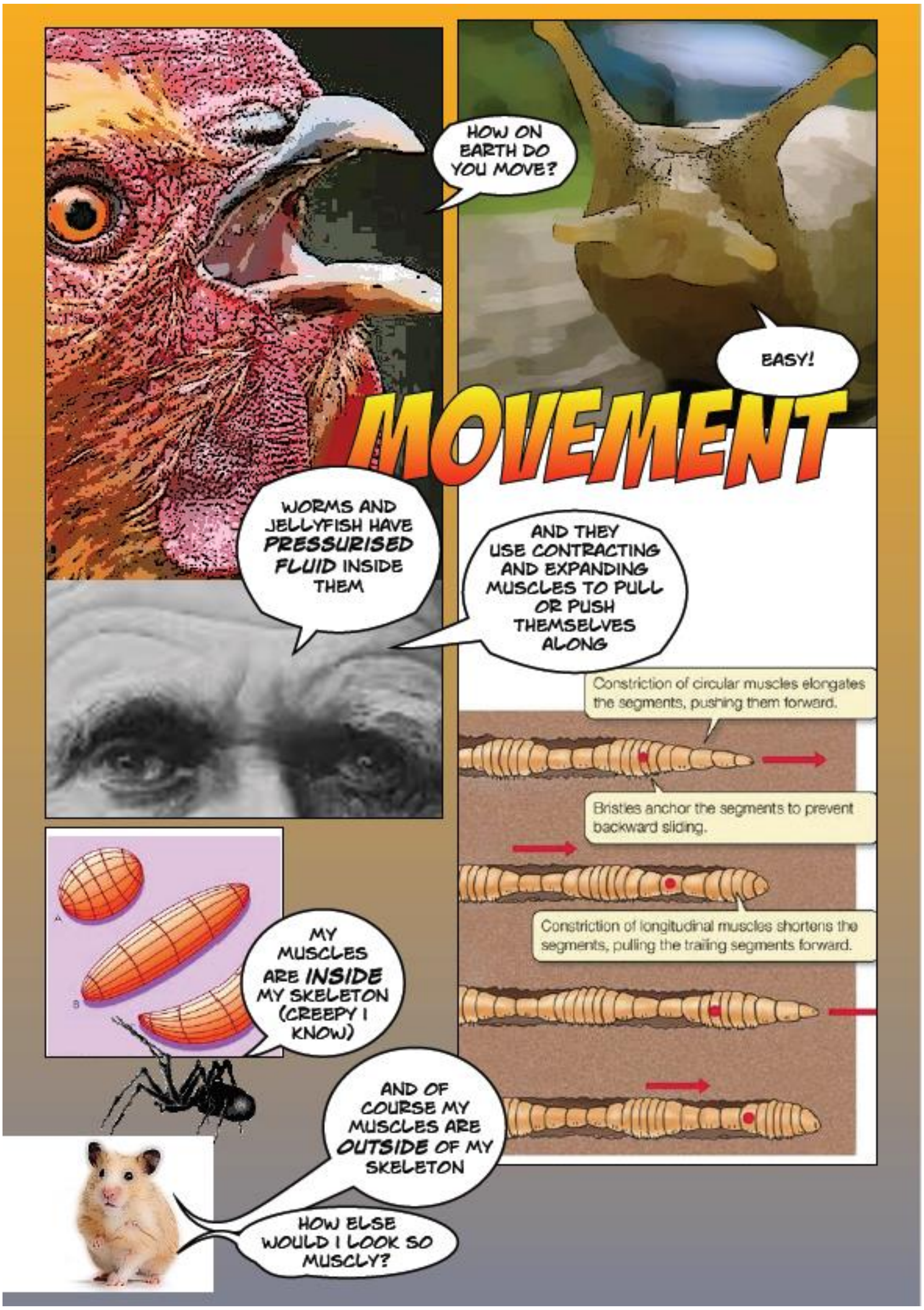



DID YOU KNOW THAT OF ALL THE ANIMAL PHYLA ONLY ONE OUT OF 34 HAVE A SKELETON?
IN FACT, CHARLES, ONLY ABOUT 4% OF ANIMALS HAVE A SKELETON! THESE ANIMALS ARE CALLED VERTEBRATE S
AND THE 96% OF ANIMALS WITHOUT A SKELETON ARE CALLED INVERTEBRATES
Parazoa
Radiata
Bilateria
Acoelomates
Pseudo-coelomates
Coelomates
Protostomia
Deuterostomia
Choanoflagellates
Porifera
Cnidaria
Ctenophora
Platyhelminthes
Nemertea
Nematoda
Rotifera
Tardigrada
Onychophora
Arthropoda
Annelida
Mollusca
Echinodermata
Hemichordata
Chordata
SO I'M THE ONLY ONE WITH A SKELETON??
WELL TECHNICALLY I DO AS WELL --- IT'S JUST CALLED AN EXOSKELETON
Segmentation
Segmentation
Pseudo coelum
Deuterostome development
True coelum
Radial symmetry
Protostome development
Three tissue layers (mesoderm)
Bilateral symmetry
Tissues (ectoderm and endoderm)
Multicellularity
Choanoflagellate ancestor

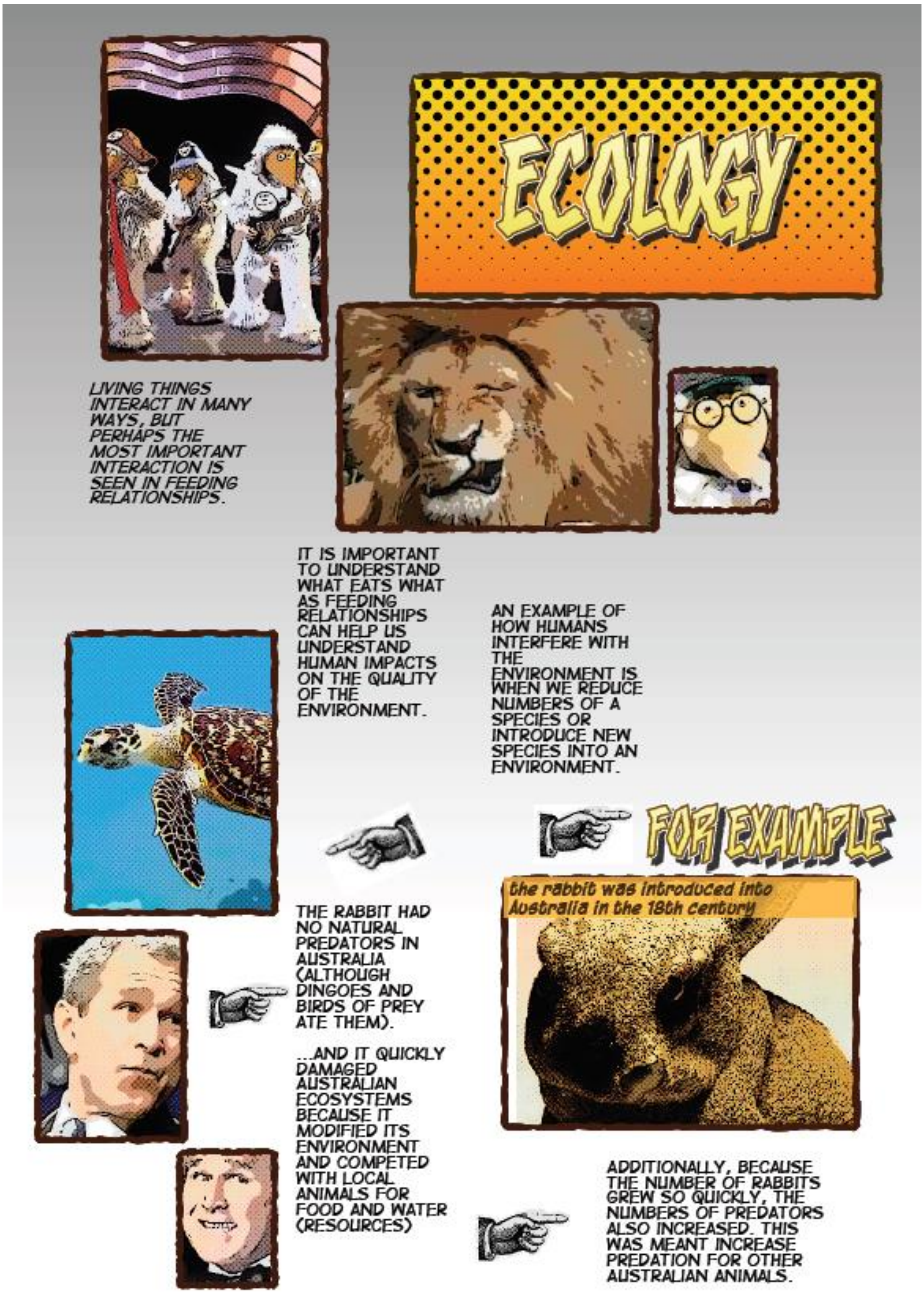


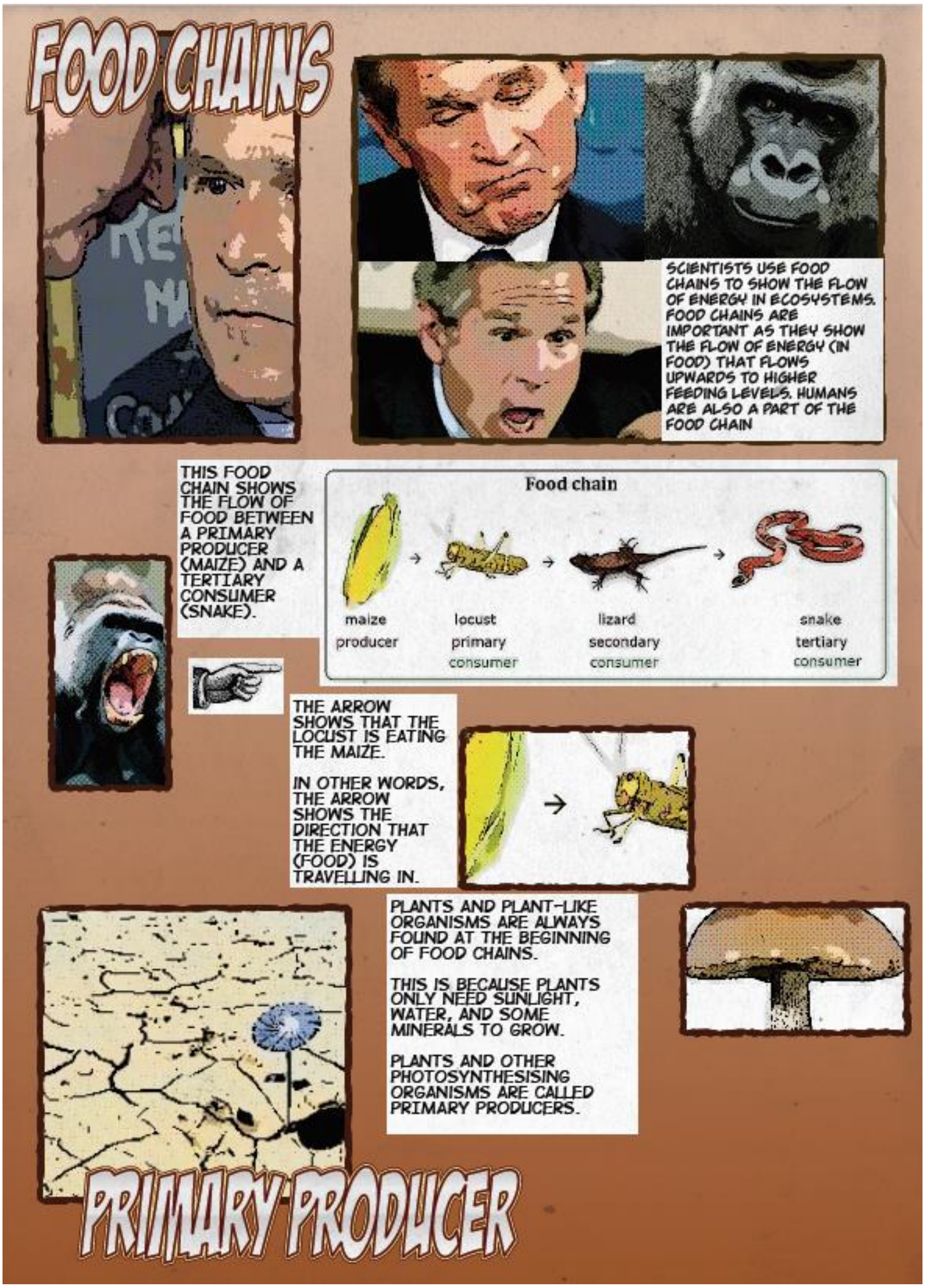
WHAT'S AN EXOSKELETON?
EXO- MEANS OUTSIDE
YUP... MY SKELETON IS ON THE OUTSIDE!
INVERTEBRATE
VERTEBRATE
WHERE'S YOURS?
...WELL MY ENDOSKELETON IS ON THE INSIDE...
AND SLIDE, AND SLIDE...NOW TURN TO THE LEFT...
endoskeletons allow animals to be more flexible

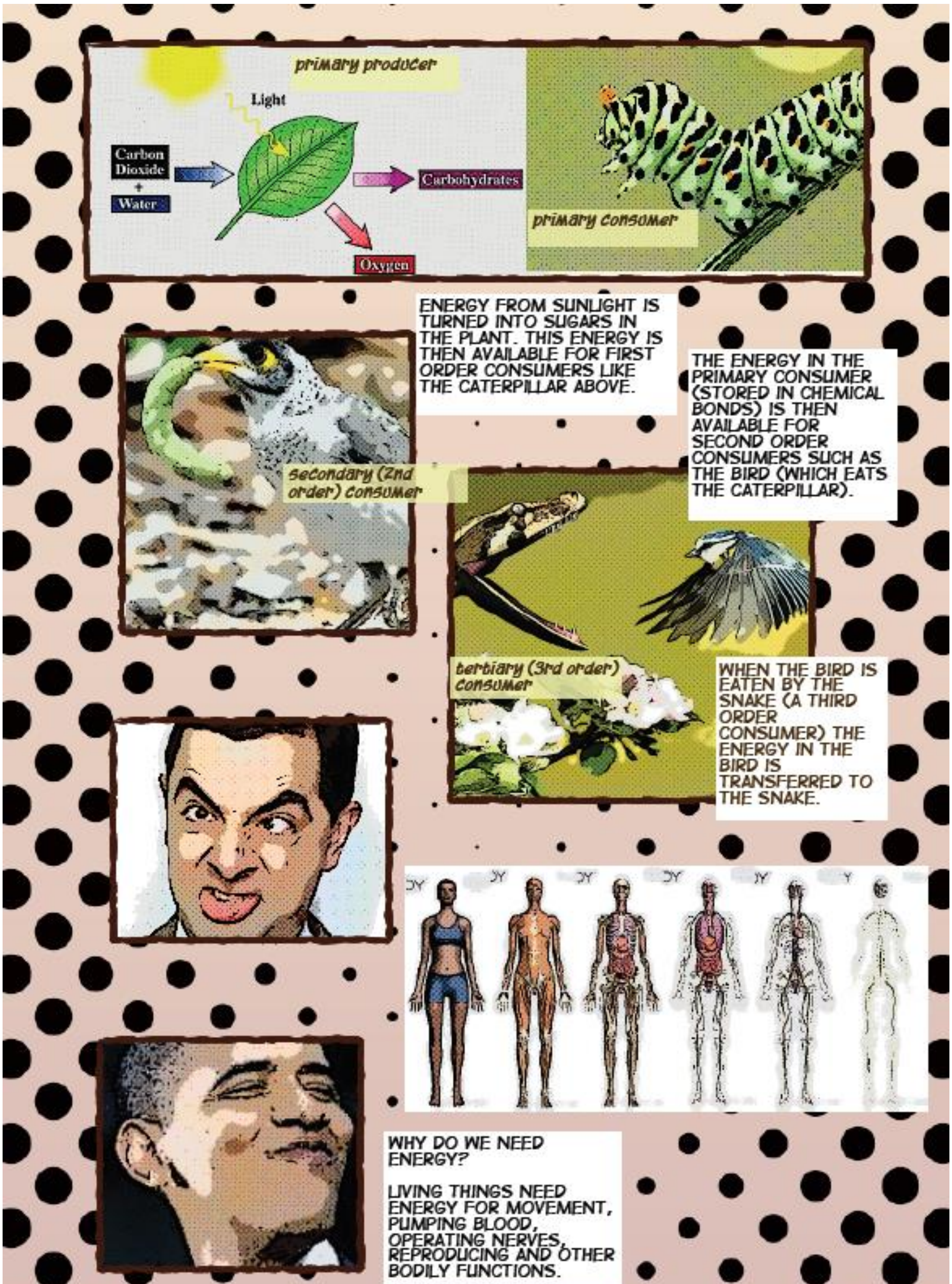

THE MUSCULAR AND SKELETAL SYSTEMS WORK TOGETHER IN VERTEBRATES
WHAT ABOUT ANIMALS WITHOUT AN INTERNAL OR EXTERNAL SKELETON?
GOOD POINT!
IF WE LOOK AT THE FIRST EIGHT PHYLA ...
THESE ANIMALS DON'T HAVE SKELETONS AT ALL!
I'M A **NEMATODE** (FANCY TALK FOR ROUNDWORM)
AND I'M A **CNIDARIAN** (THOUGH I WON'T BE OFFENDED IF YOU CALL ME A JELLYFISH)


HOW ON EARTH DO YOU MOVE?
EASY!
MOVEMENT
WORMS AND JELLYFISH HAVE PRESSURISED FLUID INSIDE THEM
AND THEY USE CONTRACTING AND EXPANDING MUSCLES TO PULL OR PUSH THEMSELVES ALONG
Constriction of circular muscles elongates the segments, pushing them forward.
Bristles anchor the segments to prevent backward sliding.
Constriction of longitudinal muscles shortens the segments, pulling the trailing segments forward.
MY MUSCLES ARE INSIDE MY SKELETON (CREEPY I KNOW)
AND OF COURSE MY MUSCLES ARE OUTSIDE OF MY SKELETON
HOW ELSE WOULD I LOOK SO MUSCLY?

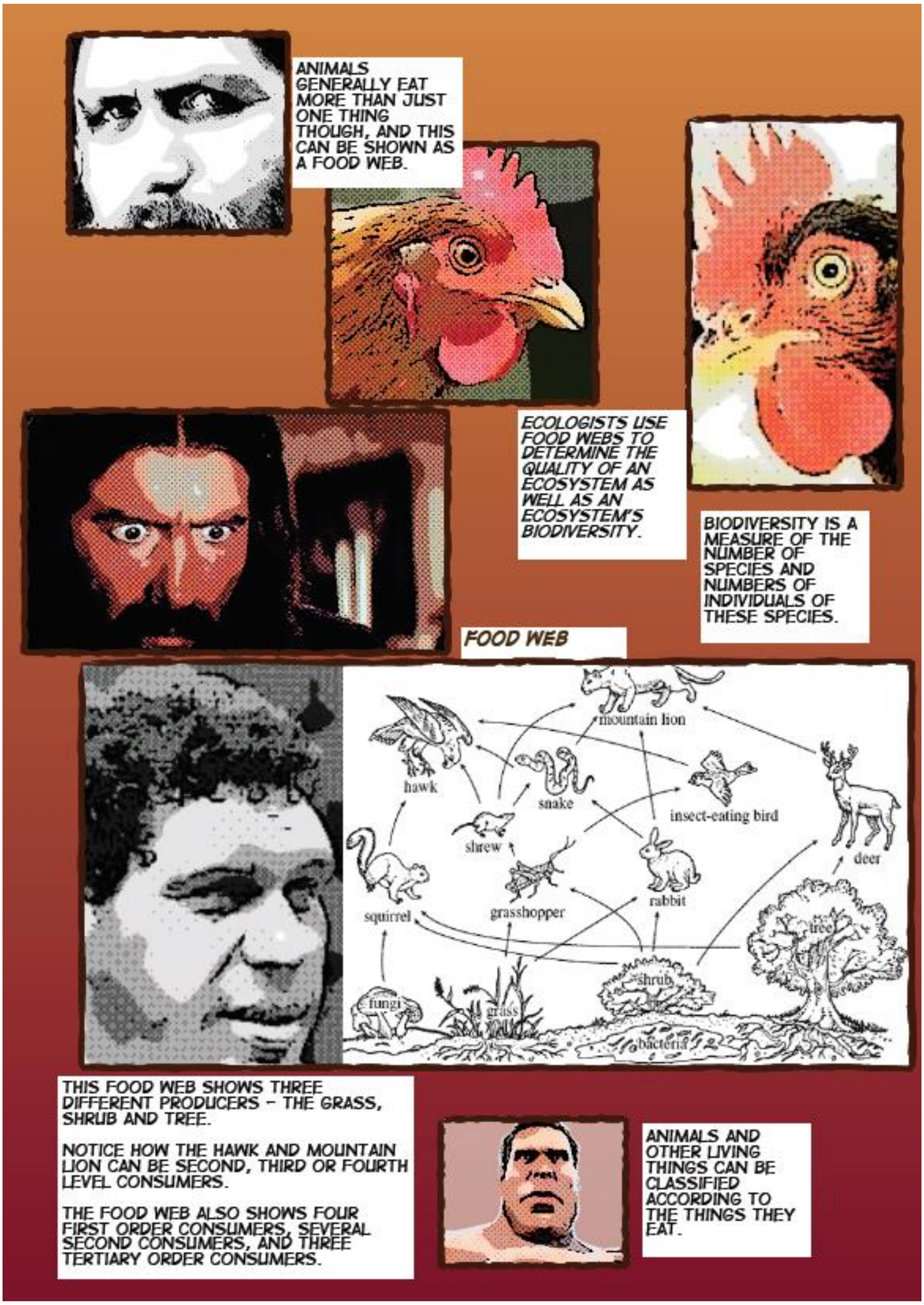
GRADE 7 WORKSHEETS (WORKSHEET 2 BIMODAL SOCIAL)

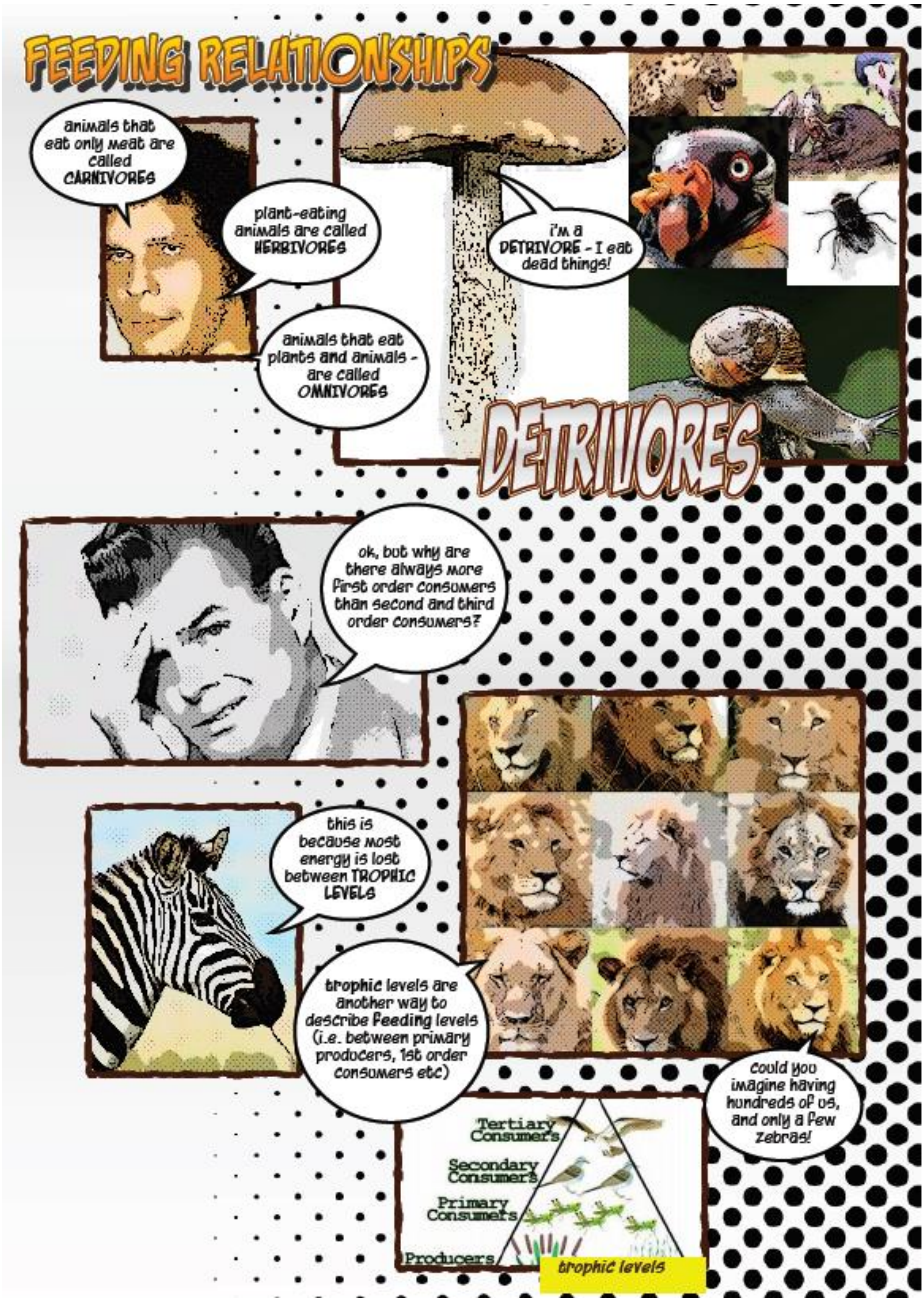


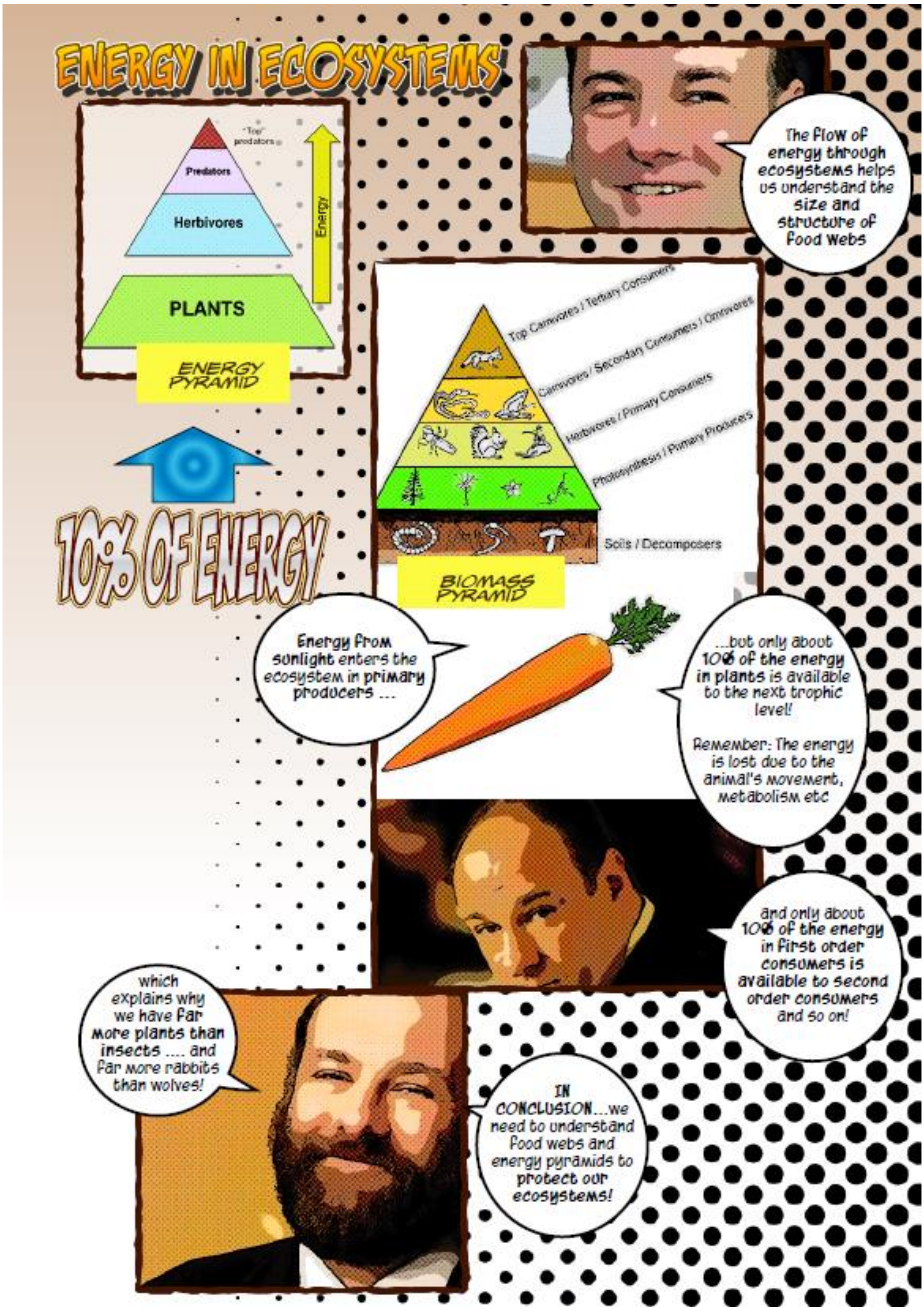

FOOD CHAINS
SCIENTISTS USE FOOD CHAINS TO SHOW THE FLOW OF ENERGY IN ECOSYSTEMS. FOOD CHAINS ARE IMPORTANT AS THEY SHOW THE FLOW OF ENERGY (IN FOOD) THAT FLOWS UPWARDS TO HIGHER FEEDING LEVELS. HUMANS ARE ALSO A PART OF THE FOOD CHAIN
THIS FOOD CHAIN SHOWS THE FLOW OF FOOD BETWEEN A PRIMARY PRODUCER (MAIZE) AND A TERTIARY CONSUMER (SNAKE).
Food chain
maize
producer
locust
primary
consumer
lizard
secondary
consumer
snake
tertiary
consumer
THE ARROW SHOWS THAT THE LOCUST IS EATING THE MAIZE.
IN OTHER WORDS, THE ARROW SHOWS THE DIRECTION THAT THE ENERGY (FOOD) IS TRAVELLING IN.
PLANTS AND PLANT-LIKE ORGANISMS ARE ALWAYS FOUND AT THE BEGINNING OF FOOD CHAINS.
THIS IS BECAUSE PLANTS ONLY NEED SUNLIGHT, WATER, AND SOME MINERALS TO GROW.
PLANTS AND OTHER PHOTOSYNTHESISING ORGANISMS ARE CALLED PRIMARY PRODUCERS.
PRIMARY PRODUCER



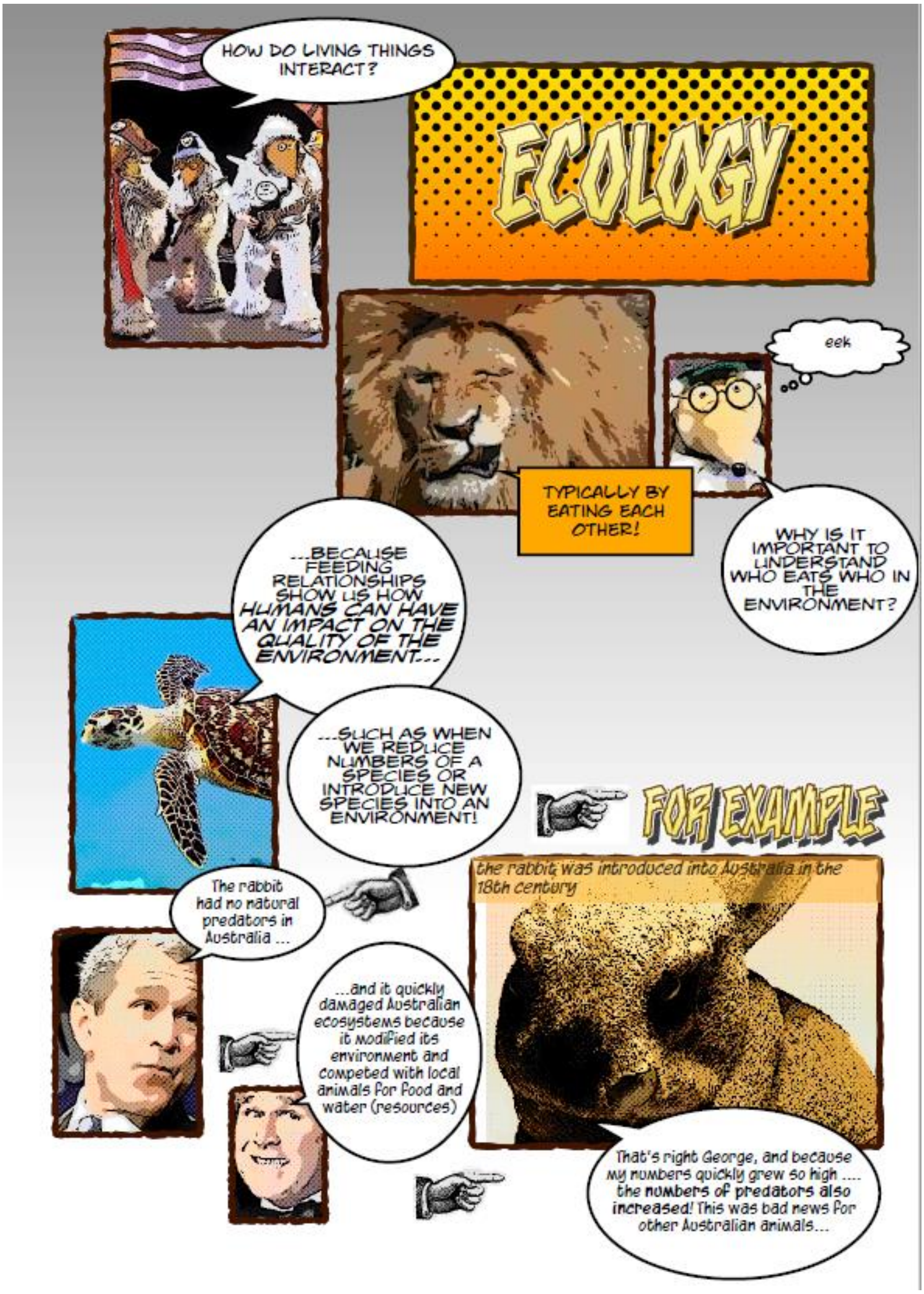
primary producer
Light
Carbon Dioxide
+
Water
Carbohydrates
Oxygen
primary consumer
ENERGY FROM SUNLIGHT IS TURNED INTO SUGARS IN THE PLANT. THIS ENERGY IS THEN AVAILABLE FOR FIRST ORDER CONSUMERS LIKE THE CATERPILLAR ABOVE.
THE ENERGY IN THE PRIMARY CONSUMER (STORED IN CHEMICAL BONDS) IS THEN AVAILABLE FOR SECOND ORDER CONSUMERS SUCH AS THE BIRD (WHICH EATS THE CATERPILLAR).
secondary (2nd order) consumer
tertiary (3rd order) consumer
WHEN THE BIRD IS EATEN BY THE SNAKE (A THIRD ORDER CONSUMER) THE ENERGY IN THE BIRD IS TRANSFERRED TO THE SNAKE.
WHY DO WE NEED ENERGY?
LIVING THINGS NEED ENERGY FOR MOVEMENT, PUMPING BLOOD, OPERATING NERVES, REPRODUCING AND OTHER BODILY FUNCTIONS.

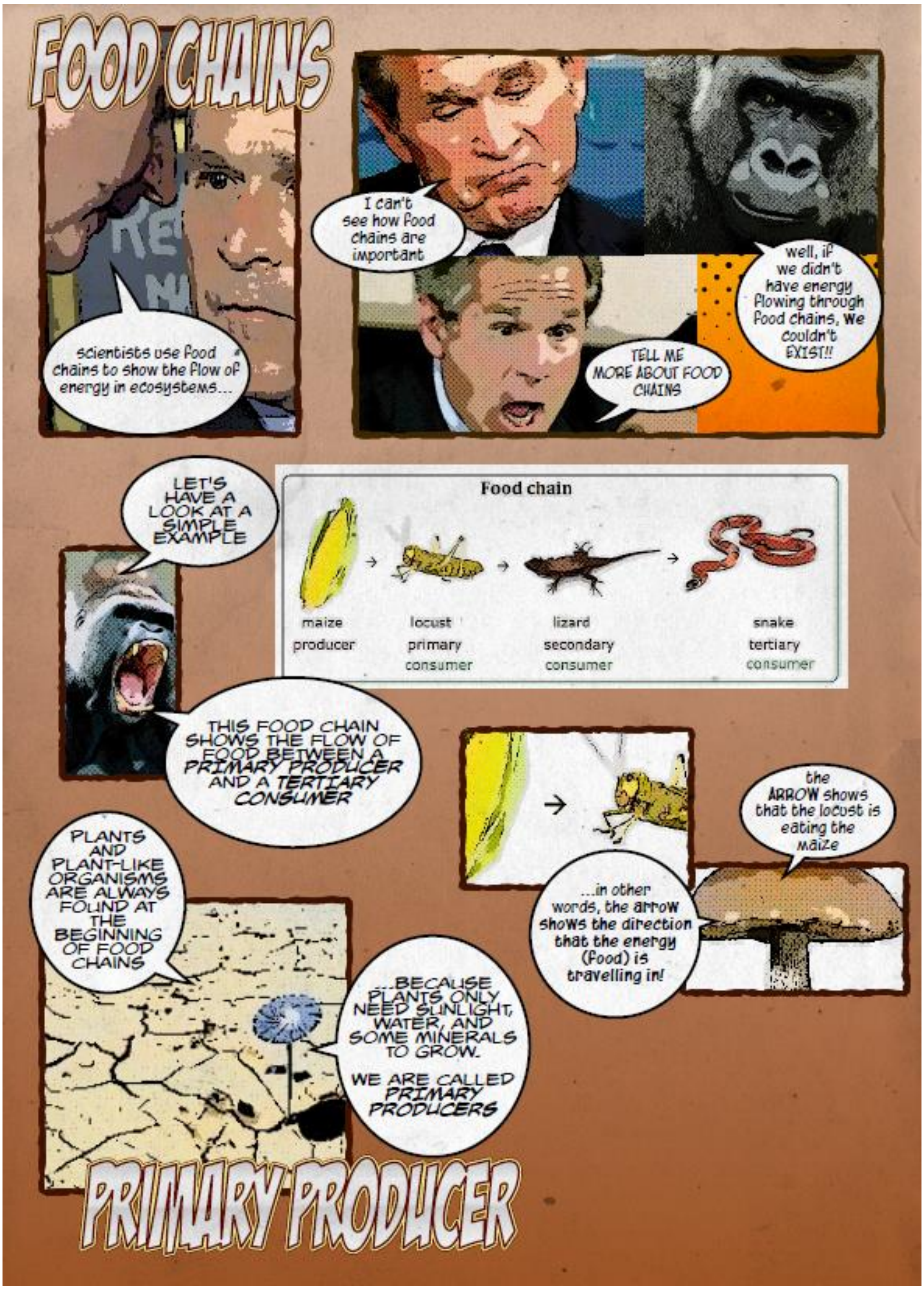

ANIMALS GENERALLY EAT MORE THAN JUST ONE THING THOUGH, AND THIS CAN BE SHOWN AS A FOOD WEB.
ECOLOGISTS USE FOOD WEBS TO DETERMINE THE QUALITY OF AN ECOSYSTEM AS WELL AS AN ECOSYSTEM'S BIODIVERSITY.
BIODIVERSITY IS A MEASURE OF THE NUMBER OF SPECIES AND NUMBERS OF INDIVIDUALS OF THESE SPECIES.
FOOD WEB
mountain lion
hawk
snake
insect-eating bird
deer
shrew
squirrel
grasshopper
rabbit
tree
shrub
fungi
grass
bacteria
THIS FOOD WEB SHOWS THREE DIFFERENT PRODUCERS - THE GRASS, SHRUB AND TREE.
NOTICE HOW THE HAWK AND MOUNTAIN LION CAN BE SECOND, THIRD OR FOURTH LEVEL CONSUMERS.
THE FOOD WEB ALSO SHOWS FOUR FIRST ORDER CONSUMERS, SEVERAL SECOND CONSUMERS, AND THREE TERTIARY ORDER CONSUMERS.
ANIMALS AND OTHER LIVING THINGS CAN BE CLASSIFIED ACCORDING TO THE THINGS THEY EAT.

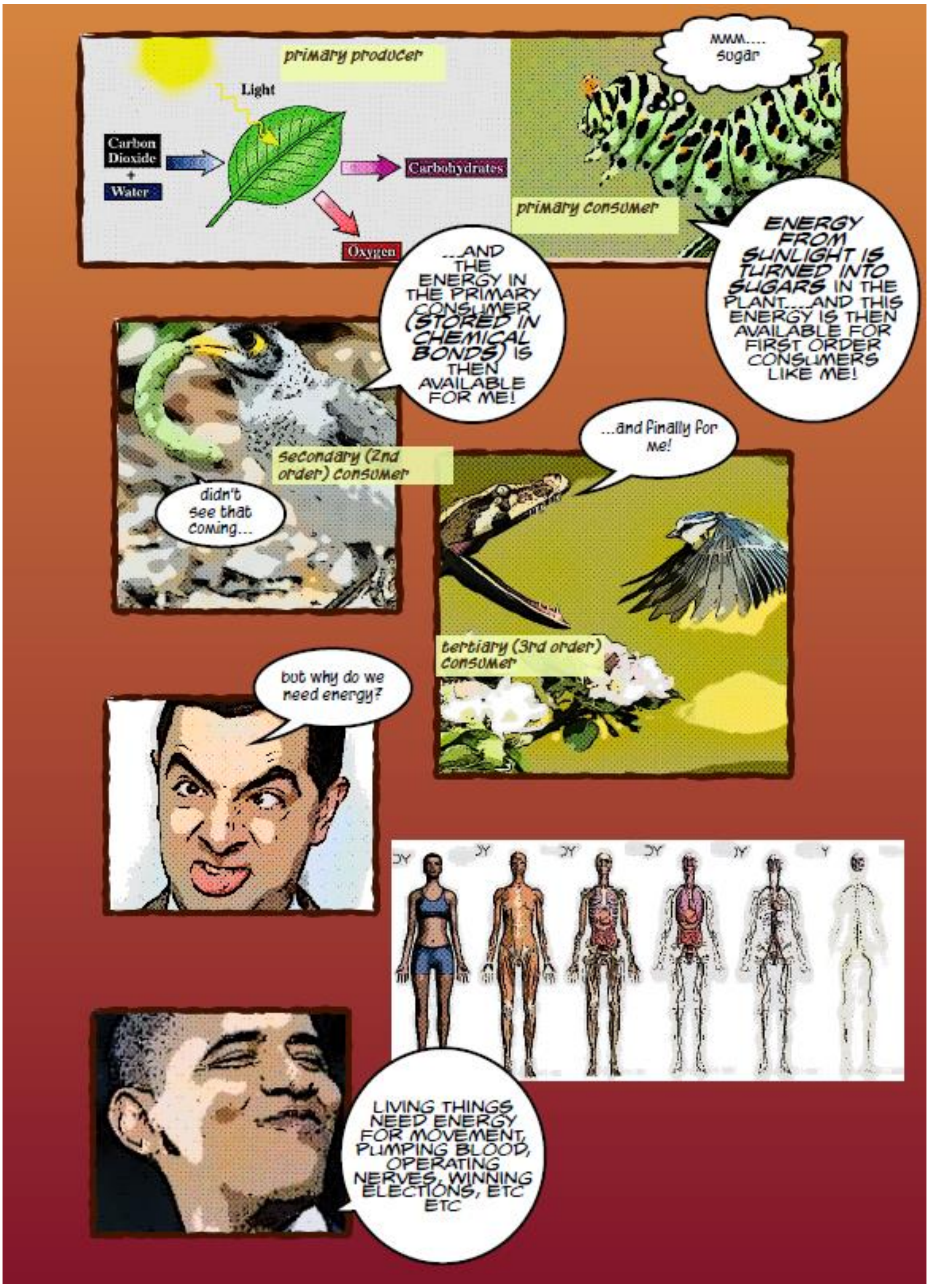

FEEDING RELATIONSHIPS
animals that eat only meat are called CARNIVORES
plant-eating animals are called HERBIVORES
animals that eat plants and animals - are called OMNIVORES
I'm a DETRIVORE - I eat dead things!
DETRIVORES
ok, but why are there always more first order consumers than second and third order consumers?
this is because most energy is lost between TROPHIC LEVELS
trophic levels are another way to describe feeding levels (i.e. between primary producers, 1st order consumers etc)
could you imagine having hundreds of us, and only a few zebras!
Tertiary Consumers
Secondary Consumers
Primary Consumers
Producers
trophic levels

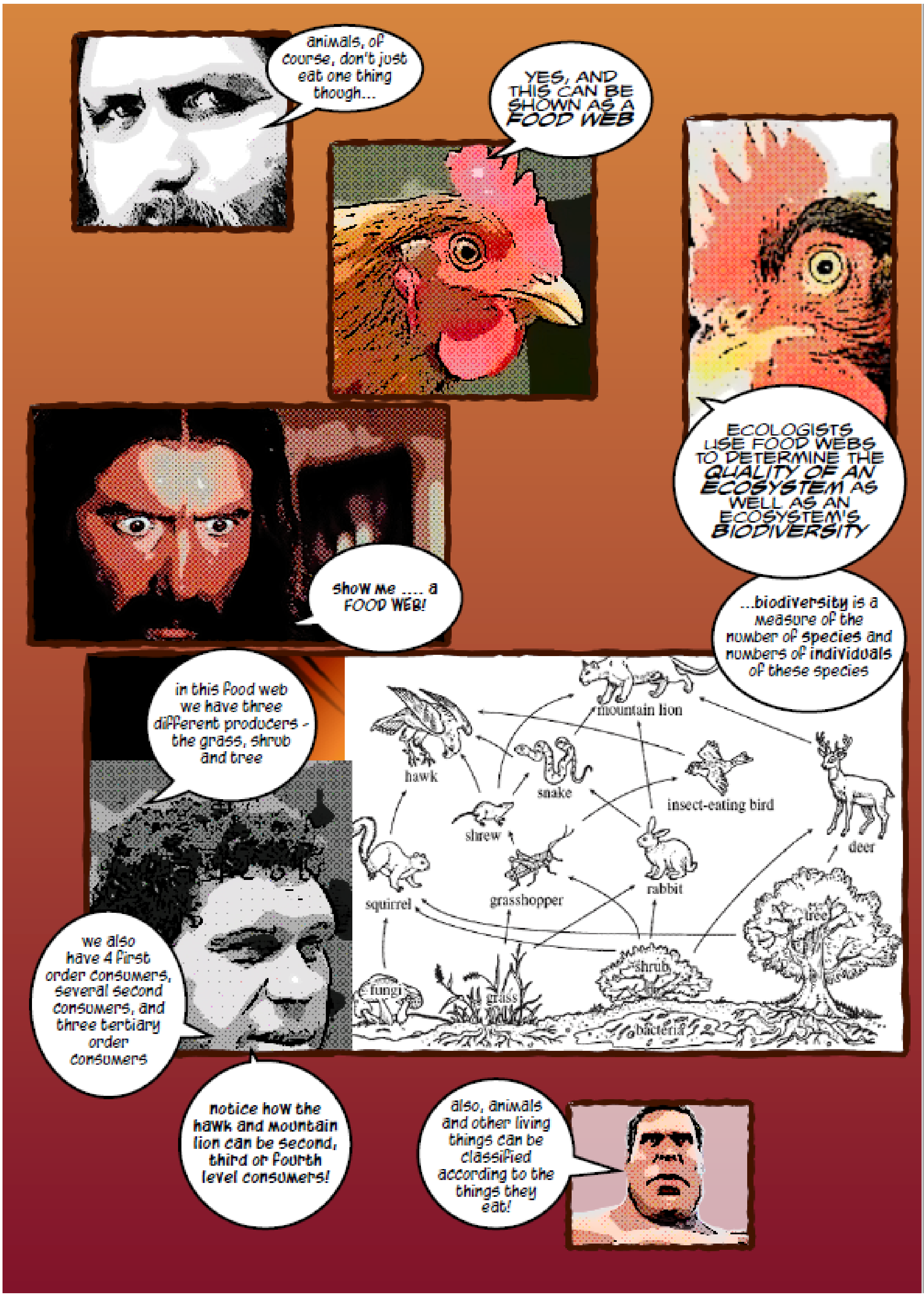

ENERGY IN ECOSYSTEMS
"Top" predators
Predators
Herbivores
PLANTS
Energy
ENERGY PYRAMID
10% OF ENERGY
The flow of energy through ecosystems helps us understand the size and structure of food webs
Top Carnivores / Tertiary Consumers
Carnivores / Secondary Consumers / Omnivores
Herbivores / Primary Consumers
Photosynthesis / Primary Producers
Soils / Decomposers
BIOMASS PYRAMID
Energy from sunlight enters the ecosystem in primary producers ...
...but only about 10% of the energy in plants is available to the next trophic level!
Remember: The energy is lost due to the animal's movement, metabolism etc
and only about 10% of the energy in first order consumers is available to second order consumers and so on!
which explains why we have far more plants than insects .... and far more rabbits than wolves!
IN CONCLUSION...we need to understand food webs and energy pyramids to protect our ecosystems!

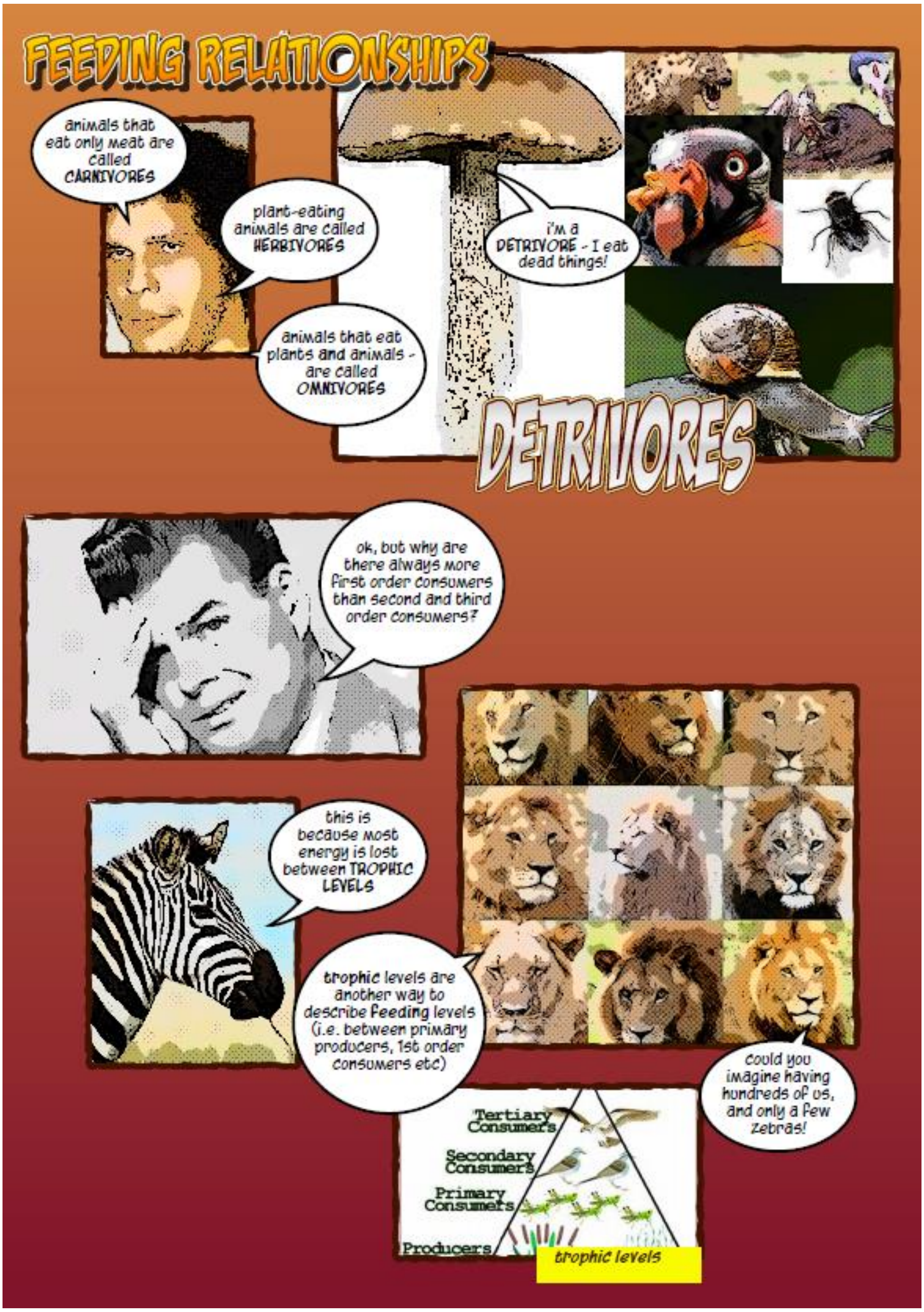
GRADE 7 WORKSHEETS (WORKSHEET 2 MULTIMODAL SOCIAL)




FOOD CHAINS
I can't see how food chains are important
scientists use food chains to show the flow of energy in ecosystems...
TELL ME MORE ABOUT FOOD CHAINS
well, if we didn't have energy flowing through food chains, we couldn't EXIST!!
LET'S HAVE A LOOK AT A SIMPLE EXAMPLE
Food chain
maize
producer
locust
primary consumer
lizard
secondary consumer
snake
tertiary consumer
THIS FOOD CHAIN SHOWS THE FLOW OF FOOD BETWEEN A PRIMARY PRODUCER AND A TERTIARY CONSUMER
the ARROW shows that the locust is eating the maize
...in other words, the arrow shows the direction that the energy (food) is travelling in!
PLANTS AND PLANT-LIKE ORGANISMS ARE ALWAYS FOUND AT THE BEGINNING OF FOOD CHAINS
...BECAUSE PLANTS ONLY NEED SUNLIGHT, WATER, AND SOME MINERALS TO GROW.
WE ARE CALLED PRIMARY PRODUCERS
PRIMARY PRODUCER


primary producer
Light
Carbon Dioxide
+
Water
Carbohydrates
Oxygen
MMM.... sugar
primary consumer
ENERGY FROM SUNLIGHT IS TURNED INTO SUGARS IN THE PLANT....AND THIS ENERGY IS THEN AVAILABLE FOR FIRST ORDER CONSUMERS LIKE ME!
...AND THE ENERGY IN THE PRIMARY CONSUMER (STORED IN CHEMICAL BONDS) IS THEN AVAILABLE FOR ME!
secondary (2nd order) consumer
didn't see that coming...
...and finally for me!
tertiary (3rd order) consumer
but why do we need energy?
LIVING THINGS NEED ENERGY FOR MOVEMENT, PUMPING BLOOD, OPERATING NERVES, WINNING ELECTIONS, ETC ETC


animals, of course, don't just eat one thing though...
YES, AND THIS CAN BE SHOWN AS A FOOD WEB
ECOLOGISTS USE FOOD WEBS TO DETERMINE THE QUALITY OF AN ECOSYSTEM AS WELL AS AN ECOSYSTEM'S BIODIVERSITY
show me .... a FOOD WEB!
...biodiversity is a measure of the number of species and numbers of individuals of these species
in this food web we have three different producers - the grass, shrub and tree
mountain lion
hawk
snake
insect-eating bird
shrew
deer
squirrel
grasshopper
rabbit
tree
shrub
fungi
grass
bacteria
we also have 4 first order consumers, several second consumers, and three tertiary order consumers
notice how the hawk and mountain lion can be second, third or fourth level consumers!
also, animals and other living things can be classified according to the things they eat!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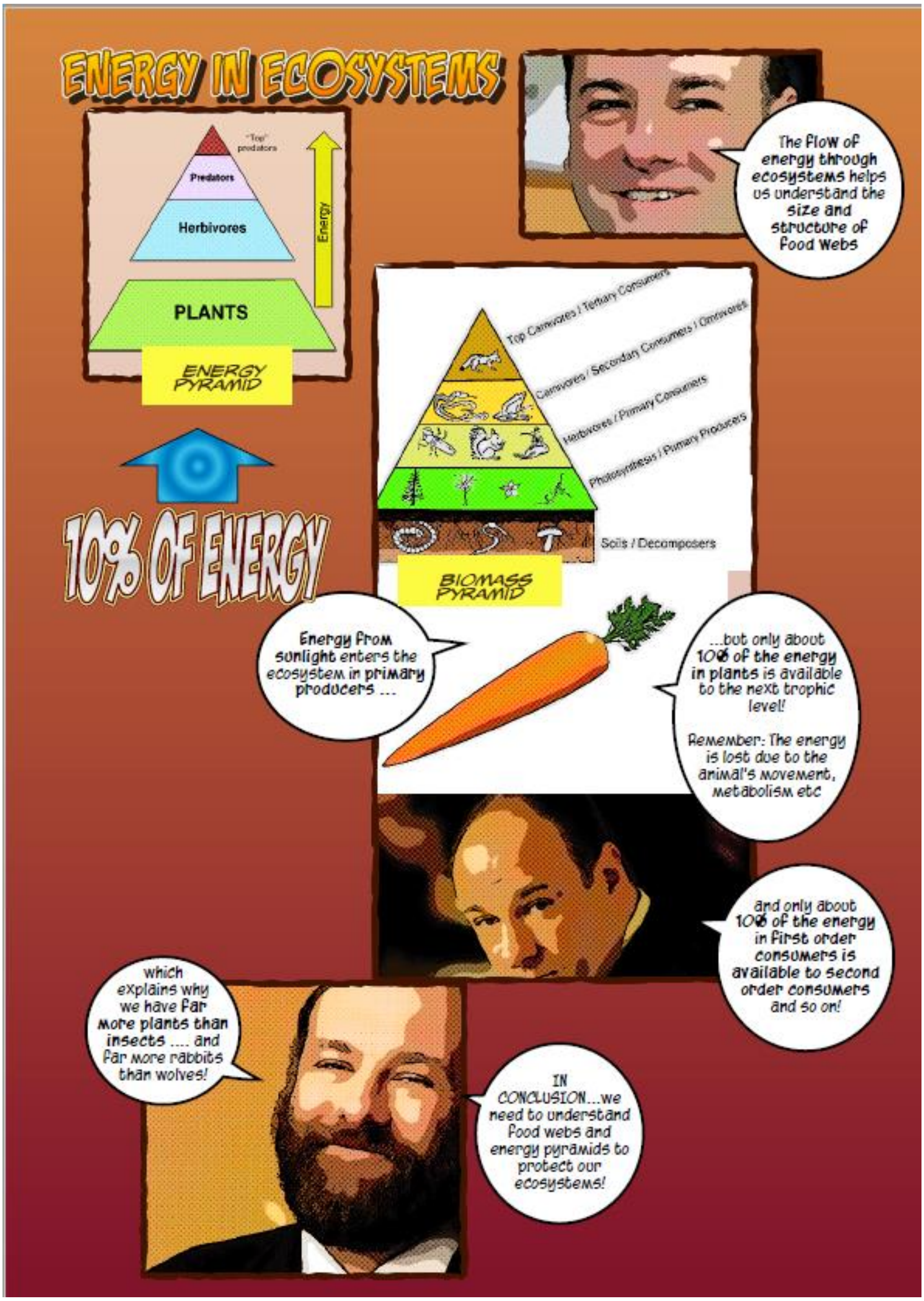
ENERGY IN ECOSYSTEMS
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10% OF ENERGY
Energy from sunlight enters the ecosystem in primary producers ...
...but only about 10% of the energy in plants is available to the next trophic level!
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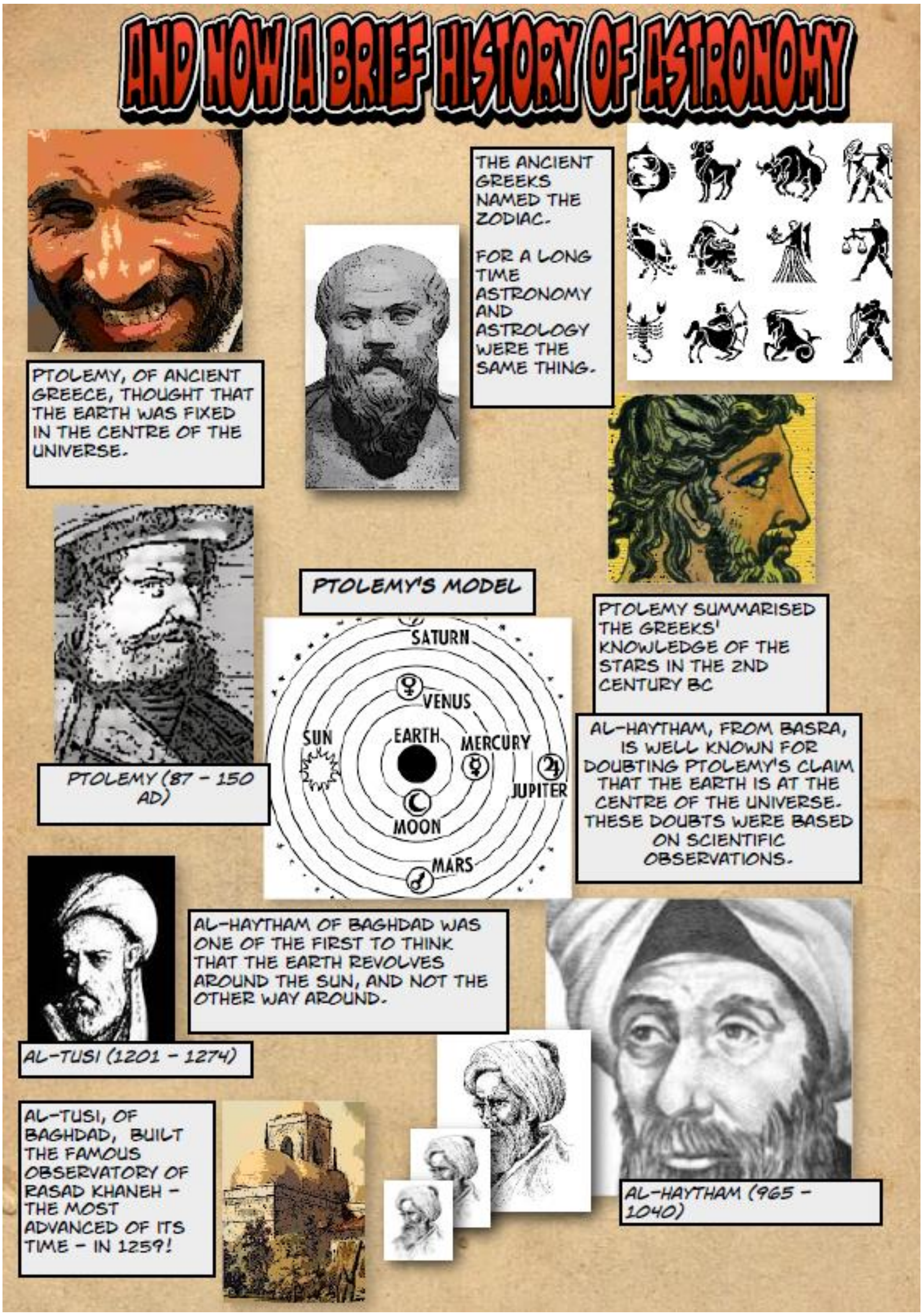
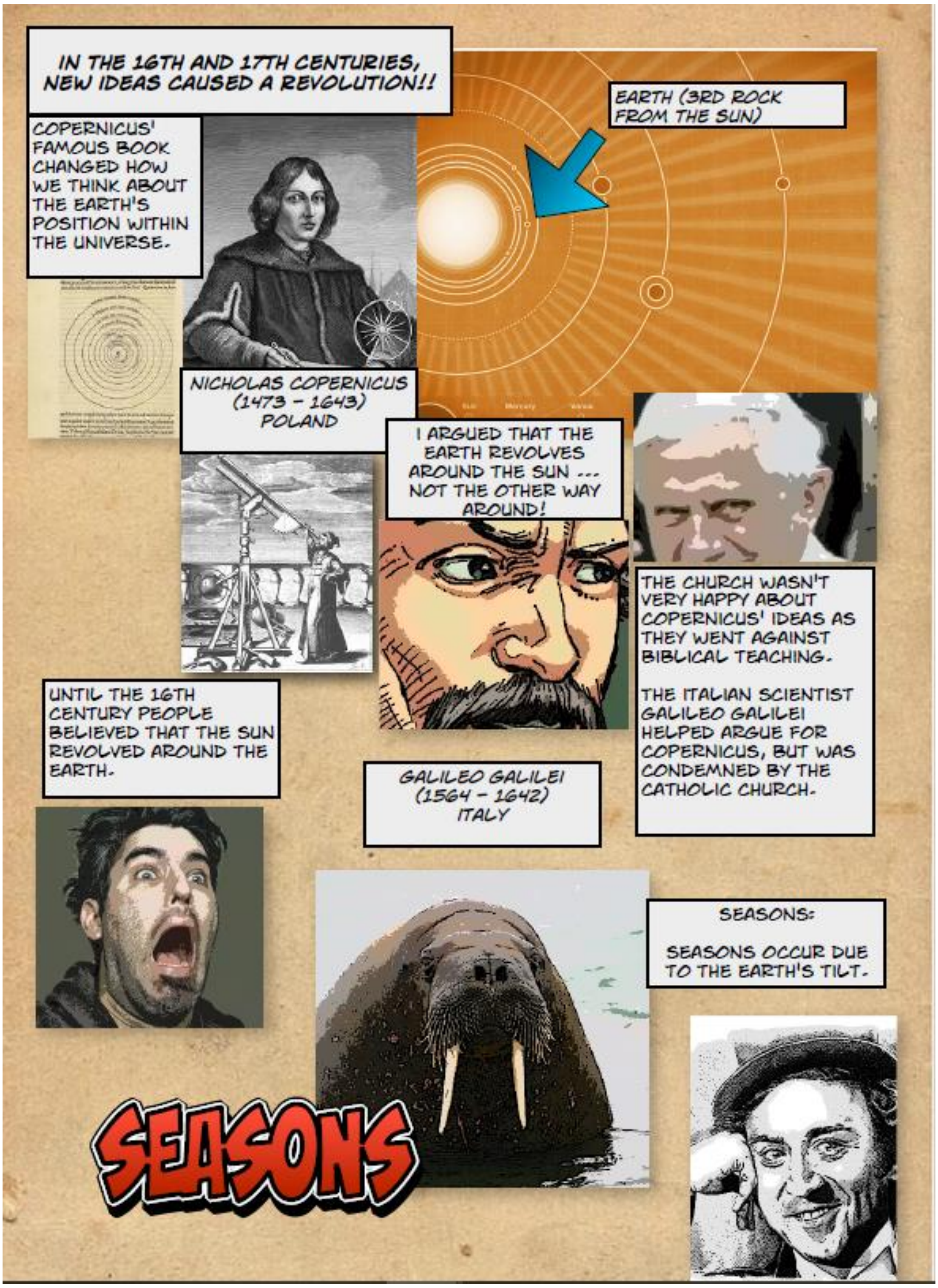
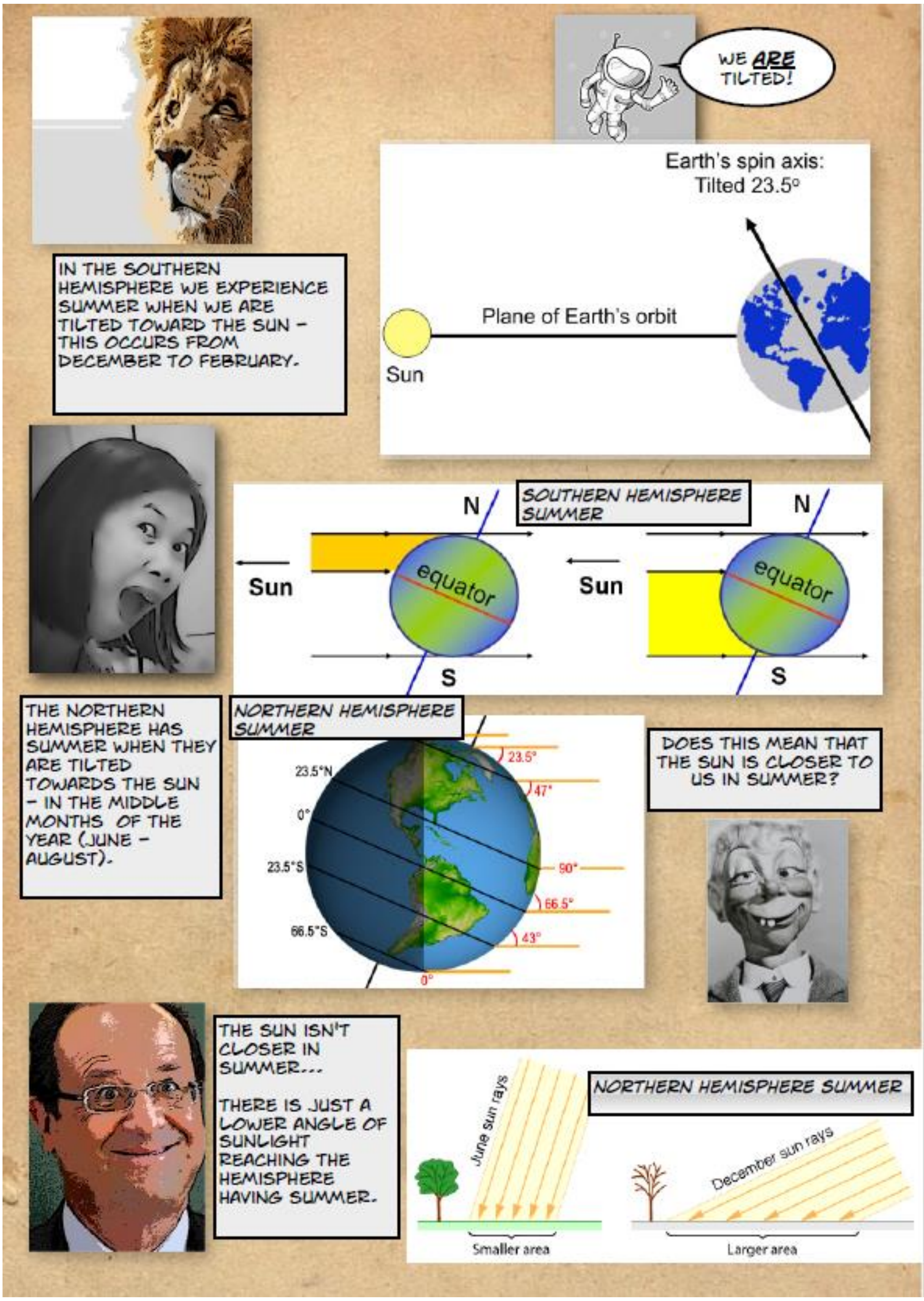
IN CONCLUSION...we need to understand food webs and energy pyramids to protect our ecosystems!

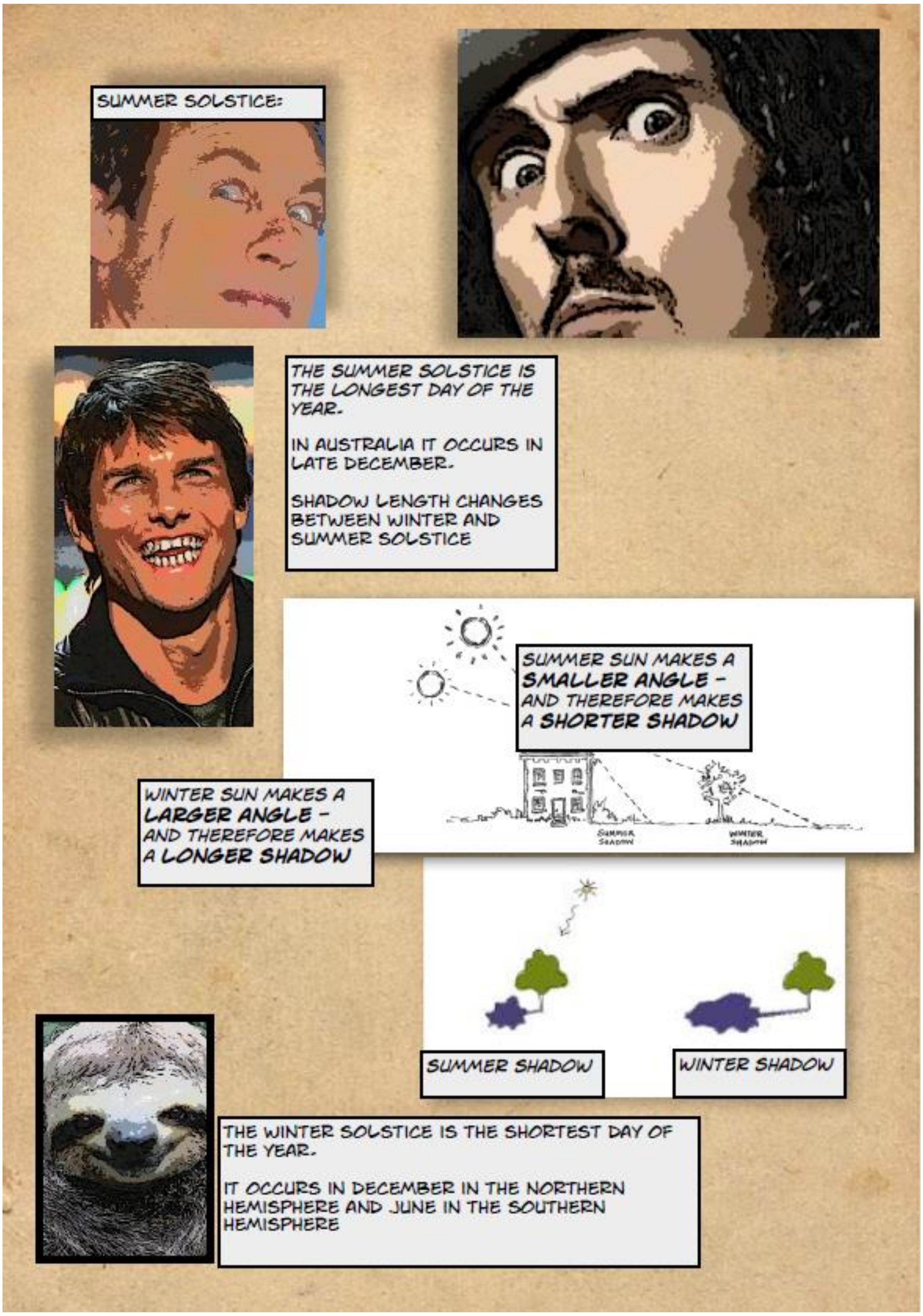
GRADE 7 WORKSHEETS (WORKSHEET 3 BIMODAL SOCIAL)

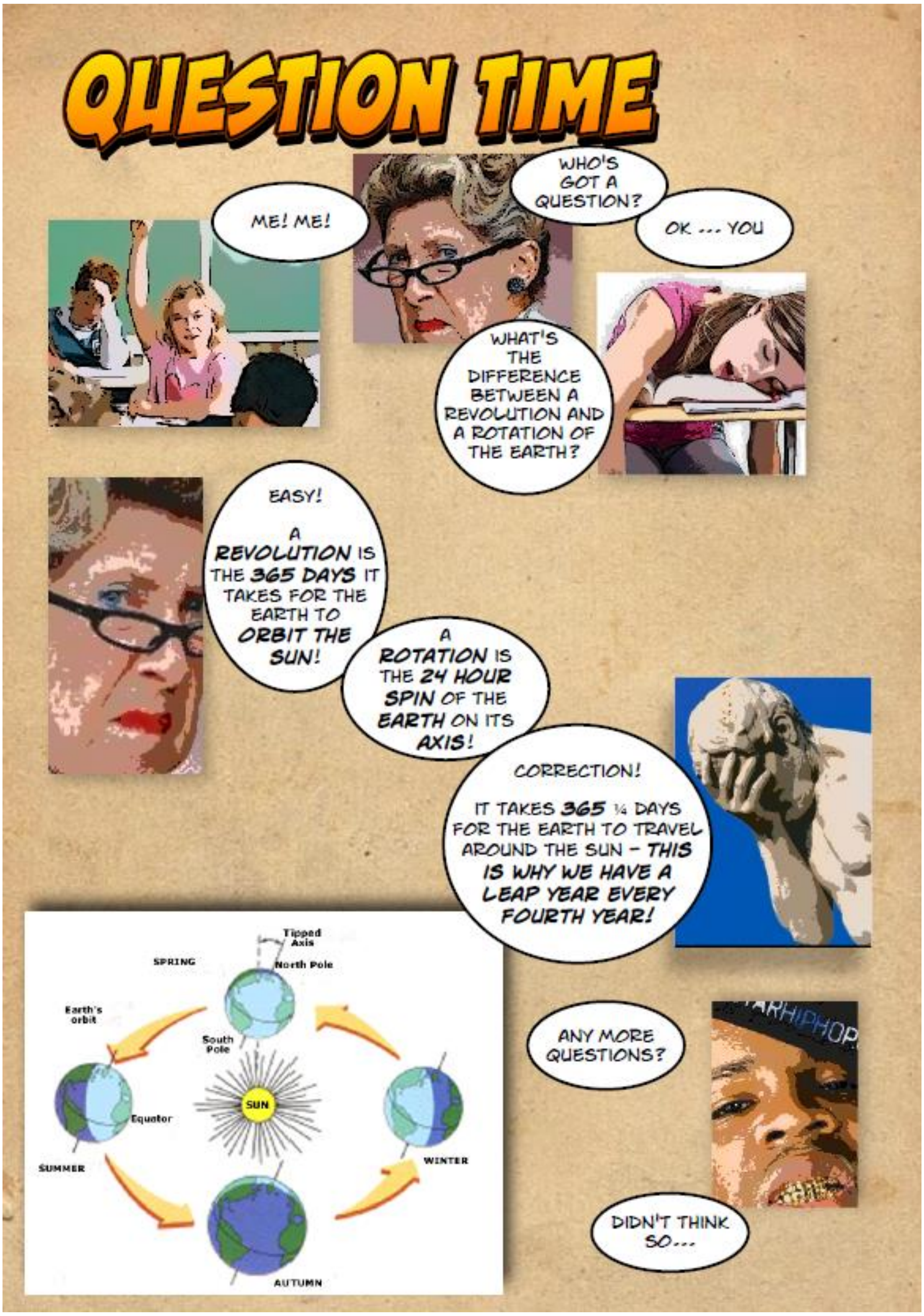

AND NOW A BRIEF HISTORY OF ASTRONOMY
PTOLEMY, OF ANCIENT GREECE, THOUGHT THAT THE EARTH WAS FIXED IN THE CENTRE OF THE UNIVERSE.
THE ANCIENT GREEKS NAMED THE ZODIAC.
FOR A LONG TIME ASTRONOMY AND ASTROLOGY WERE THE SAME THING.
PTOLEMY'S MODEL
SATURN
VENUS
SUN
EARTH
MERCURY
JUPITER
MOON
MARS
PTOLEMY SUMMARISED THE GREEKS' KNOWLEDGE OF THE STARS IN THE 2ND CENTURY BC
PTOLEMY (87 – 150 AD)
AL-HAYTHAM, FROM BASRA, IS WELL KNOWN FOR DOUBTING PTOLEMY'S CLAIM THAT THE EARTH IS AT THE CENTRE OF THE UNIVERSE. THESE DOUBTS WERE BASED ON SCIENTIFIC OBSERVATIONS.
AL-HAYTHAM OF BAGHDAD WAS ONE OF THE FIRST TO THINK THAT THE EARTH REVOLVES AROUND THE SUN, AND NOT THE OTHER WAY AROUND.
AL-TUSI (1201 – 1274)
AL-TUSI, OF BAGHDAD, BUILT THE FAMOUS OBSERVATORY OF RASAD KHANEH – THE MOST ADVANCED OF ITS TIME – IN 1259!
AL-HAYTHAM (965 – 1040)


IN THE 16TH AND 17TH CENTURIES, NEW IDEAS CAUSED A REVOLUTION!!
EARTH (3RD ROCK FROM THE SUN)
COPERNICUS' FAMOUS BOOK CHANGED HOW WE THINK ABOUT THE EARTH'S POSITION WITHIN THE UNIVERSE.
NICHOLAS COPERNICUS (1473 - 1643) POLAND
I ARGUED THAT THE EARTH REVOLVES AROUND THE SUN ... NOT THE OTHER WAY AROUND!
THE CHURCH WASN'T VERY HAPPY ABOUT COPERNICUS' IDEAS AS THEY WENT AGAINST BIBLICAL TEACHING.
THE ITALIAN SCIENTIST GALILEO GALILEI HELPED ARGUE FOR COPERNICUS, BUT WAS CONDEMNED BY THE CATHOLIC CHURCH.
UNTIL THE 16TH CENTURY PEOPLE BELIEVED THAT THE SUN REVOLVED AROUND THE EARTH.
GALILEO GALILEI (1564 - 1642) ITALY
SEASONS:
SEASONS OCCUR DUE TO THE EARTH'S TILT.
SEASONS



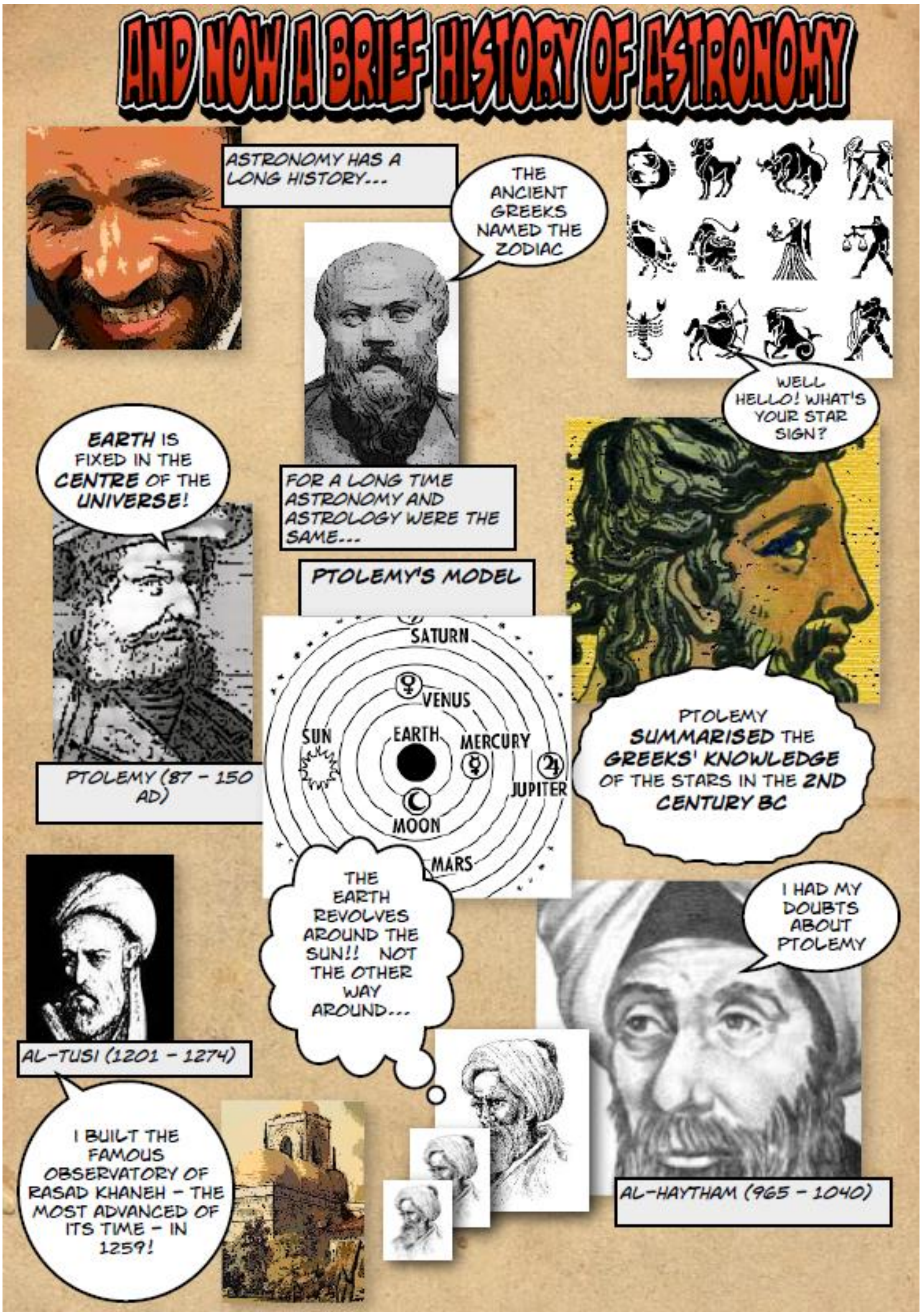
IN THE SOUTHERN HEMISPHERE WE EXPERIENCE SUMMER WHEN WE ARE TILTED TOWARD THE SUN – THIS OCCURS FROM DECEMBER TO FEBRUARY.
WE ARE TILTED!
Earth's spin axis: Tilted 23.5°
Plane of Earth's orbit
Sun
SOUTHERN HEMISPHERE SUMMER
N
Sun
equator
S
N
Sun
equator
S
THE NORTHERN HEMISPHERE HAS SUMMER WHEN THEY ARE TILTED TOWARDS THE SUN – IN THE MIDDLE MONTHS OF THE YEAR (JUNE – AUGUST).
NORTHERN HEMISPHERE SUMMER
23.5°N
0°
23.5°S
66.5°S
23.5°
47°
90°
66.5°
43°
0°
DOES THIS MEAN THAT THE SUN IS CLOSER TO US IN SUMMER?
THE SUN ISN'T CLOSER IN SUMMER...
THERE IS JUST A LOWER ANGLE OF SUNLIGHT REACHING THE HEMISPHERE HAVING SUMMER.
NORTHERN HEMISPHERE SUMMER
June sun rays
December sun rays
Smaller area
Larger area

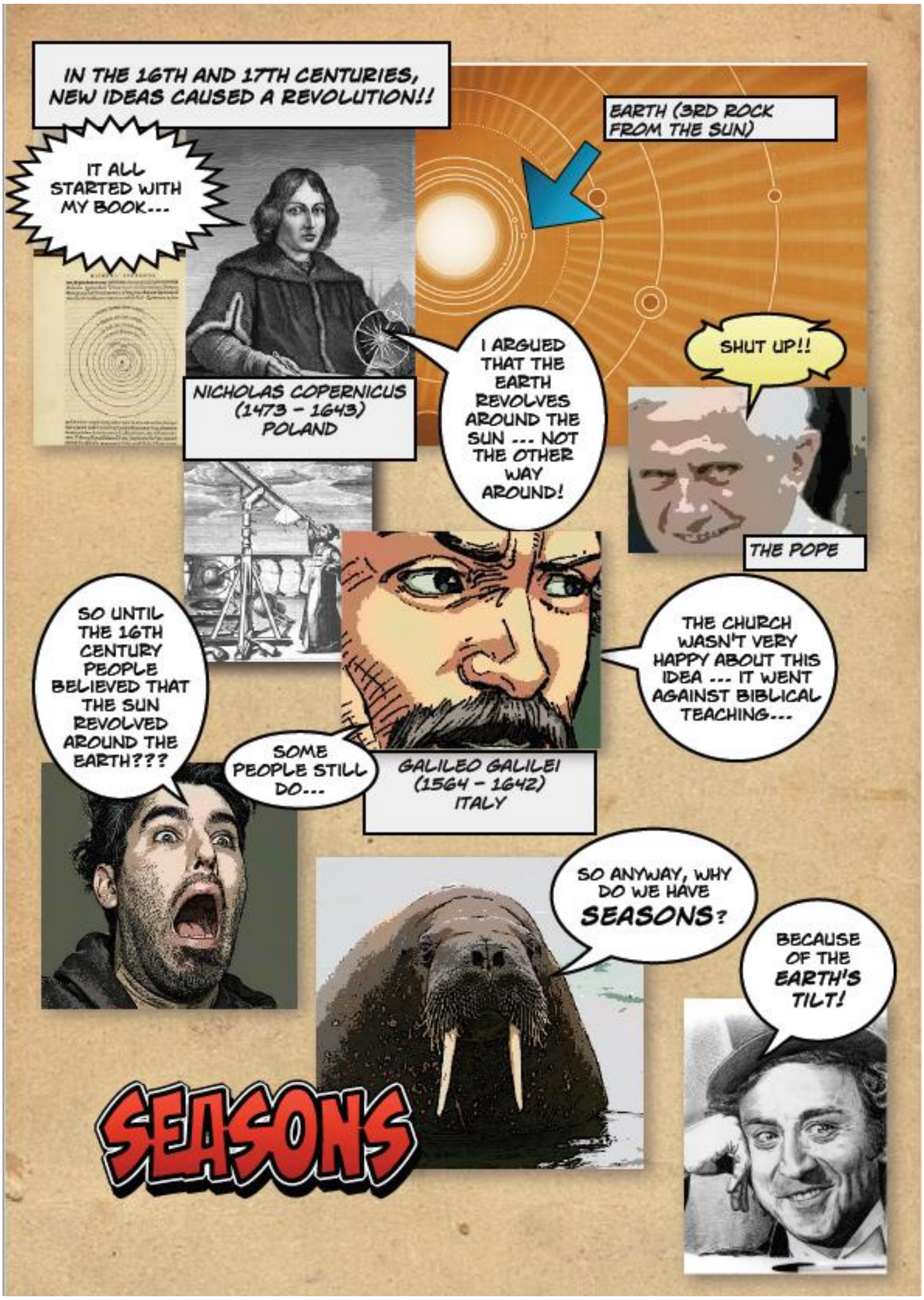

SUMMER SOLSTICE:
THE SUMMER SOLSTICE IS THE LONGEST DAY OF THE YEAR.
IN AUSTRALIA IT OCCURS IN LATE DECEMBER.
SHADOW LENGTH CHANGES BETWEEN WINTER AND SUMMER SOLSTICE
SUMMER SUN MAKES A SMALLER ANGLE – AND THEREFORE MAKES A SHORTER SHADOW
WINTER SUN MAKES A LARGER ANGLE – AND THEREFORE MAKES A LONGER SHADOW
SUMMER SHADOW
WINTER SHADOW
THE WINTER SOLSTICE IS THE SHORTEST DAY OF THE YEAR.
IT OCCURS IN DECEMBER IN THE NORTHERN HEMISPHERE AND JUNE IN THE SOUTHERN HEMISPHERE

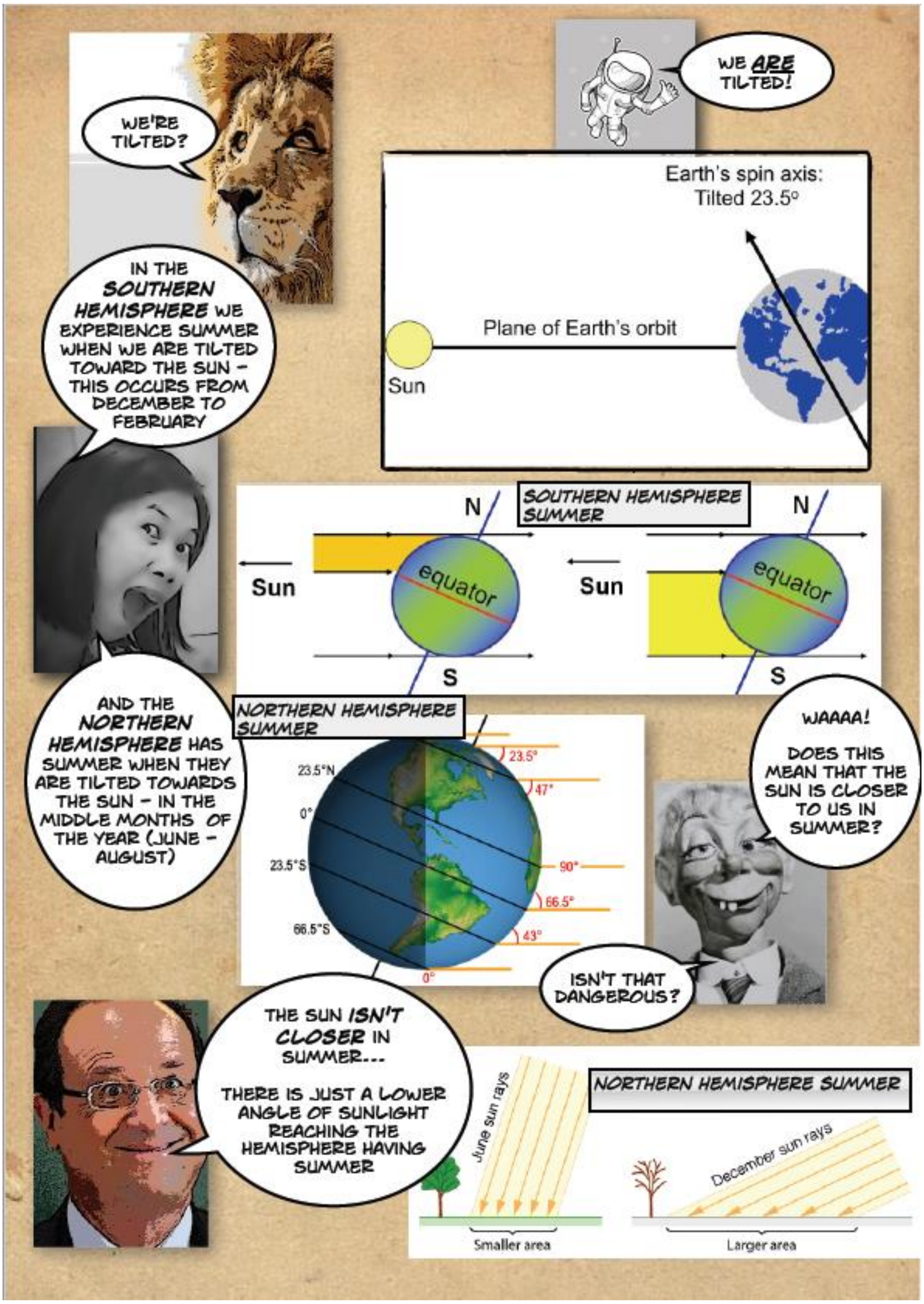


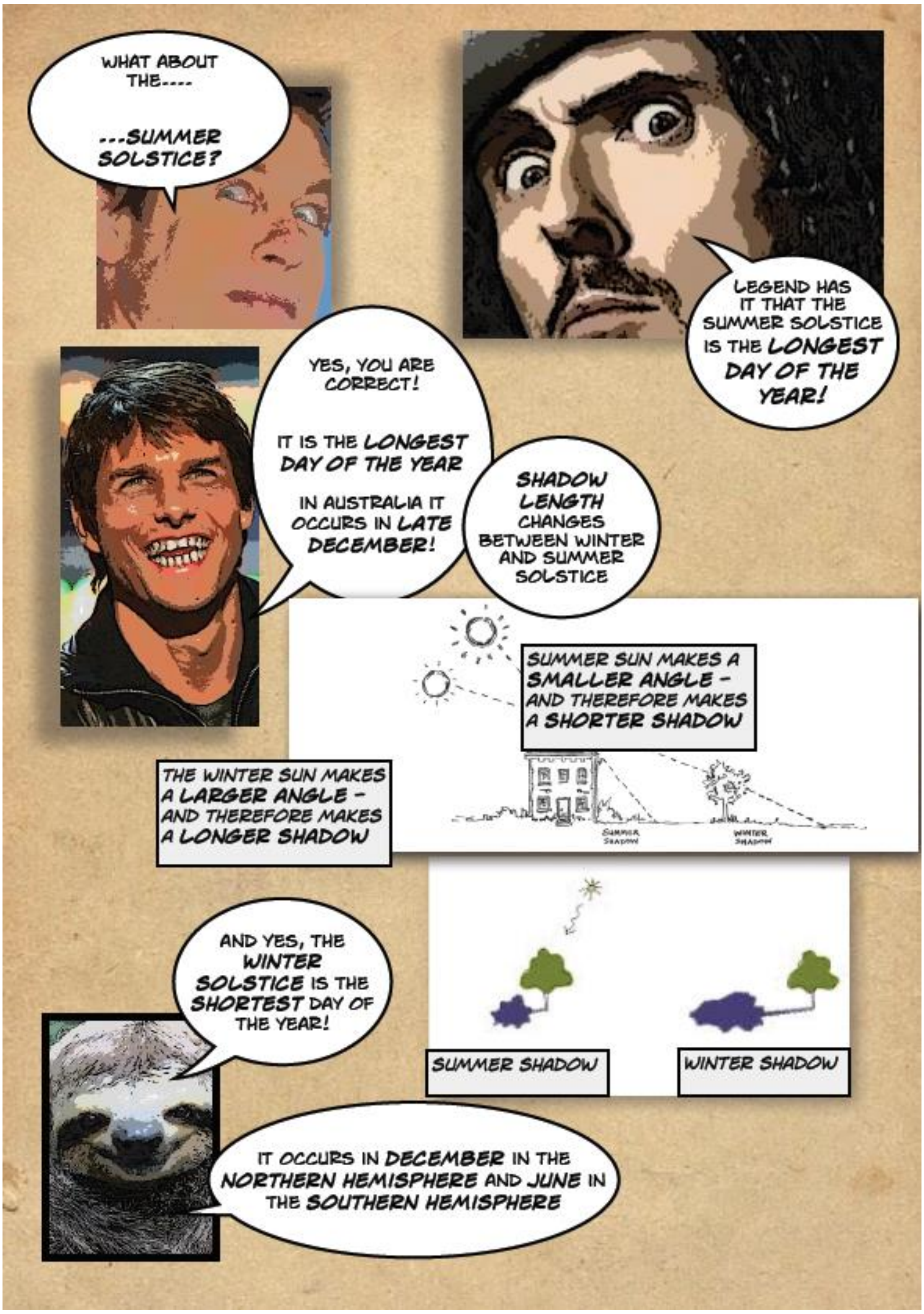
QUESTION TIME
WHO'S GOT A QUESTION?
ME! ME!
OK ... YOU
WHAT'S THE DIFFERENCE BETWEEN A REVOLUTION AND A ROTATION OF THE EARTH?
EASY!
A REVOLUTION IS THE 365 DAYS IT TAKES FOR THE EARTH TO ORBIT THE SUN!
A ROTATION IS THE 24 HOUR SPIN OF THE EARTH ON ITS AXIS!
CORRECTION!
IT TAKES 365 ¼ DAYS FOR THE EARTH TO TRAVEL AROUND THE SUN – THIS IS WHY WE HAVE A LEAP YEAR EVERY FOURTH YEAR!
Tipped Axis
SPRING
North Pole
Earth's orbit
South Pole
SUN
Equator
SUMMER
WINTER
AUTUMN
ANY MORE QUESTIONS?
DIDN'T THINK SO...

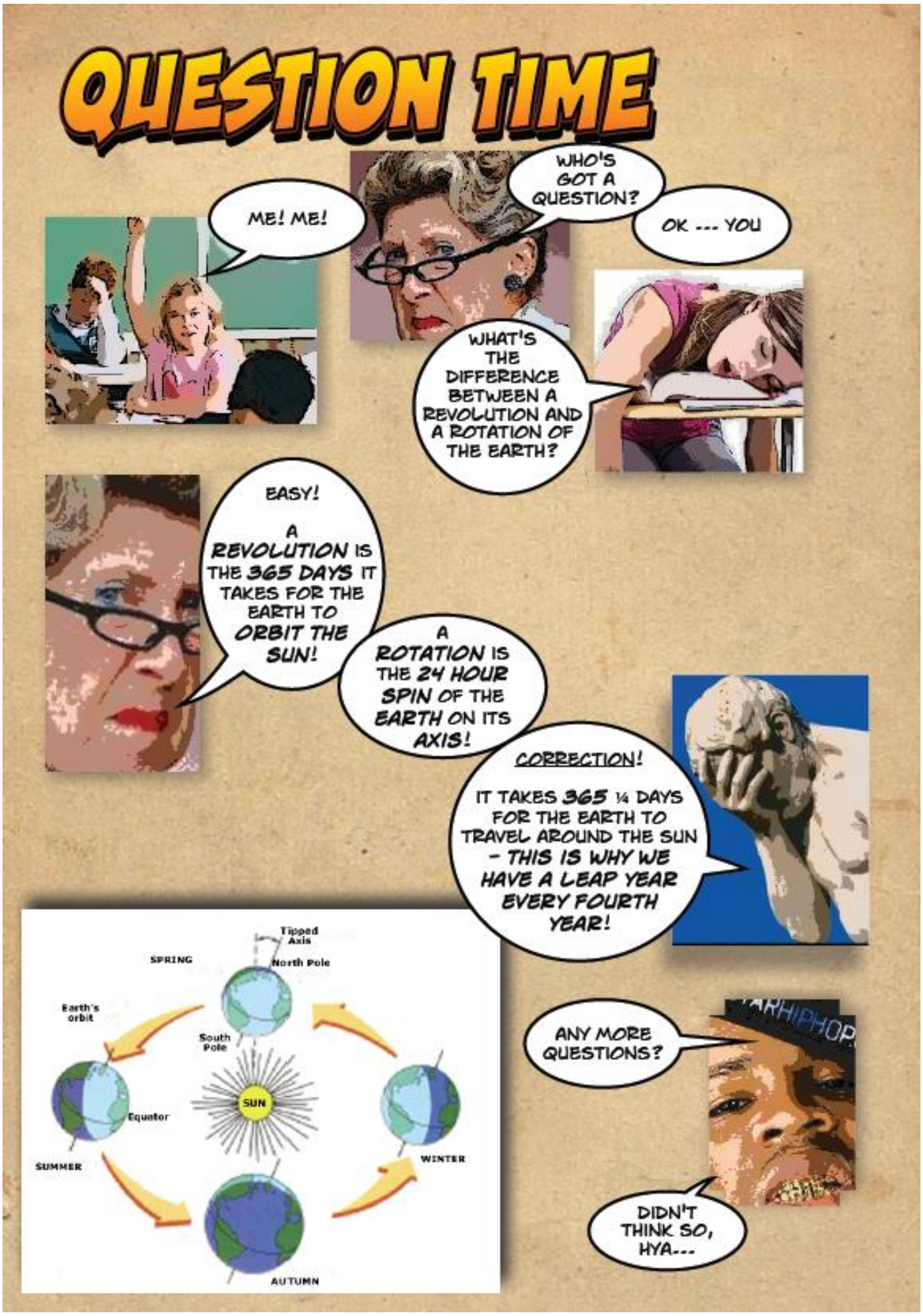
GRADE 7 WORKSHEETS (WORKSHEET 3 MULTIMODAL SOCIAL)


AND NOW A BRIEF HISTORY OF ASTRONOMY
ASTRONOMY HAS A LONG HISTORY...
THE ANCIENT GREEKS NAMED THE ZODIAC
WELL HELLO! WHAT'S YOUR STAR SIGN?
EARTH IS FIXED IN THE CENTRE OF THE UNIVERSE!
FOR A LONG TIME ASTRONOMY AND ASTROLOGY WERE THE SAME...
PTOLEMY'S MODEL
SATURN
VENUS
SUN
EARTH
MERCURY
JUPITER
MOON
MARS
PTOLEMY (87 - 150 AD)
PTOLEMY SUMMARISED THE GREEKS' KNOWLEDGE OF THE STARS IN THE 2ND CENTURY BC
THE EARTH REVOLVES AROUND THE SUN!! NOT THE OTHER WAY AROUND...
I HAD MY DOUBTS ABOUT PTOLEMY
AL-TUSI (1201 - 1274)
I BUILT THE FAMOUS OBSERVATORY OF RASAD KHANEH - THE MOST ADVANCED OF ITS TIME - IN 1259!
AL-HAYTHAM (965 - 1040)


IN THE 16TH AND 17TH CENTURIES, NEW IDEAS CAUSED A REVOLUTION!!
IT ALL STARTED WITH MY BOOK...
EARTH (3RD ROCK FROM THE SUN)
NICHOLAS COPERNICUS (1473 – 1643) POLAND
I ARGUED THAT THE EARTH REVOLVES AROUND THE SUN ... NOT THE OTHER WAY AROUND!
SHUT UP!!
THE POPE
THE CHURCH WASN'T VERY HAPPY ABOUT THIS IDEA ... IT WENT AGAINST BIBLICAL TEACHING...
SO UNTIL THE 16TH CENTURY PEOPLE BELIEVED THAT THE SUN REVOLVED AROUND THE EARTH???
SOME PEOPLE STILL DO...
GALILEO GALILEI (1564 – 1642) ITALY
SO ANYWAY, WHY DO WE HAVE SEASONS?
BECAUSE OF THE EARTH'S TILT!
SEASONS


WE'RE TILTED?
WE ARE TILTED!
Earth's spin axis: Tilted 23.5°
Plane of Earth's orbit
Sun
IN THE SOUTHERN HEMISPHERE WE EXPERIENCE SUMMER WHEN WE ARE TILTED TOWARD THE SUN – THIS OCCURS FROM DECEMBER TO FEBRUARY
SOUTHERN HEMISPHERE SUMMER
N
Sun
equator
S
AND THE NORTHERN HEMISPHERE HAS SUMMER WHEN THEY ARE TILTED TOWARDS THE SUN – IN THE MIDDLE MONTHS OF THE YEAR (JUNE – AUGUST)
NORTHERN HEMISPHERE SUMMER
23.5°N
0°
23.5°S
66.5°S
23.5°
47°
90°
66.5°
43°
0°
WAAAA! DOES THIS MEAN THAT THE SUN IS CLOSER TO US IN SUMMER?
ISN'T THAT DANGEROUS?
THE SUN ISN'T CLOSER IN SUMMER...
THERE IS JUST A LOWER ANGLE OF SUNLIGHT REACHING THE HEMISPHERE HAVING SUMMER
NORTHERN HEMISPHERE SUMMER
June sun rays
Smaller area
December sun rays
Larger area


WHAT ABOUT THE---- ...SUMMER SOLSTICE?
LEGEND HAS IT THAT THE SUMMER SOLSTICE IS THE LONGEST DAY OF THE YEAR!
YES, YOU ARE CORRECT! IT IS THE LONGEST DAY OF THE YEAR IN AUSTRALIA IT OCCURS IN LATE DECEMBER!
SHADOW LENGTH CHANGES BETWEEN WINTER AND SUMMER SOLSTICE
SUMMER SUN MAKES A SMALLER ANGLE - AND THEREFORE MAKES A SHORTER SHADOW
THE WINTER SUN MAKES A LARGER ANGLE - AND THEREFORE MAKES A LONGER SHADOW
SUMMER SHADOW
WINTER SHADOW
AND YES, THE WINTER SOLSTICE IS THE SHORTEST DAY OF THE YEAR!
IT OCCURS IN DECEMBER IN THE NORTHERN HEMISPHERE AND JUNE IN THE SOUTHERN HEMISPHERE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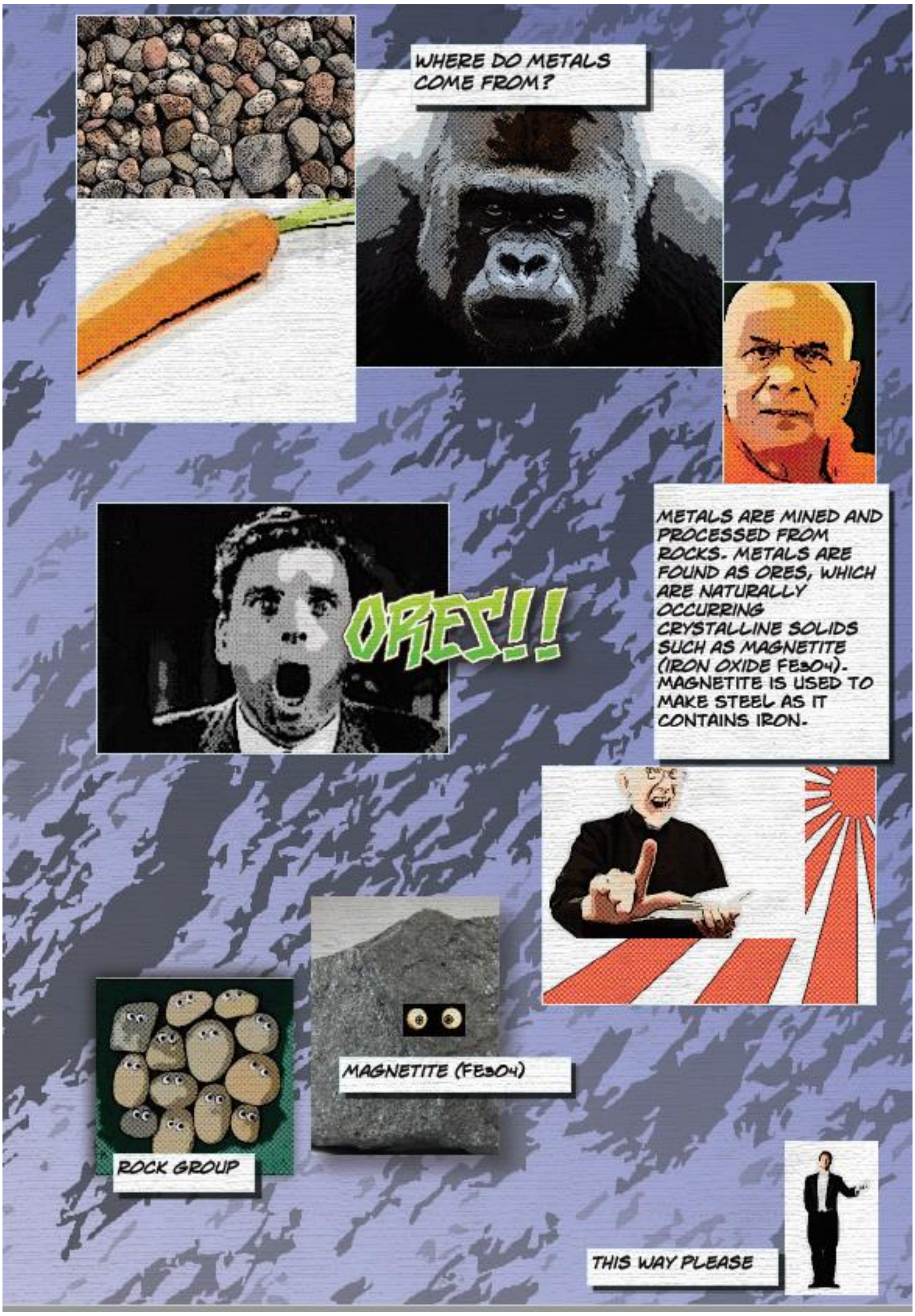
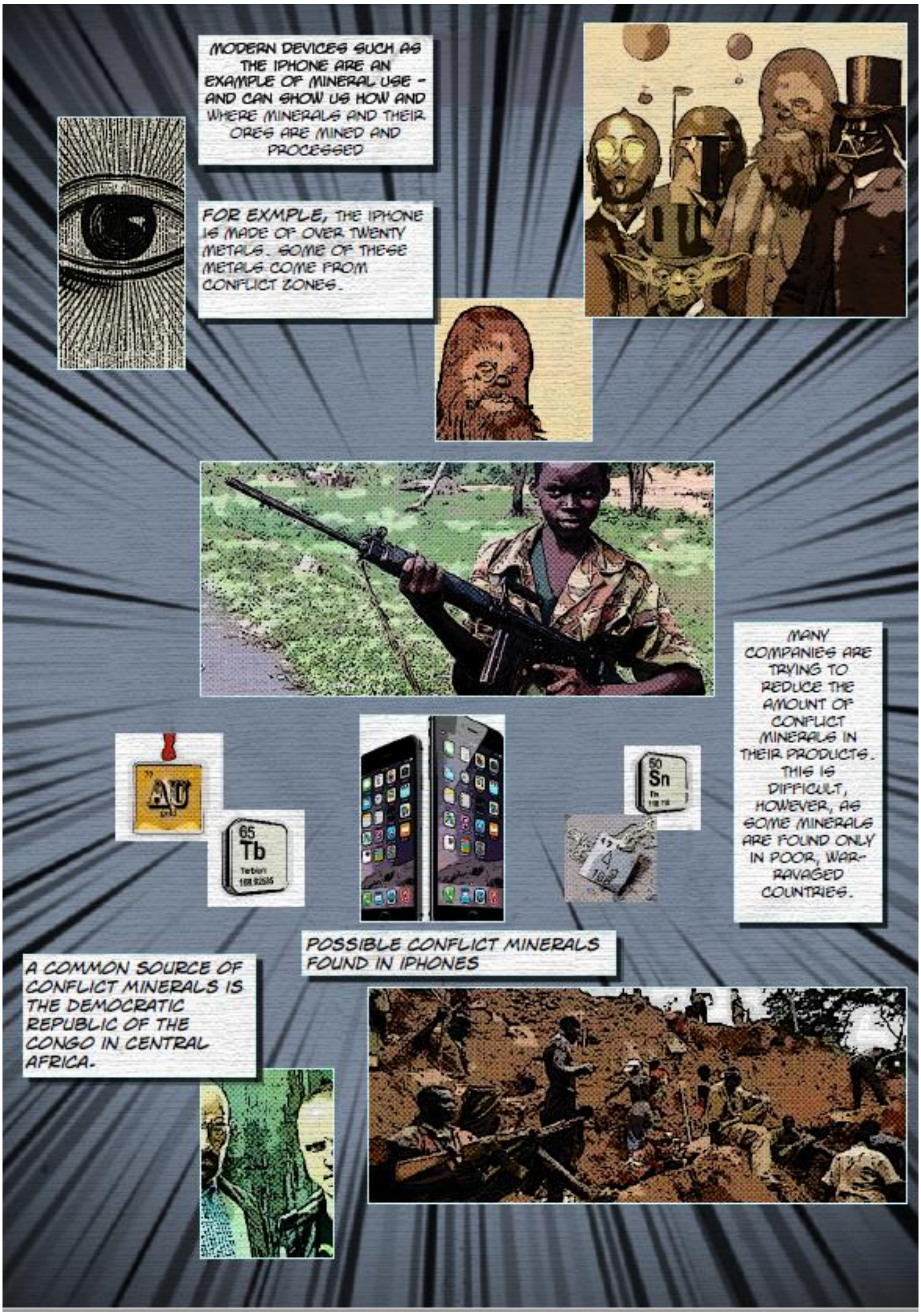
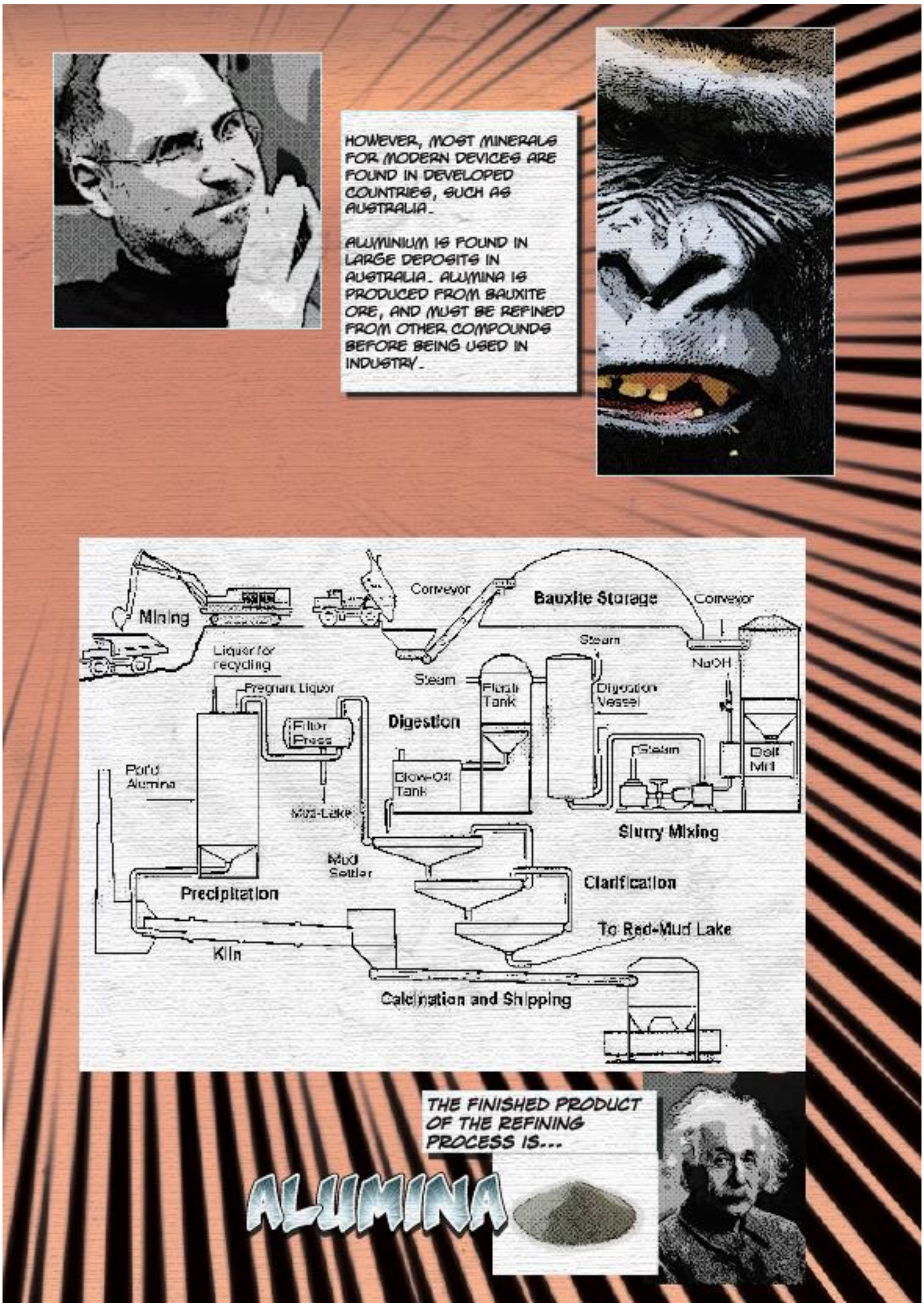
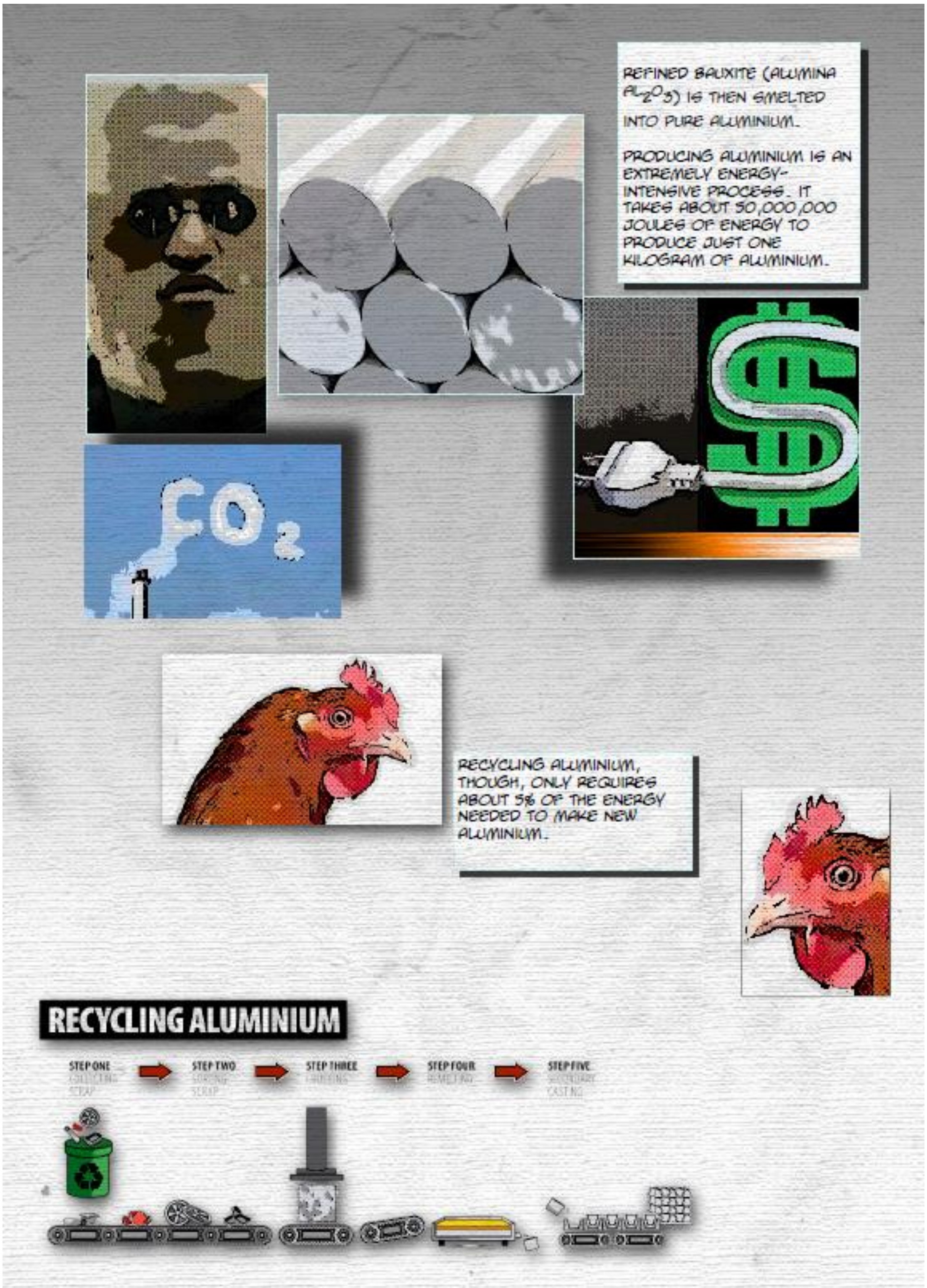
ANY MORE QUESTIONS?
DIDN'T THINK SO, HYA...

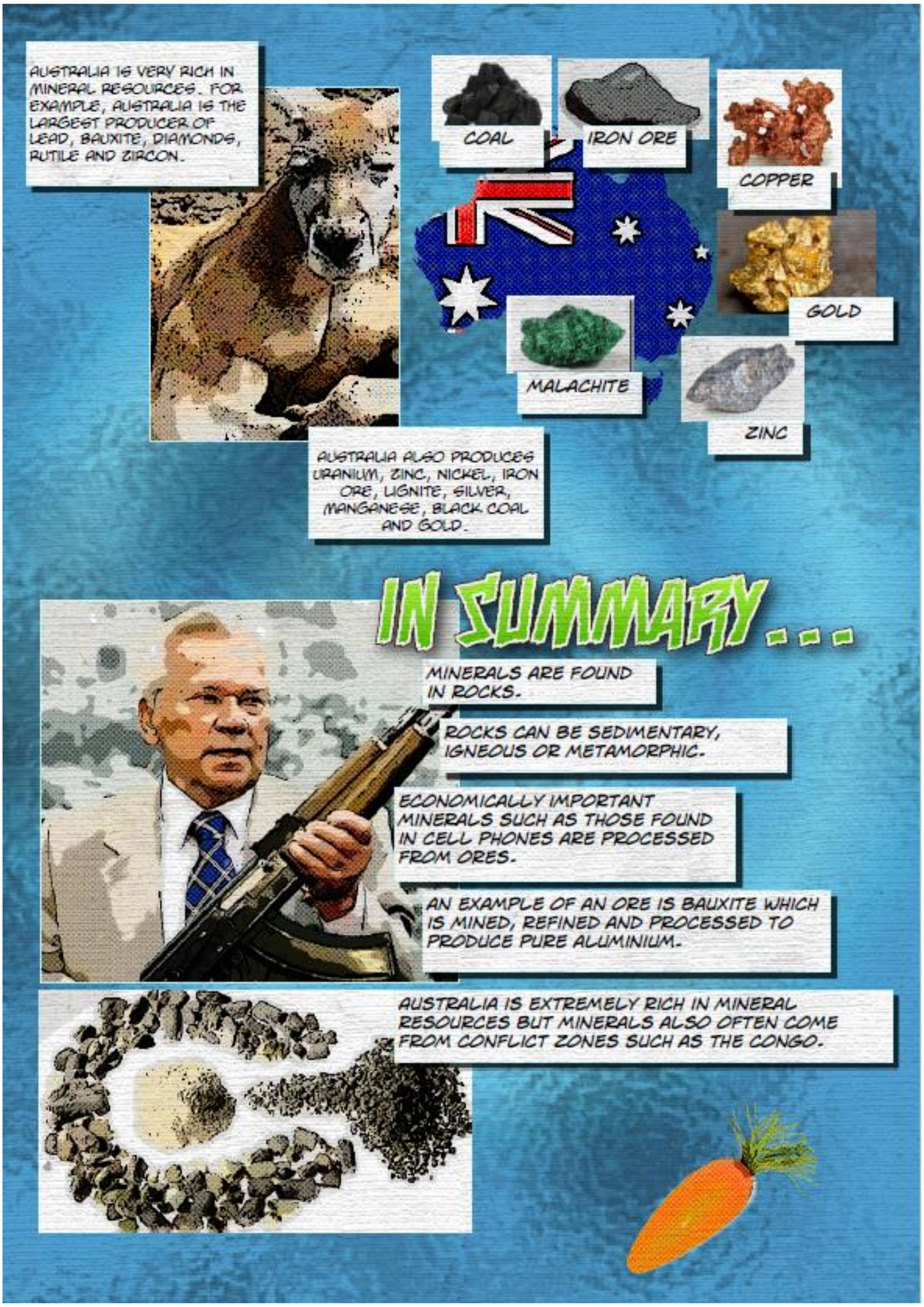
GRADE 8 WORKSHEETS (WORKSHEET 1 BIMODAL SOCIAL)



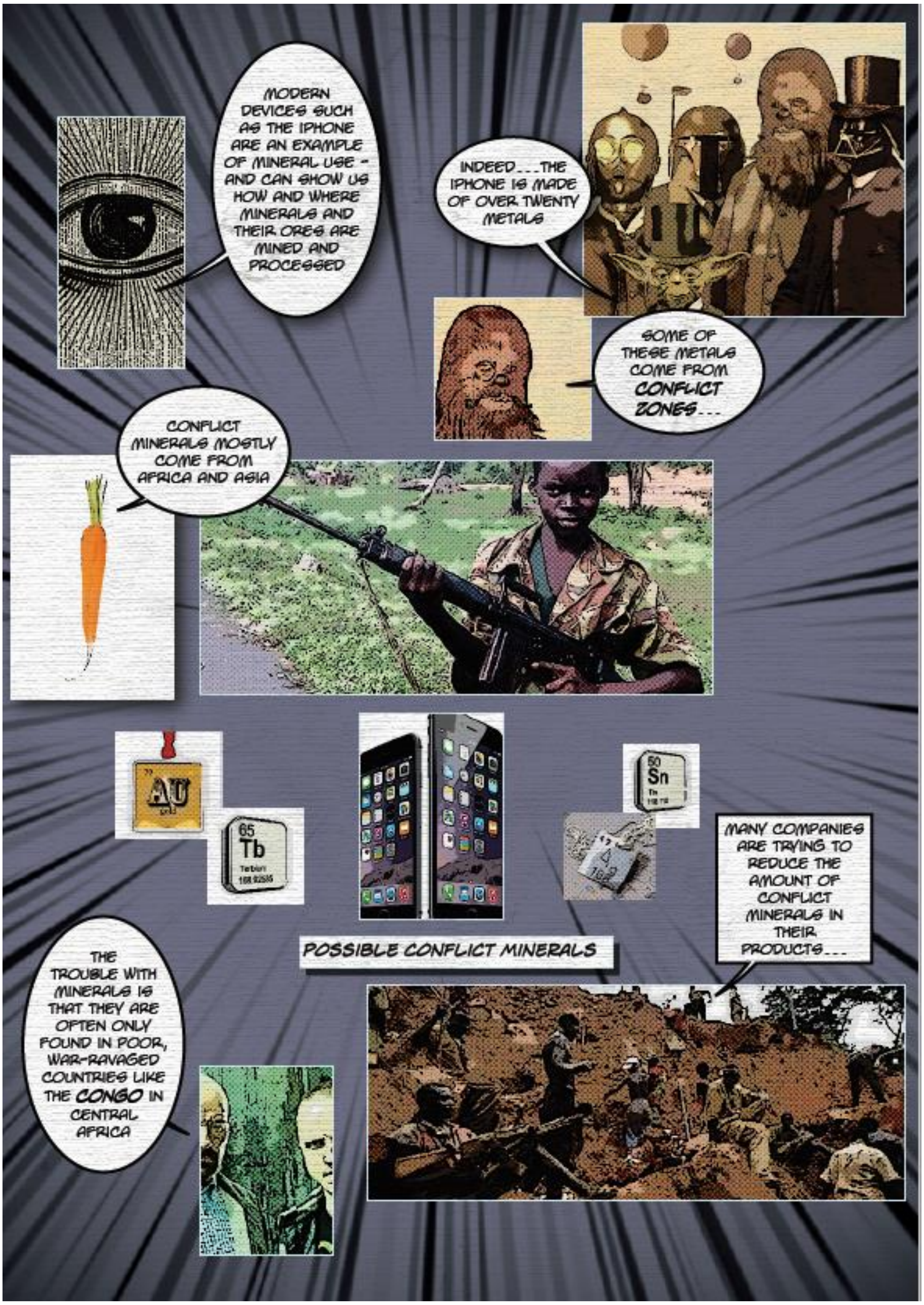

MODERN DEVICES SUCH AS THE IPHONE ARE AN EXAMPLE OF MINERAL USE - AND CAN SHOW US HOW AND WHERE MINERALS AND THEIR ORES ARE MINED AND PROCESSED
FOR EXMPLE, THE IPHONE IS MADE OF OVER TWENTY METALS. SOME OF THESE METALS COME FROM CONFLICT ZONES.
MANY COMPANIES ARE TRYING TO REDUCE THE AMOUNT OF CONFLICT MINERALS IN THEIR PRODUCTS. THIS IS DIFFICULT, HOWEVER, AS SOME MINERALS ARE FOUND ONLY IN POOR, WAR-RAVAGED COUNTRIES.
AU
65
Tb
50
Sn
POSSIBLE CONFLICT MINERALS FOUND IN IPHONES
A COMMON SOURCE OF CONFLICT MINERALS IS THE DEMOCRATIC REPUBLIC OF THE CONGO IN CENTRAL AFRICA.


HOWEVER, MOST MINERALS FOR MODERN DEVICES ARE FOUND IN DEVELOPED COUNTRIES, SUCH AS AUSTRALIA.
ALUMINIUM IS FOUND IN LARGE DEPOSITS IN AUSTRALIA. ALUMINA IS PRODUCED FROM BAUXITE ORE, AND MUST BE REFINED FROM OTHER COMPOUNDS BEFORE BEING USED IN INDUSTRY.
Mining
Conveyor
Bauxite Storage
Conveyor
Steam
NaOH
Liquor for recycling
Pregnant Liquor
Steam
Flash Tank
Digestion Vessel
Filter Press
Digestion
Steam
Ball Mill
Blow-Off Tank
Mud-Lake
Slurry Mixing
Mud Settler
Clarification
Precipitation
To Red-Mud Lake
Kiln
Calcination and Shipping
THE FINISHED PRODUCT OF THE REFINING PROCESS IS...
ALUMINA


REFINED BAUXITE (ALUMINA Al_2O_3) IS THEN SMELTED INTO PURE ALUMINIUM.
PRODUCING ALUMINIUM IS AN EXTREMELY ENERGY-INTENSIVE PROCESS. IT TAKES ABOUT 50,000,000 JOULES OF ENERGY TO PRODUCE JUST ONE KILOGRAM OF ALUMINIUM.
CO_2
RECYCLING ALUMINIUM, THOUGH, ONLY REQUIRES ABOUT 5% OF THE ENERGY NEEDED TO MAKE NEW ALUMINIUM.
RECYCLING ALUMINIUM
STEP ONE
STEP TWO
STEP THREE
STEP FOUR
STEP FIVE


AUSTRALIA IS VERY RICH IN MINERAL RESOURCES. FOR EXAMPLE, AUSTRALIA IS THE LARGEST PRODUCER OF LEAD, BAUXITE, DIAMONDS, RUTILE AND ZIRCON.
COAL
IRON ORE
COPPER
GOLD
MALACHITE
ZINC
AUSTRALIA ALSO PRODUCES URANIUM, ZINC, NICKEL, IRON ORE, LIGNITE, SILVER, MANGANESE, BLACK COAL AND GOLD.
IN SUMMARY...
MINERALS ARE FOUND IN ROCKS.
ROCKS CAN BE SEDIMENTARY, IGNEOUS OR METAMORPHIC.
ECONOMICALLY IMPORTANT MINERALS SUCH AS THOSE FOUND IN CELL PHONES ARE PROCESSED FROM ORES.
AN EXAMPLE OF AN ORE IS BAUXITE WHICH IS MINED, REFINED AND PROCESSED TO PRODUCE PURE ALUMINIUM.
AUSTRALIA IS EXTREMELY RICH IN MINERAL RESOURCES BUT MINERALS ALSO OFTEN COME FROM CONFLICT ZONES SUCH AS THE CONGO.

GRADE 8 WORKSHEETS (WORKSHEET 1 MULTIMODAL SOCIAL)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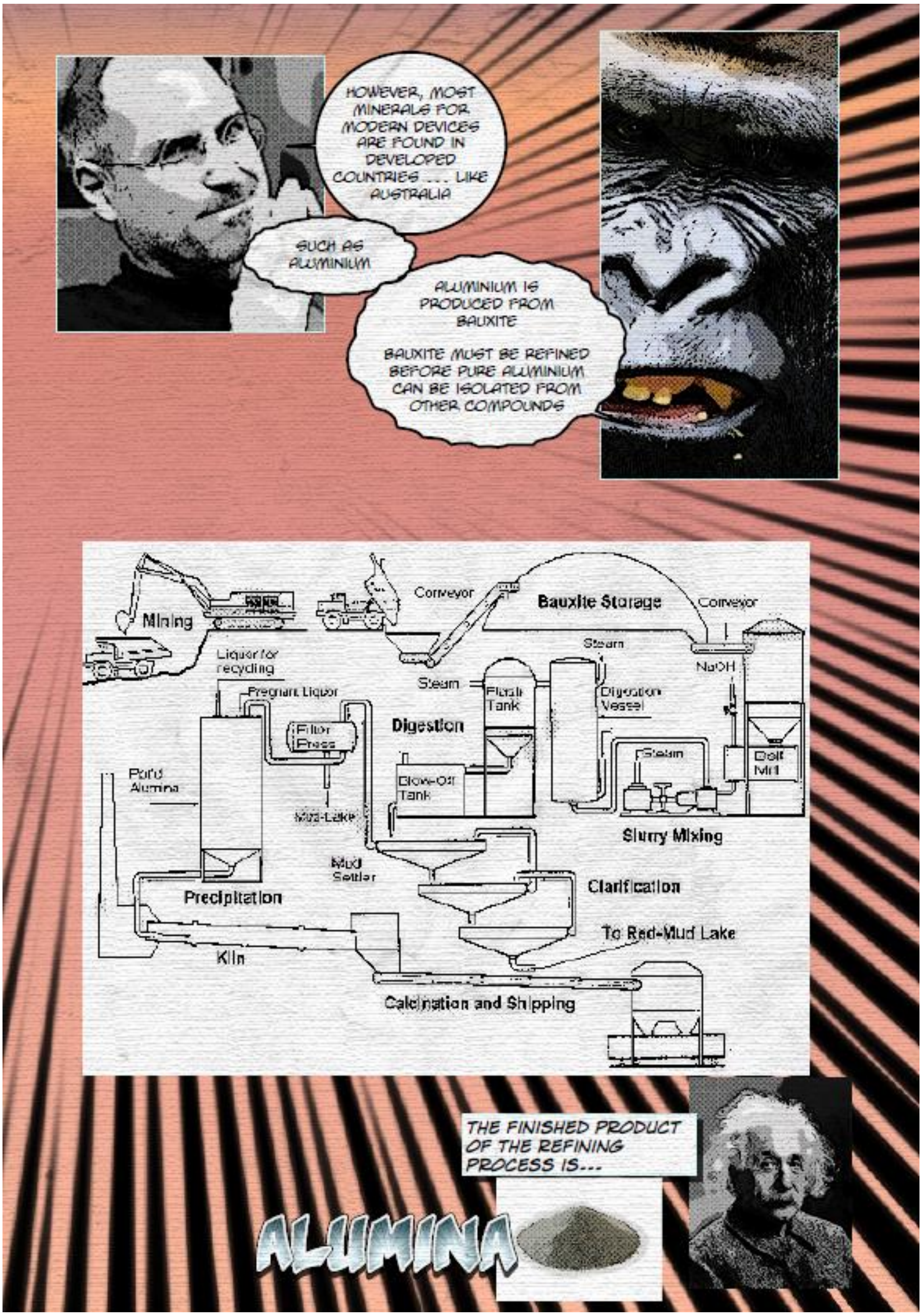
SOME OF THESE METALS COME FROM CONFLICT ZONES...
CONFLICT MINERALS MOSTLY COME FROM AFRICA AND ASIA
AU
65 Tb
50 Sn
POSSIBLE CONFLICT MINERALS
MANY COMPANIES ARE TRYING TO REDUCE THE AMOUNT OF CONFLICT MINERALS IN THEIR PRODUCTS...
THE TROUBLE WITH MINERALS IS THAT THEY ARE OFTEN ONLY FOUND IN POOR, WAR-RAVAGED COUNTRIES LIKE THE CONGO IN CENTRAL AFRICA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SUCH AS ALUMINIUM
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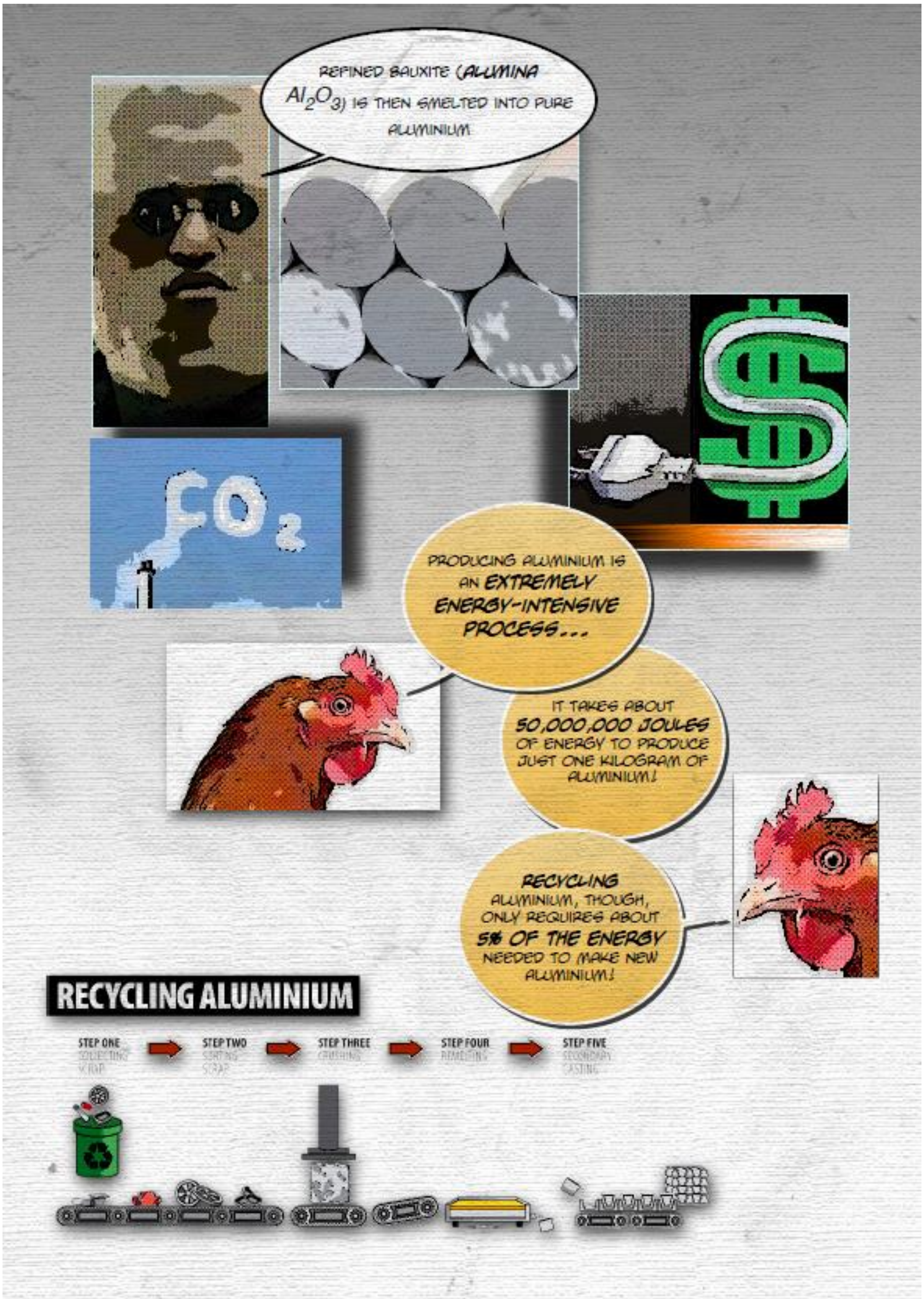
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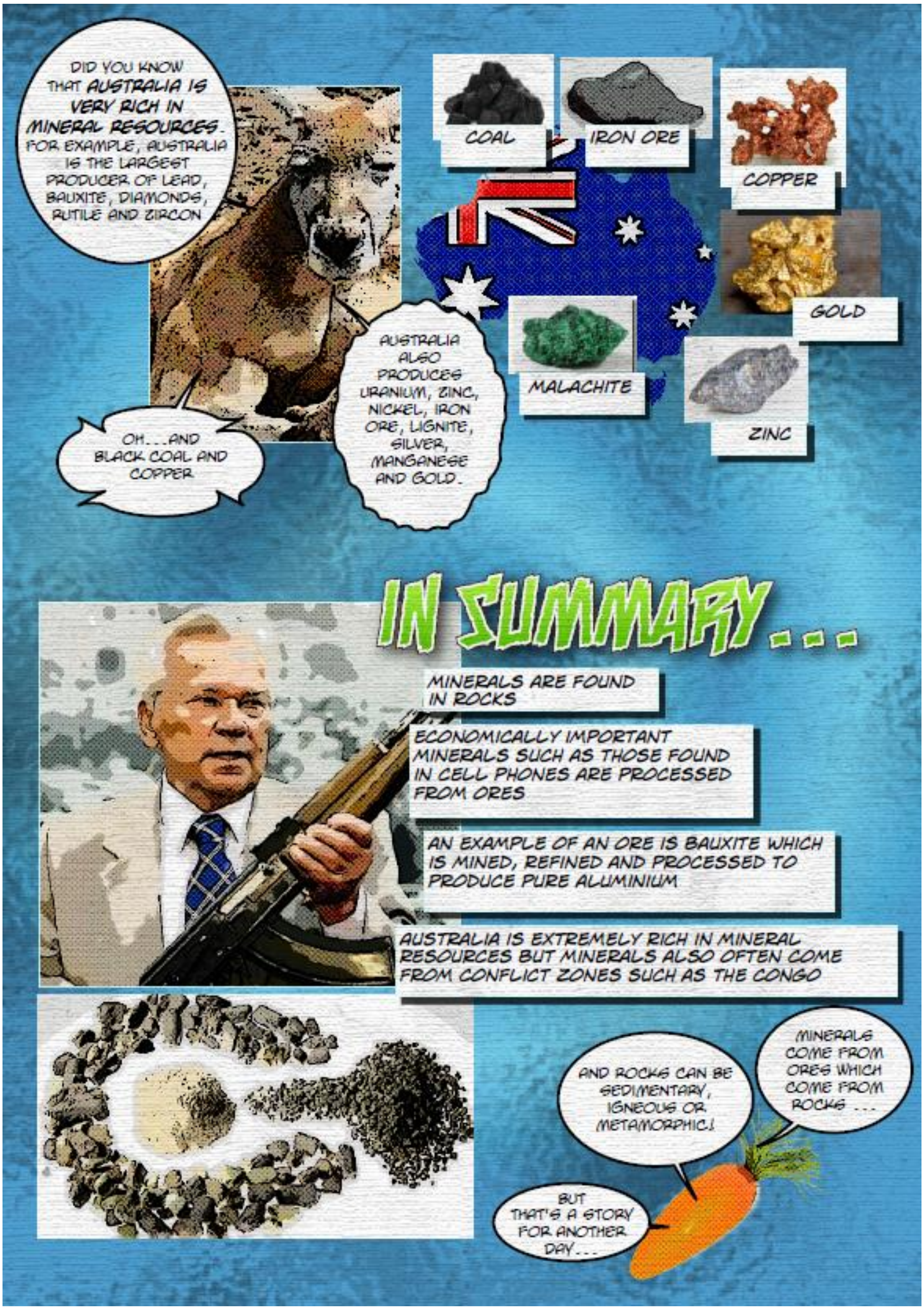
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OH...AND BLACK COAL AND COPPER
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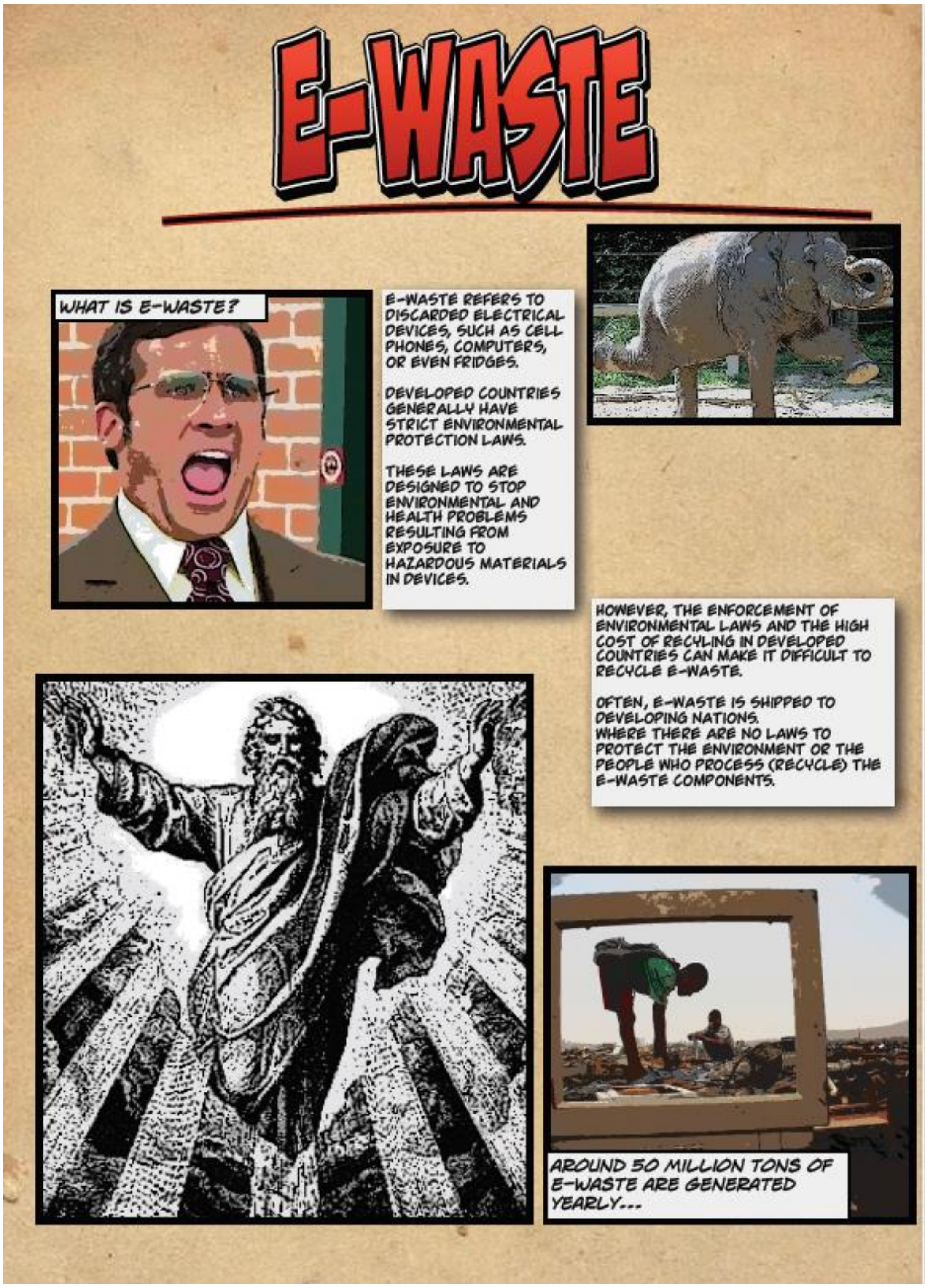
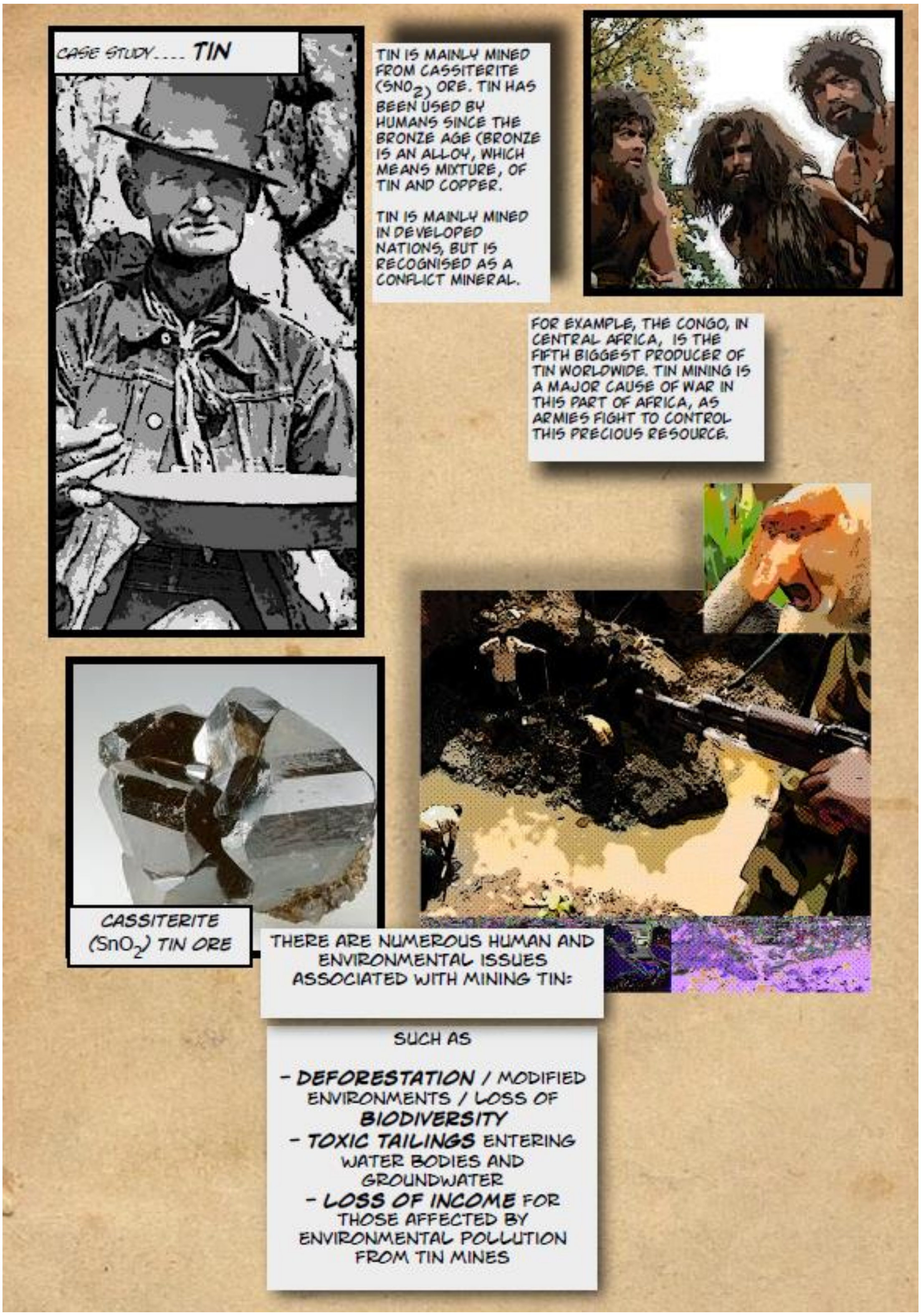
MINERALS COME FROM ORES WHICH COME FROM ROCKS ...
AND ROCKS CAN BE SEDIMENTARY, IGNEOUS OR METAMORPHIC!
BUT THAT'S A STORY FOR ANOTHER DAY...

GRADE 8 WORKSHEETS (WORKSHEET 2 BIMODAL SOCIAL)

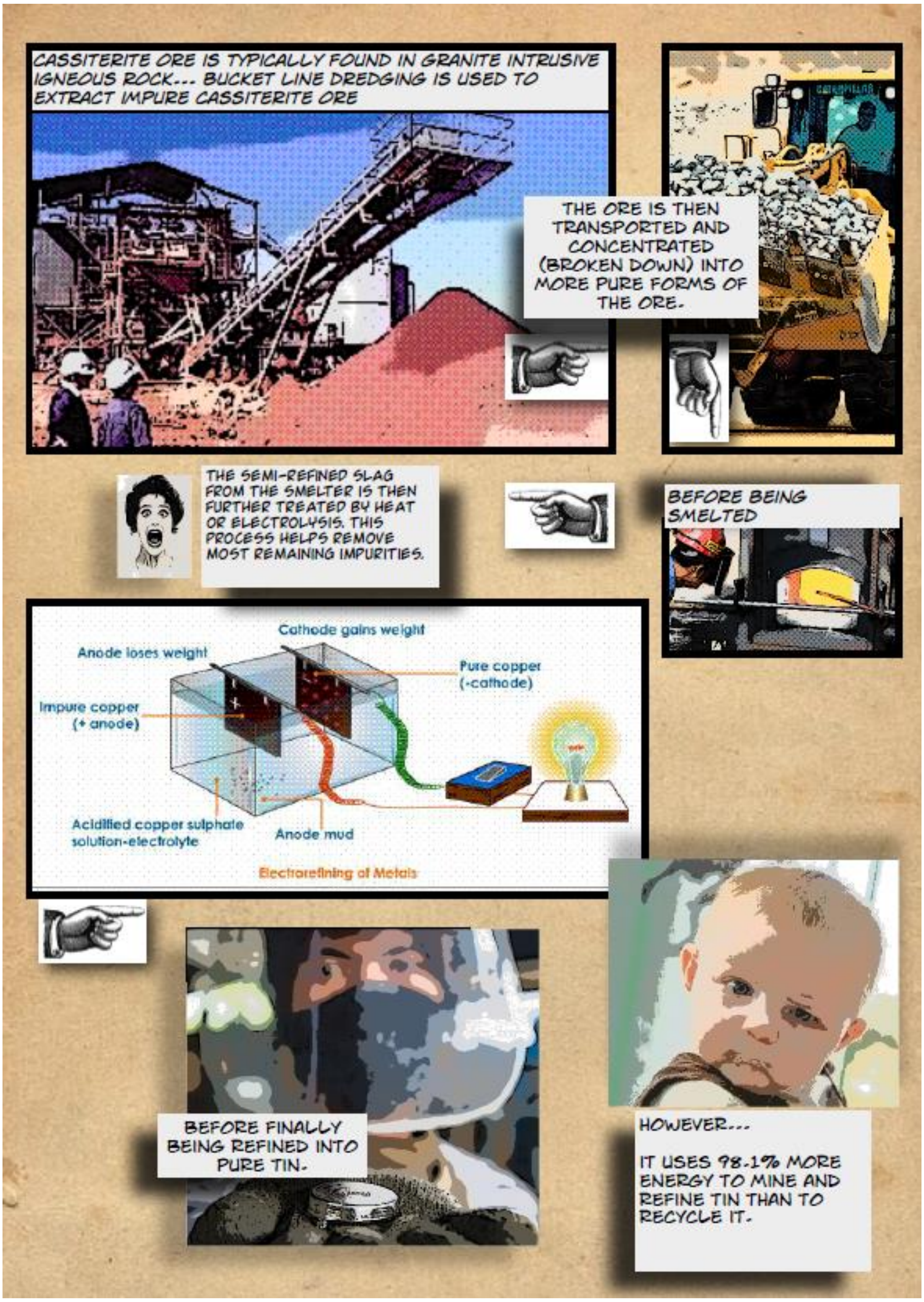


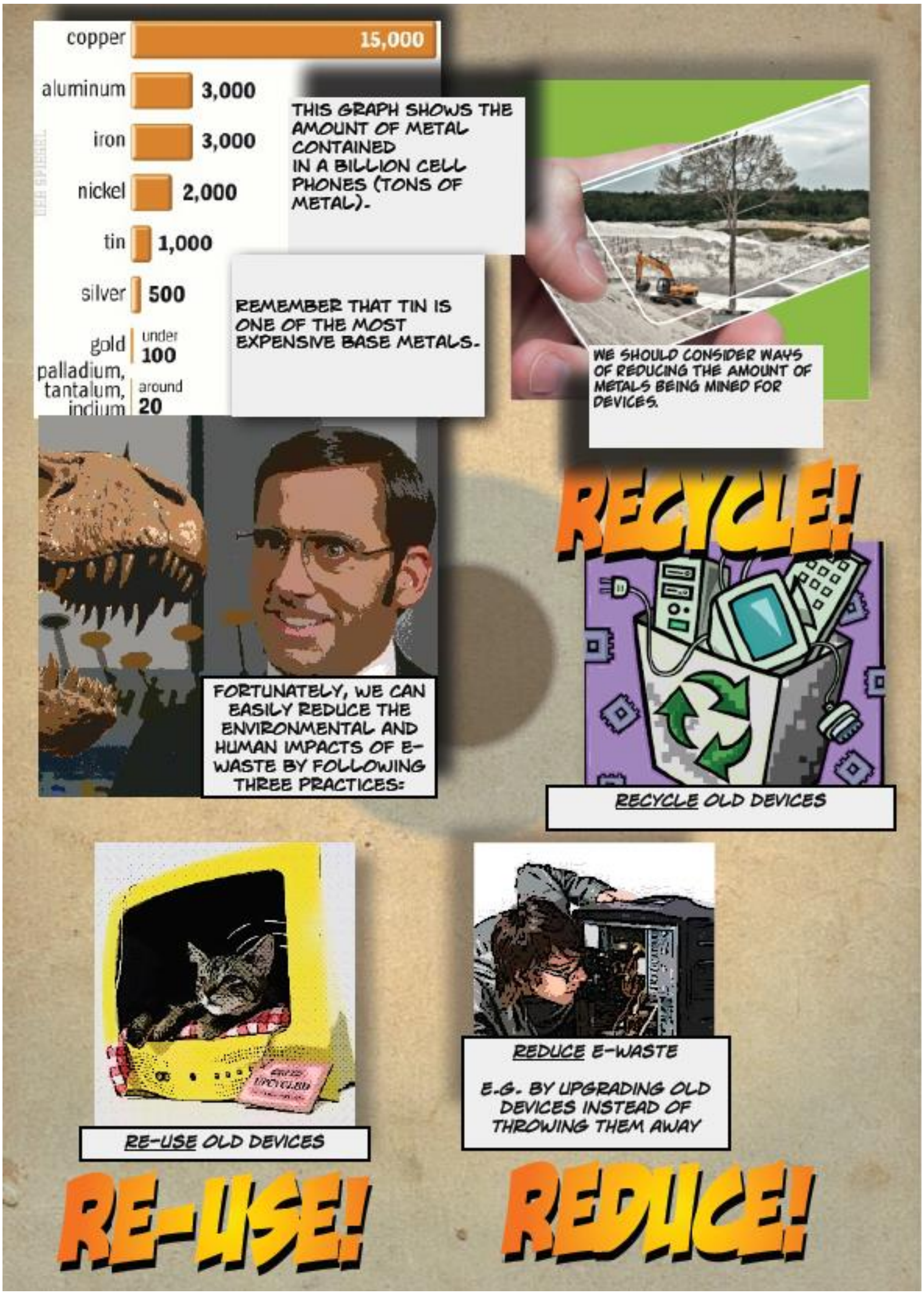

WHY DO WE END UP WITH SO MUCH E-WASTE?
PLANNED OBSOLESCENCE!
ELECTRONIC COMPANIES OFTEN DESIGN THEIR PRODUCTS TO NEED REPLACEMENT WITHIN A SET TIME FRAME. THIS PROCESS IS CALLED PLANNED OBSOLESCENCE.
COMPANIES ALSO MAKE LARGE PROFITS BY ENSURING THAT COMPONENTS OF DEVICES BECOME OBSOLETE AT DIFFERENT TIMES IN THE DEVICE'S LIFESPAN. FOR EXAMPLE, COMPUTER PROCESSORS BECOME OUTDATED WITH NEW SOFTWARE RELEASES AND CONSUMERS OFTEN BUY A WHOLE NEW COMPUTER INSTEAD OF JUST A NEW PROCESSOR.
ADDITIONALLY, MANY COMPANIES MAKE IT ALMOST IMPOSSIBLE TO FIX BROKEN DEVICES (OR TAKE A LONG TIME TO FIX BROKEN DEVICES UNDER WARRANTY).
CHANGES IN MEDIA (E.G. FLOPPY DISKS, DVDS, MP3) AND RAPID TECHNOLOGICAL CHANGES HAVE ALSO LED TO GROWING AMOUNTS OF E-WASTE AS PEOPLE CHANGE DEVICES REGULARLY.
WE NEED A WAY TO STOP THE PROBLEM OF E-WASTE!


BASEL TREATY
THE BASEL TREATY IS AN AGREEMENT BETWEEN COUNTRIES THAT BANS THE MOVEMENT OF E-WASTE FROM ONE COUNTRY TO ANOTHER.
183 COUNTRIES HAVE SIGNED IT, EXCEPT FOR A FEW, INCLUDING SIERRA LEONE, ANGOLA, SOUTH SUDAN AND THE USA.
THE BASEL TREATY WAS SET UP IN 1989, THOUGH IT HASN'T FIXED THE PROBLEM OF ENVIRONMENTAL DAMAGE.
THIS IS BECAUSE E-WASTE STILL GETS EXPORTED TO POOR COUNTRIES ... OFTEN DISGUISED AS A DONATION OR AS SECOND HAND DEVICES FOR RE-SALE.
HAZARDOUS MATERIALS IN DEVICES CAN INCLUDE TOXIC, FLAMMABLE, EXPLOSIVE OR CORROSIVE MATERIALS.
E-WASTE TYPICALLY ENDS UP IN DUMPS LIKE THE ONE ABOVE, WHERE WORKERS BURN IT TO EXTRACT VARIOUS METALS WHICH ARE SOLD FOR VERY SMALL AMOUNTS OF MONEY.
WORKERS ARE EXPOSED TO CHEMICALS SUCH AS HEAVY METALS, FLAME RETARDANTS, AND OTHERS THAT CAN CAUSE CANCER, BIRTH DEFECTS, LUNG DISEASE, AND OTHER SERIOUS DISEASES.
MENTAL RETARDATION IS A SERIOUS CONCERN WITH EXPOSURE TO LEAD AND OTHER HEAVY METALS.
WE SHOULD ALSO CONSIDER THE ENVIRONMENTAL IMPACTS OF MINING THE MATERIALS FOR DEVICES IN THE FIRST PLACE.



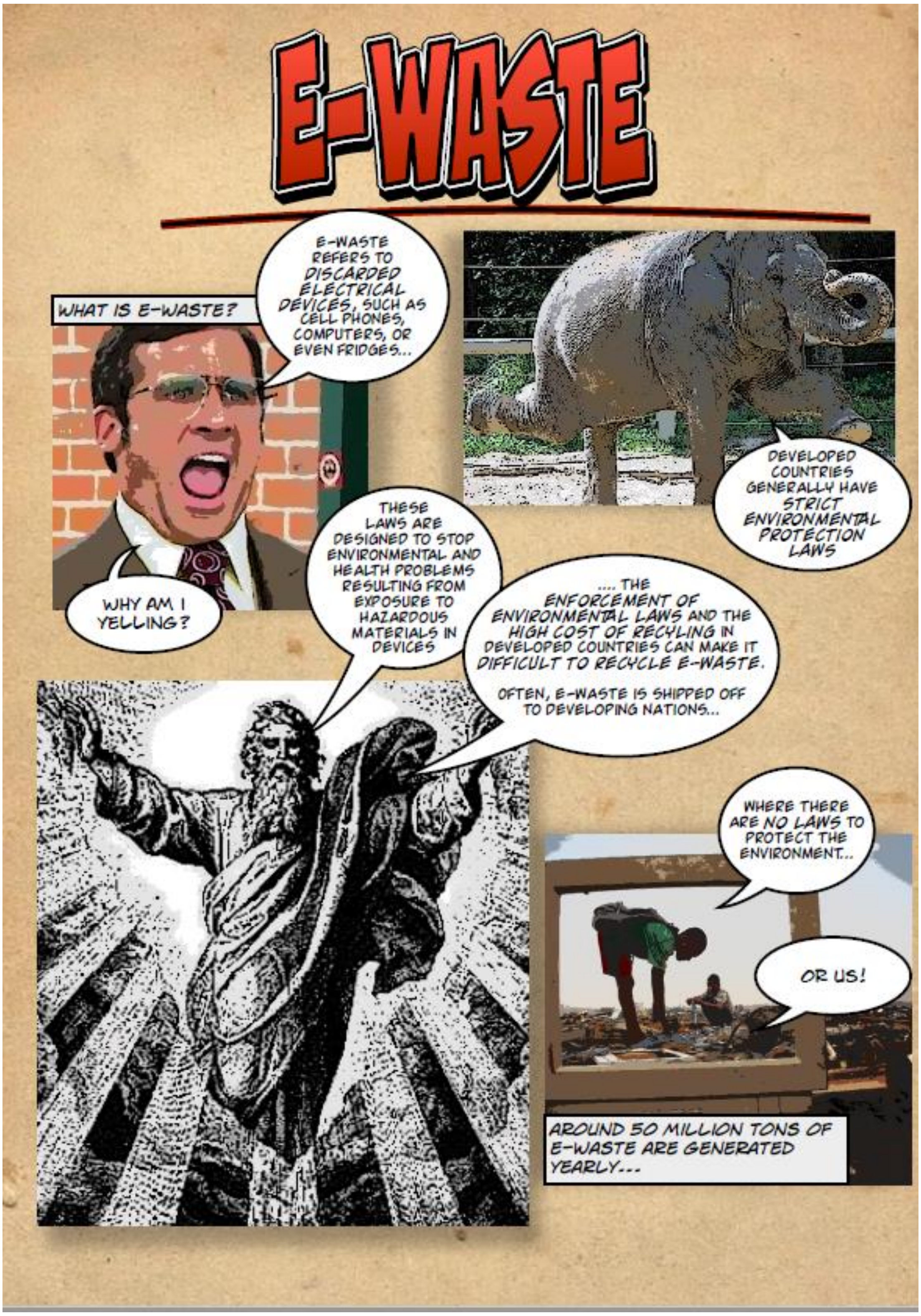
CASE STUDY.... TIN
TIN IS MAINLY MINED FROM CASSITERITE (SNO_2) ORE. TIN HAS BEEN USED BY HUMANS SINCE THE BRONZE AGE (BRONZE IS AN ALLOY, WHICH MEANS MIXTURE, OF TIN AND COPPER.
TIN IS MAINLY MINED IN DEVELOPED NATIONS, BUT IS RECOGNISED AS A CONFLICT MINERAL.
FOR EXAMPLE, THE CONGO, IN CENTRAL AFRICA, IS THE FIFTH BIGGEST PRODUCER OF TIN WORLDWIDE. TIN MINING IS A MAJOR CAUSE OF WAR IN THIS PART OF AFRICA, AS ARMIES FIGHT TO CONTROL THIS PRECIOUS RESOURCE.
CASSITERITE (SnO_2) TIN ORE
THERE ARE NUMEROUS HUMAN AND ENVIRONMENTAL ISSUES ASSOCIATED WITH MINING TIN:
SUCH AS
- DEFORESTATION / MODIFIED ENVIRONMENTS / LOSS OF BIODIVERSITY
- TOXIC TAILINGS ENTERING WATER BODIES AND GROUNDWATER
- LOSS OF INCOME FOR THOSE AFFECTED BY ENVIRONMENTAL POLLUTION FROM TIN MINES

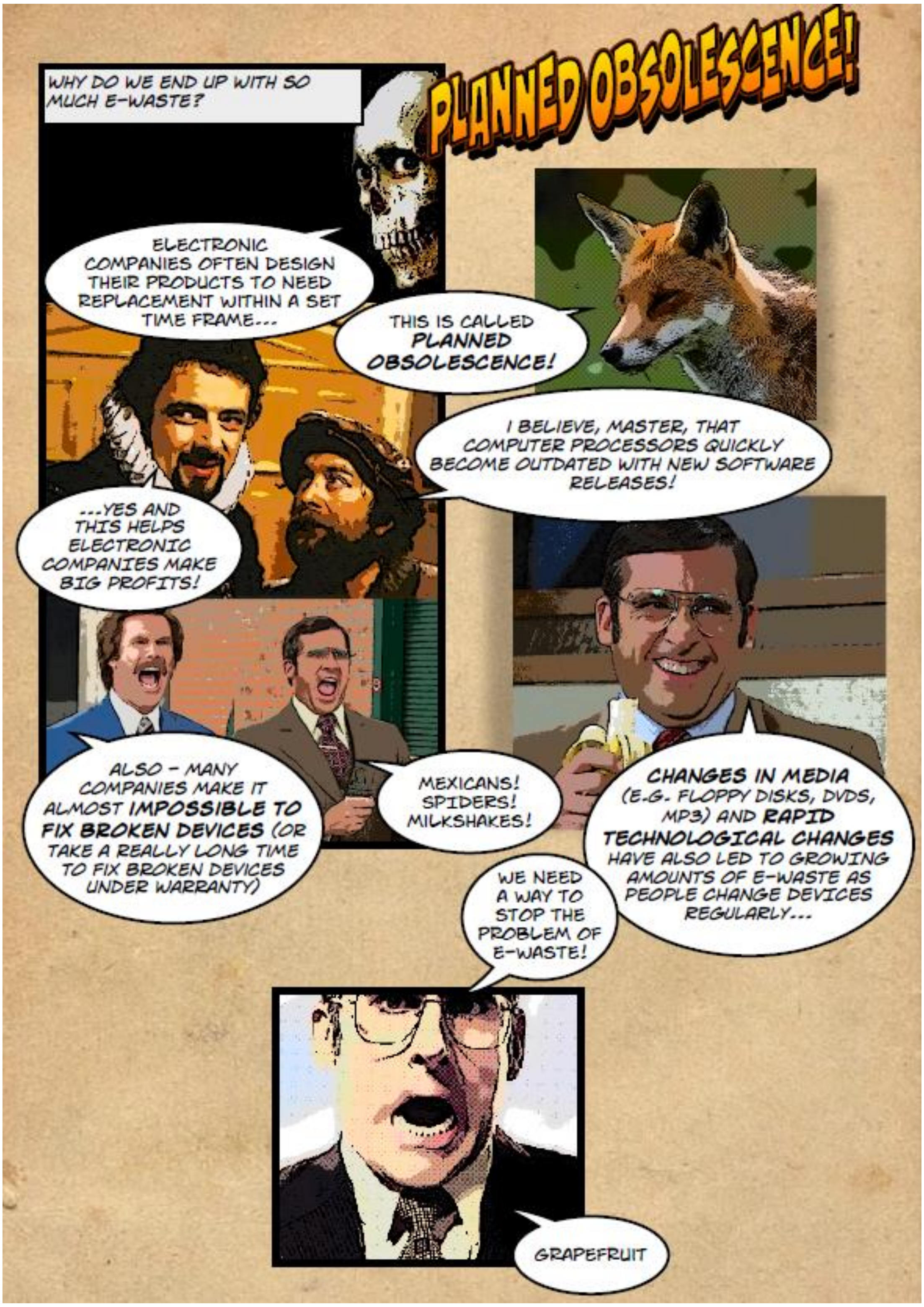

CASSITERITE ORE IS TYPICALLY FOUND IN GRANITE INTRUSIVE IGNEOUS ROCK... BUCKET LINE DREDGING IS USED TO EXTRACT IMPURE CASSITERITE ORE
THE ORE IS THEN TRANSPORTED AND CONCENTRATED (BROKEN DOWN) INTO MORE PURE FORMS OF THE ORE.
BEFORE BEING SMELTED
THE SEMI-REFINED SLAG FROM THE SMELTER IS THEN FURTHER TREATED BY HEAT OR ELECTROLYSIS. THIS PROCESS HELPS REMOVE MOST REMAINING IMPURITIES.
Cathode gains weight
Anode loses weight
Pure copper
(-cathode)
Impure copper
(+ anode)
Acidified copper sulphate
solution-electrolyte
Anode mud
Electrorefining of Metals
BEFORE FINALLY BEING REFINED INTO PURE TIN.
HOWEVER...
IT USES 98.1% MORE ENERGY TO MINE AND REFINE TIN THAN TO RECYCLE IT.



copper 15,000
aluminum 3,000
iron 3,000
nickel 2,000
tin 1,000
silver 500
gold under 100
palladium, tantalum, indium around 20
THIS GRAPH SHOWS THE AMOUNT OF METAL CONTAINED IN A BILLION CELL PHONES (TONS OF METAL).
REMEMBER THAT TIN IS ONE OF THE MOST EXPENSIVE BASE METALS.
WE SHOULD CONSIDER WAYS OF REDUCING THE AMOUNT OF METALS BEING MINED FOR DEVICES.
FORTUNATELY, WE CAN EASILY REDUCE THE ENVIRONMENTAL AND HUMAN IMPACTS OF E-WASTE BY FOLLOWING THREE PRACTICES:
RECYCLE!
RECYCLE OLD DEVICES
RE-USE OLD DEVICES
REDUCE E-WASTE
E.G. BY UPGRADING OLD DEVICES INSTEAD OF THROWING THEM AWAY
RE-USE!
REDUCE!

GRADE 8 WORKSHEETS (WORKSHEET 2 MULTIMODAL SOCIAL)

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THIS IS CALLED PLANNED OBSOLESCENCE!
I BELIEVE, MASTER, THAT COMPUTER PROCESSORS QUICKLY BECOME OUTDATED WITH NEW SOFTWARE RELEASES!
...YES AND THIS HELPS ELECTRONIC COMPANIES MAKE BIG PROFITS!
ALSO – MANY COMPANIES MAKE IT ALMOST IMPOSSIBLE TO FIX BROKEN DEVICES (OR TAKE A REALLY LONG TIME TO FIX BROKEN DEVICES UNDER WARRANTY)
MEXICANS! SPIDERS! MILKSHAKES!
CHANGES IN MEDIA (E.G. FLOPPY DISKS, DVDS, MP3) AND RAPID TECHNOLOGICAL CHANGES HAVE ALSO LED TO GROWING AMOUNTS OF E-WASTE AS PEOPLE CHANGE DEVICES REGULARLY...
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GRAPEFRUIT


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TIN HAS BEEN USED BY HUMANS SINCE THE BRONZE AGE...
NATURALLY! BRONZE IS AN ALLOY (MIXTURE) OF TIN AND COPPER!
TIN IS ONE OF THE MOST EXPENSIVE BASE METALS... AND IS RECOGNISED AS A CONFLICT MINERAL
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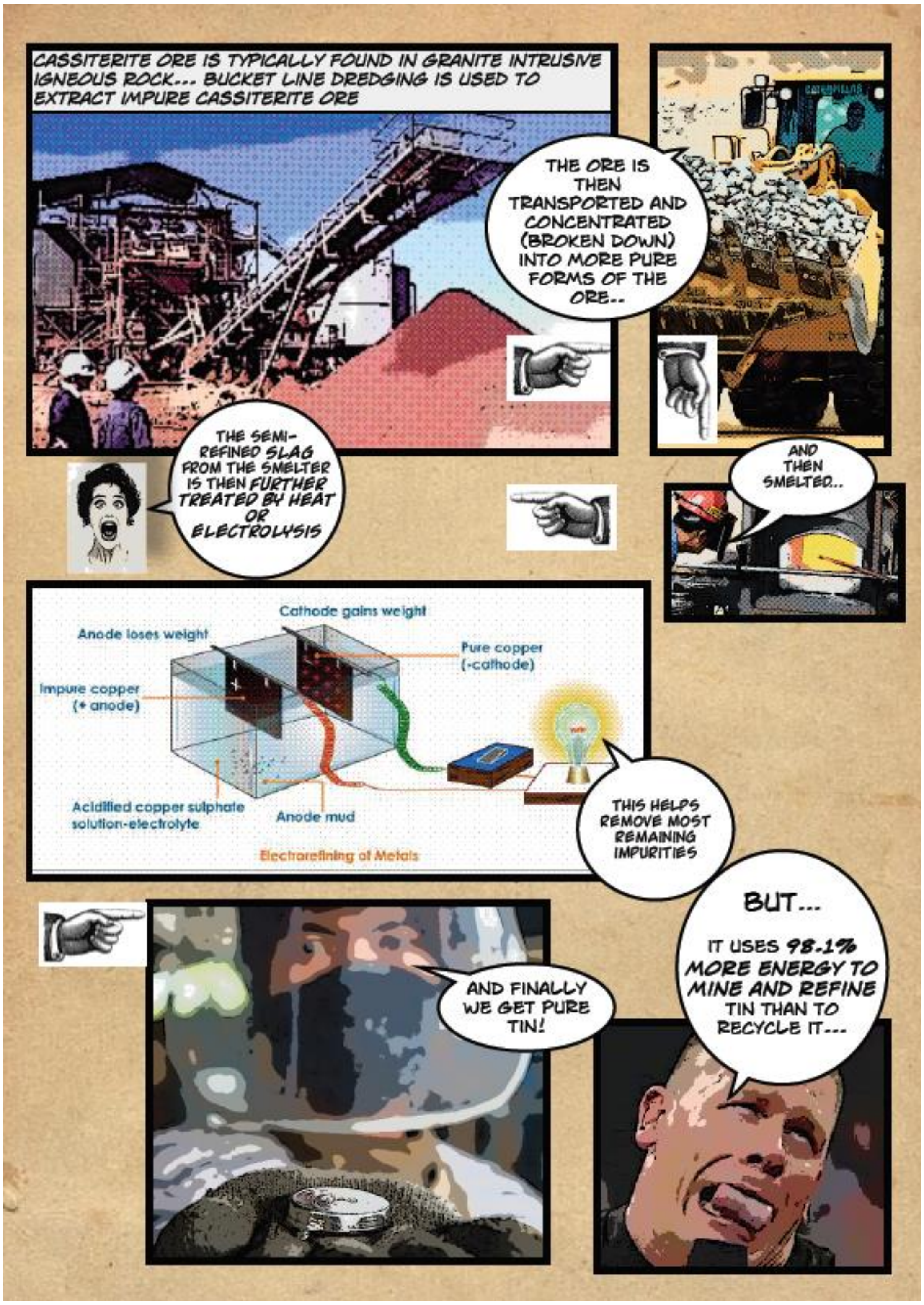
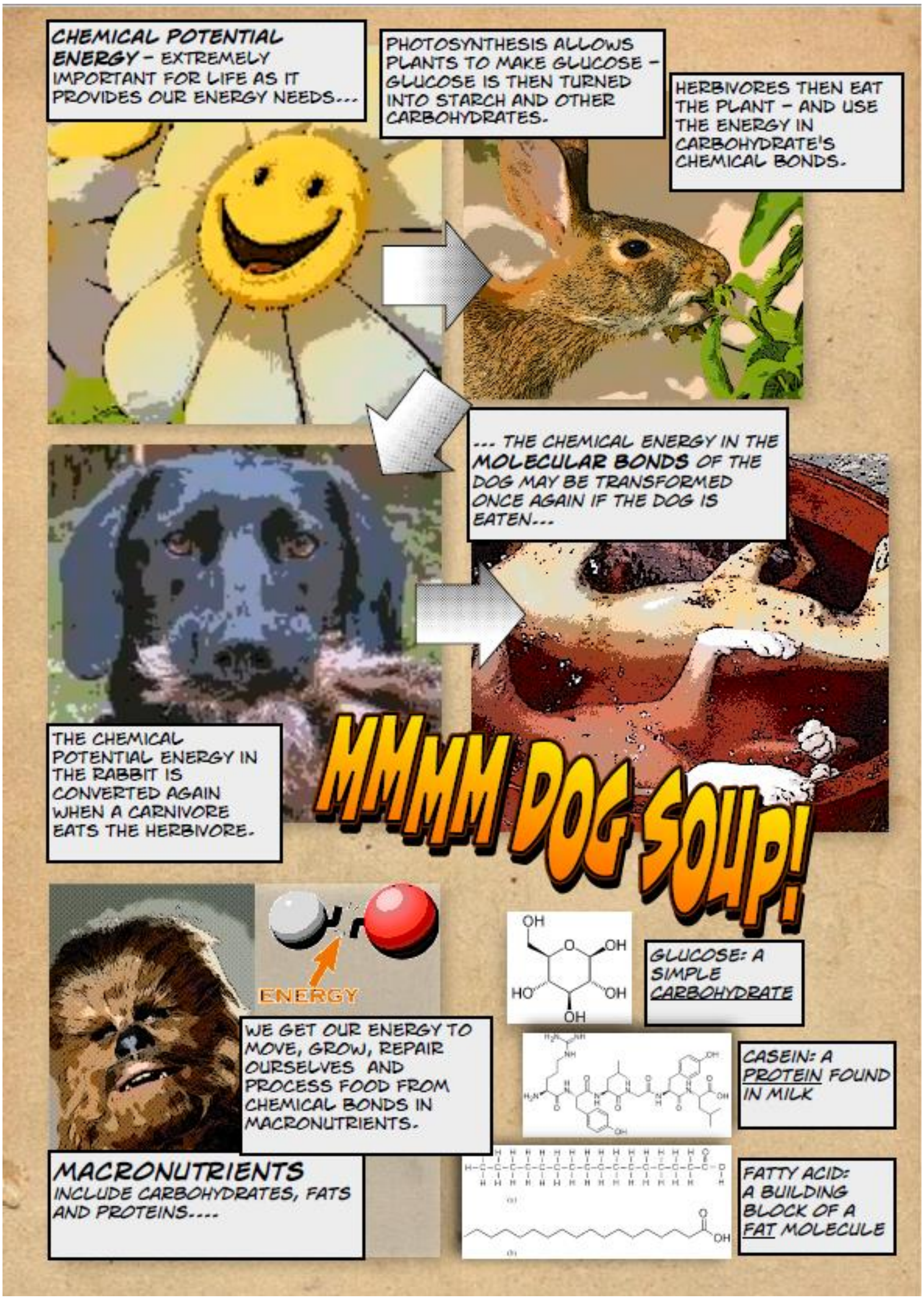
SUCH AS
- DEFORESTATION / MODIFIED ENVIRONMENTS / LOSS OF BIODIVERSITY
- TOXIC TAILINGS ENTERING WATER BODIES AND GROUNDWATER
- LOSS OF INCOME FOR THOSE AFFECTED BY ENVIRONMENTAL POLLUTION FROM TIN MINES


CASSITERITE ORE IS TYPICALLY FOUND IN GRANITE INTRUSIVE IGNEOUS ROCK... BUCKET LINE DREDGING IS USED TO EXTRACT IMPURE CASSITERITE ORE
THE ORE IS THEN TRANSPORTED AND CONCENTRATED (BROKEN DOWN) INTO MORE PURE FORMS OF THE ORE..
AND THEN SMELTED..
THE SEMI-REFINED SLAG FROM THE SMELTER IS THEN FURTHER TREATED BY HEAT OR ELECTROLYSIS
Cathode gains weight
Anode loses weight
Pure copper (-cathode)
Impure copper (+ anode)
Acidified copper sulphate solution-electrolyte
Anode mud
Electrorefining of Metals
THIS HELPS REMOVE MOST REMAINING IMPURITIES
AND FINALLY WE GET PURE TIN!
BUT...
IT USES 98.1% MORE ENERGY TO MINE AND REFINE TIN THAN TO RECYCLE IT...


copper 15,000
aluminum 3,000
iron 3,000
nickel 2,000
tin 1,000
silver 500
gold under 100
palladium, tantalum, indium around 20
AMOUNT OF METAL CONTAINED IN A BILLION CELL PHONES IN TONS
REMEMBER THAT TIN IS ONE OF THE MOST EXPENSIVE BASE METALS...
WE NEED TO REDUCE THE AMOUNT OF METALS BEING MINED...
LUCKILY WE CAN EASILY REDUCE THE ENVIRONMENTAL AND HUMAN IMPACTS OF E-WASTE...
BELGIUM
RECYCLE!
RECYCLE OLD DEVICES
RE-USE OLD DEVICES
REDUCE E-WASTE
E.G. BY UPGRADING OLD DEVICES INSTEAD OF THROWING THEM AWAY
RE-USE!
REDUCE!

GRADE 8 WORKSHEETS (WORKSHEET 3 BIMODAL SOCIAL)

GRAVITATIONAL POTENTIAL ENERGY IS EASILY CALCULATED...
FIRSTLY, MEASURE THE HEIGHT IN METERS
THEN MEASURE THE MASS OF THE OBJECT IN KILOGRAMS
GRAVITY IS A FORCE ... AND IS APPROXIMATELY 9.8 M/S2 ON EARTH
AND USE THE FORMULA:
PE = MGH
800 KG
PE = MGH
M = MASS
G = GRAVITY
H = HEIGHT
1 METER
WE CAN CALCULATE THAT PETER WILL SOON EXPERIENCE:
PE = MGH
PE = 800 KG x 9.8M/S2 x 1 M
= 7840 JOULES OF GRAVITATIONAL POTENTIAL ENERGY
PETER
THERE ARE OTHER TYPES OF POTENTIAL ENERGY ALL AROUND US.
REMEMBER THAT ENERGY IS MEASURED IN JOULES.
ELASTIC POTENTIAL ENERGY
ELASTIC POTENTIAL ENERGY IS THE ENERGY STORED IN SPRINGS AND ELASTIC MATS.
THIS ENERGY IS STORED AND THEN RETURNED TO OUR BODY OR TO AN OBJECT SUCH AS AN ARROW.

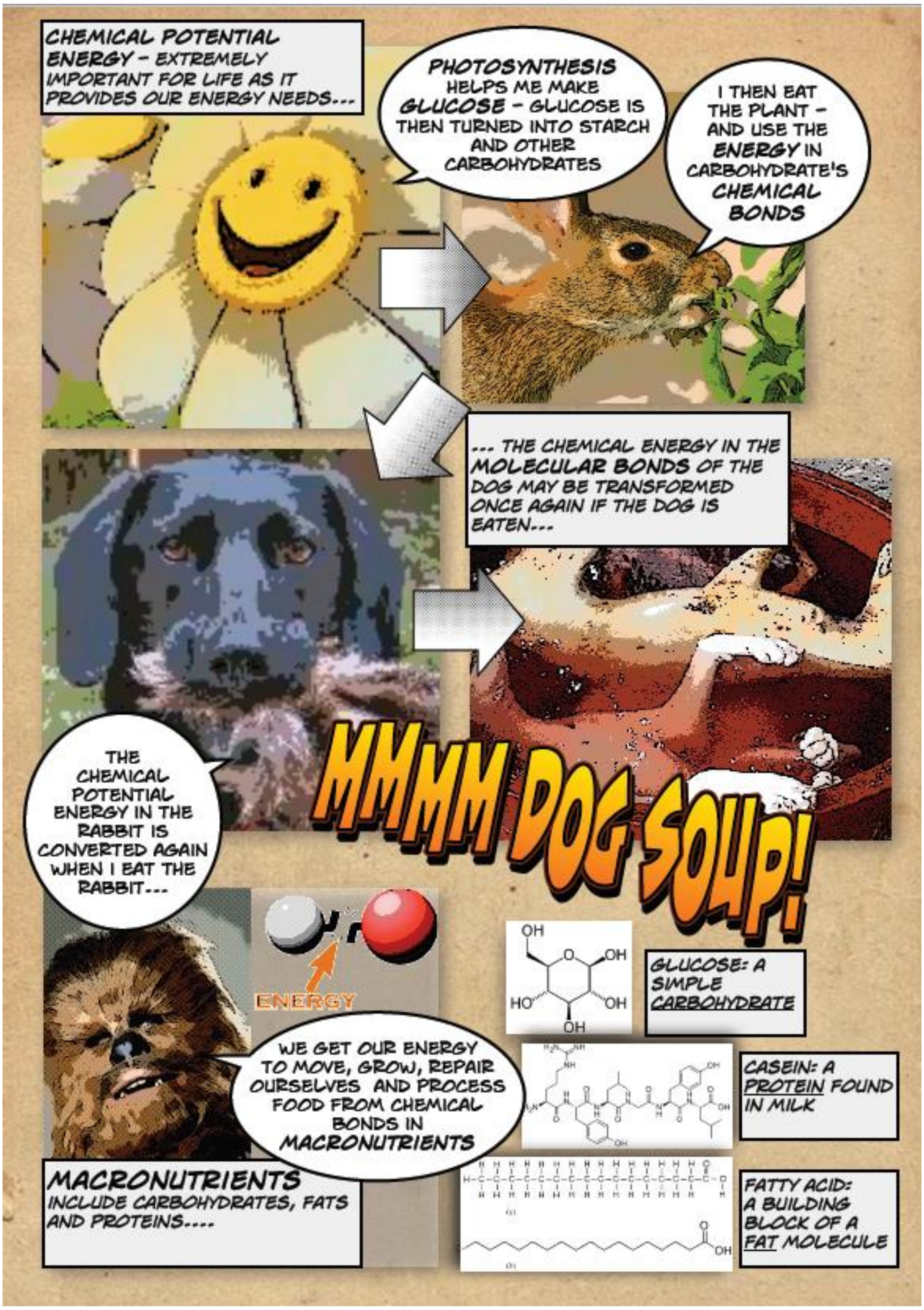


CHEMICAL POTENTIAL ENERGY – EXTREMELY IMPORTANT FOR LIFE AS IT PROVIDES OUR ENERGY NEEDS...
PHOTOSYNTHESIS ALLOWS PLANTS TO MAKE GLUCOSE – GLUCOSE IS THEN TURNED INTO STARCH AND OTHER CARBOHYDRATES.
HERBIVORES THEN EAT THE PLANT – AND USE THE ENERGY IN CARBOHYDRATE'S CHEMICAL BONDS.
THE CHEMICAL POTENTIAL ENERGY IN THE RABBIT IS CONVERTED AGAIN WHEN A CARNIVORE EATS THE HERBIVORE.
... THE CHEMICAL ENERGY IN THE MOLECULAR BONDS OF THE DOG MAY BE TRANSFORMED ONCE AGAIN IF THE DOG IS EATEN...
MMMM DOG SOUP!
ENERGY
WE GET OUR ENERGY TO MOVE, GROW, REPAIR OURSELVES AND PROCESS FOOD FROM CHEMICAL BONDS IN MACRONUTRIENTS.
MACRONUTRIENTS INCLUDE CARBOHYDRATES, FATS AND PROTEINS....
GLUCOSE: A SIMPLE CARBOHYDRATE
CASEIN: A PROTEIN FOUND IN MILK
FATTY ACID: A BUILDING BLOCK OF A FAT MOLECULE

BIOMASS POTENTIAL ENERGY IS A FORM OF CHEMICAL POTENTIAL ENERGY AND IS AN IMPORTANT SOURCE OF ENERGY IN MANY COUNTRIES...
PLEASE - NO MORE TALK OF DOG SOUP!
WE USE BIOMASS POTENTIAL ENERGY WHEN WE FERMENT PLANTS AND FRUITS, OR BURN WOOD FOR HEAT.
Crops like corn
are finely ground
and separated into their component sugars.
The sugars are distilled to make ethanol,
which can be used as an alternative fuel
CO_2
which releases carbon dioxide
that is reabsorbed by the original crops.
ETHANOL CAN BE MADE FROM FERMENTED CROPS - SUCH AS CORN - AND THEN USED AS A SUBSTITUTE FOR PETROL
IN AUSTRALIA, PETROL CONTAINING 10% ETHANOL IS USED.
THIS HELPS PROTECT THE ENVIRONMENT AS ETHANOL RELEASES LESS CO2 THAN PETROL WHEN BURNT
NUCLEAR ENERGY IS ALSO A FORM OF POTENTIAL ENERGY.
A HUGE AMOUNT OF ENERGY CAN BE RELEASED FROM THE NUCLEUS OF CERTAIN ATOMS, LIKE URANIUM.
NUCLEAR ENERGY AND NUCLEAR WEAPONS AREN'T USED IN AUSTRALIA.

GRADE 8 WORKSHEETS (WORKSHEET 3 MULTIMODAL SOCIAL)

***N.B. Some images from original worksheet lost.**



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THE CHEMICAL POTENTIAL ENERGY IN THE RABBIT IS CONVERTED AGAIN WHEN I EAT THE RABBIT...
... THE CHEMICAL ENERGY IN THE MOLECULAR BONDS OF THE DOG MAY BE TRANSFORMED ONCE AGAIN IF THE DOG IS EATEN...
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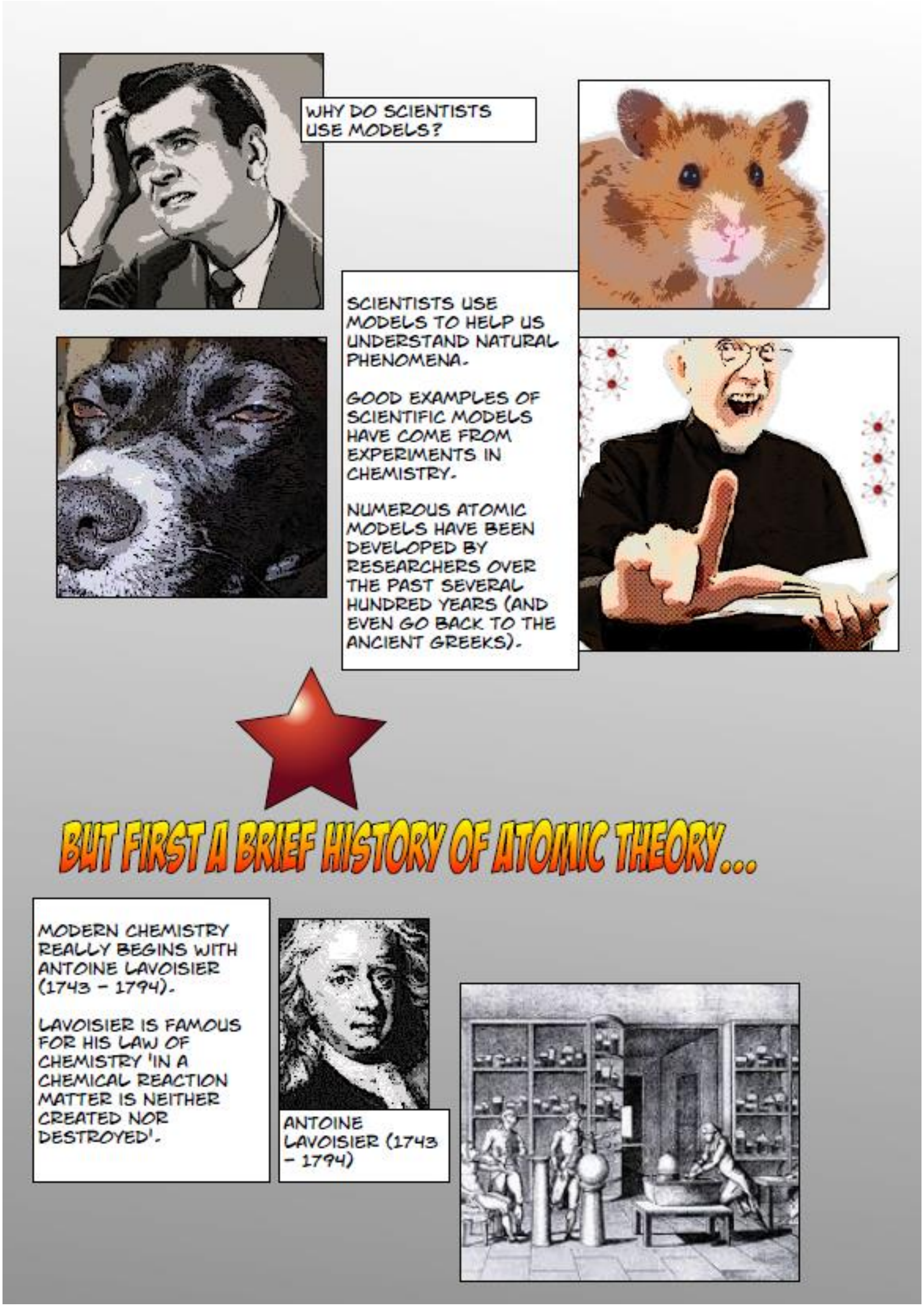
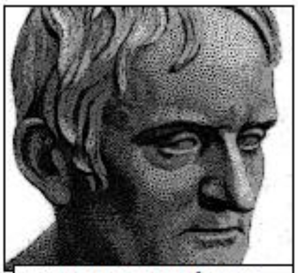
GRADE 9 WORKSHEETS (WORKSHEET 1 BIMODAL SOCIAL)



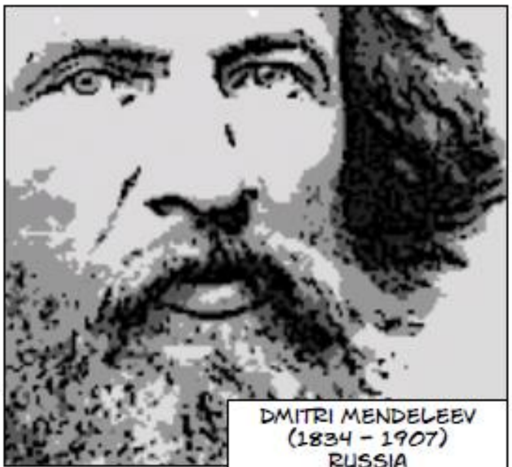
JOHN DALTON (1760 – 1844) FURTHERED THE ATOMIC THEORY OF LAVOISIER BY PROPOSING THAT ATOMS OF PARTICULAR ELEMENTS HAVE UNIQUE PROPERTIES AND ARE INDIVISABLE.



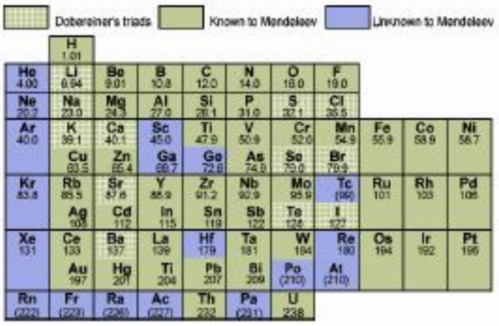
JOHN DALTON (1760 – 1844)
ENGLAND

DMITRI MENDELEEV (1834 – 1907) IS THE FAMOUS RUSSIAN CHEMIST WHO DEVELOPED THE MODERN PERIODIC TABLE. HE NOTICED THAT ATOMS COULD BE ARRANGED BY THEIR ATOMIC MASS (WEIGHT) IN PERIODS (ROWS) OF THE TABLE.

HE PREDICTED THE DISCOVERY OF ADDITIONAL ELEMENTS BASED ON 19TH CENTURY GAPS IN THE PERIODIC TABLE.



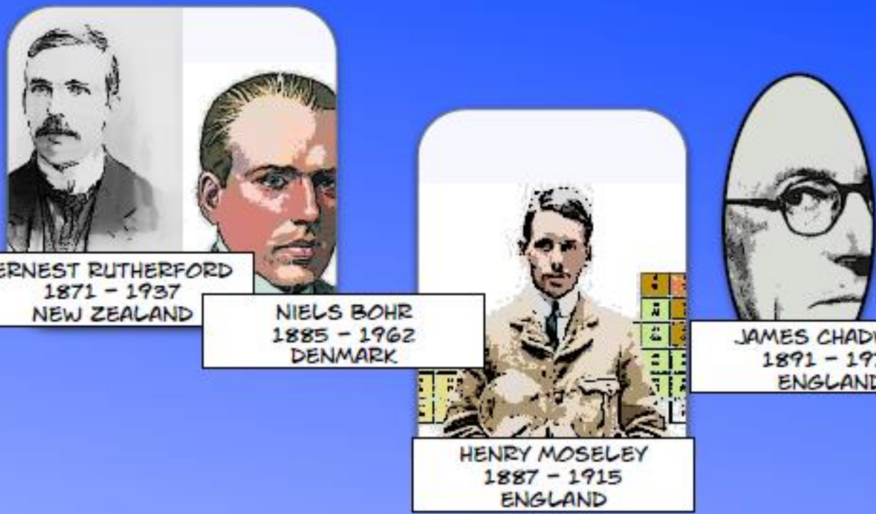
DMITRI MENDELEEV
(1834 – 1907)
RUSSIA



Dobereiner's triads | Known to Mendeleev | Unknown to Mendeleev

	H 1.01									
He 4.00	Li 6.94	Be 9.01	B 10.8	C 12.0	N 14.0	O 16.0	F 19.0			
Ne 20.2	Na 23.0	Mg 24.3	Al 27.0	Si 28.1	P 31.0	S 32.1	Cl 35.5			
Ar 40.0	K 39.1	Ca 40.1	Sc 45.0	Ti 47.9	V 50.9	Cr 52.0	Mn 54.9	Fe 55.9	Co 58.9	Ni 58.7
	Cu 63.5	Zn 65.4	Ga 69.7	Ge 72.6	As 74.9	Se 79.0	Br 79.9			
Kr 83.8	Rb 85.5	Sr 87.6	Y 88.9	Zr 91.2	Nb 92.9	Mo 95.9	Tc (99)	Ru 101	Rh 103	Pd 106
	Ag 108	Cd 112	In 115	Sn 119	Sb 122	Te 128	I 127			
Xe 131	Cs 133	Ba 137	La 139	Hf 179	Ta 181	W 184	Re 186	Os 194	Ir 192	Pt 195
	Au 197	Hg 201	Tl 204	Pb 207	Bi 209	Po (210)	At (210)			
Rn (222)	Fr (223)	Ra (226)	Ac (227)	Th 232	Pa (231)	U 238				

MENDELEEV DISCOVERED THAT, WHEN YOU ARRANGE ELEMENTS ACCORDING TO THEIR ATOMIC MASS CERTAIN PROPERTIES REPEAT THEMSELVES – IN PERIODS.



ERNEST RUTHERFORD
1871 – 1937
NEW ZEALAND

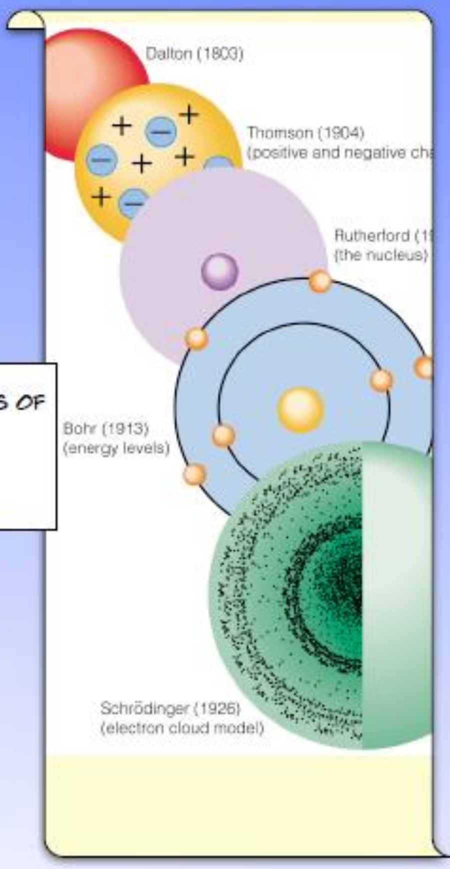
NIELS BOHR
1885 – 1962
DENMARK

HENRY MOSELEY
1887 – 1915
ENGLAND

JAMES CHADWICK
1891 – 1974
ENGLAND

SCIENTIFIC DEVELOPMENTS IN THE LATE 19TH AND 20TH CENTURIES CAME FROM MEN LIKE ERNEST RUTHERFORD, NIELS BOHR, HENRY MOSELEY AND JAMES CHADWICK.

RUTHERFORD (1871 – 1937) PROPOSED THAT THE ATOM IS MOSTLY EMPTY SPACE, AND HAS A NUCLEUS WITH ORBITING ELECTRONS. BOHR (1885 – 1962) PROPOSED THAT THE NEGATIVE ELECTRONS ORBITED IN FIXED SHELLS. THESE THEORIES WERE BASED ON EXPERIMENTAL EVIDENCE.

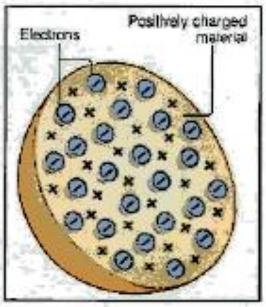


NUMEROUS MODELS OF THE ATOM WERE DEVELOPED AS A RESULT OF SUCH EXPERIMENTS.

EVIDENCE, EITHER EXPERIMENTAL OR THEORETICAL, HAS LED THINKERS THROUGH HISTORY TO DEVELOP DIFFERENT MODELS OF THE ATOM.

DEMOCRITUS THE GREEK PHILOSOPHER (400 BC) CONSIDERED THE ATOM TO BE THE SMALLEST NON-DIVIDABLE UNIT OF NATURE. HIS MODEL OF THE ATOM WAS A SOLID BALL.

JOHN DALTON (EARLY 18TH CENTURY) EXTENDED DEMOCRITUS' IDEAS, AND PROPOSED A NEW MODEL (SUPERFICIALLY SIMILAR TO THAT OF DEMOCRITUS' MODEL).

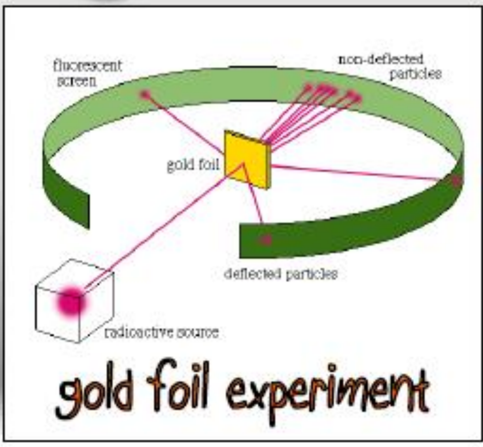


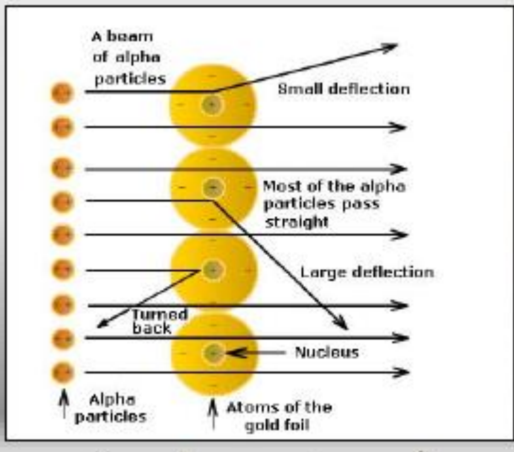
J. J. THOMPSON 1856 – 1940 ENGLAND

J. J. THOMPSON (LATE 18TH CENTURY) PROPOSED THAT THE ATOM IS A BALL OF POSITIVELY CHARGED MATTER WITH NEGATIVE ELECTRONS EMBEDDED IN IT. THIS WAS CALLED THE 'PLUM PUDDING MODEL' FOR ITS RESEMBLANCE TO A PUDDING (CAKE).

ERNEST RUTHERFORD, 1912, REALISED THAT THE ATOM IS MOSTLY EMPTY SPACE. IN HIS MODEL, HE THEORISED THAT THE ATOM CONTAINS A TINY NUCLEUS WITH POSITIVE PROTONS SURROUNDED BY ORBITING ELECTIONS WHICH HAVE A NEGATIVE CHARGE.

NO SCIENTIST HAS EVER SEEN AN ATOM OF COURSE. MODELS OF ATOMS HAVE BEEN DEVELOPED THROUGH EXPERIMENTS. EXPERIMENTAL EVIDENCE LEADS SCIENTISTS TO DEVELOP SPECIFIC ATOMIC MODELS.





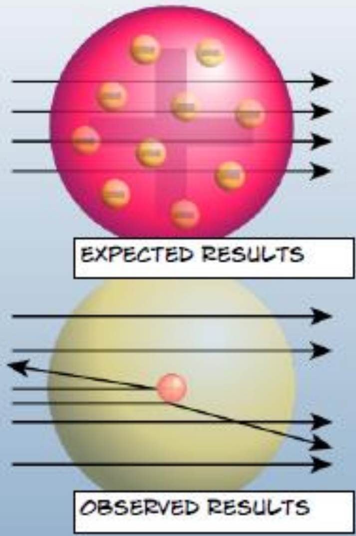
the observed results

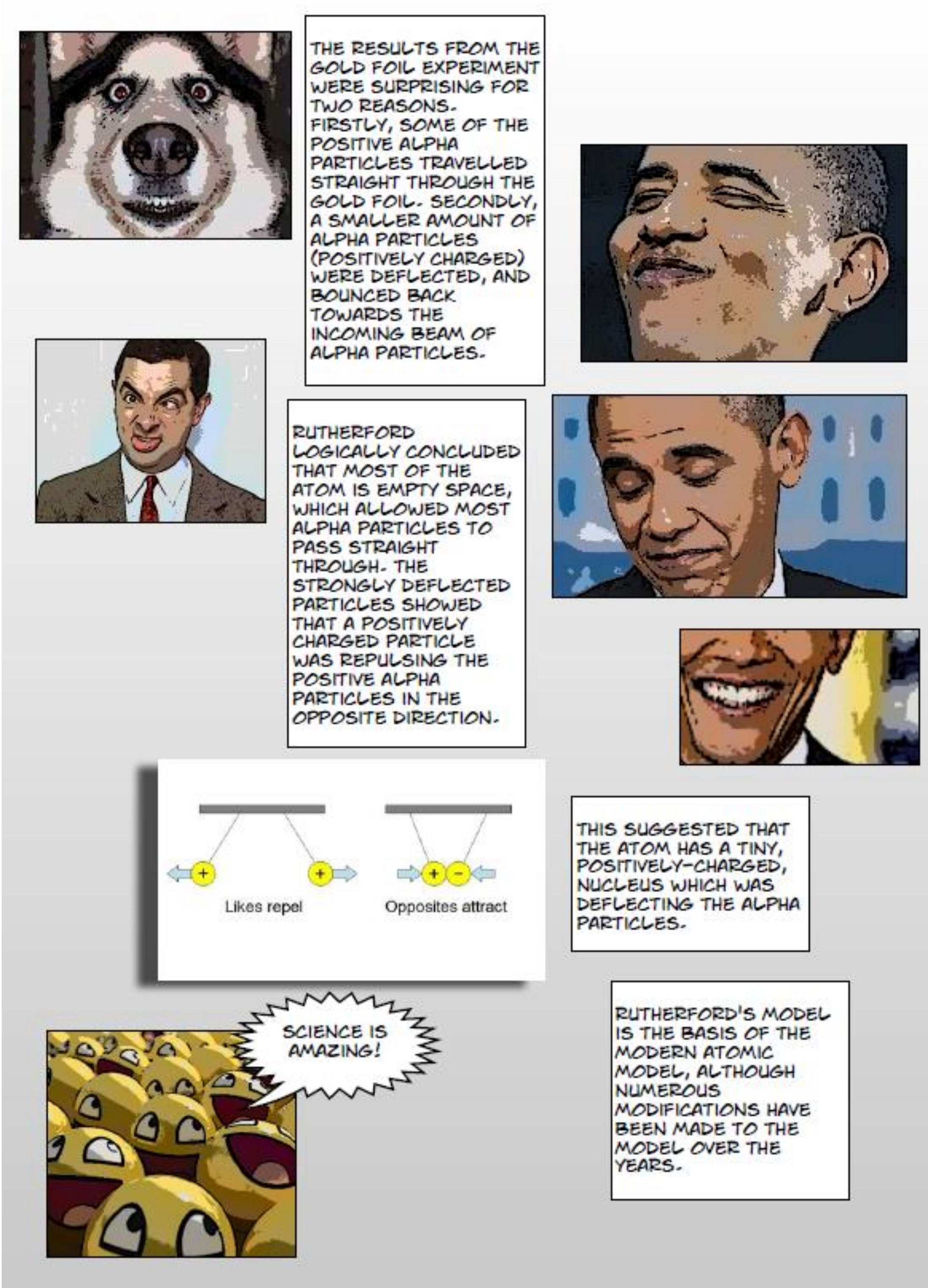
RUTHERFORD'S ATOMIC MODEL WAS DEVELOPED FOLLOWING ANALYSIS OF A FAMOUS 1908 EXPERIMENT AT THE UNIVERSITY OF MANCHESTER.

RUTHERFORD'S 'GOLD FOIL' EXPERIMENT IN 1908 WAS CONDUCTED TO OBSERVE PROPERTIES OF THE ATOM. RUTHERFORD FIRED POSITIVELY CHARGED 'ALPHA PARTICLES' AT A LAYER OF GOLD.

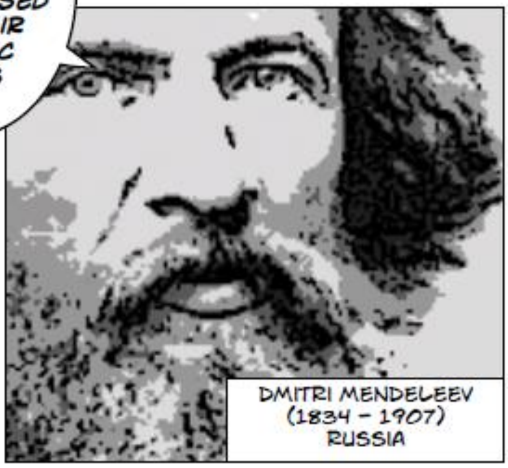
RUTHERFORD'S OBSERVATIONS SHOWED DIFFERENCES FROM THE EXPECTED RESULTS.

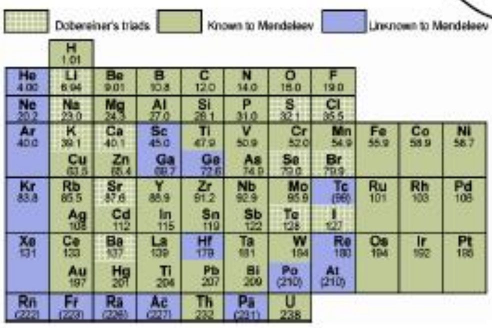
HE CONCLUDED FROM THE RESULTS THAT ATOMS HAVE NEGATIVE ELECTRONS ORBITING A POSITIVELY CHARGED NUCLEUS AND THAT ATOMS ARE MOSTLY EMPTY SPACE.




THE RESULTS FROM THE GOLD FOIL EXPERIMENT WERE SURPRISING FOR TWO REASONS. FIRSTLY, SOME OF THE POSITIVE ALPHA PARTICLES TRAVELLED STRAIGHT THROUGH THE GOLD FOIL. SECONDLY, A SMALLER AMOUNT OF ALPHA PARTICLES (POSITIVELY CHARGED) WERE DEFLECTED, AND BOUNCED BACK TOWARDS THE INCOMING BEAM OF ALPHA PARTICLES.
RUTHERFORD LOGICALLY CONCLUDED THAT MOST OF THE ATOM IS EMPTY SPACE, WHICH ALLOWED MOST ALPHA PARTICLES TO PASS STRAIGHT THROUGH. THE STRONGLY DEFLECTED PARTICLES SHOWED THAT A POSITIVELY CHARGED PARTICLE WAS REPULSING THE POSITIVE ALPHA PARTICLES IN THE OPPOSITE DIRECTION.
+
+
Likes repel
+
−
Opposites attract
THIS SUGGESTED THAT THE ATOM HAS A TINY, POSITIVELY-CHARGED, NUCLEUS WHICH WAS DEFLECTING THE ALPHA PARTICLES.
SCIENCE IS AMAZING!
RUTHERFORD'S MODEL IS THE BASIS OF THE MODERN ATOMIC MODEL, ALTHOUGH NUMEROUS MODIFICATIONS HAVE BEEN MADE TO THE MODEL OVER THE YEARS.

GRADE 9 WORKSHEETS (WORKSHEET 1 MULTIMODAL SOCIAL)

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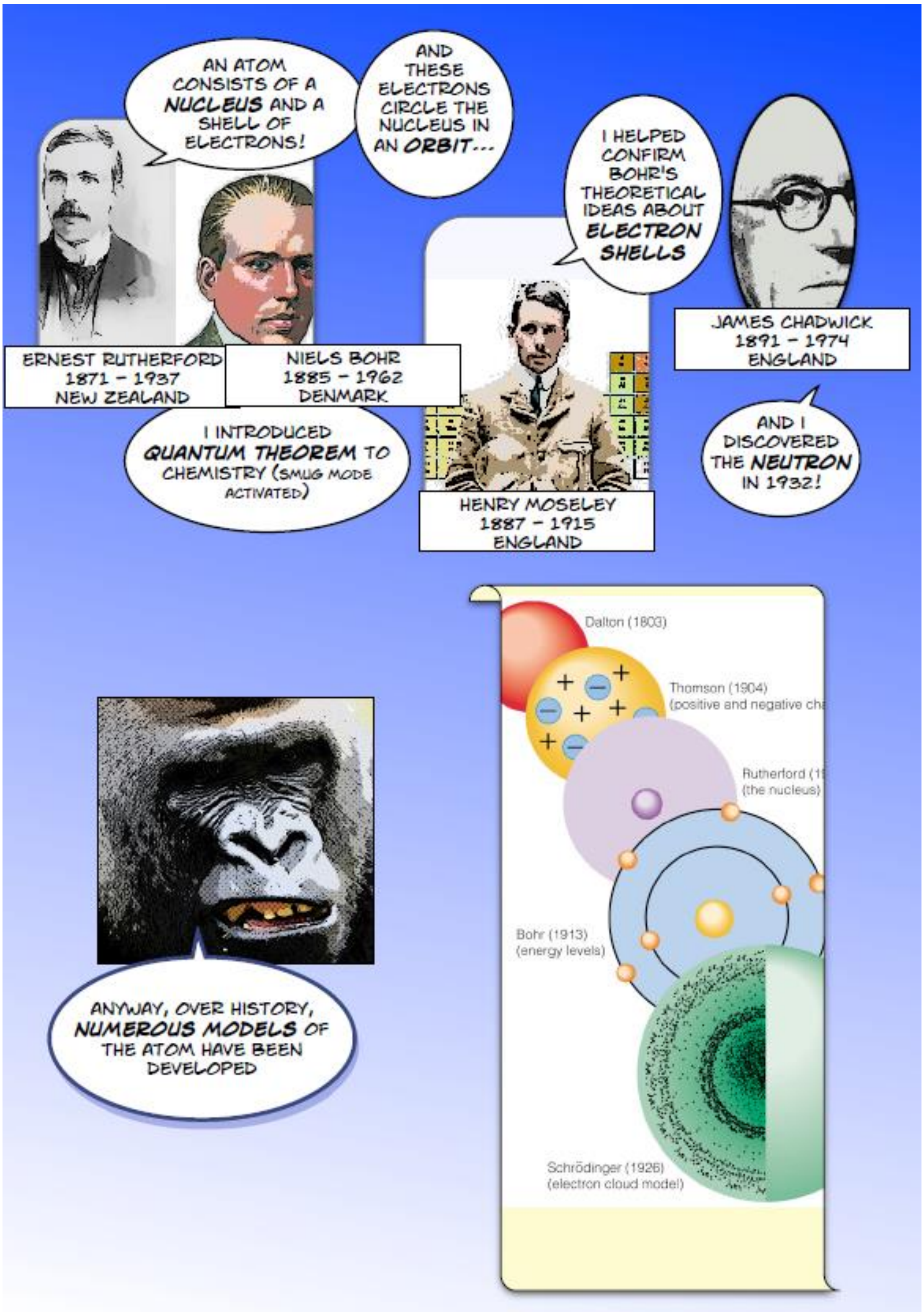
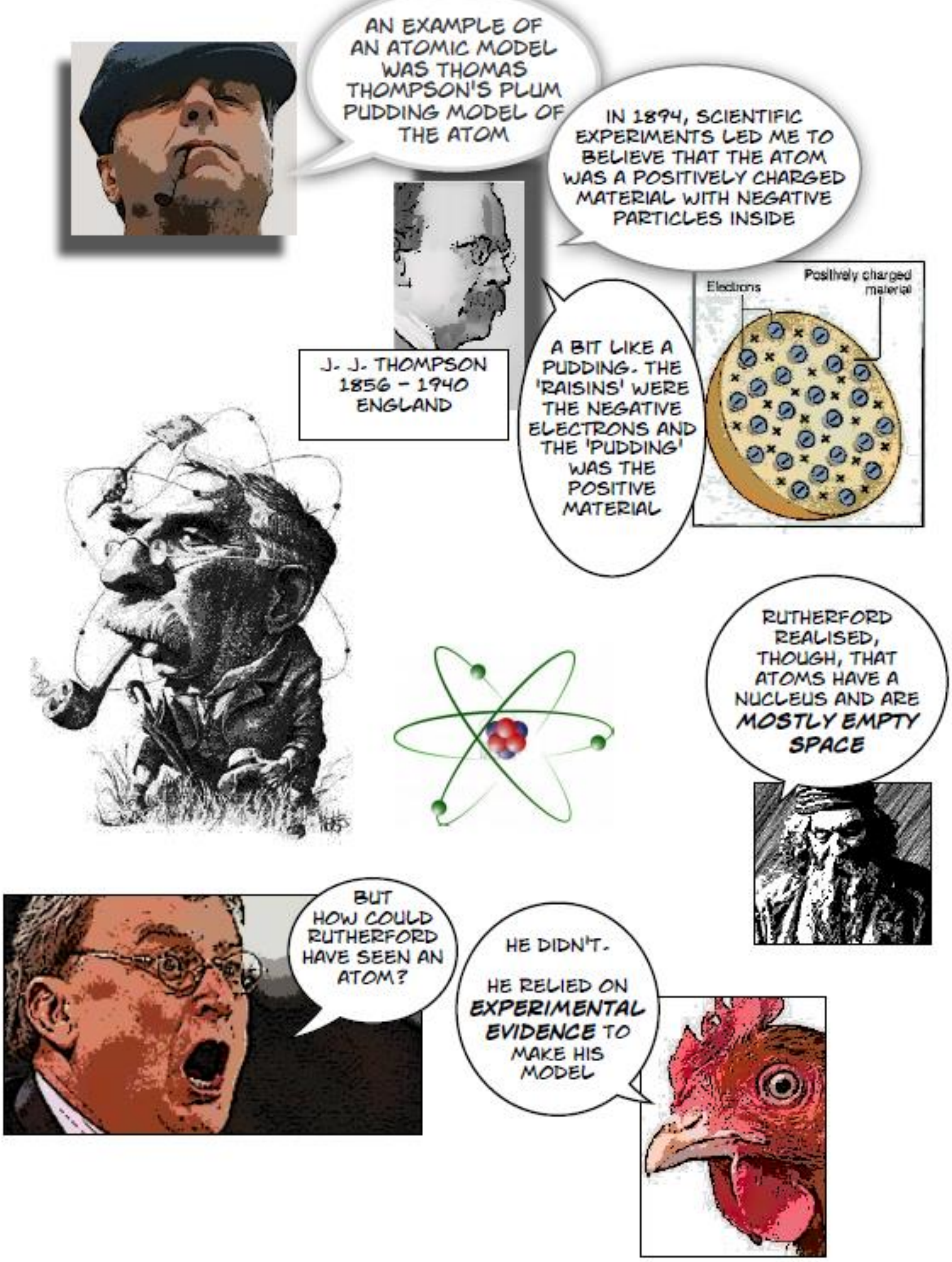
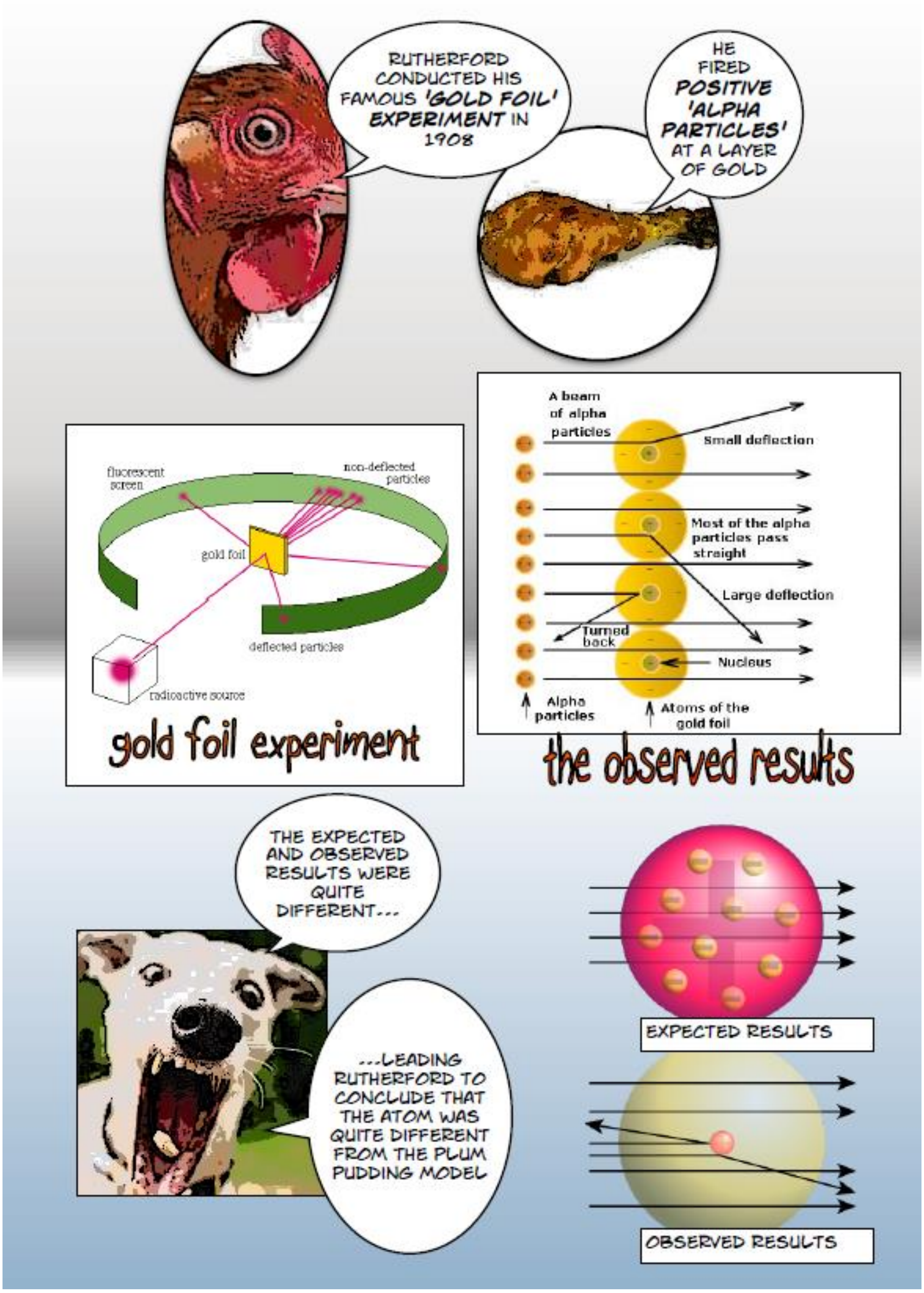

AN ATOM CONSISTS OF A NUCLEUS AND A SHELL OF ELECTRONS!
AND THESE ELECTRONS CIRCLE THE NUCLEUS IN AN ORBIT...
ERNEST RUTHERFORD 1871 – 1937 NEW ZEALAND
NIELS BOHR 1885 – 1962 DENMARK
I INTRODUCED QUANTUM THEOREM TO CHEMISTRY (SMUG MODE ACTIVATED)
I HELPED CONFIRM BOHR'S THEORETICAL IDEAS ABOUT ELECTRON SHELLS
HENRY MOSELEY 1887 – 1915 ENGLAND
JAMES CHADWICK 1891 – 1974 ENGLAND
AND I DISCOVERED THE NEUTRON IN 1932!
ANYWAY, OVER HISTORY, NUMEROUS MODELS OF THE ATOM HAVE BEEN DEVELOPED
Dalton (1803)
Thomson (1904)
Rutherford
(the nucleus)
Bohr (1913)
(energy levels)
Schrödinger (1926)
(electron cloud model)

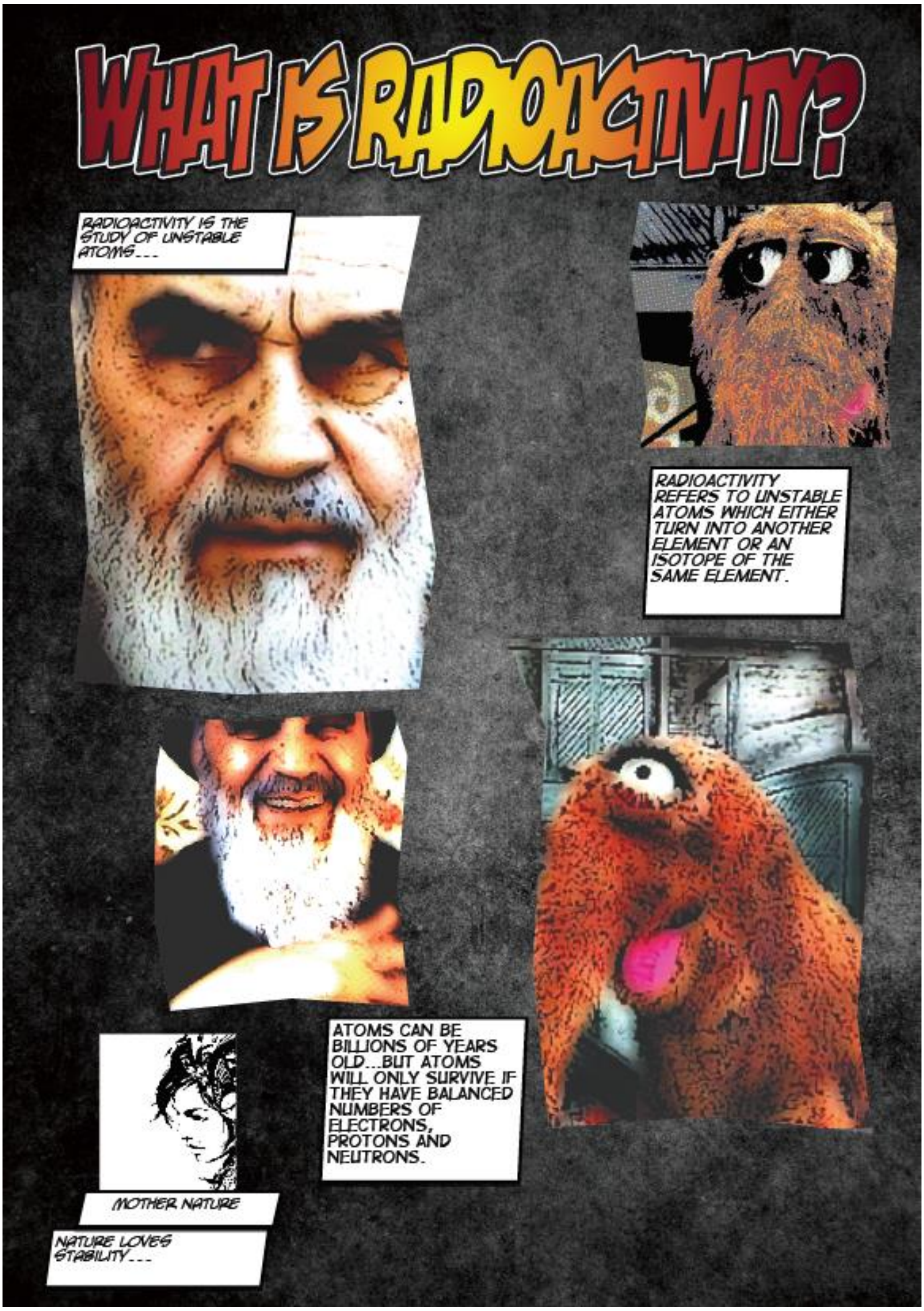

AN EXAMPLE OF AN ATOMIC MODEL WAS THOMAS THOMPSON'S PLUM PUDDING MODEL OF THE ATOM
IN 1894, SCIENTIFIC EXPERIMENTS LED ME TO BELIEVE THAT THE ATOM WAS A POSITIVELY CHARGED MATERIAL WITH NEGATIVE PARTICLES INSIDE
J. J. THOMPSON 1856 – 1940 ENGLAND
A BIT LIKE A PUDDING. THE 'RAISINS' WERE THE NEGATIVE ELECTRONS AND THE 'PUDDING' WAS THE POSITIVE MATERIAL
Electrons
Positively charged material
RUTHERFORD REALISED, THOUGH, THAT ATOMS HAVE A NUCLEUS AND ARE ***MOSTLY EMPTY SPACE***
BUT HOW COULD RUTHERFORD HAVE SEEN AN ATOM?
HE DIDN'T.
HE RELIED ON ***EXPERIMENTAL EVIDENCE*** TO MAKE HIS MODEL

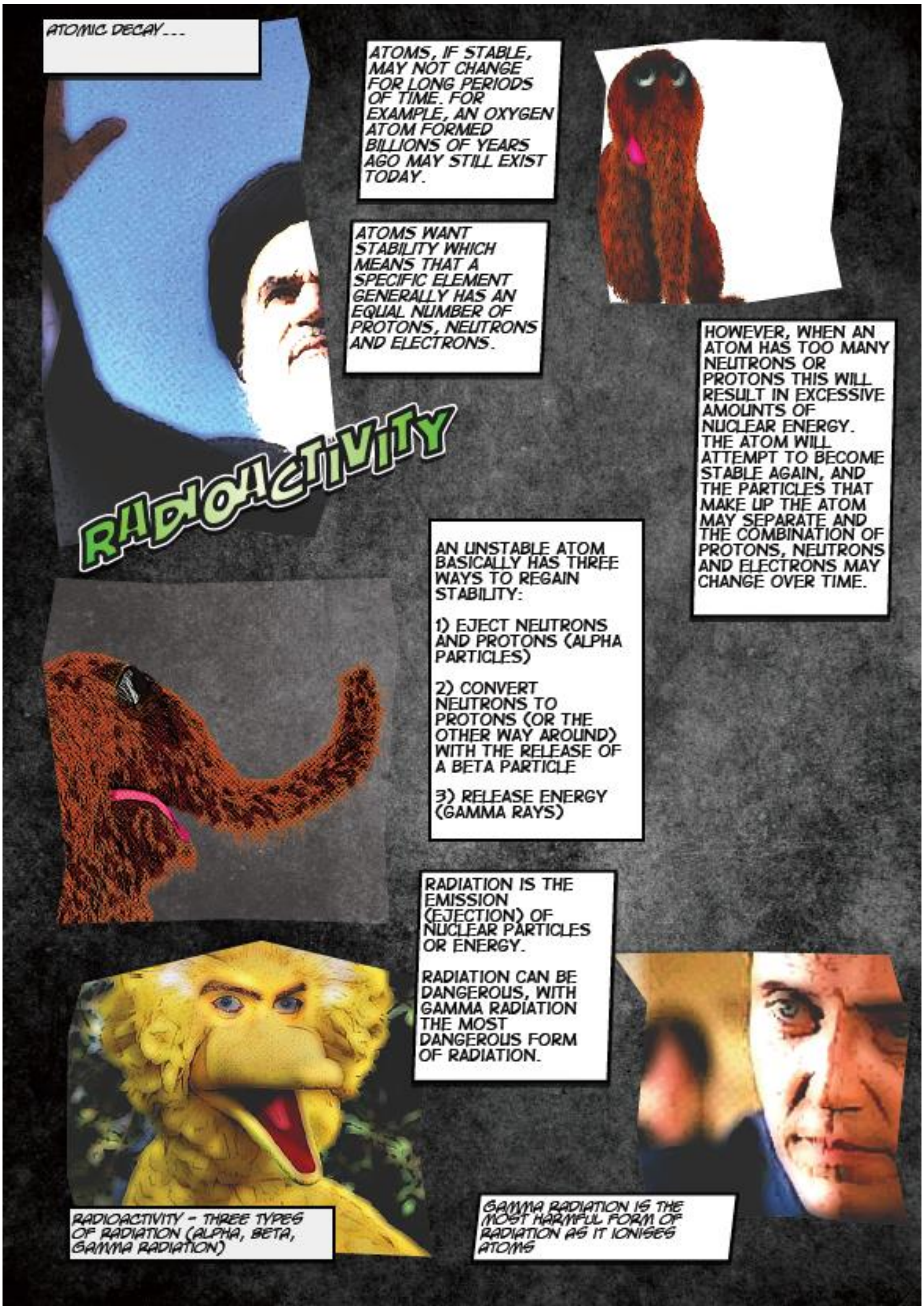


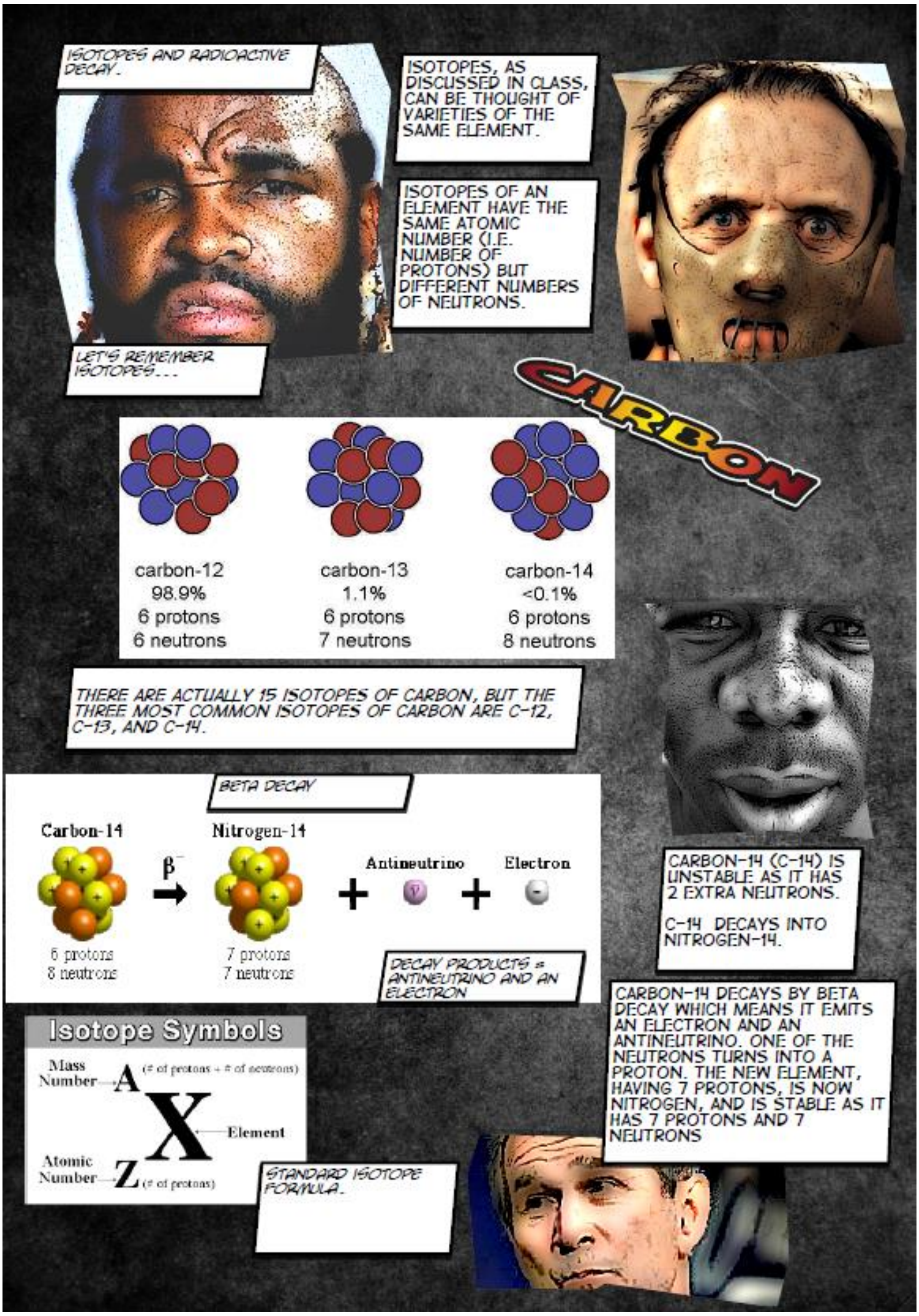
RUTHERFORD CONDUCTED HIS FAMOUS 'GOLD FOIL' EXPERIMENT IN 1908
HE FIRED POSITIVE 'ALPHA PARTICLES' AT A LAYER OF GOLD
fluorescent screen
non-deflected particles
gold foil
deflected particles
radioactive source
gold foil experiment
A beam of alpha particles
Small deflection
Most of the alpha particles pass straight
Large deflection
Turned back
Nucleus
Alpha particles
Atoms of the gold foil
the observed results
THE EXPECTED AND OBSERVED RESULTS WERE QUITE DIFFERENT...
...LEADING RUTHERFORD TO CONCLUDE THAT THE ATOM WAS QUITE DIFFERENT FROM THE PLUM PUDDING MODEL
EXPECTED RESULTS
OBSERVED RESULTS

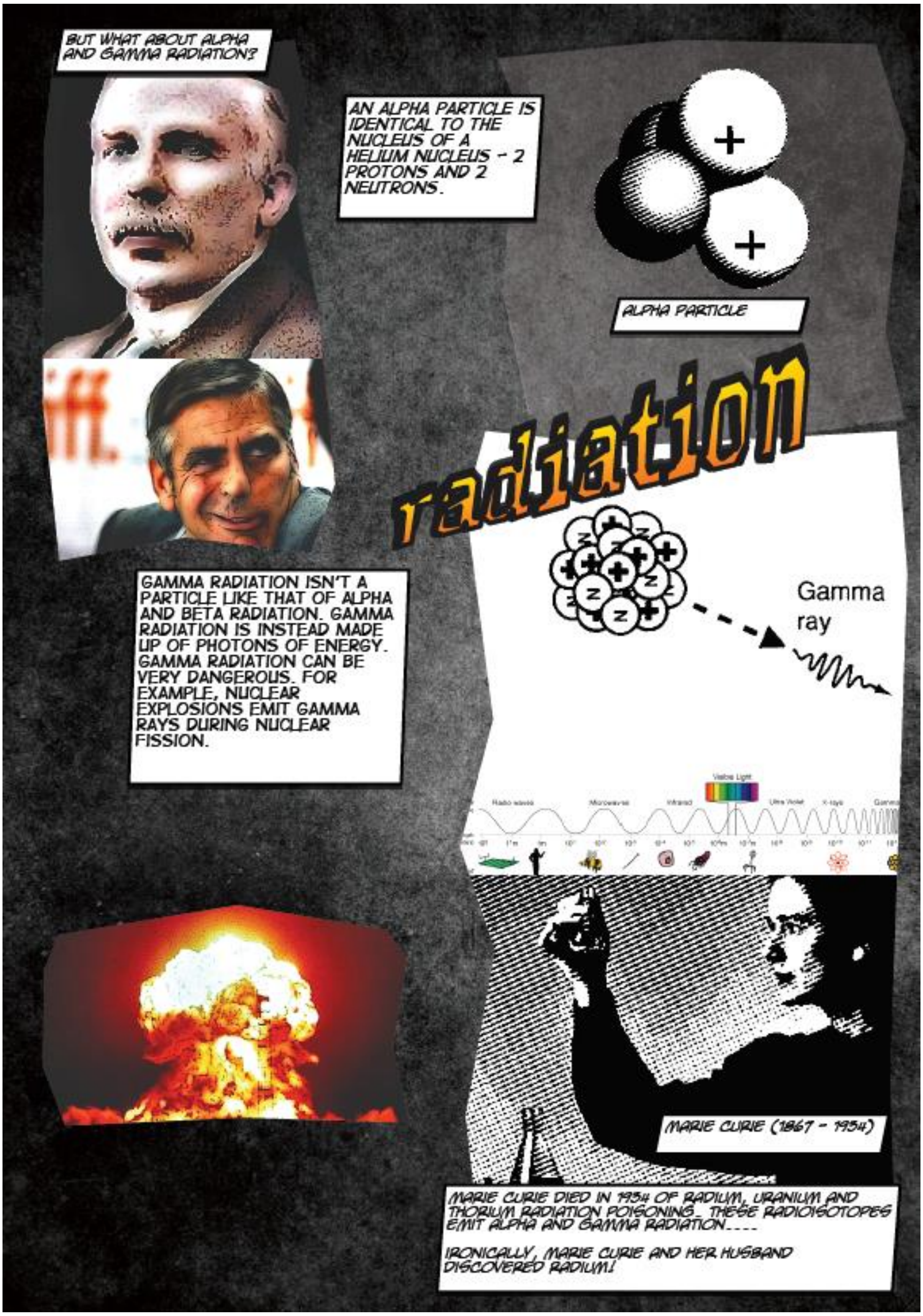

RUTHERFORD REALISED THAT ATOMS MUST HAVE A TINY POSITIVE NUCLEUS AND ARE SURROUNDED BY NEGATIVELY CHARGED PARTICLES
WHAT ELSE COULD EXPLAIN THE SMALL AMOUNT OF POSITIVE ALPHA PARTICLES BEING DEFLECTED!
SO IF MOST OF THE POSITIVE ALPHA PARTICLES TRAVELLED STRAIGHT THROUGH THE GOLD ATOMS...
...THE SMALL AMOUNT OF ALPHA PARTICLES BEING DEFLECTED INDICATE A TINY, POSITIVE NUCLEUS INSIDE A MOSTLY EMPTY SPACE FILLED WITH TINY, NEGATIVE ELECTRONS
WITH SOME ALPHA PARTICLES DEFLECTING DUE TO POSITIVE CHARGES REPELLING EACH OTHER ...
SCIENCE IS AMAZING!
Likes repel
Opposites attract

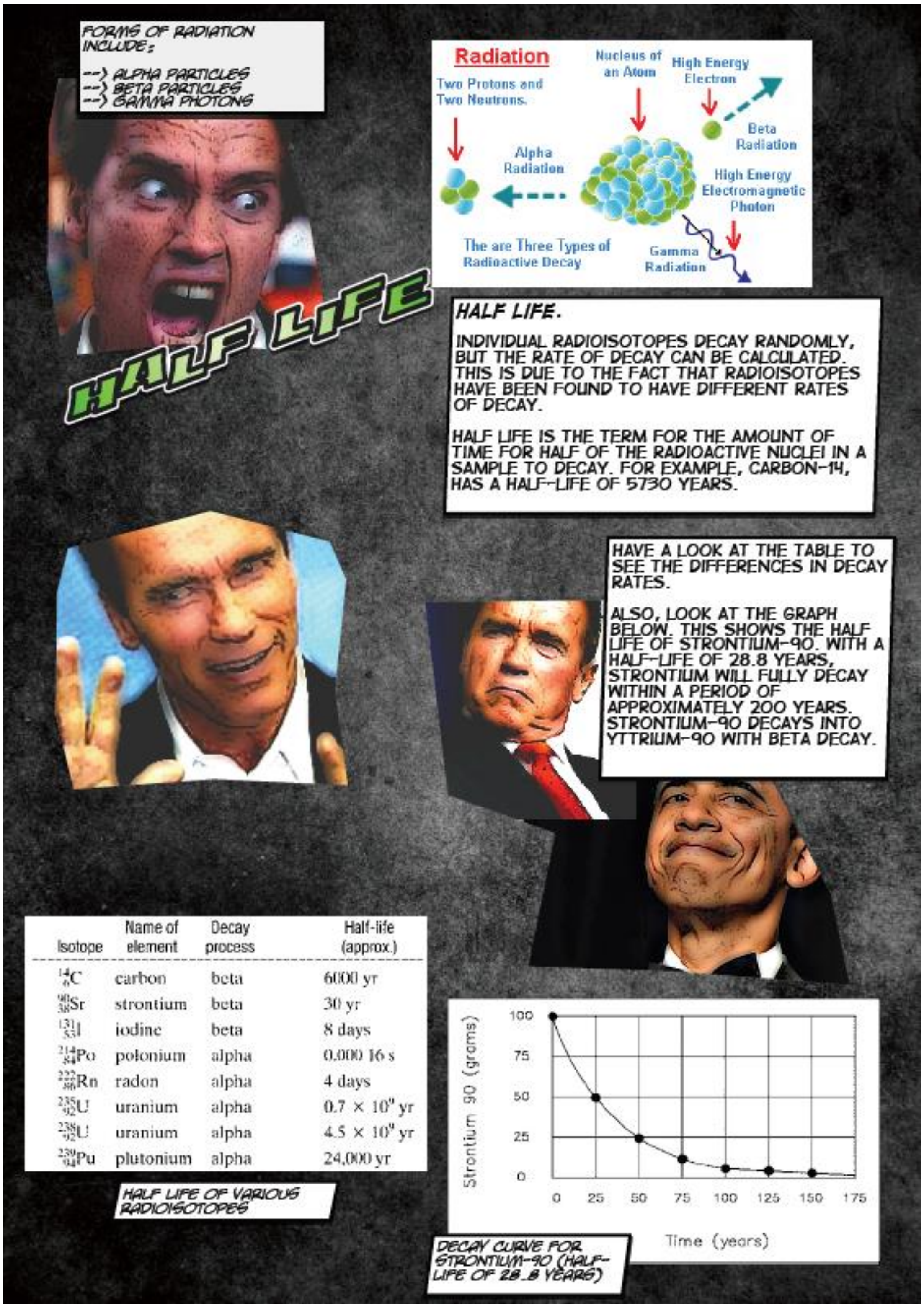
GRADE 9 WORKSHEETS (WORKSHEET 2 BIMODAL SOCIAL)




ATOMIC DECAY...
ATOMS, IF STABLE, MAY NOT CHANGE FOR LONG PERIODS OF TIME. FOR EXAMPLE, AN OXYGEN ATOM FORMED BILLIONS OF YEARS AGO MAY STILL EXIST TODAY.
ATOMS WANT STABILITY WHICH MEANS THAT A SPECIFIC ELEMENT GENERALLY HAS AN EQUAL NUMBER OF PROTONS, NEUTRONS AND ELECTRONS.
HOWEVER, WHEN AN ATOM HAS TOO MANY NEUTRONS OR PROTONS THIS WILL RESULT IN EXCESSIVE AMOUNTS OF NUCLEAR ENERGY. THE ATOM WILL ATTEMPT TO BECOME STABLE AGAIN, AND THE PARTICLES THAT MAKE UP THE ATOM MAY SEPARATE AND THE COMBINATION OF PROTONS, NEUTRONS AND ELECTRONS MAY CHANGE OVER TIME.
RADIOACTIVITY
AN UNSTABLE ATOM BASICALLY HAS THREE WAYS TO REGAIN STABILITY:
1) EJECT NEUTRONS AND PROTONS (ALPHA PARTICLES)
2) CONVERT NEUTRONS TO PROTONS (OR THE OTHER WAY AROUND) WITH THE RELEASE OF A BETA PARTICLE
3) RELEASE ENERGY (GAMMA RAYS)
RADIATION IS THE EMISSION (EJECTION) OF NUCLEAR PARTICLES OR ENERGY.
RADIATION CAN BE DANGEROUS, WITH GAMMA RADIATION THE MOST DANGEROUS FORM OF RADIATION.
RADIOACTIVITY - THREE TYPES OF RADIATION (ALPHA, BETA, GAMMA RADIATION)
GAMMA RADIATION IS THE MOST HARMFUL FORM OF RADIATION AS IT IONISES ATOMS


ISOTOPES AND RADIOACTIVE DECAY.
ISOTOPES, AS DISCUSSED IN CLASS, CAN BE THOUGHT OF VARIETIES OF THE SAME ELEMENT.
ISOTOPES OF AN ELEMENT HAVE THE SAME ATOMIC NUMBER (I.E. NUMBER OF PROTONS) BUT DIFFERENT NUMBERS OF NEUTRONS.
LET'S REMEMBER ISOTOPES...
CARBON
carbon-12
98.9%
6 protons
6 neutrons
carbon-13
1.1%
6 protons
7 neutrons
carbon-14
<0.1%
6 protons
8 neutrons
THERE ARE ACTUALLY 15 ISOTOPES OF CARBON, BUT THE THREE MOST COMMON ISOTOPES OF CARBON ARE C-12, C-13, AND C-14.
BETA DECAY
Carbon-14
6 protons
8 neutrons
β⁻
Nitrogen-14
7 protons
7 neutrons
Antineutrino
Electron
DECAY PRODUCTS = ANTINEUTRINO AND AN ELECTRON
CARBON-14 (C-14) IS UNSTABLE AS IT HAS 2 EXTRA NEUTRONS.
C-14 DECAYS INTO NITROGEN-14.
CARBON-14 DECAYS BY BETA DECAY WHICH MEANS IT EMITS AN ELECTRON AND AN ANTINEUTRINO. ONE OF THE NEUTRONS TURNS INTO A PROTON. THE NEW ELEMENT, HAVING 7 PROTONS, IS NOW NITROGEN, AND IS STABLE AS IT HAS 7 PROTONS AND 7 NEUTRONS
Isotope Symbols
Mass Number
A
(# of protons + # of neutrons)
X
Element
Atomic Number
Z
(# of protons)
STANDARD ISOTOPE FORMULA.

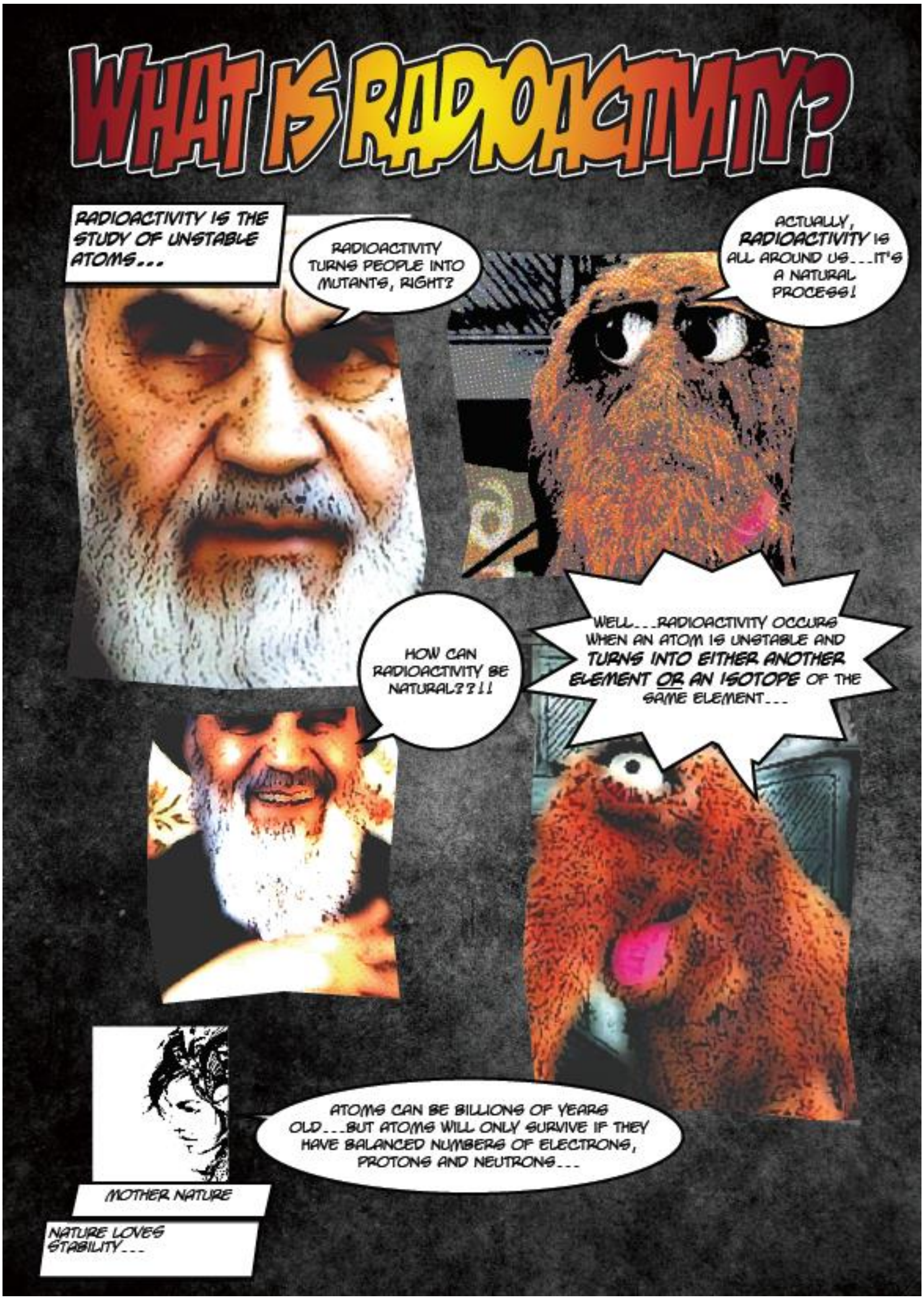

BUT WHAT ABOUT ALPHA AND GAMMA RADIATION?
AN ALPHA PARTICLE IS IDENTICAL TO THE NUCLEUS OF A HELIUM NUCLEUS - 2 PROTONS AND 2 NEUTRONS.
+
+
ALPHA PARTICLE
radiation
GAMMA RADIATION ISN'T A PARTICLE LIKE THAT OF ALPHA AND BETA RADIATION. GAMMA RADIATION IS INSTEAD MADE UP OF PHOTONS OF ENERGY. GAMMA RADIATION CAN BE VERY DANGEROUS. FOR EXAMPLE, NUCLEAR EXPLOSIONS EMIT GAMMA RAYS DURING NUCLEAR FISSION.
Gamma ray
MARIE CURIE (1867 - 1934)
MARIE CURIE DIED IN 1934 OF RADIUM, URANIUM AND THORIUM RADIATION POISONING. THESE RADIOISOTOPES EMIT ALPHA AND GAMMA RADIATION....
IRONICALLY, MARIE CURIE AND HER HUSBAND DISCOVERED RADIUM!



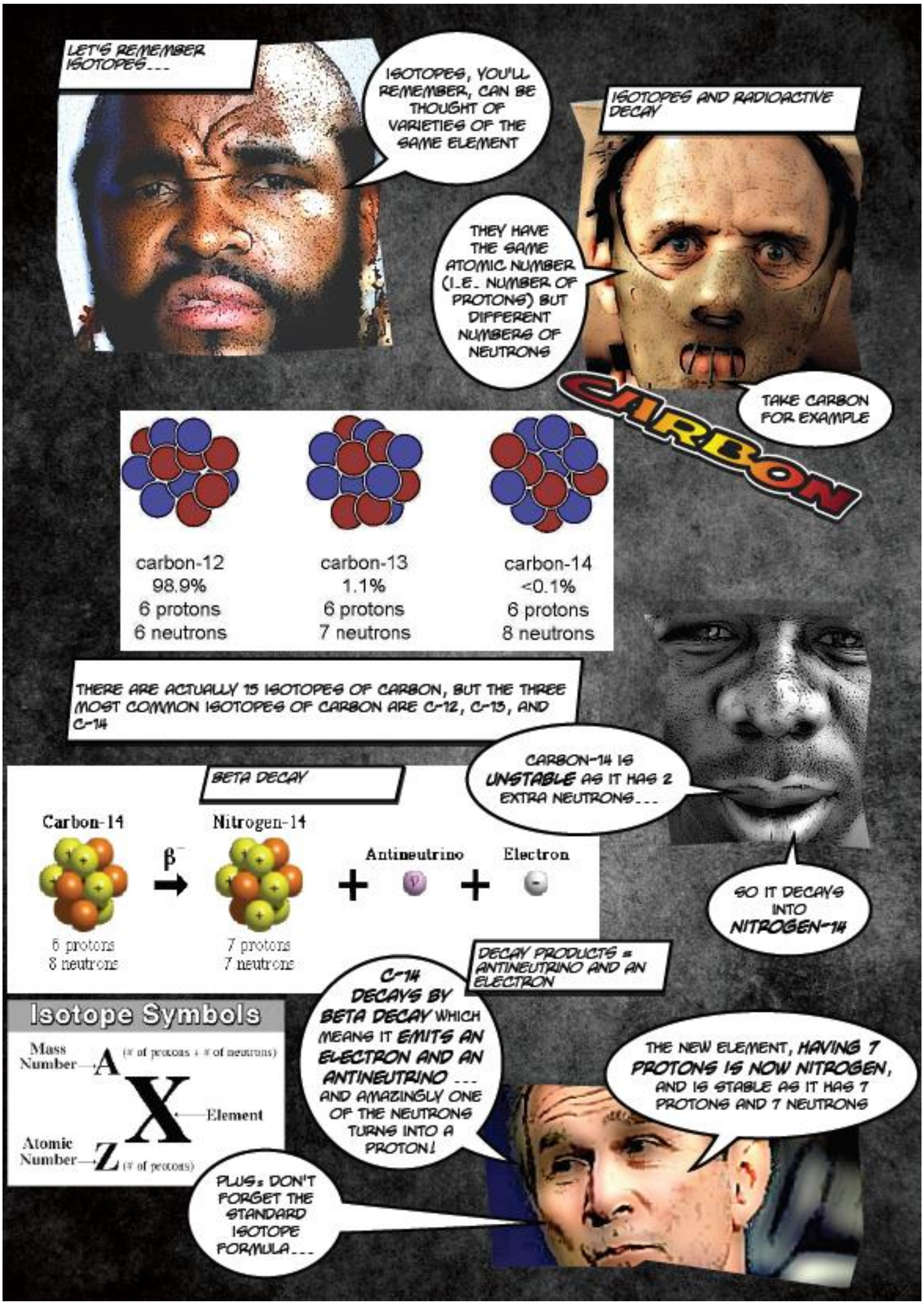
Isotope	Name of element	Decay process	Half-life (approx.)
$^{14}_{6}C$	carbon	beta	6000 yr
$^{90}_{38}Sr$	strontium	beta	30 yr
$^{131}_{53}I$	iodine	beta	8 days
$^{214}_{84}Po$	polonium	alpha	0.000 16 s
$^{222}_{86}Rn$	radon	alpha	4 days
$^{235}_{92}U$	uranium	alpha	0.7×10^{9} yr
$^{238}_{92}U$	uranium	alpha	4.5×10^{9} yr
$^{239}_{94}Pu$	plutonium	alpha	24,000 yr

HALF LIFE OF VARIOUS RADIOISOTOPES

GRADE 9 WORKSHEETS (WORKSHEET 2 MULTIMODAL SOCIAL)




ATOMIC DECAY...
DESCRIBE THIS RADIOACTIVE DECAY...
OK... REMEMBER THAT ATOMS WANT STABILITY...
...MEANING THAT A SPECIFIC ELEMENT GENERALLY HAS AN EQUAL NUMBER OF PROTONS, NEUTRONS AND ELECTRONS...
BUT WHEN AN ATOM HAS TOO MANY NEUTRONS OR PROTONS THIS WILL RESULT IN TOO MUCH NUCLEAR ENERGY... AND THE ATOM WILL ATTEMPT TO BECOME STABLE AGAIN
RADIOACTIVITY
AN UNSTABLE ATOM BASICALLY HAS THREE WAYS TO REGAIN STABILITY:
1) EJECT NEUTRONS AND PROTONS (ALPHA PARTICLES)
2) CONVERT NEUTRONS TO PROTONS (OR THE OTHER WAY AROUND) WITH THE RELEASE OF A BETA PARTICLE
3) RELEASE ENERGY (GAMMA RAYS)
SO RADIATION IS THE EMISSION (EJECTION) OF NUCLEAR PARTICLES OR ENERGY!
CAN THIS BE DANGEROUS?
YES - BUT IT DEPENDS ON WHETHER THE EMITTED PARTICLES ARE ALPHA, BETA OR GAMMA RADIATION
RADIOACTIVITY - THREE TYPES OF RADIATION (ALPHA, BETA, GAMMA RADIATION)
GAMMA RADIATION IS THE MOST HARMFUL FORM OF RADIATION AS IT IONISES ATOMS


LET'S REMEMBER ISOTOPES...
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Mass Number
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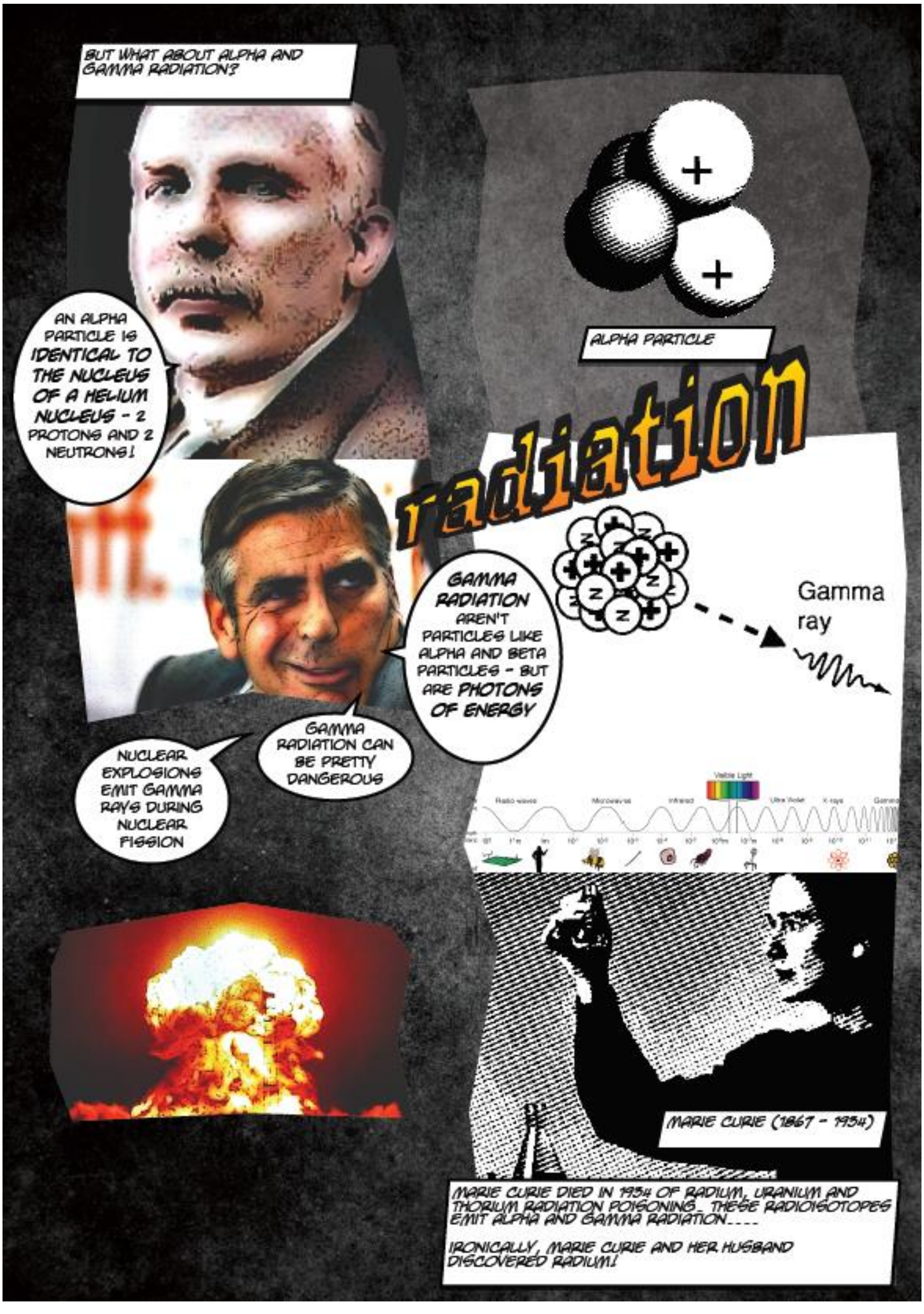
(# of protons + # of neutrons)
X
Element
Atomic Number
Z
(# of protons)
THE NEW ELEMENT, HAVING 7 PROTONS IS NOW NITROGEN, AND IS STABLE AS IT HAS 7 PROTONS AND 7 NEUTRONS
PLUS: DON'T FORGET THE STANDARD ISOTOPE FORMULA...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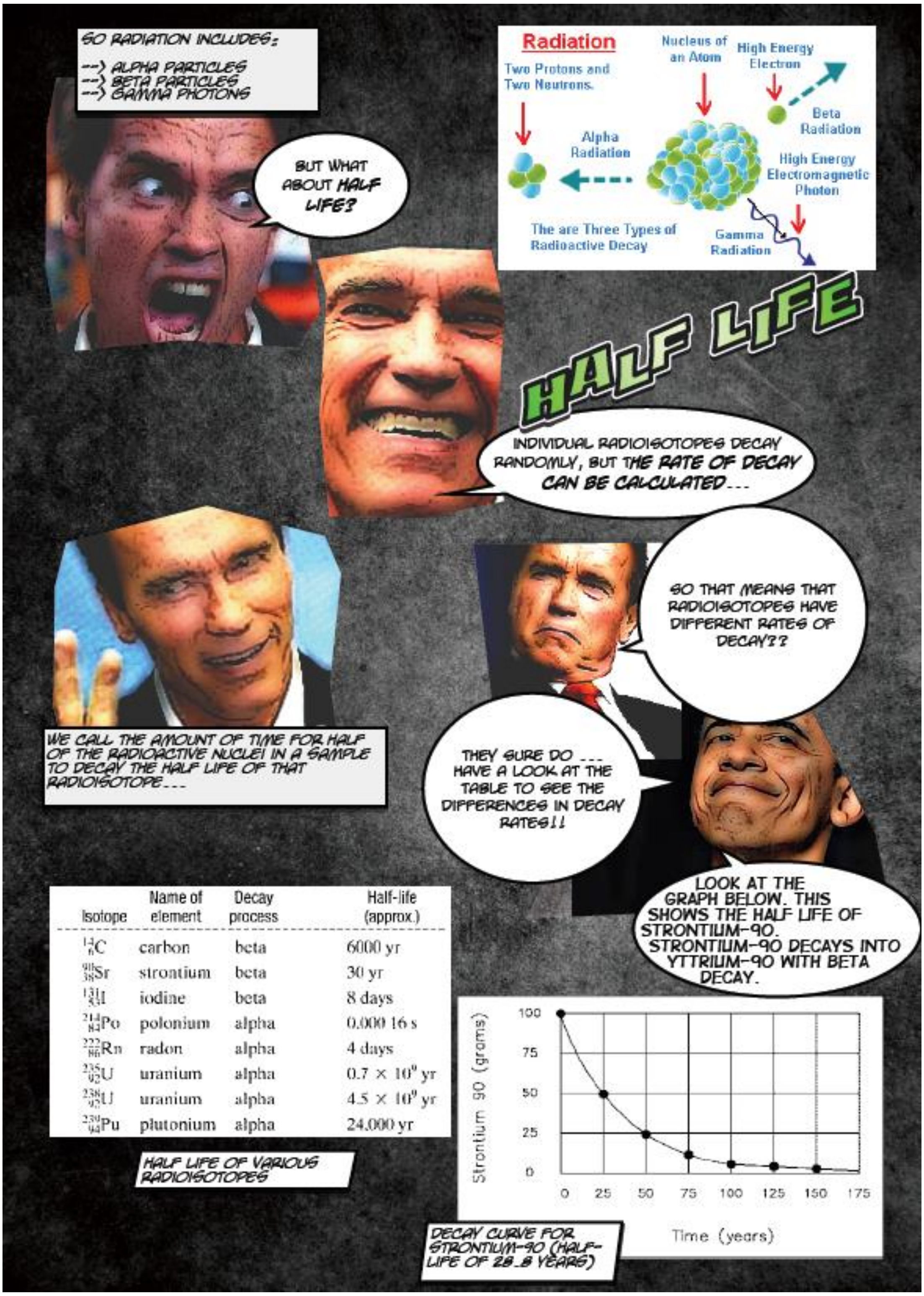

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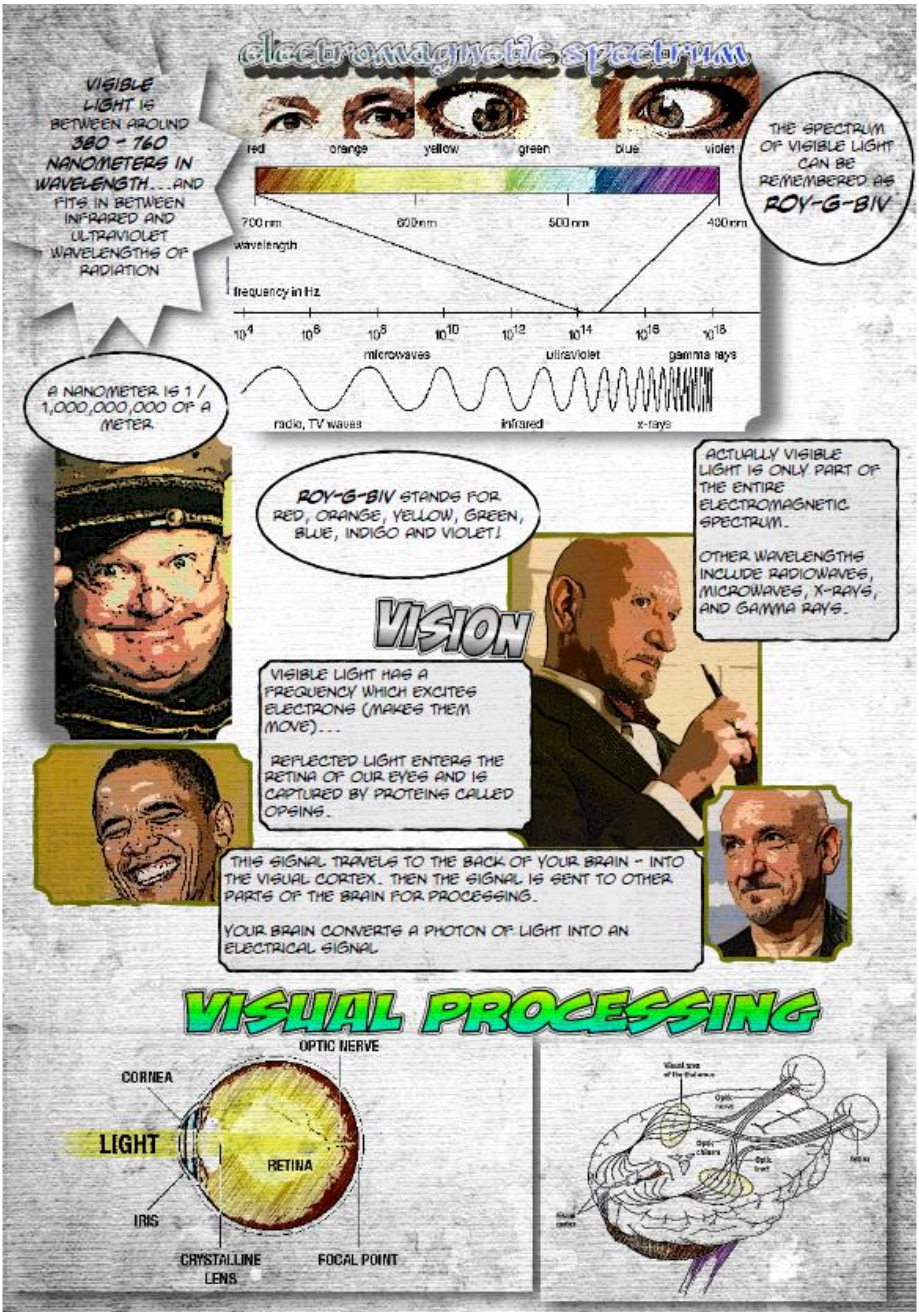
GRADE 9 WORKSHEETS (WORKSHEET 3 BIMODAL SOCIAL)



electromagnetic spectrum
VISIBLE LIGHT IS BETWEEN AROUND 380 - 760 NANOMETERS IN WAVELENGTH... AND FITS IN BETWEEN INFRARED AND ULTRAVIOLET WAVELENGTHS OF RADIATION
red
orange
yellow
green
blue
violet
700 nm
600 nm
500 nm
400 nm
wavelength
frequency in Hz
10^4
10^6
10^8
10^{10}
10^{12}
10^{14}
10^{16}
10^{18}
microwaves
ultraviolet
gamma rays
radio, TV waves
infrared
x-rays
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REFLECTED LIGHT ENTERS THE RETINA OF OUR EYES AND IS CAPTURED BY PROTEINS CALLED OPSINS.
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RETINA
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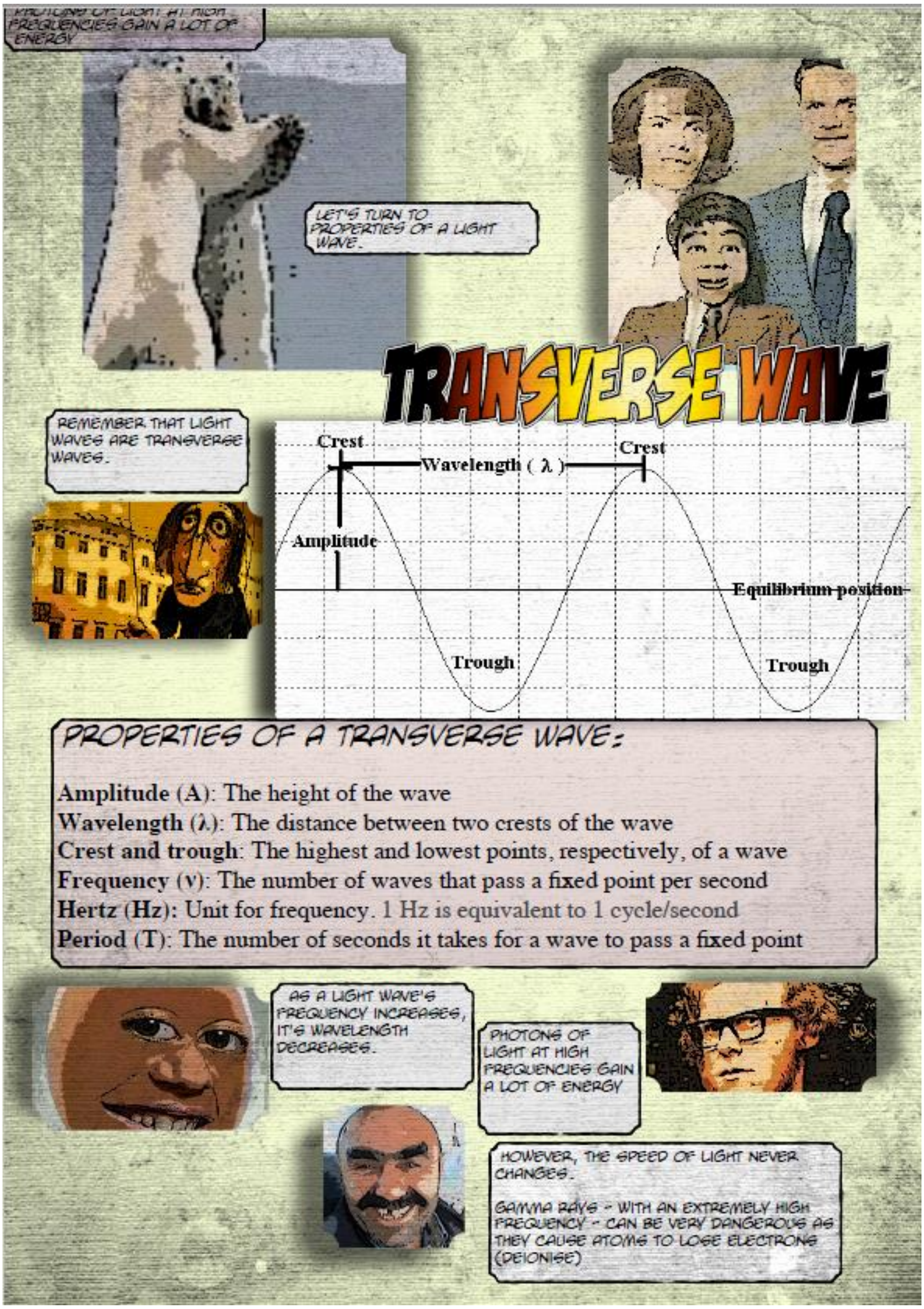
FREQUENCIES GAIN A LOT OF ENERGY
LET'S TURN TO PROPERTIES OF A LIGHT WAVE.
TRANSVERSE WAVE
REMEMBER THAT LIGHT WAVES ARE TRANSVERSE WAVES.
Crest
Wavelength (λ)
Crest
Amplitude
Equilibrium position
Trough
Trough
PROPERTIES OF A TRANSVERSE WAVE:
Amplitude (A): The height of the wave
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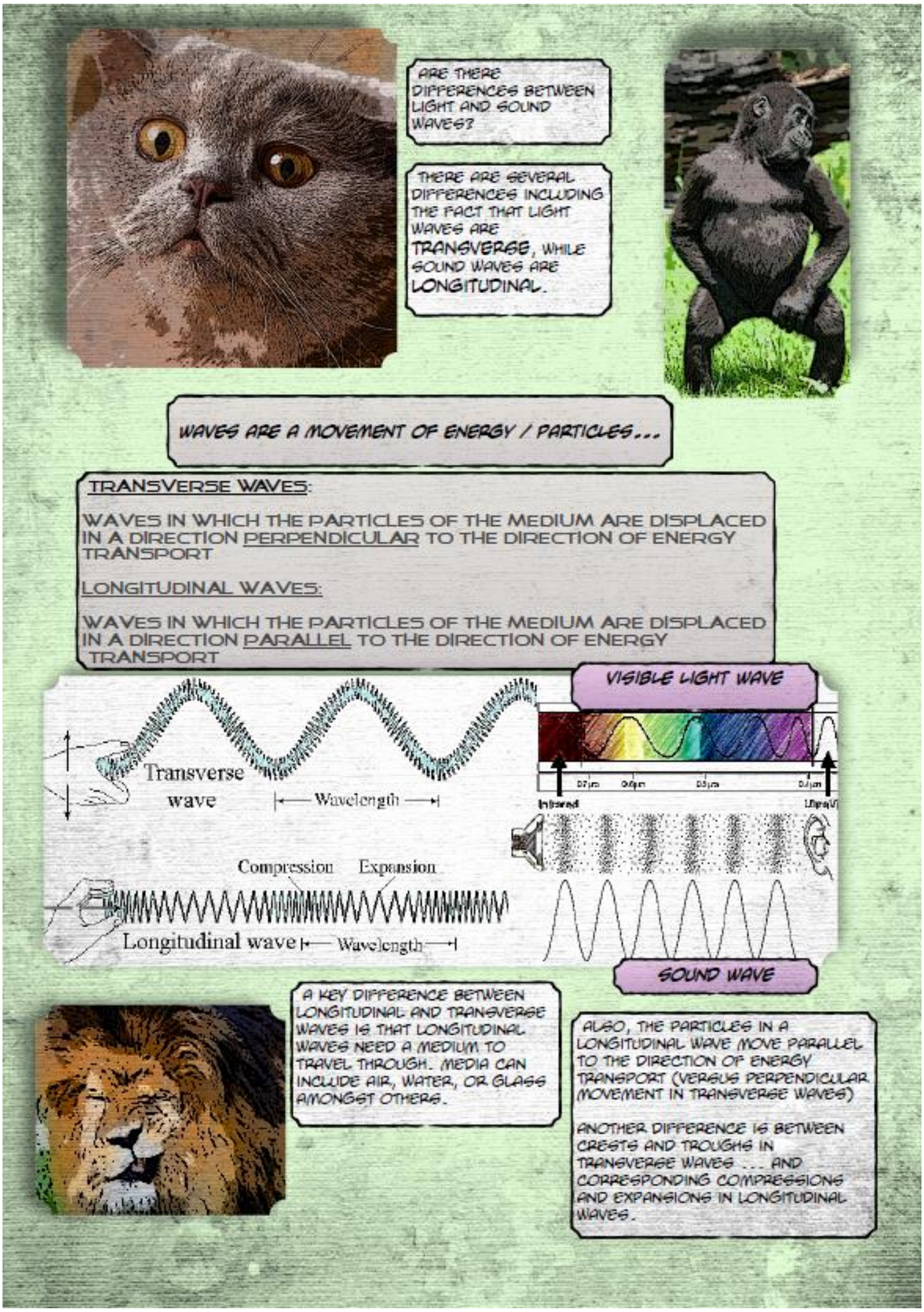
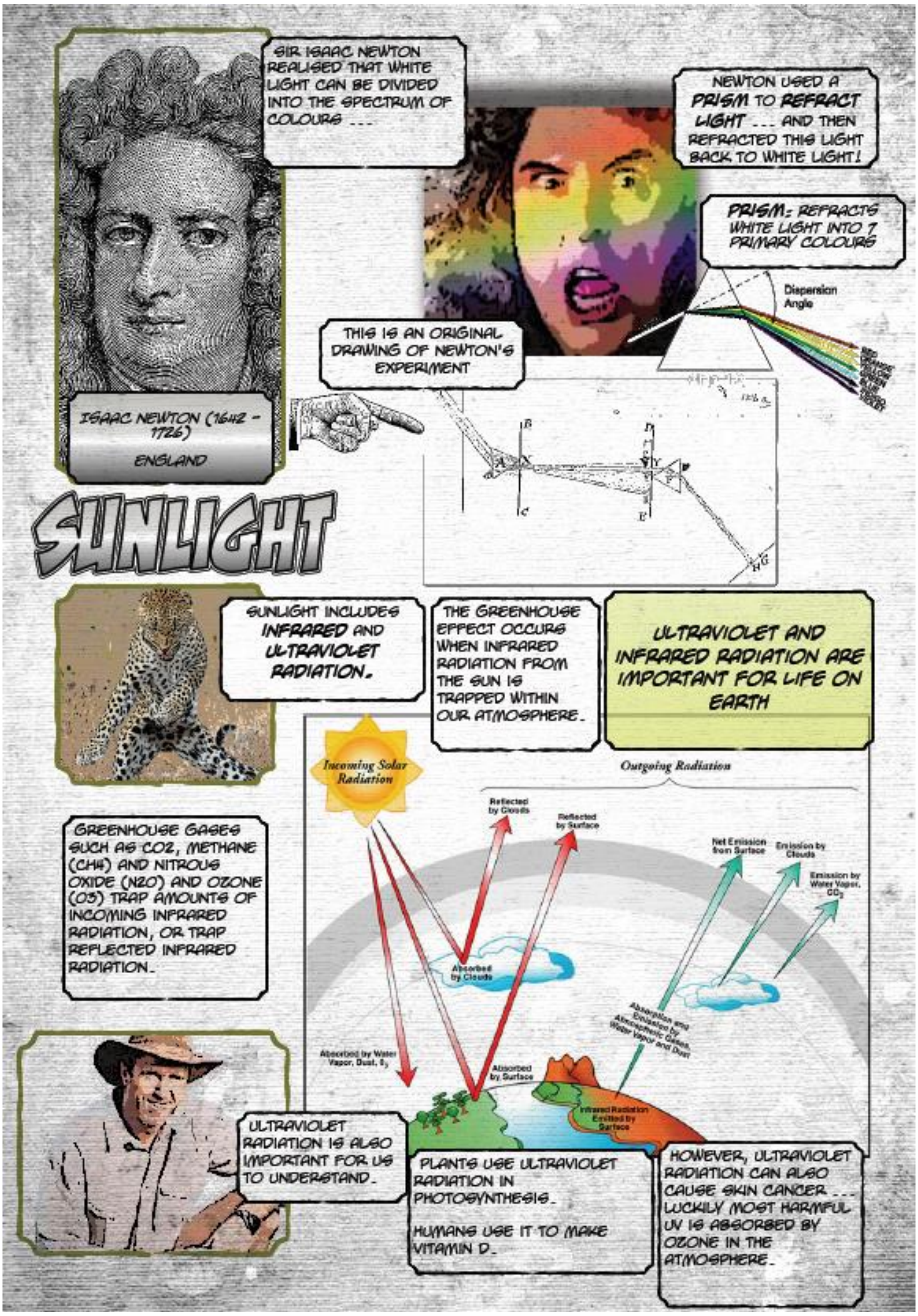
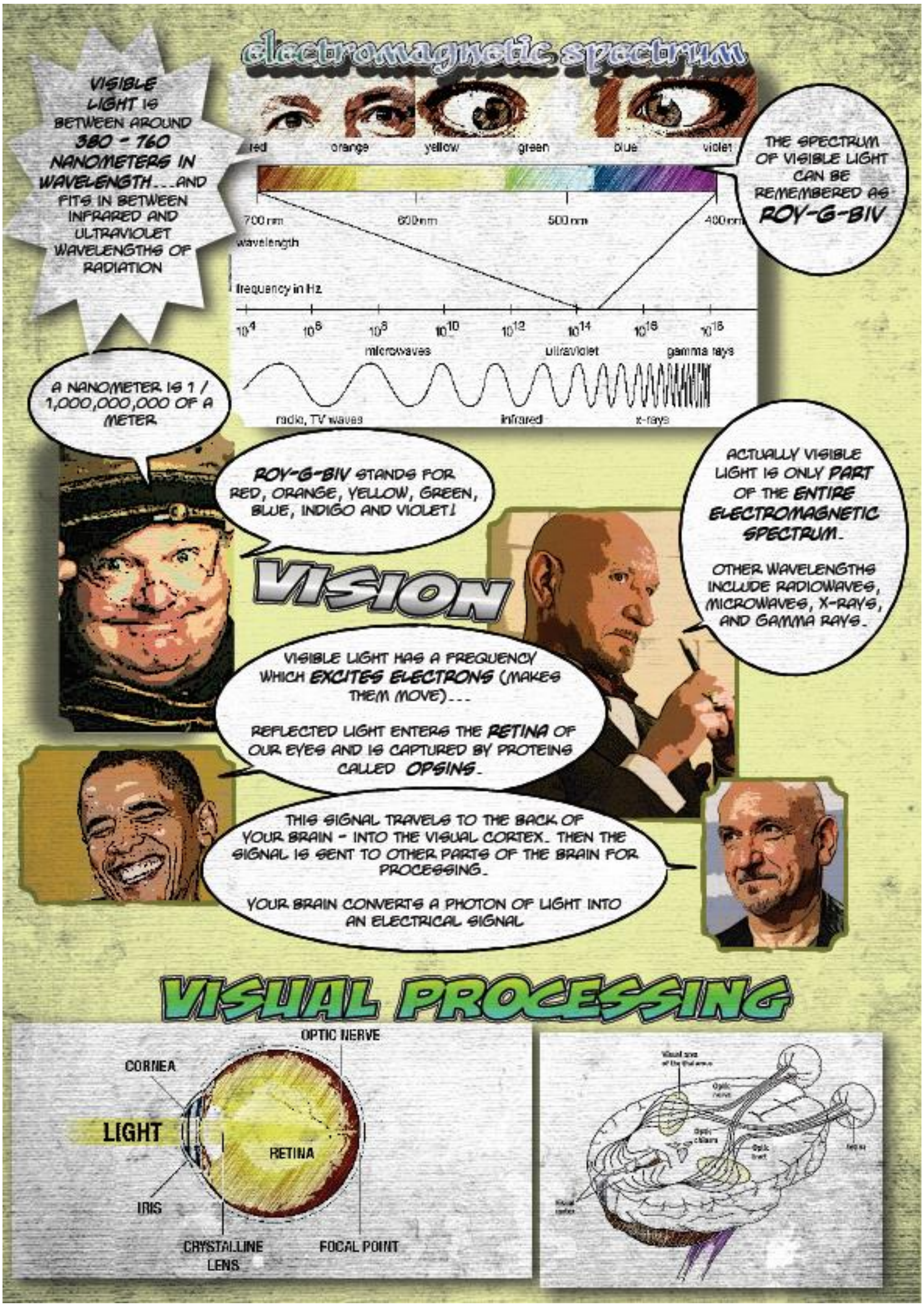
Crest and trough: The highest and lowest points, respectively, of a wave
Frequency (v): The number of waves that pass a fixed point per second
Hertz (Hz): Unit for frequency. 1 Hz is equivalent to 1 cycle/second
Period (T): The number of seconds it takes for a wave to pass a fixed point
AS A LIGHT WAVE'S FREQUENCY INCREASES, IT'S WAVELENGTH DECREASES.
PHOTONS OF LIGHT AT HIGH FREQUENCIES GAIN A LOT OF ENERGY
HOWEVER, THE SPEED OF LIGHT NEVER CHANGES.
GAMMA RAYS - WITH AN EXTREMELY HIGH FREQUENCY - CAN BE VERY DANGEROUS AS THEY CAUSE ATOMS TO LOSE ELECTRONS (DEIONISE)


ARE THERE DIFFERENCES BETWEEN LIGHT AND SOUND WAVES?
THERE ARE SEVERAL DIFFERENCES INCLUDING THE FACT THAT LIGHT WAVES ARE TRANSVERSE, WHILE SOUND WAVES ARE LONGITUDINAL.
WAVES ARE A MOVEMENT OF ENERGY / PARTICLES...
TRANSVERSE WAVES:
WAVES IN WHICH THE PARTICLES OF THE MEDIUM ARE DISPLACED IN A DIRECTION PERPENDICULAR TO THE DIRECTION OF ENERGY TRANSPORT
LONGITUDINAL WAVES:
WAVES IN WHICH THE PARTICLES OF THE MEDIUM ARE DISPLACED IN A DIRECTION PARALLEL TO THE DIRECTION OF ENERGY TRANSPORT
VISIBLE LIGHT WAVE
Transverse wave
Wavelength
Compression
Expansion
Longitudinal wave
Wavelength
SOUND WAVE
A KEY DIFFERENCE BETWEEN LONGITUDINAL AND TRANSVERSE WAVES IS THAT LONGITUDINAL WAVES NEED A MEDIUM TO TRAVEL THROUGH. MEDIA CAN INCLUDE AIR, WATER, OR GLASS AMONGST OTHERS.
ALSO, THE PARTICLES IN A LONGITUDINAL WAVE MOVE PARALLEL TO THE DIRECTION OF ENERGY TRANSPORT (VERSUS PERPENDICULAR MOVEMENT IN TRANSVERSE WAVES)
ANOTHER DIFFERENCE IS BETWEEN CRESTS AND TROUGHS IN TRANSVERSE WAVES ... AND CORRESPONDING COMPRESSIONS AND EXPANSIONS IN LONGITUDINAL WAVES.


SIR ISAAC NEWTON REALISED THAT WHITE LIGHT CAN BE DIVIDED INTO THE SPECTRUM OF COLOURS ...
NEWTON USED A PRISM TO REFRACT LIGHT ... AND THEN REFRACTED THIS LIGHT BACK TO WHITE LIGHT!
PRISM: REFRACTS WHITE LIGHT INTO 7 PRIMARY COLOURS
Dispersion Angle
THIS IS AN ORIGINAL DRAWING OF NEWTON'S EXPERIMENT
ISAAC NEWTON (1642 - 1726)
ENGLAND
SUNLIGHT
SUNLIGHT INCLUDES INFRARED AND ULTRAVIOLET RADIATION.
THE GREENHOUSE EFFECT OCCURS WHEN INFRARED RADIATION FROM THE SUN IS TRAPPED WITHIN OUR ATMOSPHERE.
ULTRAVIOLET AND INFRARED RADIATION ARE IMPORTANT FOR LIFE ON EARTH
Incoming Solar Radiation
Outgoing Radiation
Reflected by Clouds
Reflected by Surface
Net Emission from Surface
Emission by Clouds
Emission by Water Vapor, CO2
Absorbed by Clouds
Absorption and Emission by Atmospheric Gases, Water Vapor and Dust
Absorbed by Water Vapor, Dust, O3
Absorbed by Surface
Infrared Radiation Emitted by Surface
GREENHOUSE GASES SUCH AS CO2, METHANE (CH4) AND NITROUS OXIDE (N2O) AND OZONE (O3) TRAP AMOUNTS OF INCOMING INFRARED RADIATION, OR TRAP REFLECTED INFRARED RADIATION.
ULTRAVIOLET RADIATION IS ALSO IMPORTANT FOR US TO UNDERSTAND.
PLANTS USE ULTRAVIOLET RADIATION IN PHOTOSYNTHESIS.
HUMANS USE IT TO MAKE VITAMIN D.
HOWEVER, ULTRAVIOLET RADIATION CAN ALSO CAUSE SKIN CANCER ... LUCKILY MOST HARMFUL UV IS ABSORBED BY OZONE IN THE ATMOSPHERE.

GRADE 9 WORKSHEETS (WORKSHEET 3 MULTIMODAL SOCIAL)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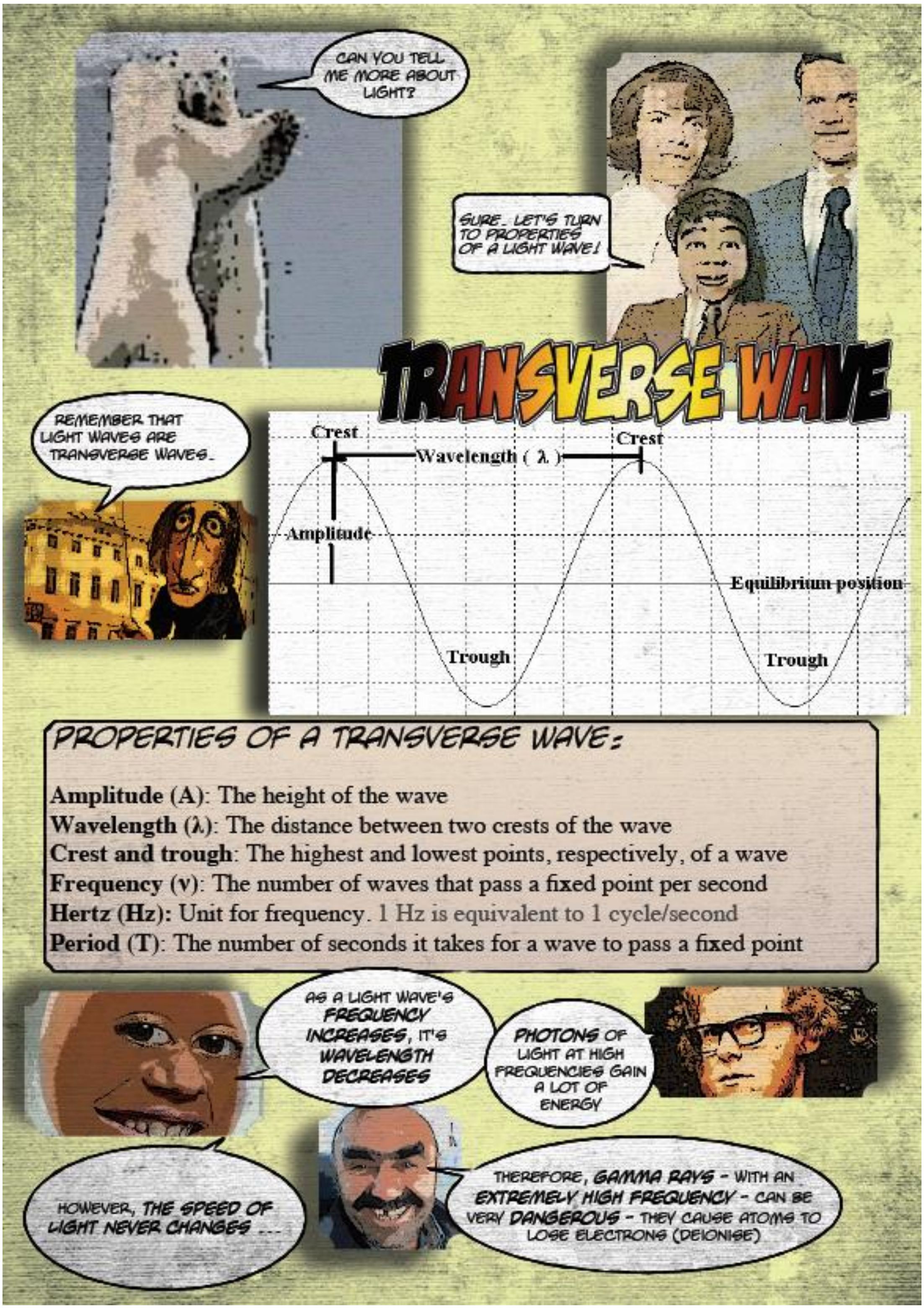
CAN YOU TELL ME MORE ABOUT LIGHT?
SURE.. LET'S TURN TO PROPERTIES OF A LIGHT WAVE!
TRANSVERSE WAVE
REMEMBER THAT LIGHT WAVES ARE TRANSVERSE WAVES..
Crest
Wavelength (λ)
Crest
Amplitude
Equilibrium position
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Trough
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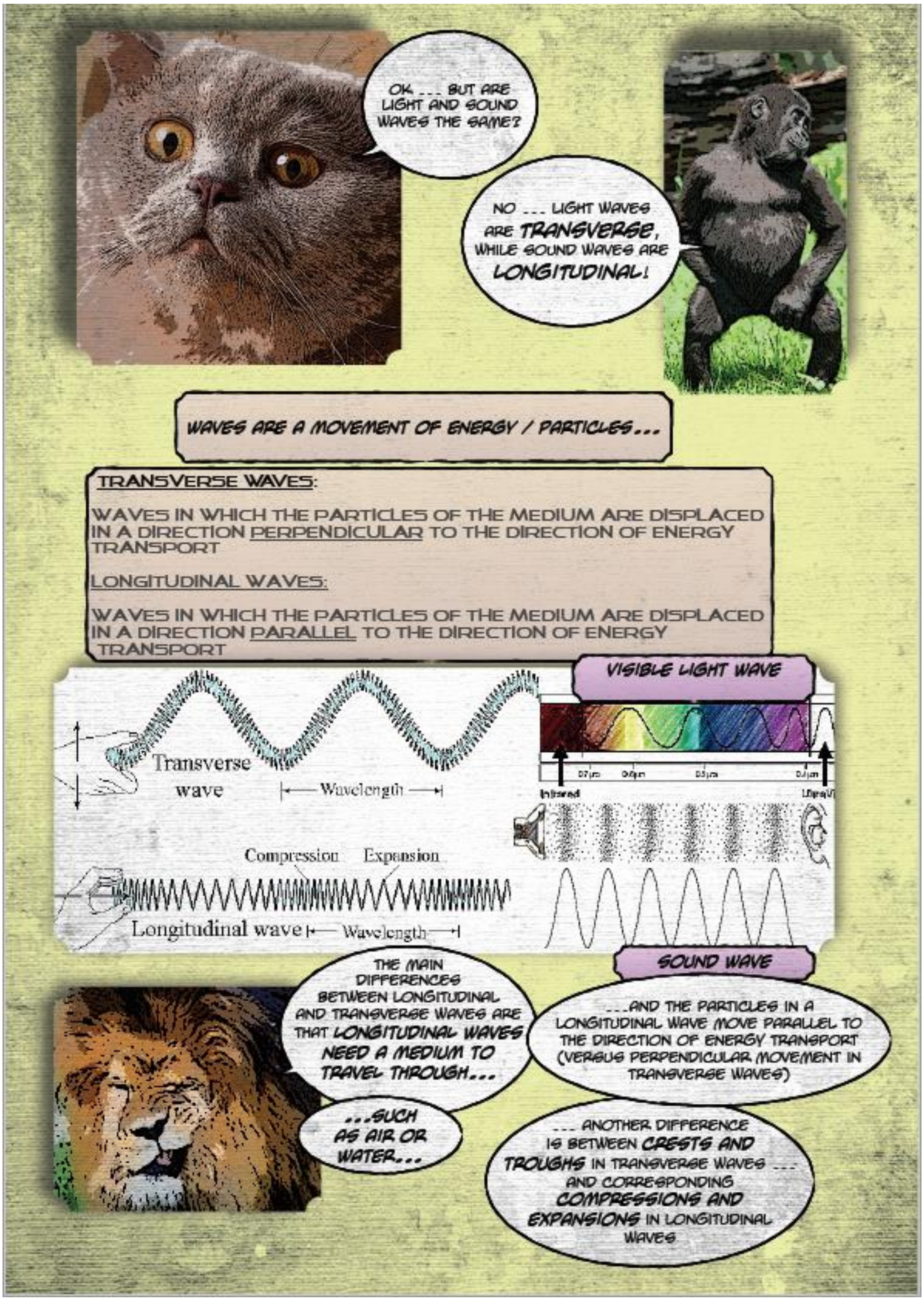
OK ... BUT ARE LIGHT AND SOUND WAVES THE SAME?
NO ... LIGHT WAVES ARE TRANSVERSE, WHILE SOUND WAVES ARE LONGITUDINAL!
WAVES ARE A MOVEMENT OF ENERGY / PARTICLES...
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WAVES IN WHICH THE PARTICLES OF THE MEDIUM ARE DISPLACED IN A DIRECTION PERPENDICULAR TO THE DIRECTION OF ENERGY TRANSPORT
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...SUCH AS AIR OR WATER...
...AND THE PARTICLES IN A LONGITUDINAL WAVE MOVE PARALLEL TO THE DIRECTION OF ENERGY TRANSPORT (VERSUS PERPENDICULAR MOVEMENT IN TRANSVERSE WAVES)
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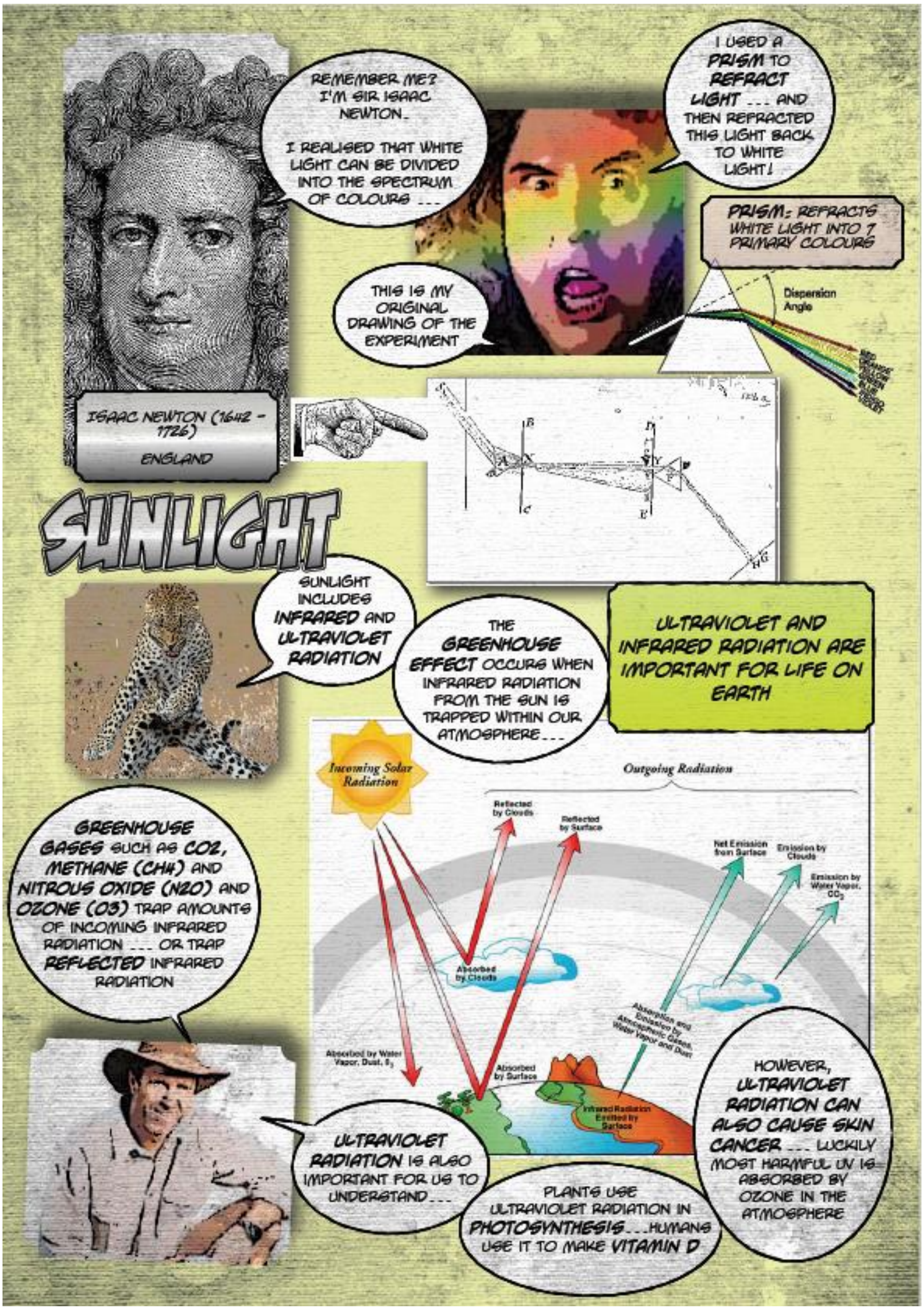
REMEMBER ME? I'M SIR ISAAC NEWTON. I REALISED THAT WHITE LIGHT CAN BE DIVIDED INTO THE SPECTRUM OF COLOURS ...
I USED A PRISM TO REFRACT LIGHT ... AND THEN REFRACTED THIS LIGHT BACK TO WHITE LIGHT!
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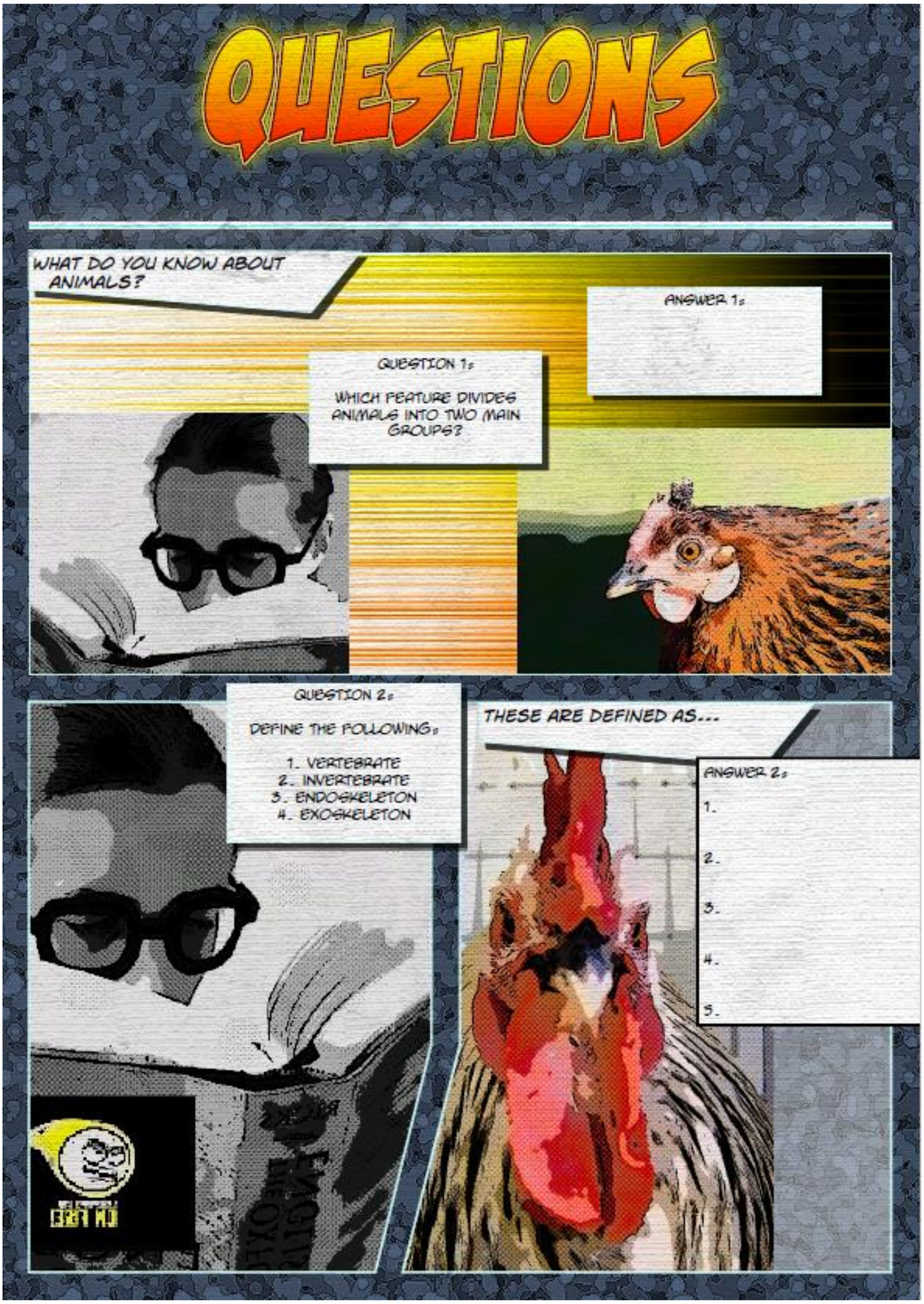
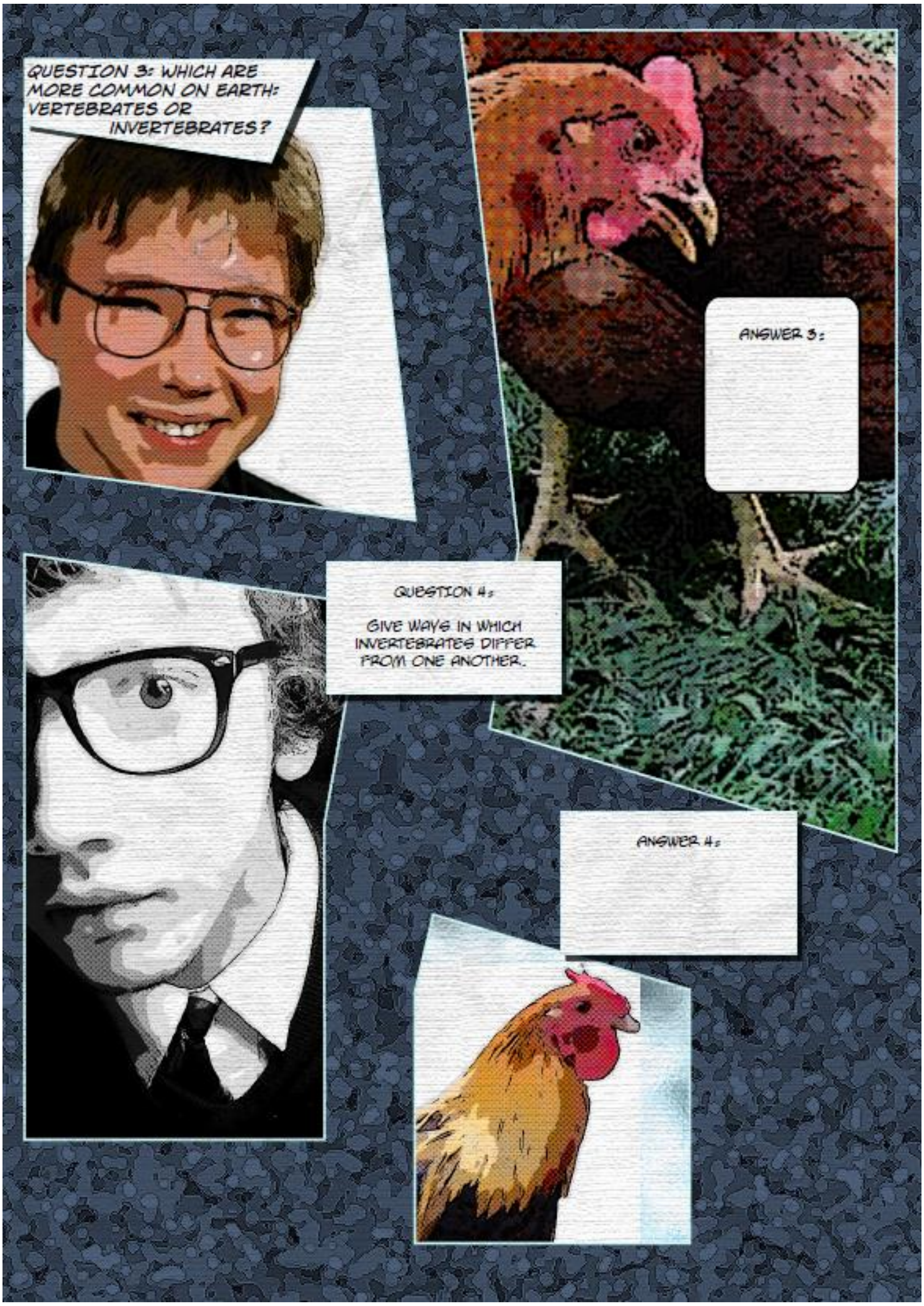
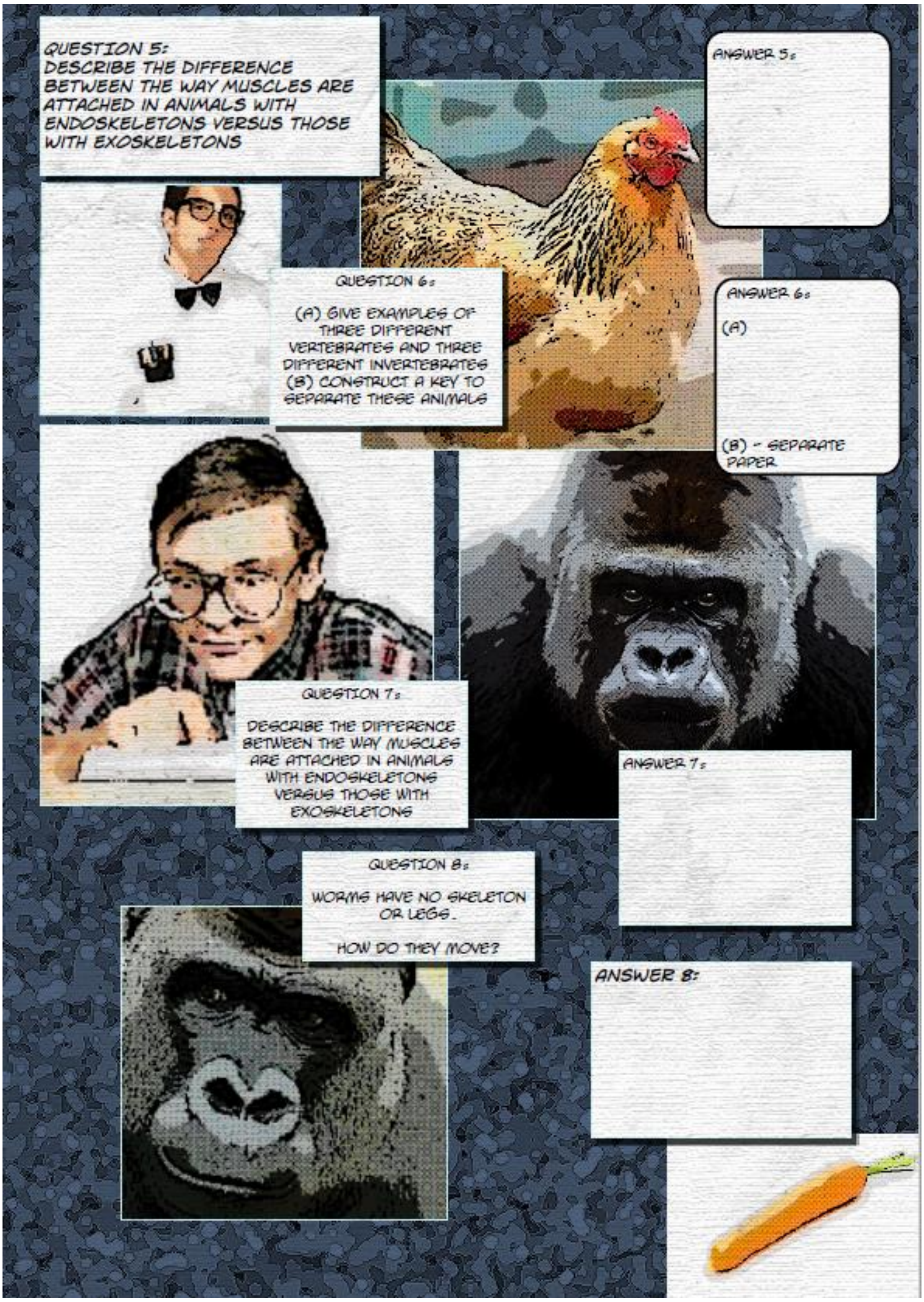
APPENDIX 4

WORKSHEET QUESTIONS (YEAR 7 – BIMODAL TEXT 1)

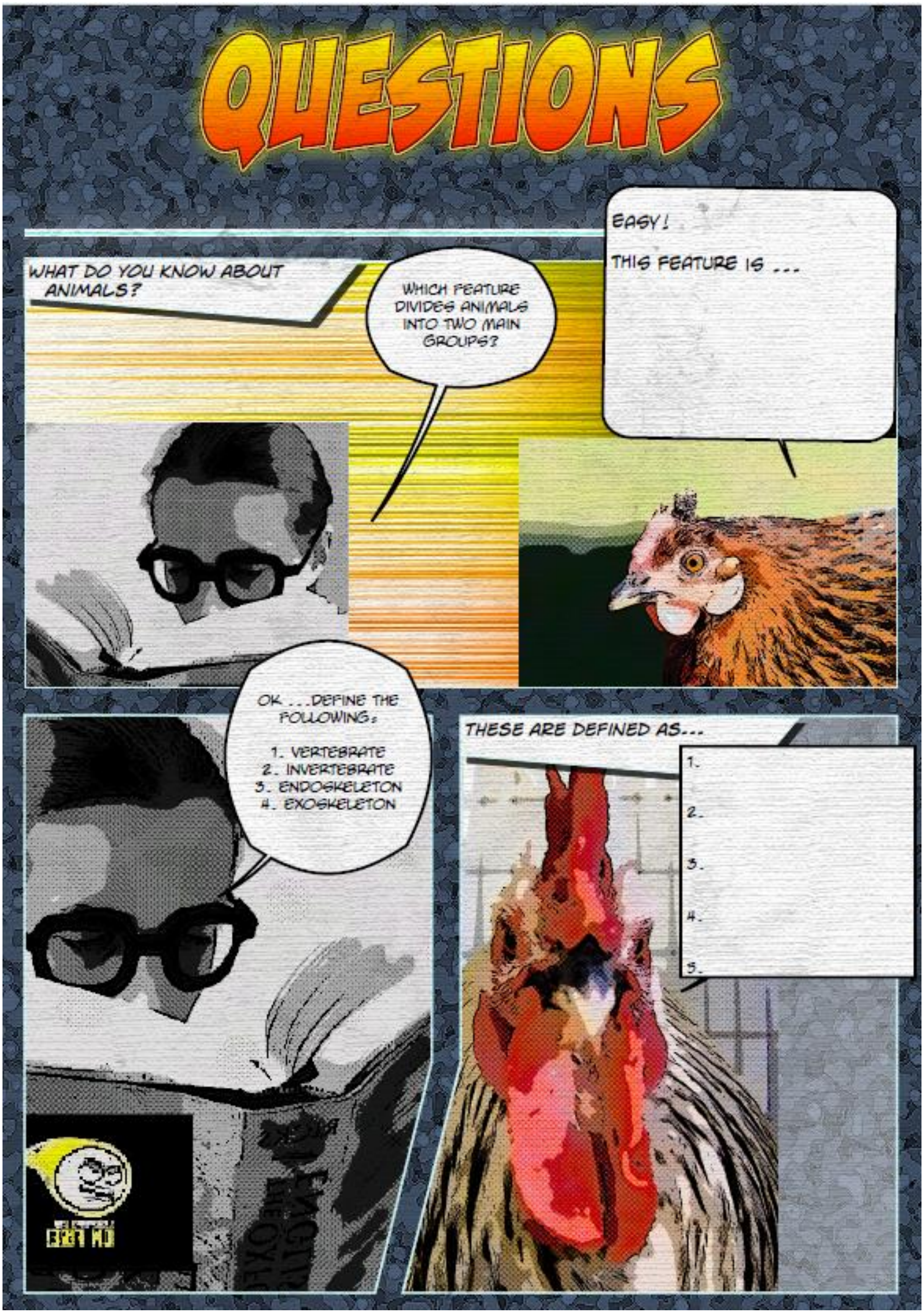

QUESTIONS
WHAT DO YOU KNOW ABOUT ANIMALS?
QUESTION 1:
WHICH FEATURE DIVIDES ANIMALS INTO TWO MAIN GROUPS?
ANSWER 1:
QUESTION 2:
DEFINE THE FOLLOWING:
1. VERTEBRATE
2. INVERTEBRATE
3. ENDOSKELETON
4. EXOSKELETON
THESE ARE DEFINED AS...
ANSWER 2:
1.
2.
3.
4.
5.



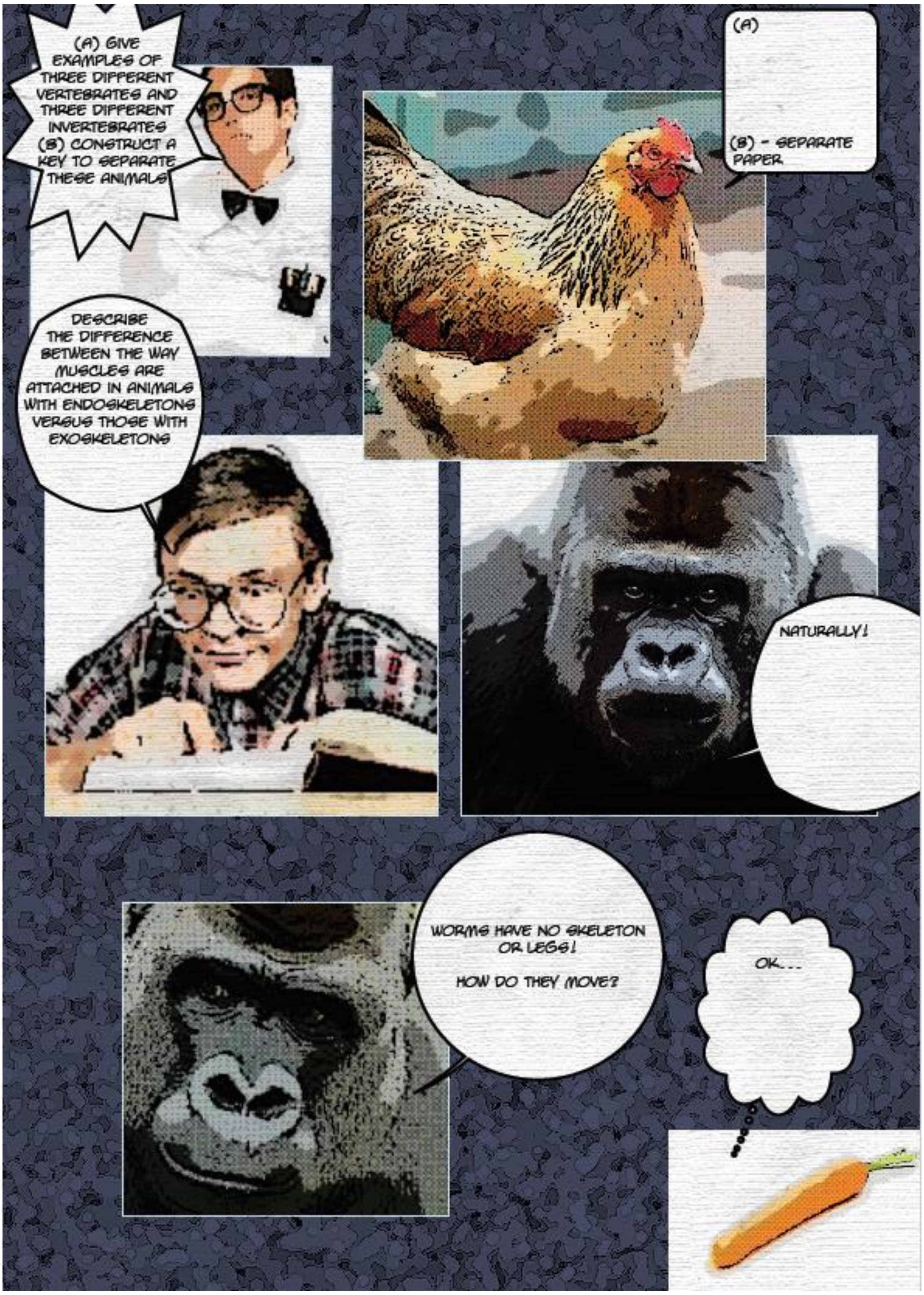
QUESTION 3: WHICH ARE MORE COMMON ON EARTH: VERTEBRATES OR INVERTEBRATES?
ANSWER 3:
QUESTION 4:
GIVE WAYS IN WHICH INVERTEBRATES DIFFER FROM ONE ANOTHER.
ANSWER 4:


QUESTION 5:
DESCRIBE THE DIFFERENCE BETWEEN THE WAY MUSCLES ARE ATTACHED IN ANIMALS WITH ENDOSKELETONS VERSUS THOSE WITH EXOSKELETONS
ANSWER 5:
QUESTION 6:
(A) GIVE EXAMPLES OF THREE DIFFERENT VERTEBRATES AND THREE DIFFERENT INVERTEBRATES
(B) CONSTRUCT A KEY TO SEPARATE THESE ANIMALS
ANSWER 6:
(A)
(B) – SEPARATE PAPER
QUESTION 7:
DESCRIBE THE DIFFERENCE BETWEEN THE WAY MUSCLES ARE ATTACHED IN ANIMALS WITH ENDOSKELETONS VERSUS THOSE WITH EXOSKELETONS
ANSWER 7:
QUESTION 8:
WORMS HAVE NO SKELETON OR LEGS.
HOW DO THEY MOVE?
ANSWER 8:

WORKSHEET QUESTIONS (YEAR 7 – MULTIMODAL TEXT 1)

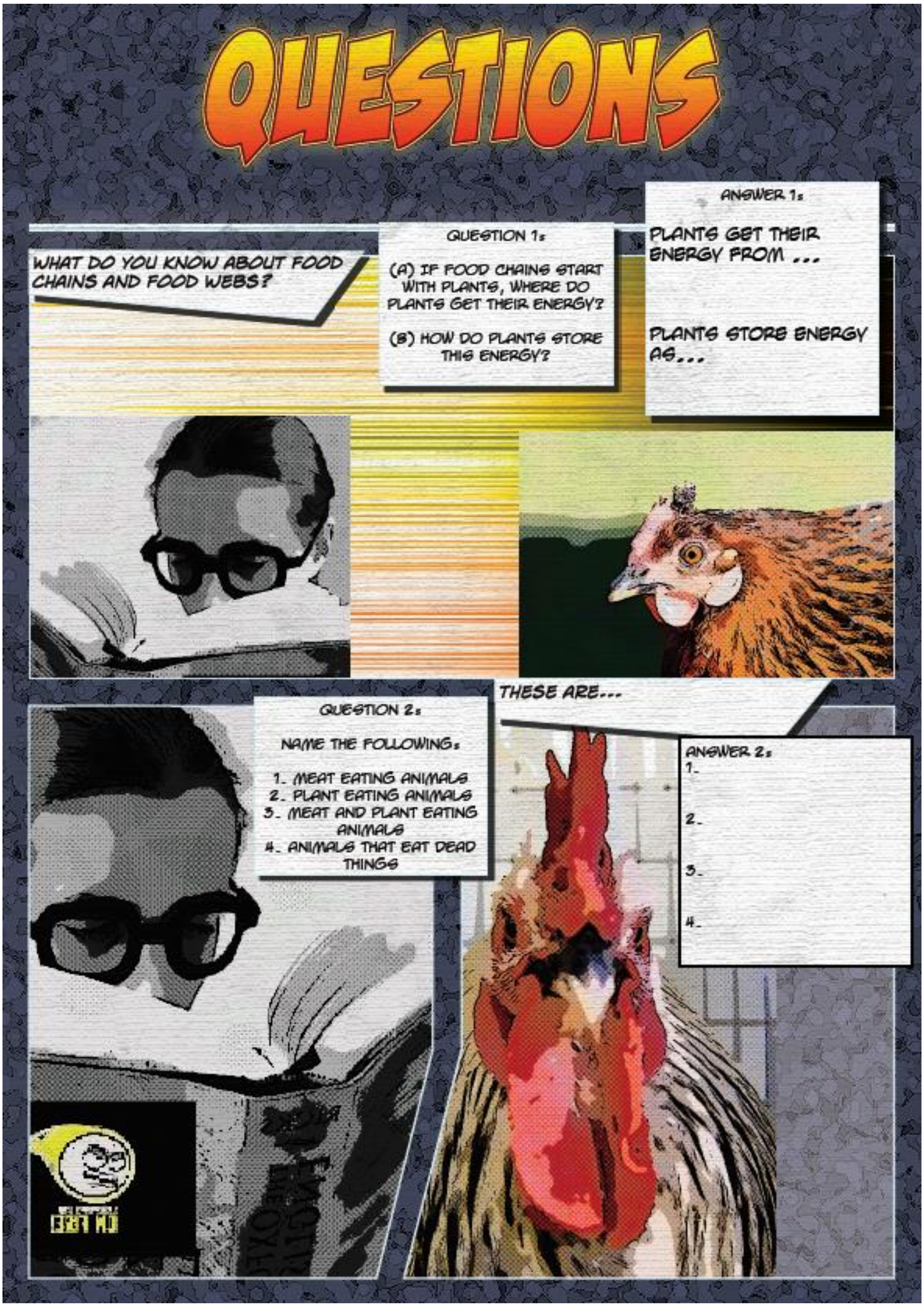



WHICH ARE MORE COMMON ON EARTH: VERTEBRATES OR INVERTEBRATES?
WELL...
...AND CAN YOU GIVE WAYS IN WHICH INVERTEBRATES DIFFER FROM ONE ANOTHER?
NATURALLY!

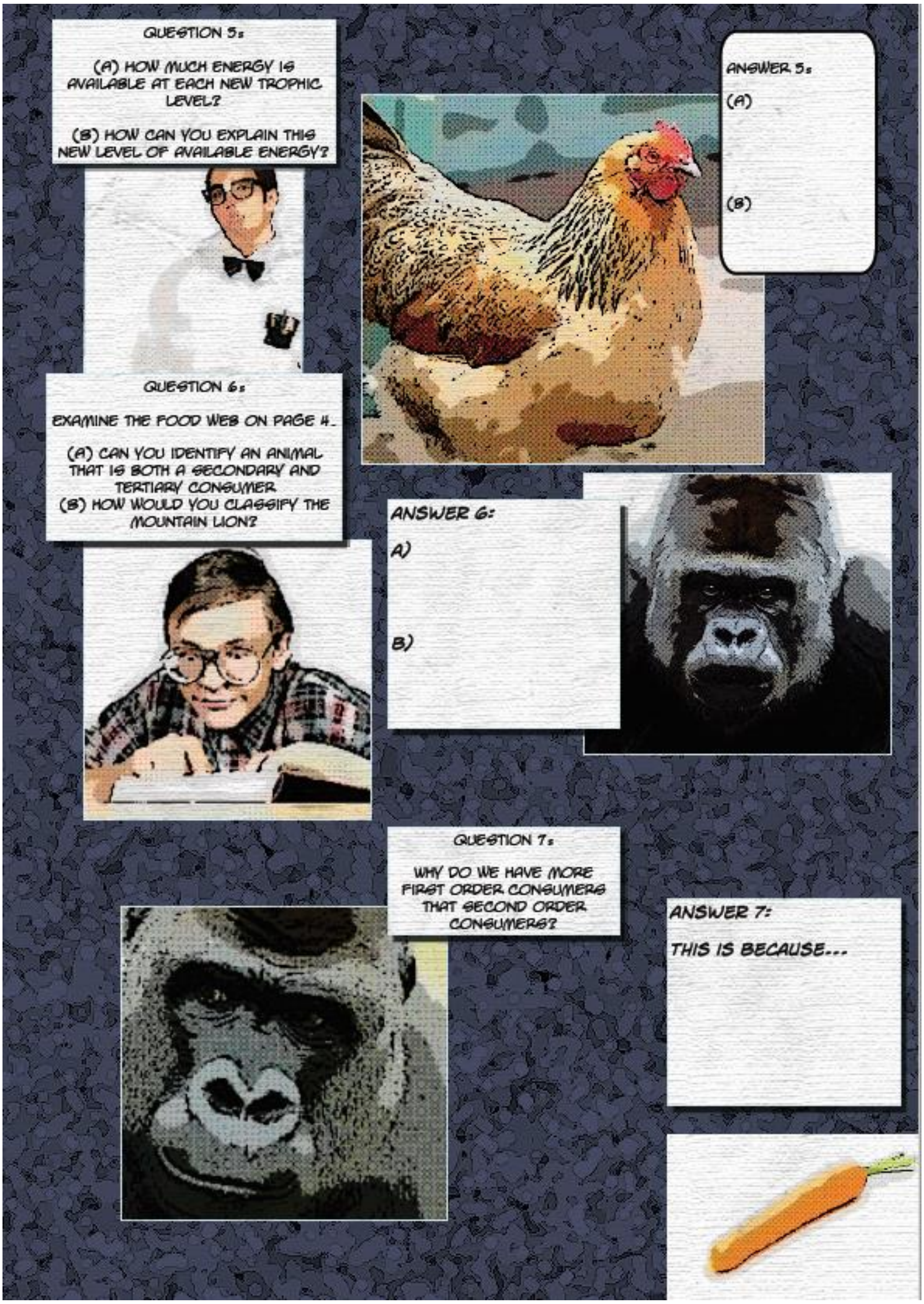


(A) GIVE EXAMPLES OF THREE DIFFERENT VERTEBRATES AND THREE DIFFERENT INVERTEBRATES (B) CONSTRUCT A KEY TO SEPARATE THESE ANIMALS
(A)
(B) - SEPARATE PAPER
DESCRIBE THE DIFFERENCE BETWEEN THE WAY MUSCLES ARE ATTACHED IN ANIMALS WITH ENDOSKELETONS VERSUS THOSE WITH EXOSKELETONS
NATURALLY!
WORMS HAVE NO SKELETON OR LEGS! HOW DO THEY MOVE?
OK...

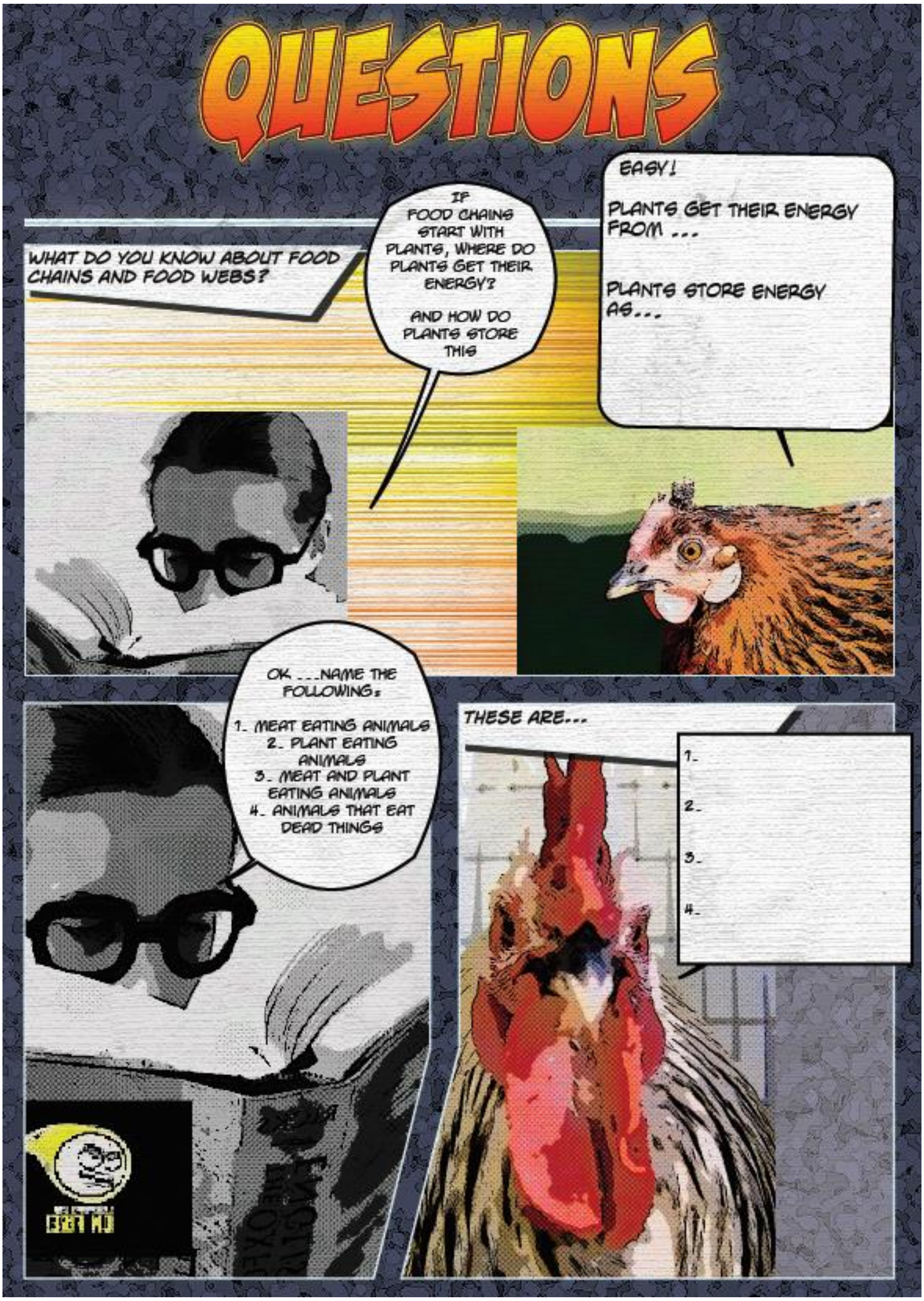
WORKSHEET QUESTIONS (YEAR 7 – BIMODAL TEXT 2)




QUESTION 3:
WHY IS IT IMPORTANT TO UNDERSTAND FEEDING RELATIONSHIPS IN ECOSYSTEMS?
ANSWER 3:
QUESTION 4:
(1) WHAT IS AN EXAMPLE OF A DISRUPTION TO AN ECOSYSTEM?
(2) WHAT ARE THE POSSIBLE CONSEQUENCES OF THIS DISRUPTION?
ANSWER 4:
1)
2)

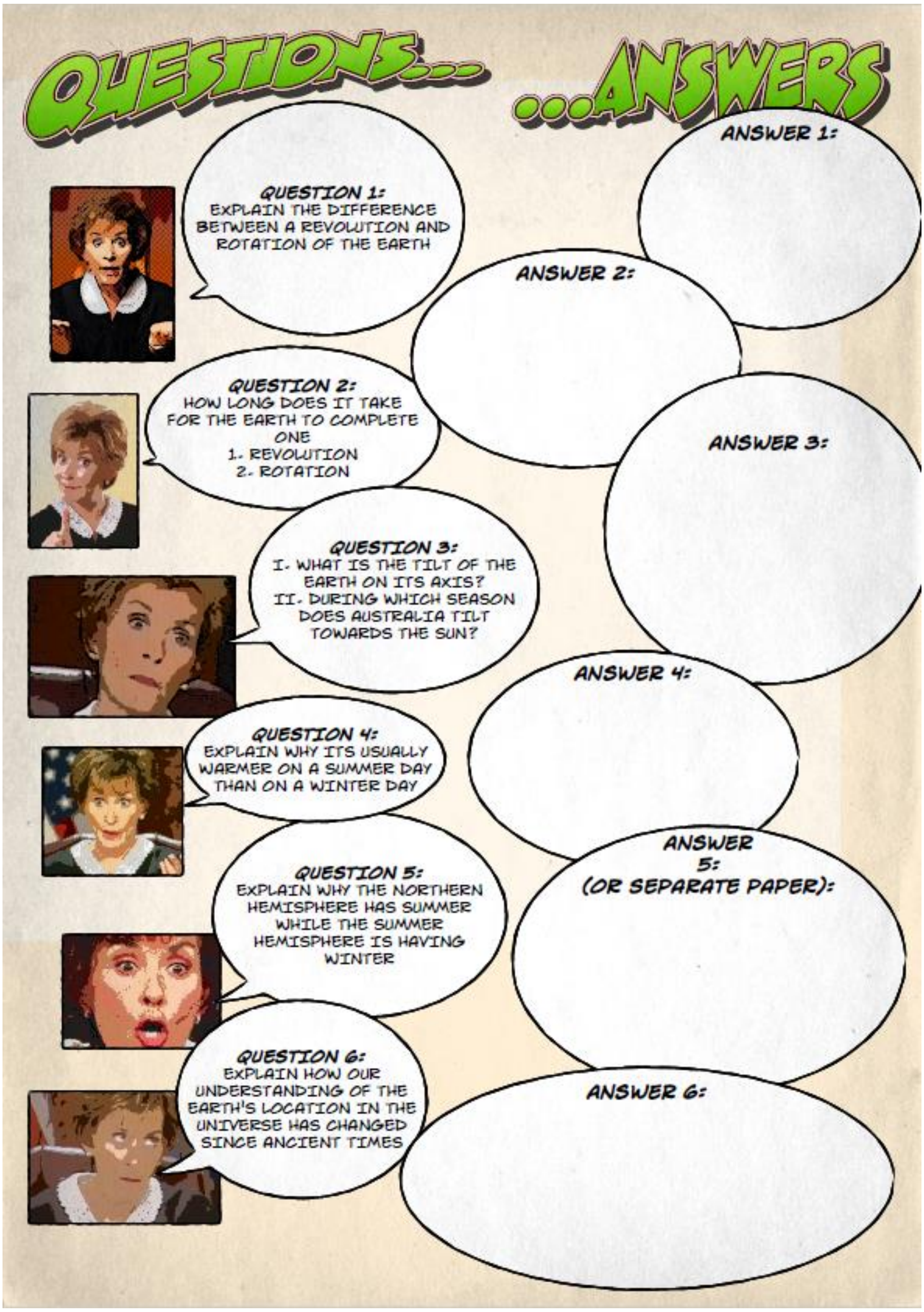

QUESTION 5:
(A) HOW MUCH ENERGY IS AVAILABLE AT EACH NEW TROPHIC LEVEL?
(B) HOW CAN YOU EXPLAIN THIS NEW LEVEL OF AVAILABLE ENERGY?
ANSWER 5:
(A)
(B)
QUESTION 6:
EXAMINE THE FOOD WEB ON PAGE 4.
(A) CAN YOU IDENTIFY AN ANIMAL THAT IS BOTH A SECONDARY AND TERTIARY CONSUMER
(B) HOW WOULD YOU CLASSIFY THE MOUNTAIN LION?
ANSWER 6:
A)
B)
QUESTION 7:
WHY DO WE HAVE MORE FIRST ORDER CONSUMERS THAT SECOND ORDER CONSUMERS?
ANSWER 7:
THIS IS BECAUSE...

WORKSHEET QUESTIONS (YEAR 7 – MULTIMODAL TEXT 2)

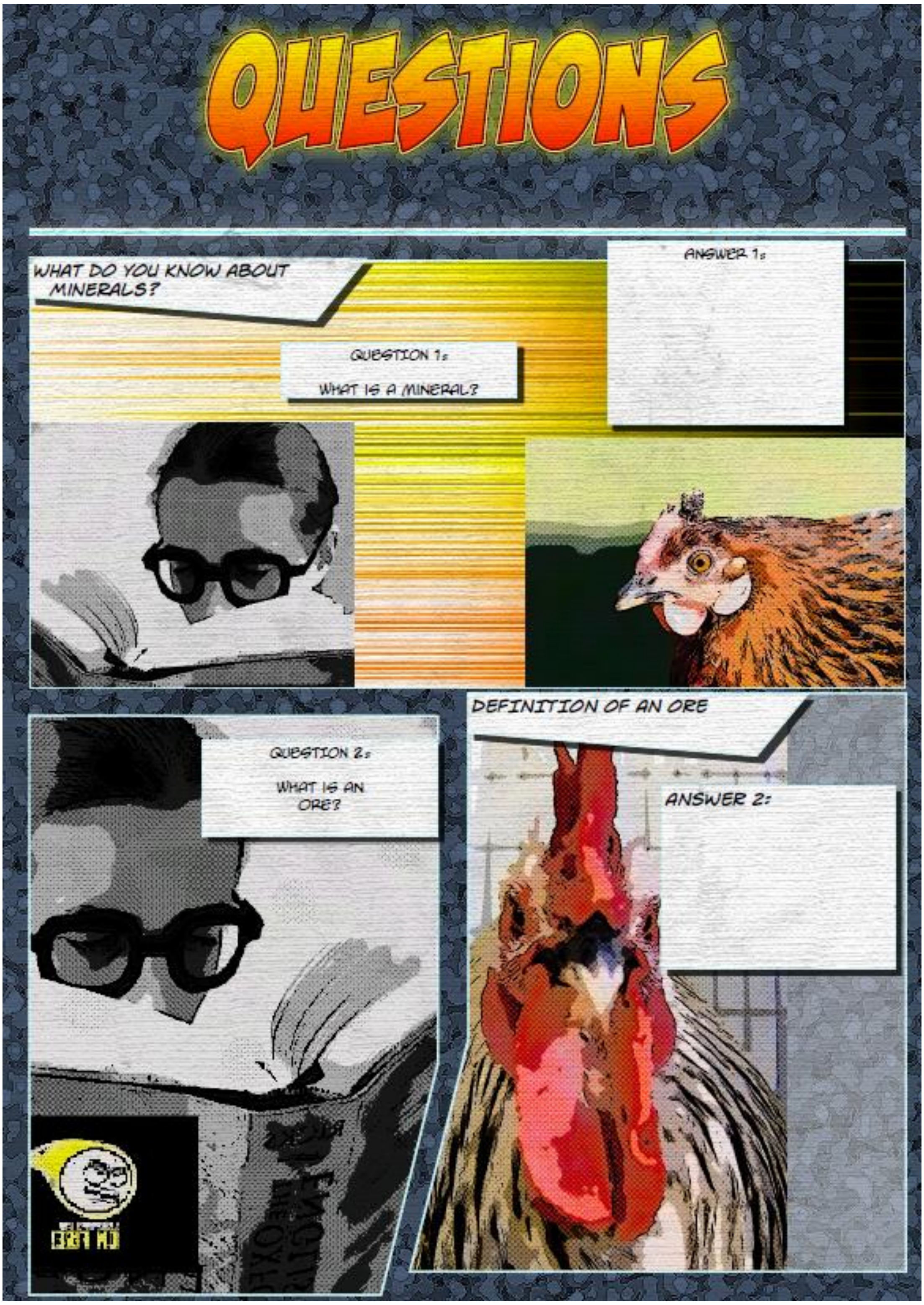


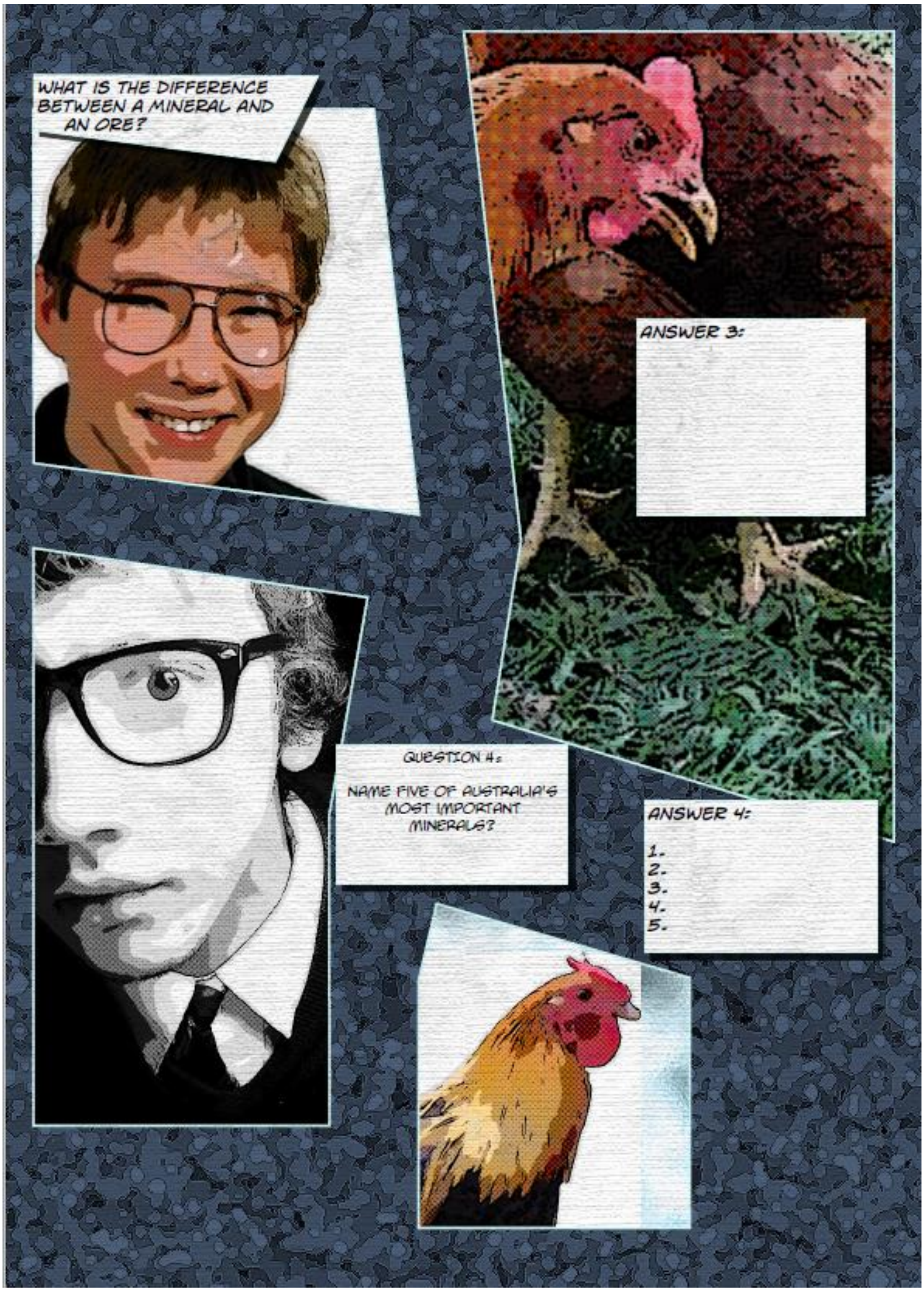

WHY IS IT IMPORTANT TO UNDERSTAND FEEDING RELATIONSHIPS IN ECOSYSTEMS?
WELL...
WHAT IS AN EXAMPLE OF A DISRUPTION TO AN ECOSYSTEM? WHAT ARE THE POSSIBLE CONSEQUENCES OF THIS DISRUPTION?

WORKSHEET QUESTIONS (YEAR 7 – BIMODAL TEXT 3)

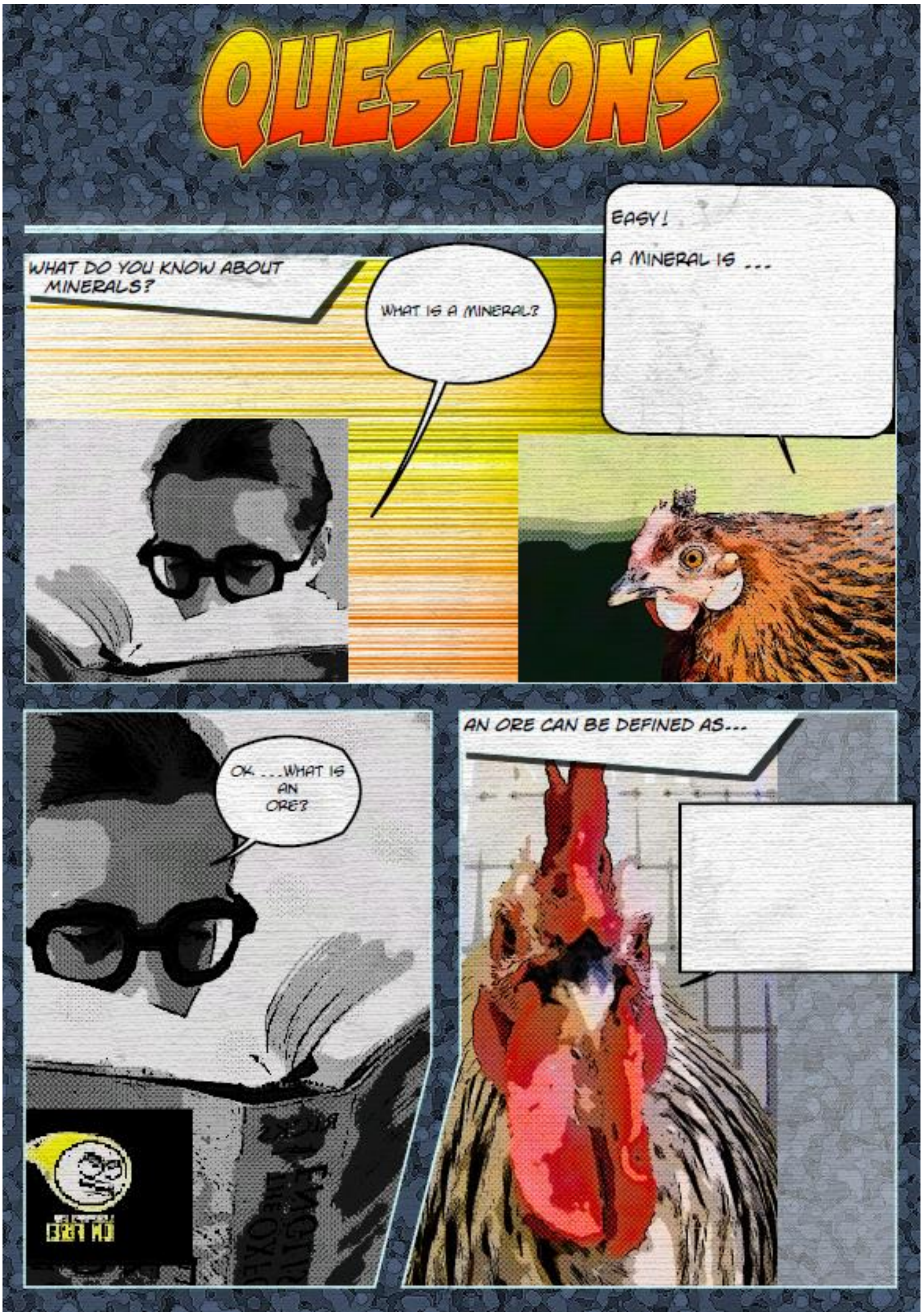


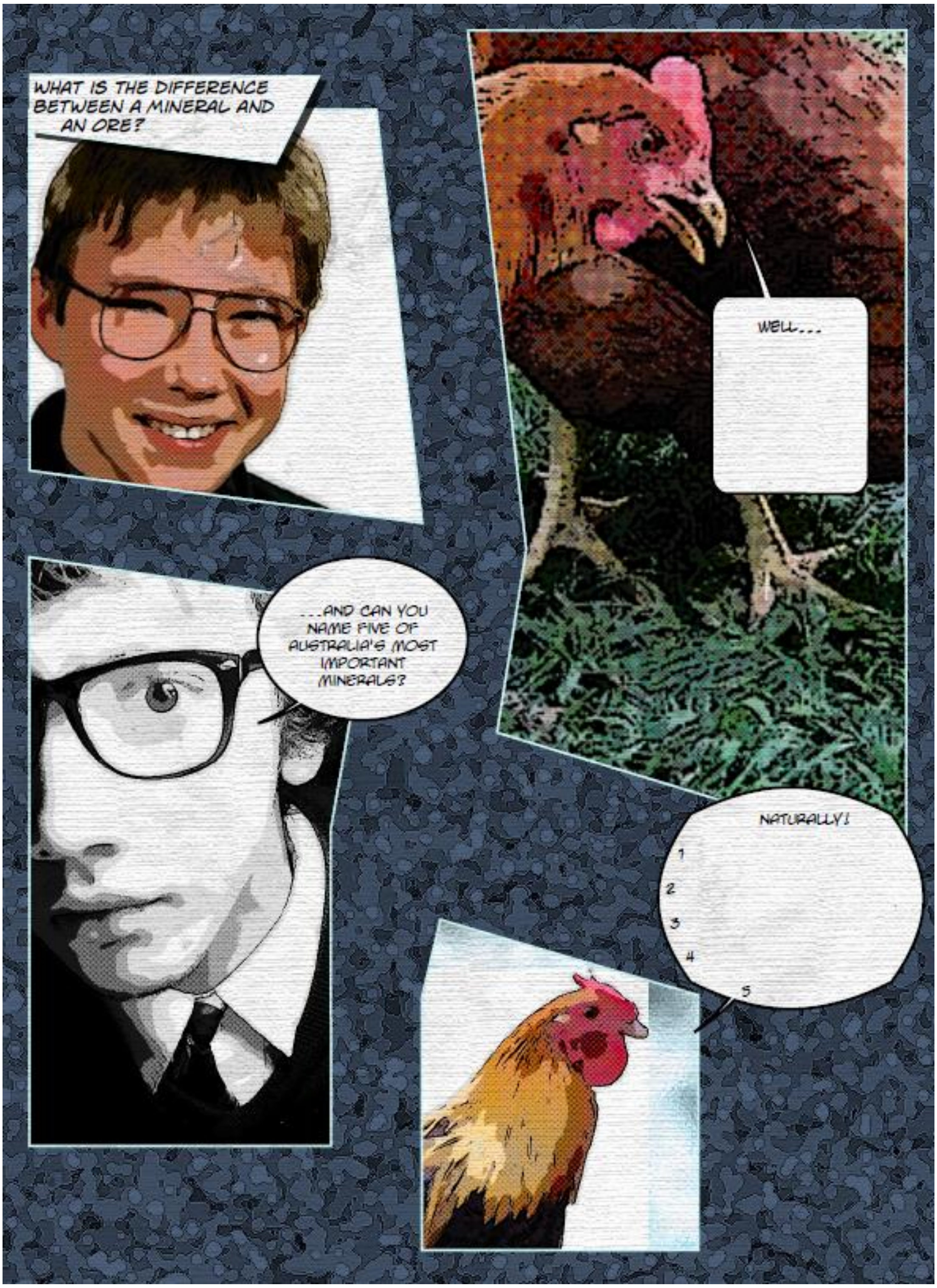
WORKSHEET QUESTIONS (YEAR 8 – BIMODAL TEXT 1)




WHAT IS THE DIFFERENCE BETWEEN A MINERAL AND AN ORE?
ANSWER 3:
QUESTION 4:
NAME FIVE OF AUSTRALIA'S MOST IMPORTANT MINERALS?
ANSWER 4:
1.
2.
3.
4.
5.

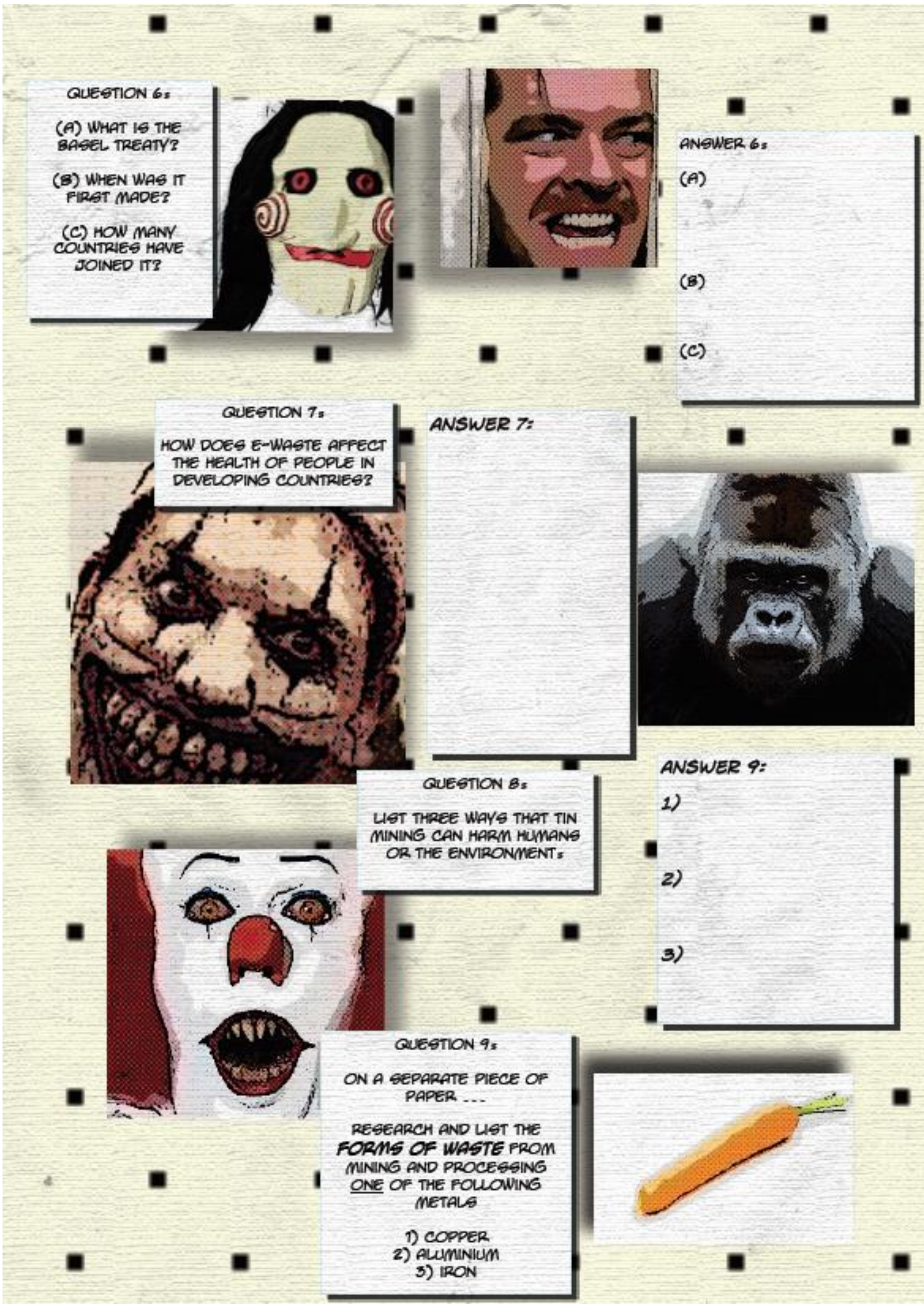
WORKSHEET QUESTIONS (YEAR 8 – MULTIMODAL TEXT 1)




WHAT IS THE DIFFERENCE BETWEEN A MINERAL AND AN ORE?
WELL...
...AND CAN YOU NAME FIVE OF AUSTRALIA'S MOST IMPORTANT MINERALS?
NATURALLY!
1
2
3
4
5

WORKSHEET QUESTIONS (YEAR 8 – BIMODAL TEXT 2)


QUESTION 3:
WHAT IS PLANNED OBSOLESCENCE?
ANSWER 4:
QUESTION 5:
WHAT ARE TWO OTHER WAYS IN WHICH ELECTRONIC COMPANIES MAKE SURE WE KEEP REPLACING DEVICES?
ANSWER 5:
1)
2)

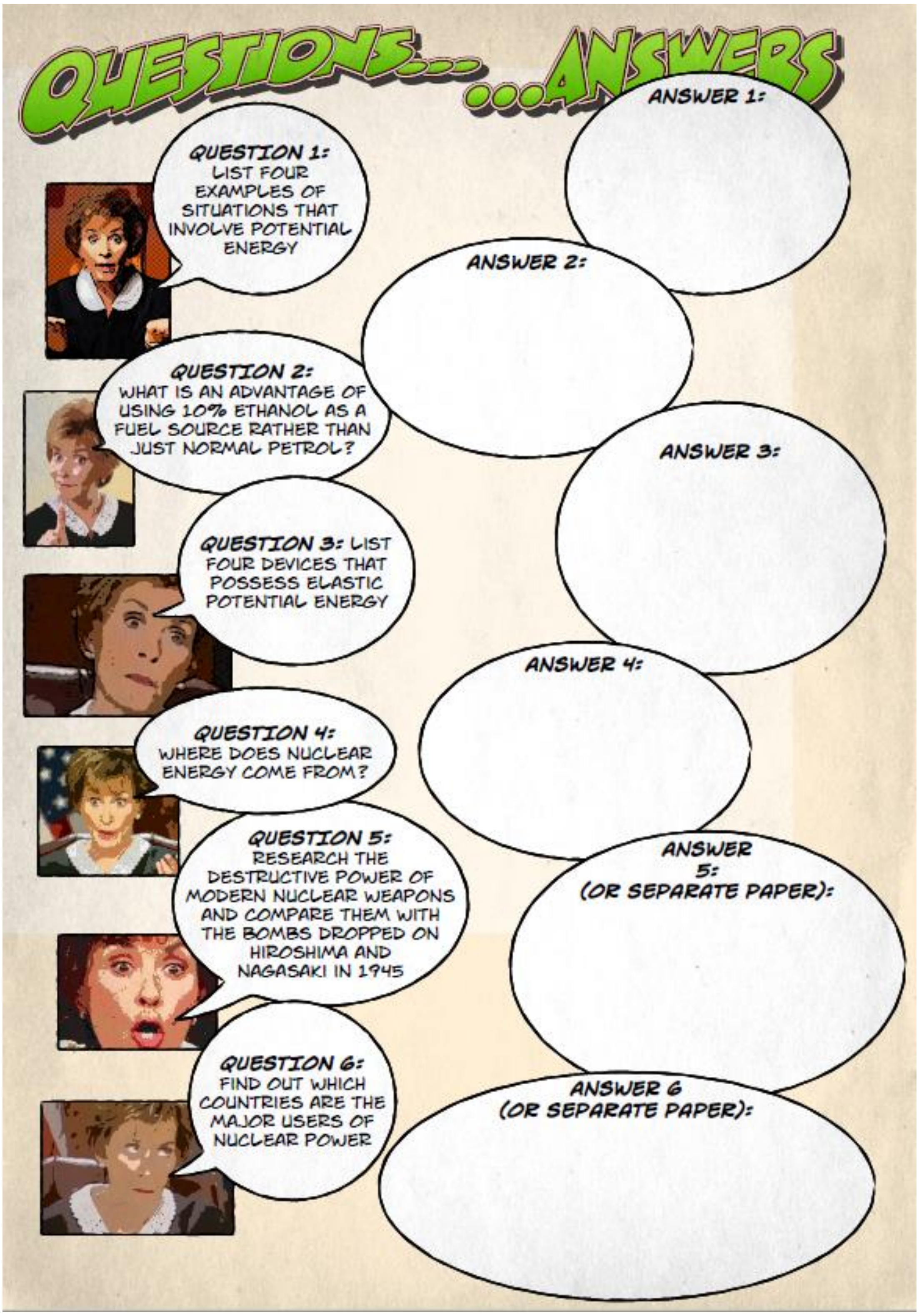

QUESTION 6:
(A) WHAT IS THE BASEL TREATY?
(B) WHEN WAS IT FIRST MADE?
(C) HOW MANY COUNTRIES HAVE JOINED IT?
ANSWER 6:
(A)
(B)
(C)
QUESTION 7:
HOW DOES E-WASTE AFFECT THE HEALTH OF PEOPLE IN DEVELOPING COUNTRIES?
ANSWER 7:
ANSWER 9:
1)
2)
3)
QUESTION 8:
LIST THREE WAYS THAT TIN MINING CAN HARM HUMANS OR THE ENVIRONMENT:
QUESTION 9:
ON A SEPARATE PIECE OF PAPER ...
RESEARCH AND LIST THE FORMS OF WASTE FROM MINING AND PROCESSING ONE OF THE FOLLOWING METALS
1) COPPER
2) ALUMINIUM
3) IRON

WORKSHEET QUESTIONS (YEAR 8 – MULTIMODAL TEXT 2)

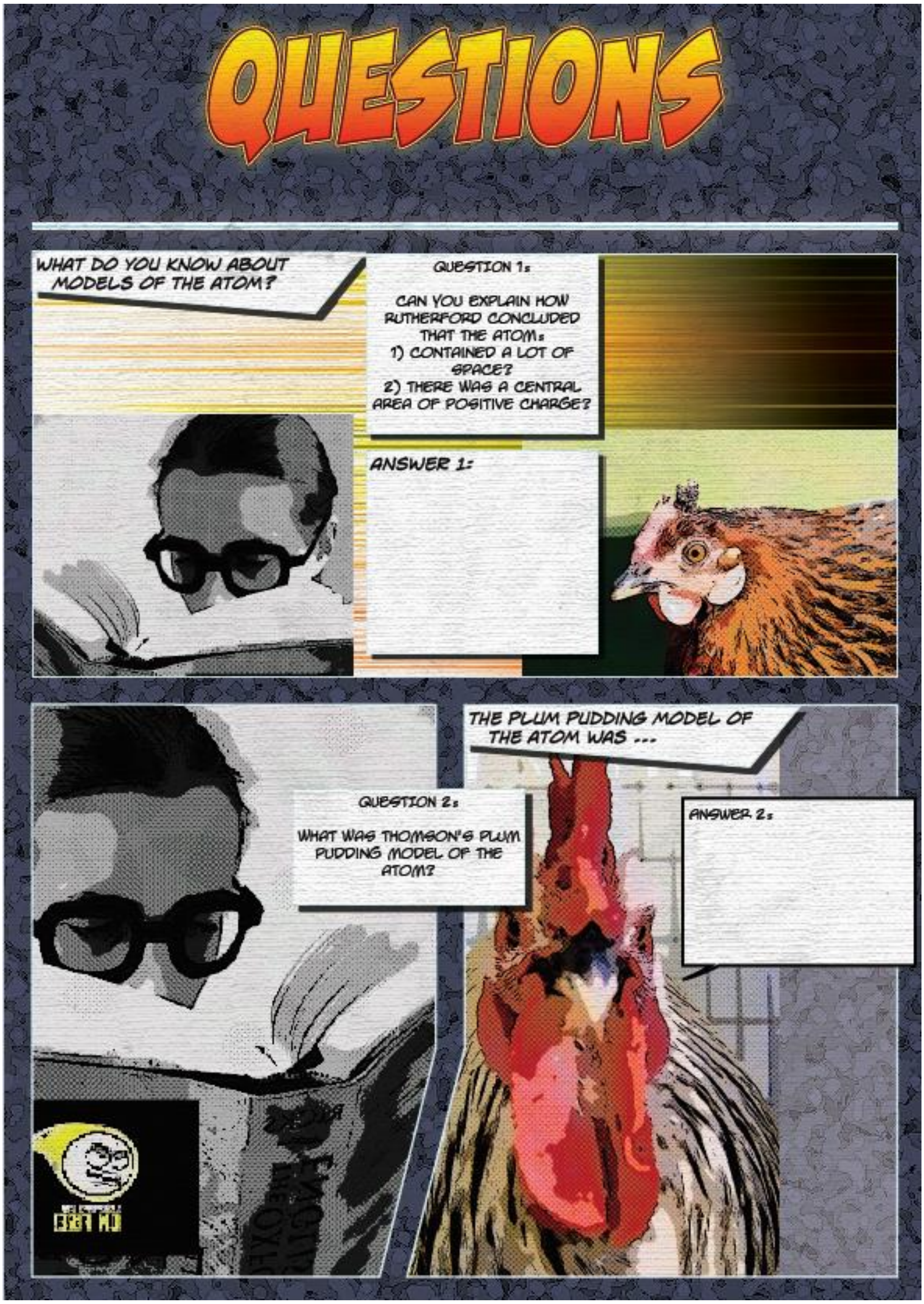

WHAT IS PLANNED OBSOLESCENCE?
WELL...
...AND CAN YOU TELL ME TWO OTHER WAYS IN WHICH ELECTRONIC COMPANIES MAKE SURE WE KEEP REPLACING OUR DEVICES?
NATURALLY!
1.
2.

(A) WHAT IS THE BASEL TREATY?
(B) WHEN WAS IT FIRST MADE?
(C) HOW MANY COUNTRIES HAVE JOINED IT?
(A)
(B)
(C)
HOW DOES E-WASTE AFFECT THE HEALTH OF PEOPLE IN DEVELOPING COUNTRIES?
OK...
NAME THREE WAYS THAT TIN MINING CAN HARM HUMANS AND THE ENVIRONMENT.
1.
2.
3.
FINALLY... ON A SEPARATE PIECE OF PAPER ...
RESEARCH THE FORMS OF WASTE FROM MINING AND PROCESSING ONE OF THE FOLLOWING METALS
1) COPPER
2) ALUMINIUM
3) IRON

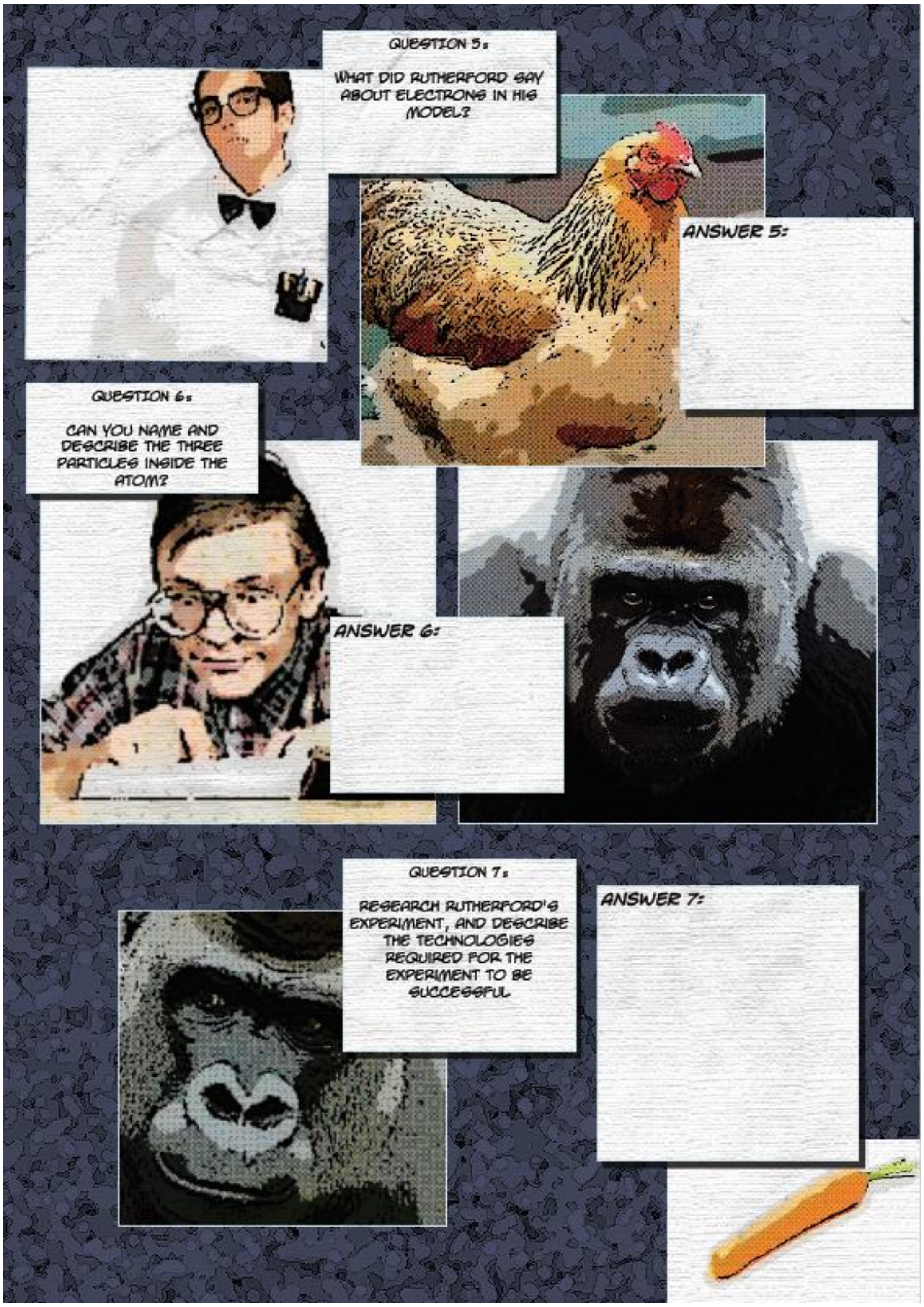
WORKSHEET QUESTIONS (YEAR 8 – BI- / MULTIMODAL TEXT 3)



WORKSHEET QUESTIONS (YEAR 9 – BIMODAL TEXT 1)

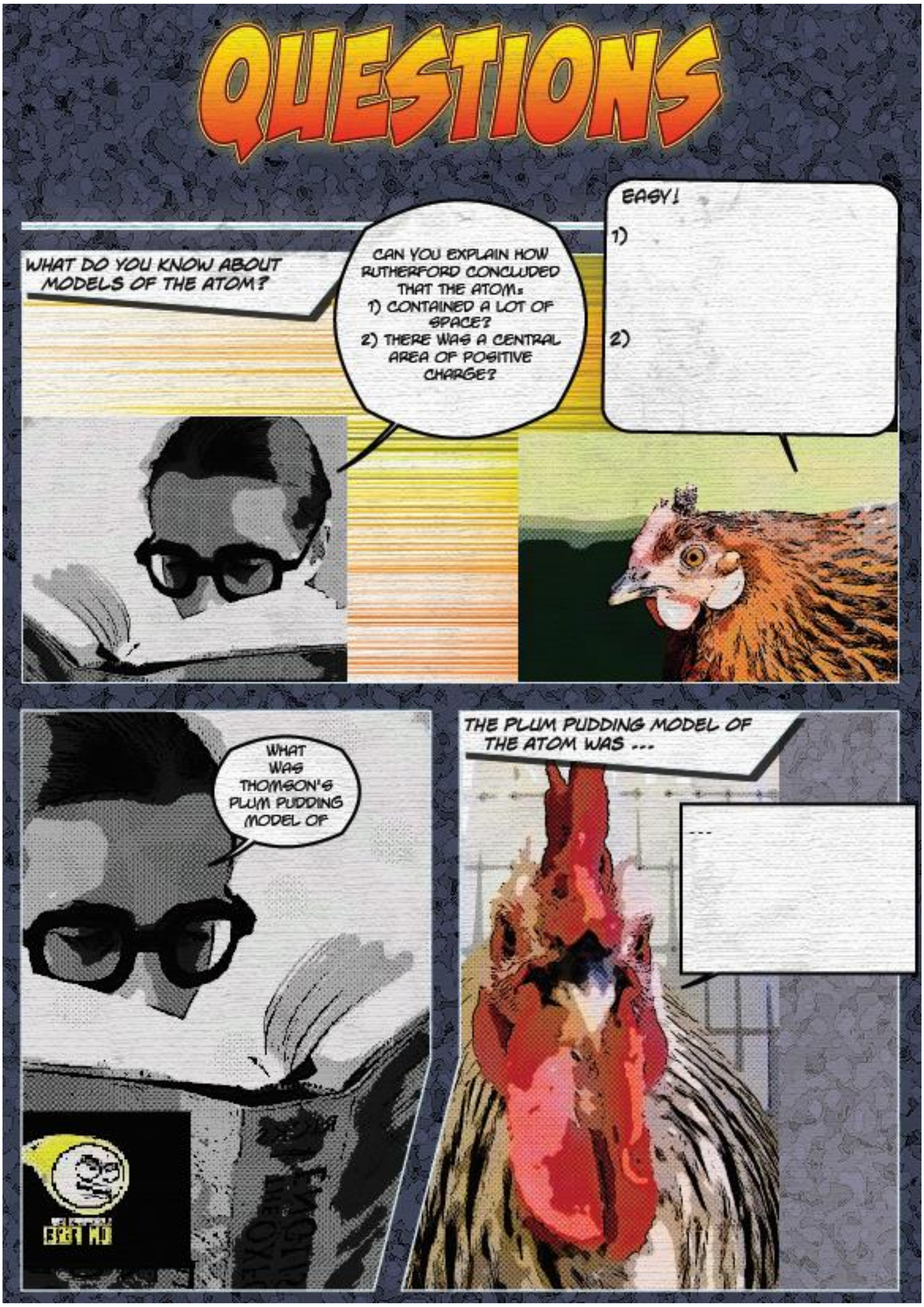



QUESTION 3:
WHAT IS AN ALPHA PARTICLE?
ANSWER 4:
QUESTION 4:
HOW DID ALPHA PARTICLES HELP RUTHERFORD DEVELOP HIS NEW MODEL?
ANSWER 4:

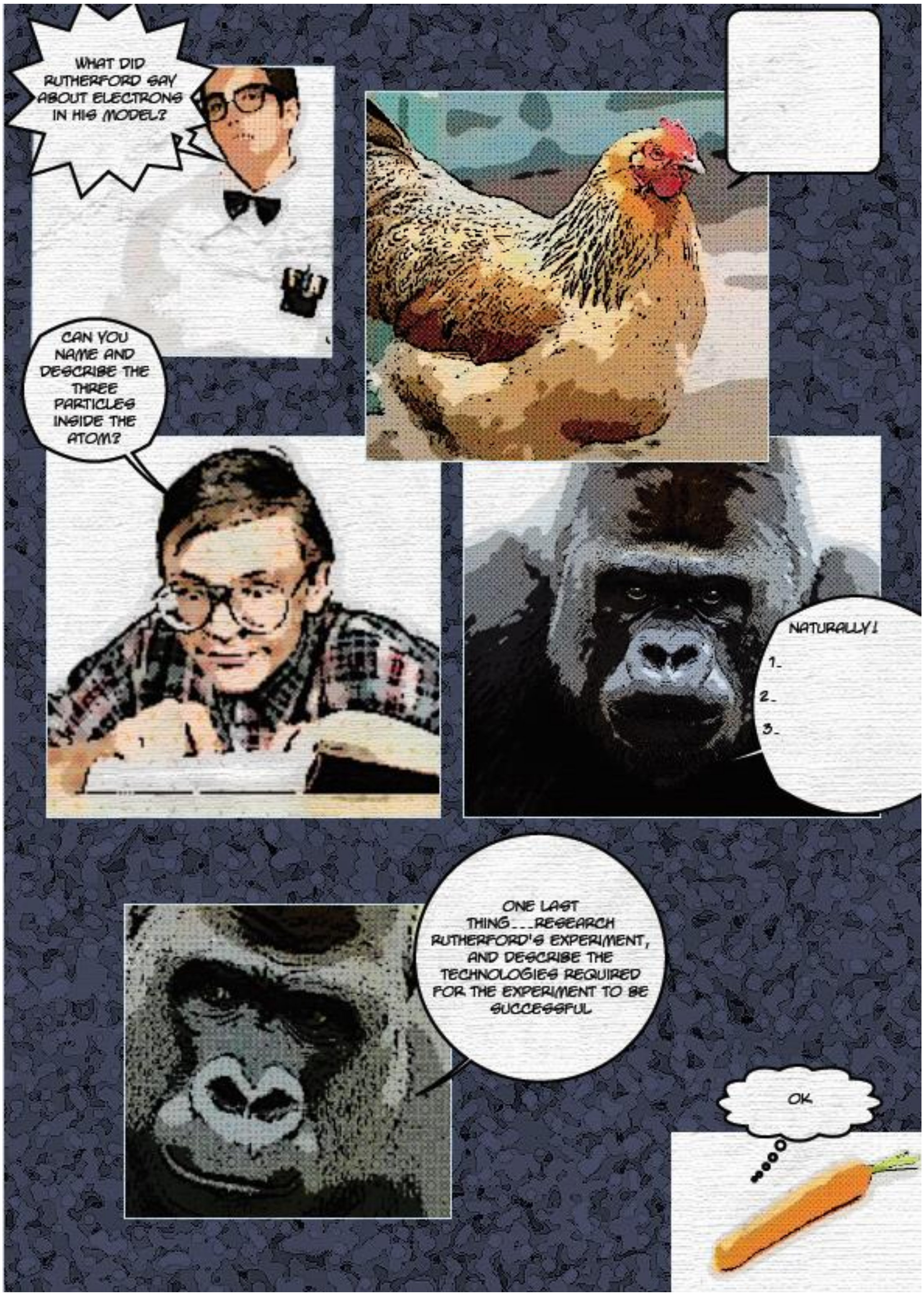


QUESTION 5:
WHAT DID RUTHERFORD SAY ABOUT ELECTRONS IN HIS MODEL?
ANSWER 5:
QUESTION 6:
CAN YOU NAME AND DESCRIBE THE THREE PARTICLES INSIDE THE ATOM?
ANSWER 6:
QUESTION 7:
RESEARCH RUTHERFORD'S EXPERIMENT, AND DESCRIBE THE TECHNOLOGIES REQUIRED FOR THE EXPERIMENT TO BE SUCCESSFUL
ANSWER 7:

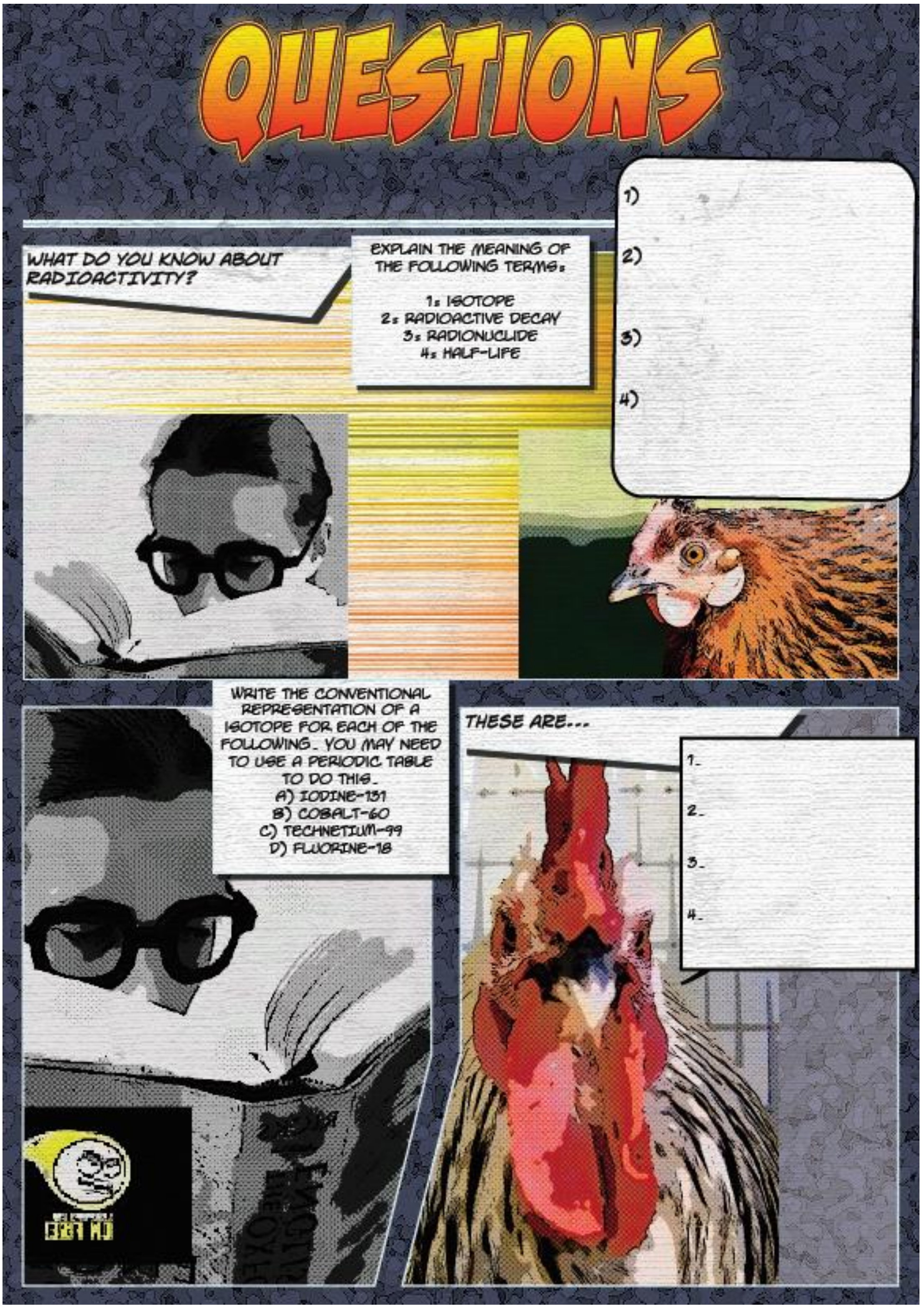
WORKSHEET QUESTIONS (YEAR 9 – MULTIMODAL TEXT 1)




WHAT IS AN ALPHA PARTICLE?
OK .. AN ALPHA PARTICLE IS ...
HOW DID ALPHA PARTICLES HELP RUTHERFORD DEVELOP HIS NEW MODEL?
ALPHA PARTICLES...


WHAT DID RUTHERFORD SAY ABOUT ELECTRONS IN HIS MODEL?
CAN YOU NAME AND DESCRIBE THE THREE PARTICLES INSIDE THE ATOM?
NATURALLY!
1.
2.
3.
ONE LAST THING...RESEARCH RUTHERFORD'S EXPERIMENT, AND DESCRIBE THE TECHNOLOGIES REQUIRED FOR THE EXPERIMENT TO BE SUCCESSFUL
OK

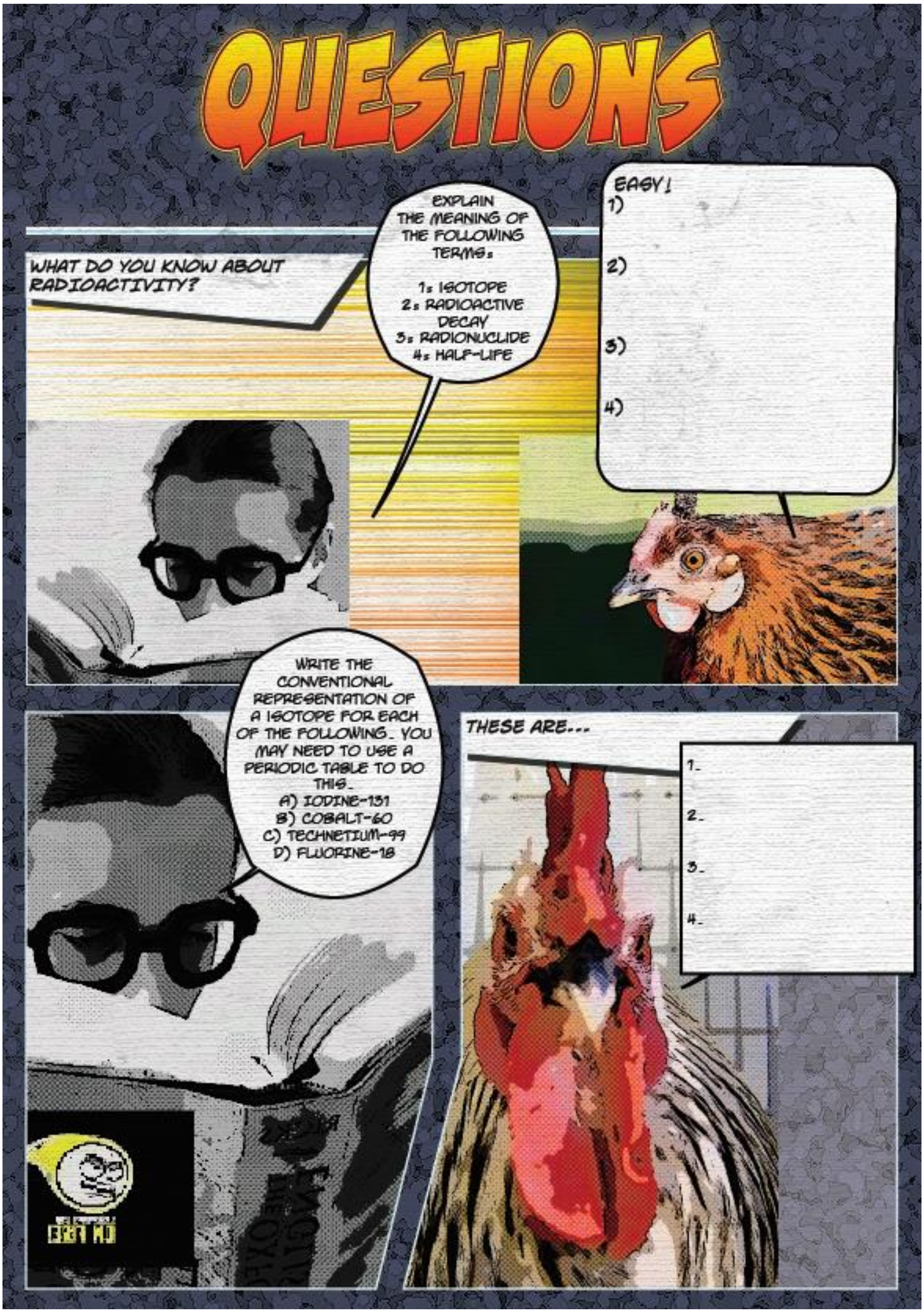
WORKSHEET QUESTIONS (YEAR 9 – BIMODAL TEXT 2)



THE RATE OF DECAY OF A RADIONUCLIDE FALLS FROM 800 COUNTS PER MINUTE TO 100 COUNTS PER MINUTE IN 6 HOURS.
1) WHAT IS THE HALF-LIFE OF THIS RADIONUCLIDE
2) SKETCH A RADIOACTIVE DECAY CHART FOR THIS RADIONUCLIDE
3) PREDICT WHAT THE COUNT RATE WOULD BE IN ANOTHER 4 HOURS TIME
1)
2) ON SEPARATE PAPER
3)
INVESTIGATE THE MEDICAL USAGE OF A RADIOACTIVE ISOTOPE.
(A) STATE THE SYMBOL OF THE RADIOISOTOPE.
(B) HOW DOES IT WORK?
(C) WHAT BENEFITS ARE THERE IN USING THIS RADIOISOTOPE (COMPARED WITH OTHER TREATMENTS)?
(D) WHAT PRECAUTIONS MUST BE TAKEN WHEN USING THIS RADIOISOTOPE?
ANSWER ON SEPARATE PAPER.

(A) HOW MUCH ENERGY IS AVAILABLE AT EACH NEW TROPHIC LEVEL? (B) HOW CAN YOU EXPLAIN THIS DROP IN ENERGY?
(A)
(B)
EXAMINE THE FOOD WEB ON PAGE 4.
(A) CAN YOU IDENTIFY AN ANIMAL THAT IS BOTH A SECONDARY AND TERTIARY CONSUMER
(B) HOW WOULD YOU CLASSIFY THE MOUNTAIN LION?
LET'S HAVE A GO...
(A)
(B)
WHY DO WE HAVE MORE FIRST ORDER CONSUMERS THAT SECOND ORDER CONSUMERS?
OK...

WORKSHEET QUESTIONS (YEAR 9 – MULTIMODAL TEXT 2)




THE RATE OF DECAY OF A RADIONUCLIDE FALLS FROM 800 COUNTS PER MINUTE TO 100 COUNTS PER MINUTE IN 6 HOURS.
1) WHAT IS THE HALF-LIFE OF THIS RADIONUCLIDE
2) SKETCH A RADIOACTIVE DECAY CHART FOR THIS RADIONUCLIDE
3) PREDICT WHAT THE COUNT RATE WOULD BE IN ANOTHER 4 HOURS TIME
WELL...
1)
2) ON SEPARATE PAPER
3)
INVESTIGATE THE MEDICAL USAGE OF A RADIOACTIVE ISOTOPE.
(A) STATE THE SYMBOL OF THE RADIOISOTOPE.
(B) HOW DOES IT WORK?
(C) WHAT BENEFITS ARE THERE IN USING THIS RADIOISOTOPE (COMPARED WITH OTHER TREATMENTS)?
(D) WHAT PRECAUTIONS MUST BE TAKEN WHEN USING THIS RADIOISOTOPE?
ANSWER ON SEPARATE PAPER.


(A) HOW MUCH ENERGY IS AVAILABLE AT EACH NEW TROPHIC LEVEL? (B) HOW CAN YOU EXPLAIN THIS DROP IN ENERGY?
(A)
(B)
EXAMINE THE FOOD WEB ON PAGE 4.
(A) CAN YOU IDENTIFY AN ANIMAL THAT IS BOTH A SECONDARY AND TERTIARY CONSUMER
(B) HOW WOULD YOU CLASSIFY THE MOUNTAIN LION?
LET'S HAVE A GO...
(A)
(B)
WHY DO WE HAVE MORE FIRST ORDER CONSUMERS THAT SECOND ORDER CONSUMERS?
OK...

WORKSHEET QUESTIONS (YEAR 9 – BIMODAL TEXT 3)

APPENDIX 5

WORKSHEET POST-TEST (YEAR 7 – WORKSHEET 1)

GRADE 7: GROUPING ANIMALS QUIZ

- name:________________
- class:________________
- date:________________

1) What is the physical feature that divides vertebrates and invertebrates? Circle the correct answer:

A) tail / no tail
B) backbone / no backbone
C) gills / lungs
D) eggs / live birth

2) Define the following:

A) **Vertebrate**:

____
____

B) **Invertebrate**:

____
____

C) **Endoskeleton**:

____
____

D) **Exoskeleton**:

____
____

3) Which are more common on earth, invertebrates or vertebrates?

____
____

4) What are two ways invertebrates differ from each other?

A) ____________________

B) ____________________

GRADE 7: GROUPING ANIMALS QUIZ

5) Give examples of <u>three different</u> vertebrates:

A) ____________________

B) ____________________

C) ____________________

6) Give examples of <u>three different</u> invertebrates:

A) ____________________

B) ____________________

C) ____________________

7) <u>Describe the difference</u> between the way muscles are attached to skeletons in animals with endoskeletons compared with those with exoskeletons:

____
____
____
____
____
____

8) How do worms, and other invertebrates without an exoskeleton, move?

____
____
____
____
____

WORKSHEET POST-TEST (YEAR 7 – WORKSHEET 2)

GRADE 7: ECOLOGY QUIZ

- name:________________
- class:________________
- date:________________

1) All food chains get their original energy from:

A) primary producers
B) detrivores
C) herbivores
D) the sun

2) Name the following using scientific terms:

A) meat eating animals:______________________________

B) Plant eating animals: ______________________________

C) Animals that eat meat and plants: ______________________________

D) Animals that eat dead things: ______________________________

3) Give reasons why it is important to understand feeding relationships in ecosystems:

____
____
____
____
____
____

4) What is an example of a disruption to an ecosystem?

____

5) What are possible consequences of the disruption to the ecosystem that you mentioned in question 4 (above)?

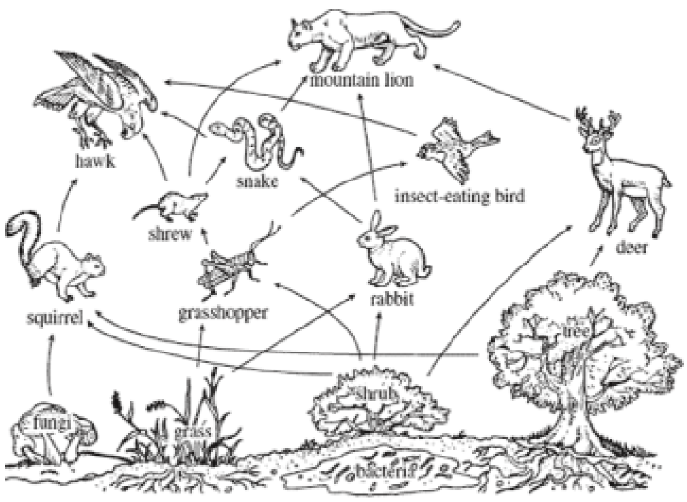
____
____
____
____
____
____

GRADE 7: ECOLOGY QUIZ

6) About how much energy is available at each new trophic (feeding) level?

A) 20%
B) 1%
C) 10%
D) 100%

7) Examine the food web below.



(A) Identify a primary producer: ______________________________

(B) Identify a first order consumer: ______________________________

(C) Identify a second order consumer: ______________________________

(D) Identify a detrivore: ______________________________

(E) Identify an animal that is both a secondary and tertiary consumer: ____________________

8) Give reasons why ecosystems always have more first order consumers than second or third order consumers:

____

____

____

____

____

____

WORKSHEET POST-TEST (YEAR 7 – WORKSHEET 3)

GRADE 7: ASTRONOMY QUIZ

- name:________________
- class:________________
- date:_________________

Question 1: What is the main cause of Earth's seasons?

(A) The earth gets closer to the sun during summer, and further away in winter
(B) The earth is on a tilt
(C) The sun gets hotter at certain times of the year
(D) The sun is tilted and therefore gives the earth more sunshine during its orbit of the earth

Question 2: What tilt is the earth's axis on:

(A) 13.5°
(B) 23.5°
(C) 3.5°
(D) 17.5°

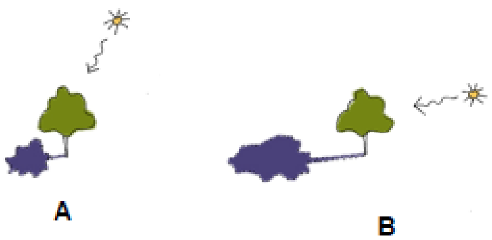
Question 3: Explain the difference between a revolution and rotation of the earth

____
____
____
____

Question 4: How long does it take for the earth to complete:

(A) One rotation: __________
(B) One revolution: ________

Question 5: Look at the shadows below. Circle the correct season for each shadow.



SHADOW (A) Winter / summer

SHADOW (B) Winter / summer

Question 6: Australia is in the southern hemisphere. Answer these questions.

(A) During which season does Australia tilt towards the sun: ___________
(B) During which months does Australia tilt towards the sun: ___________
(C) Australia's winter solstice is in which month: __________

GRADE 7: ASTRONOMY QUIZ

Question 7: <u>Explain</u> why the northern hemisphere is having summer while the southern hemisphere is having winter:

Question 8: <u>Explain</u> why a summer day is warmer than a winter day:

WORKSHEET POST-TEST (YEAR 8 – WORKSHEET 1)

GRADE 8: MINERAL RESOURCES QUIZ

- name:________________
- class:________________
- date:________________

1) What is a mineral? <u>Circle the correct answer:</u>

A) An artificial combination of metals, made in the laboratory
B) Any type of rock, such as sedimentary, igneous, or metamorphic rock
C) A solid inorganic substance from which metals are found
D) Gases found deep underground.

2) What is an ore? <u>Circle the correct answer:</u>

A) A pure metal, such as aluminium (Al) or silver (Ag)
B) A combination of minerals which are considered waste products of mining
C) A type of machinery used in underground mining
D) A concentration of minerals which are valuable to mine

3) What are <u>differences</u> between a mineral and an ore?

____
____
____
____

4) What are five of <u>Australia's</u> most <u>important minerals</u>:

a) ____________________
b) ____________________
c) ____________________
d) ____________________
e) ____________________

5) Describe the <u>basic processes of mining a metal such as aluminium or tin.</u> In your answer include details about type of mine, refining processes, minerals, metals, and ores.

____
____
____
____
____
____
____
____

WORKSHEET POST-TEST (YEAR 8 – WORKSHEET 2)

GRADE 8: E-WASTE QUIZ

- name:________________
- class:________________
- date:________________

1) E-waste refers to:

A) an online form of waste
B) wastage from electronic devices
C) Industrial waste
D) Residential waste relating to all modern products

2) Give two reasons why E-waste is often shipped to developing countries:

1.
____
____
____

2.
____
____
____

3) What is planned obsolescence?

____

4) What are two other ways that electronic companies ensure we replace our devices at set time intervals:

1.
____
____
____

2.
____
____
____

5) What is the BASEL TREATY?

A) An international agreement that sets the limits to how much e-waste countries can produce
B) An international agreement that determines how we should recycle E-waste
C) An international agreement that bans the movement of E-waste between countries
D) An international agreement that establishes how many devices companies can manufacture per year

GRADE 8: E-WASTE QUIZ

7) Give reasons how E-waste harms the health of people in developing countries:

8) Describe different ways that mining can harm the environment:

WORKSHEET POST-TEST (YEAR 8 – WORKSHEET 3)

GRADE 8: POTENTIAL ENERGY

- name:________________
- class:________________
- date:________________

Question 1: All energy can be classified as:

(A) potential / kinaesthetic
(B) gravitational / mechanical
(C) potential / kinetic
(D) moving / stationary

Question 2: Chemical potential energy is released:

(A) By the breaking and formation of chemical bonds between atoms
(B) When objects are raised and held against gravity
(C) By the splitting and fusing of atoms
(D) When objects have their mass increased.

Question 3: What are three types of potential energy:

(1) ______________________________________
(2) ______________________________________
(3) ______________________________________

Question 4: List four situations that involve potential energy:

(1) ______________________________________
(2) ______________________________________
(3) ______________________________________
(4) ______________________________________

Question 5: List four objects that possess elastic potential energy:

(1) ______________________________________
(2) ______________________________________
(3) ______________________________________
(4) ______________________________________

Question 6: Define chemical potential energy:

____
____
____
____
____

Question 7: How is nuclear energy used?

____
____
____
____

WORKSHEET POST-TEST (YEAR 9 – WORKSHEET 1)

GRADE 9: ATOMIC MODELS QUIZ

- name:_______________
- class:_______________
- date:_______________

1) What was JJ Thomson's atomic model called? <u>Circle the correct answer:</u>

A) the plum pudding model
B) the electron cloud model
C) the solid ball model
D) the electron orbit model

2) Why do scientists use models? <u>Circle the correct answer:</u>

A) to represent what they have directly observed in the laboratory
B) to prove that their ideas are correct
C) to help people understand natural phenomena
D) to compete in scientific competitions / shows

3) What is an alpha particle? <u>Circle the correct answer:</u>

A) positively charged particles
B) negatively charged particles
C) tiny particles with no charge (neutral charge)
D) the first sub-atomic particles ever detected in the laboratory

4) What were the three subatomic particles known about by the early twentieth century?

A) nucleus, neutrinos, albinos
B) quarks, positrons, antineutrinos
C) electrons, neutrons, protons
D) leptons, quarks, gluons

5) Describe <u>Ernest Rutherford's gold foil experiment</u>. Give as much detail in your answer as possible.

____
____
____
____
____
____
____

GRADE 9: ATOMIC MODELS QUIZ

6) How did the observed results of Ernest Rutherford's gold foil experiment differ from the expected results?

7) How did the observed results of Ernest Rutherford's gold foil experiment help him determine that the atom is mostly empty space with a positively charged nucleus?

WORKSHEET POST-TEST (YEAR 9 – WORKSHEET 2)

GRADE 9: E-WASTE QUIZ

- name:_________________
- class:_________________
- date:_________________

1) <u>An isotope is</u>:

A) forms of the same element with the same number of protons but different numbers of electrons
B) forms of the same element with the same number of neutrons but different numbers of protons
C) forms of the same element with the same number of protons but different numbers of neutrons
D) different types of elements which have the same numbers of protons

2) <u>Define</u>:

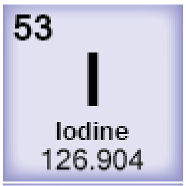
1. Radioactive decay:

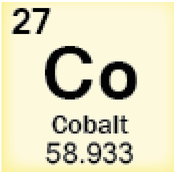
2. Half-life

3. Explain how Radiocarbon (C-14) dating works:

3) Look at the elements from the periodic table below:

a) Write the conventional representation of iodine-131 ______________________________
b) Write the conventional representation of cobalt-60______________________________
c) Write the conventional representation of Fluorine-18______________________________





GRADE 9: E-WASTE QUIZ

4) The rate of decay of a radioisotope falls from 800 counts per minute to 100 counts per minute in 6 hours:

a) What is the half-life of this radioisotope? ______________________________

b) Predict what the count rate would be in another four hours time: ______________________

c) Sketch a radioactive decay chart for this radioisotope (in the box below)

WORKSHEET POST-TEST (YEAR 9 – WORKSHEET 3)

GRADE 9: POTENTIAL ENERGY

Question 1: Choose the appropriate response:

(A) Light waves are longitudinal and sound waves are transverse
(B) Light waves are transverse and sound waves are also transverse
(C) Light waves are transverse and sound waves are longitudinal
(D) All waves are transverse, but differ in certain properties, such as amplitude and wavelength

Question 2: Draw two transverse waves. Label the waves A and B. Draw wave A with a longer wavelength than wave B.

Question 3: What is the difference between ultraviolet and infrared radiation?

____
____
____
____

Question 4: WHAT IS MEANT BY THESE TERMS:

I. WAVELENGTH ____

II. VISIBLE SPECTRUM ____

III. REFRACTION ____

IV. REFLECTION ____

V. SPEED OF LIGHT____

Question 5: What happens when light passes from air into water?

____
____
____
____

Question 6: What is the difference between reflection and refraction?

____
____
____
____

GRADE 9: POTENTIAL ENERGY

Question 6: <u>How</u> are light and sound waves <u>different</u>? (give at least three differences in your answer)

Question 7:

(A) WHY DO HUMANS NEED SOME UV LIGHT?

(B) WHY DO PLANTS NEED UV LIGHT?

APPENDIX 5 (cont.)

MARKING RUBRIC (all worksheet quizzes i.e. grade 7, 8 and 9 worksheets)

	KNOWLEDGE / UNDERSTANDING	REASONING	FLUENCY / COMMUNICATION
A	Student displays very strong recall of content with 80 - 100% of questions answered correctly.	Student provides a very strong level of reasoning in short answer / extended response questions. Student's answers involve very strong elements of problem solving / applied reasoning.	Answers given with highly appropriate usage of scientific terminology. Answers highly consistent with original language from text.
B	Student displays strong recall of content with 60 - 80% of questions answered correctly	Student provides a strong level of reasoning in short answer / extended response questions. Student's answers involve strong elements of problem solving / applied reasoning.	Answers given with appropriate usage of scientific terminology. Answers consistent with original language from text.
C	Student displays moderate recall of content with 50 - 60% of questions answered correctly	Student provides a moderate level of reasoning in short answer / extended response questions. Student's answers involve moderate elements of problem solving / applied reasoning.	Answers given with a combination of everyday terms and appropriate scientific terminology. Answers generally consistent with original language from text.
D	Student displays inconsistent recall of content with 30 - 50% of questions answered correctly	Student provides a limited level of reasoning in short answer / extended response questions. Student's answers involve elements of problem solving / applied reasoning.	Answers given using lay language - though generally compatible with scientific terminology. Answers generally inconsistent with original language from text.
E	Student displays weak recall of content with < 30% of questions answered correctly	Student provides a very limited (or non-existant) level of reasoning in short answer / extended response questions. Student's answers involve very limited elements of problem solving / applied reasoning.	Answers given using lay language - and generally incompatible with scientific terminology. Answers omitted or inconsistent with original language from text.

APPENDIX 6

AFFECTIVE OUTCOMES SCALE (AOS) INSTRUMENT

STUDENT SURVEY 3: **AFFECTIVE OUTCOMES SCALE**

Directions:

(1) This questionnaire contains a number of statements about learning in science. You will be asked what you personally think about these statements. There are no 'right' or 'wrong' answers. Some questions are about what you actually do or think; other questions are about preferred or ideal learning in science.

(2) All answers should be made on the following sheet.

(3) For each statement draw a circle around

0 if you feel that you **never agree** with the statement

1 if you feel that you **rarely agree** with the statement

2 if you feel that you **sometimes agree** with the statement

3 if you feel that you **usually agree** with the statement

4 if you feel that you **always agree** with the statement

(4) Numerous questions ask about graphic novels in science learning. An example of a graphic novel is presented here in case you haven't seen one before.

	NEVER				ALWAYS	TEACHER USE
1. I easily understand scientific information.	0	1	2	3	4	U
2. I enjoy reading about science.	0	1	2	3	4	E
3. Scientific concepts are important to learn about.	0	1	2	3	4	I
4. Information is easier to understand when it is spoken and not written.	0	1	2	3	4	U
5. Spoken information gets my attention more than written information.	0	1	2	3	4	E
6. Spoken information is as important as written information.	0	1	2	3	4	I
7. The way information is presented helps me learn.	0	1	2	3	4	U
8. Science would be more interesting if I could see how scientists developed their ideas.	0	1	2	3	4	E
9. Science textbooks make me feel that scientists are very important people.	0	1	2	3	4	I
10. Science textbooks help me understand ideas in science easily.	0	1	2	3	4	U
11. Science textbooks are enjoyable to read.	0	1	2	3	4	E
12. Science textbooks make me feel that science is an important subject.	0	1	2	3	4	I
13. I find it difficult to understand concepts when a lot of information is given.	0	1	2	3	4	U
14. I prefer to read non-science textbooks.	0	1	2	3	4	E
15. The information in science textbooks makes me feel that science is a difficult career to enter.	0	1	2	3	4	I
16. I think that I would understand information in graphic novels.	0	1	2	3	4	U
17. Graphic novels would be enjoyable to read.	0	1	2	3	4	E
18. Information in graphic novels can be taken seriously.	0	1	2	3	4	I
19. Scientific information in graphic novels would be easy to understand.	0	1	2	3	4	U
20. Scientific graphic novels would be interesting to read.	0	1	2	3	4	E
21. Scientific information in graphic novels could be taken seriously.	0	1	2	3	4	I
22. Graphic novels could be used to teach anything.	0	1	2	3	4	U
23. Graphic novels could make me more interested in a subject.	0	1	2	3	4	E
24. Graphic novels could be used for teaching important subjects.	0	1	2	3	4	I
25. Speech bubbles in graphic novels make it obvious who is talking.	0	1	2	3	4	U
26. Seeing people interact in graphic novels is interesting.	0	1	2	3	4	E
27. Seeing people interact makes me feel that science is important.	0	1	2	3	4	I
28. I think I would remember science concepts better using a graphic novel than a textbook.	0	1	2	3	4	U
29. Students would be more focussed on science if we used a graphic novel instead of a textbook.	0	1	2	3	4	E
30. Students would be more likely to take senior science subjects if graphic novels were used in class.	0	1	2	3	4	I

For teacher use only: U: _____ E: ______ I: ______

APPENDIX 7

MODIFIED TEST OF SCIENCE RELATED ATTITUDES (TOSRA) (adapted from Fraser, 1981; Fisher et al., 1995)

STUDENT SURVEY 1: **Modified test of Science Related Attitudes (TOSRA)**

NAME: ______________________________

Test of Science Related Attitudes (TOSRA)

Directions:

1. This test contains a number of statements about science. You will be asked what you think about these statements. There are no "right" or "wrong" answers. Your opinion is what is wanted.
2. For each statement, draw a circle around the specific number value corresponding to how you feel about each statement. **Please circle only ONE value per statement.**

4 = Strongly Agree (SA)
3 = Agree (A)
2 = Disagree (D)
1 = Strongly Disagree (SD)

statement	SA	A	D	SD
Science lessons are fun.	4	3	2	1
I dislike science lessons.	4	3	2	1
School should have more science lessons each week.	4	3	2	1
Science lessons bore me.	4	3	2	1
Science is one of the most interesting school subjects.	4	3	2	1
Science lessons are a waste of time.	4	3	2	1
I really enjoy going to science lessons.	4	3	2	1
The material covered in science lessons is uninteresting.	4	3	2	1
I look forward to science lessons.	4	3	2	1
I would enjoy school more if there were no science lessons.	4	3	2	1

APPENDIX 8

MODIFIED MACARTHUR SCALE OF SUBJECTIVE SOCIAL STATUS – YOUTH VERSION

SOCIAL LADDER SCALE

NAME: ______________________________

1A. Imagine that this ladder shows how United Arab Emirates (UAE) society is set up

- at the top of the ladder are those who are best off. These people have the best jobs, the most money, and the highest education. These people have jobs which bring the most respect.

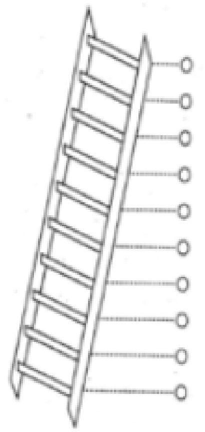
- at the bottom of the ladder are those who are worst off. These people have the worst jobs, the least money, and the lowest education. These people have jobs which bring the least respect.

Now think about your family. Please tell us where you think your family would be on this ladder. **Fill in the circle which best represents where <u>your family</u> would be on this ladder.**

1B. Now assume that the ladder is a way of picturing your school.

- at the top of the ladder are the people with the most respect, the best grades, and the highest standing.

- at the bottom of the ladder are the people with the least respect, the worst grades, and the lowest standing.



Where would you place yourself on this ladder? **Fill in the circle which best represents where <u>you</u> would be on this ladder.**

APPENDIX 9

PARENT SURVEY: MODIFIED MACARTHUR SCALE OF OBJECTIVE SOCIAL STATUS

Directions:

1. This survey contains a number of statements about your education, income and occupation.
2. For each question please indicate your personal response. Note: some questions have a *no response* answer if you feel that the question is too personal.

N.b. All data is confidential and is to be used for the purposes of study only. Please see attached consent and information forms for more information on confidentiality.

Name: ____________________

Parent / guardian of: _________________ **Class:** _____________

Question 1: What is the highest grade (or year) of regular school you have completed? (Check one.)

Primary school	High school	University (undergraduate)	University (postgraduate)
01____	08____	13____	17____
02____	09____	14____	18____
03____	10____	15____	19____
04____	11____	16____	20+___
05____	12____		
06____			
07____			

Question 2: What is the highest degree you have earned?

___ high school certificate or equivalent
___ Certificate I / II / III / IV
___ Diploma
___ Bachelor's degree
___ Master's degree
___ Doctorate
___ none of the above (less than high school)

Question 3:

Which of the following best describes your current main daily activities and / or responsibilities?

___ Working full time

___ Working part time

___ Unemployed or laid off

___ Looking for work

___ Keeping house or raising children full time

___ Retired

Question 4. With regard to your current or most recent job activity:

a. In what kind of business or industry do (did) you work?

____

(For example: hospital, newspaper publishing, mail order house, auto engine manufacturing, breakfast cereal manufacturing.)

b. What kind of work do (did) you do? (Job Title)

____

(For example: registered nurse, personnel manager, supervisor of order department, gasoline engine assembler, grinder operator.)

c. How much did you earn, before any deductions, during the past 12 months?
_____Less than 10,000 AED
_____10,000 AED through 20,000 AED
_____20,000 AED through 30,000 AED
_____30,000 AED through 40,000 AED
_____50,000 AED through 60,000 AED
_____70,000 AED through 80,000 AED
_____80,000 AED through 90,000 AED
_____90,000 AED through 120,000 AED
_____120,000 AED through 150,000 AED
_____150,000 AED through 180,000 AED
_____180,000 AED through 210,000 AED
_____ 210,000 AED through 250,000 AED
_____ 250,000 AED through 300,000 AED
_____ 300,000 AED through 400,000 AED
_____ 400,000 AED through 500,000 AED
_____ greater than 500,000 AED
_____ Don't know
_____ No response

Question 5. How many people are currently living in your household, including yourself?

_____Number of people
_____Of these people, how many are children?
_____Of these people, how many are adults?
_____Of the adults, how many bring income into the household?

Question 6. Is the home where you live:

_____Owned or being bought by you (or someone in the household)?
_____Rented for money?
_____Occupied without payment of money or rent?
_____Other (specify)________________________________

Question 7. Which of these categories best describes your total combined family income for the past 12 months?

This should include income from all sources, wages, rent from properties, social security, disability and/or veteran's benefits, unemployment benefits, workman's compensation, help from relatives (including child payments and alimony), and so on.

_____Less than 10,000 AED
_____10,000 through 30,000 AED
_____30,000 through 50,000 AED
_____60,000 through 80,000 AED
_____80,000 through 100,000 AED
_____100,000 through 200,000 AED
_____200,000 through 300,000 AED
_____300,000 through 400,000 AED
_____400,000 through 500,000 AED
_____ greater than 500,000 AED
_____Don't know
_____No response

Question 8. If you lost all your current source(s) of household income (your paycheck, public assistance, or other forms of income), how long could you continue to live at your current address and standard of living?

______ Less than 1 month
______ 1 to 2 months
______ 3 to 6 months
______ 7 to 12 months
______ More than 1 year

Question 9. Suppose you needed money quickly, and you cashed in all of your (and your spouse's) checking and savings accounts, and any shares and bonds. If you added up what you would get, about how much would this amount to?

_____Less than 10,000 AED
_____10,000 through 30,000 AED
_____30,000 through 50,000 AED
_____60,000 through 80,000 AED
_____80,000 through 100,000 AED
_____100,000 through 200,000 AED
_____200,000 through 300,000 AED
_____300,000 through 400,000 AED
_____400,000 through 500,000 AED
_____ greater than 500,000 AED

_____Don't know
_____No response

If you now subtracted out any debt that you have (credit card debt, unpaid loans including car loans, home mortgage), about how much would you have left?

_____Less than 10,000 AED
_____10,000 through 30,000 AED
_____30,000 through 50,000 AED
_____60,000 through 80,000 AED
_____80,000 through 100,000 AED
_____100,000 through 200,000 AED
_____200,000 through 300,000 AED
_____300,000 through 400,000 AED
_____400,000 through 500,000 AED
_____ greater than 500,000 AED
_____Don't know
_____No response

APPENDIX 10

MENTAL EFFORT INSTRUMENT

NAME: ________________ CLASS: _____________ DATE: ________________

This questionnaire asks you about how well you understand scientific content from different types of texts.

DIRECTIONS:

1) Please look at the following **three texts**.

2) **Rate each one** on how easy **<u>you THINK it would be to understand the content</u>** that is shown.

3) For each text, please **CIRCLE** the appropriate response about how easily you think you would understand the scientific content on the page.

<u>TEXT 1:</u>

Circle the appropriate answer (one answer only)

THIS TEXT WOULD BE:

One (1) = **extremely easy** to understand
Two (2) = **easy** to understand
Three (3) = **fairly easy** to understand
Four (4) = **slightly easier** to understand than another type of text
Five (5) = the **text type doesn't make any difference** in my understanding
Six (6) = **slightly harder** to understand than another type of text
Seven (7) = **fairly difficult** to understand
Eight (8) = **difficult** to understand
Nine (9) = **extremely difficult** to understand

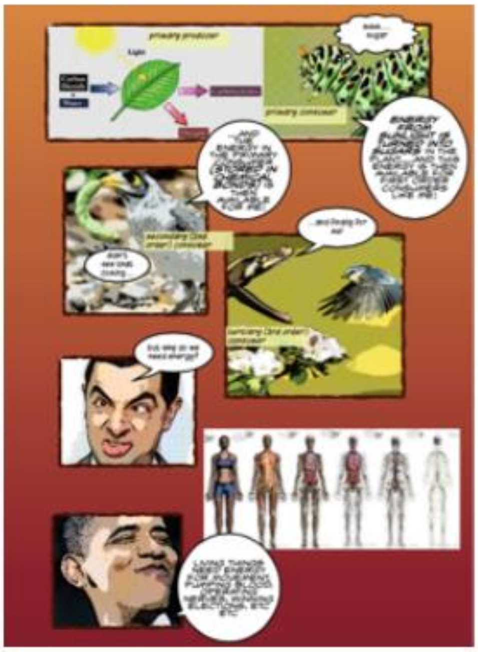
TEXT 2:

Circle the appropriate answer (one answer only)

THIS TEXT WOULD BE:

One (1) = **extremely easy** to understand
Two (2) = **easy** to understand
Three (3) = **fairly easy** to understand
Four (4) = **slightly easier** to understand than another type of text
Five (5) = the **text type doesn't make any difference** in my understanding
Six (6) = **slightly harder** to understand than another type of text
Seven (7) = **fairly difficult** to understand
Eight (8) = **difficult** to understand
Nine (9) = **extremely difficult** to understand

TEXT 3:



Circle the appropriate answer (one answer only)

THIS TEXT WOULD BE:

One (1) = **extremely easy** to understand
Two (2) = **easy** to understand
Three (3) = **fairly easy** to understand
Four (4) = **slightly easier** to understand than another type of text
Five (5) = the **text type doesn't make any difference** in my understanding
Six (6) = **slightly harder** to understand than another type of text
Seven (7) = **fairly difficult** to understand
Eight (8) = **difficult** to understand
Nine (9) = **extremely difficult** to understand

APPENDIX 11

APPROVAL LETTER FROM CURTIN UNIVERSITY'S HUMAN RESEARCH ETHICS OFFICE

MEMORANDUM

Curtin University

To:	Jill Aldridge
	School of Science
CC:	
From	Dr Catherine Gangell, Manager Research Integrity
Subject	Ethics approval Approval number: RDSE-15-15
Date	30-Apr-15

Office of Research and Development
Human Research Ethics Office

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL hrec@curtin.edu.au

Thank you for your application submitted to the Human Research Ethics Office for the project: 5560

Investigation of Perceived and Objective Indicators of Success in Multimedia Learning

Your application has been approved through the low risk ethics approvals process at Curtin University.

Please note the following conditions of approval:

1. Approval is granted for a period of four years from **30-Apr-15** to **30-Apr-19**
2. Research must be conducted as stated in the approved protocol.
3. Any amendments to the approved protocol must be approved by the Ethics Office.
4. An annual progress report must be submitted to the Ethics Office annually, on the anniversary of approval.
5. All adverse events must be reported to the Ethics Office.
6. A completion report must be submitted to the Ethics Office on completion of the project.
7. Data must be stored in accordance with WAUSDA and Curtin University policy.
8. The Ethics Office may conduct a randomly identified audit of a proportion of research projects approved by the HREC.

Should you have any queries about the consideration of your project please contact the Ethics Support Officer for your faculty, or the Ethics Office at hrec@curtin.edu.au or on 9266 2784. All human research ethics forms and guidelines are available on the ethics website.

Yours sincerely,

Dr Catherine Gangell
Manager, Research Integrity

APPENDIX 12

INFORMATION AND CONSENT LETTERS (PARENT / STUDENT / TEACHER)

Science and mathematics Education Centre
Malcolm Kirkwood
Teacher
Australian International School, Sharjah
PO Box 43364
Sharjah, UAE
Tel: +971 6 558 9967

Dear parent / carer,

Perceived and objective indicators of success study

My name is Malcolm Kirkwood and I am from Curtin University. I am doing a study that involves the collection of information that I will use to see which science textbooks work the best for student learning. This information allows teachers to choose or design the type of text that helps students best remember science information from lessons. This is for a student research (PhD) project.

I am writing to ask your permission for your child to take part in the project. Your child also has a letter from me that I hope you'll discuss with him / her further. Further, I'd like to ask you, as a parent, to participate in the study by filling in a questionnaire which I'll discuss below.

Participation in the project will require your child to complete several surveys. The first survey is a survey of your child's feelings about his or her social standing within UAE society, and within the school community. This survey is quick to fill in, and should take approximately five minutes to complete. I also have a parent version of this survey. This survey asks questions about your family's social standing, and includes questions relating to income, home ownership, and employment. The second and third surveys ask of your child's attitude towards science as a subject, and of your child's attitudes towards science texts. These surveys are also quick to finish, and shouldn't take any longer than five to ten minutes per survey to complete.

Participation is voluntary and I will respect your decision to participate or not. Your decision will not affect your family's relationship with the school or your child's teacher. If you decide to participate, I need to know before the end of term 2 (week 8) for your child to be included in this study. If you decide to participate, either you or your child can change your mind at any time.

We can remove information that we collect from your child's participation at any point.

The information from the surveys is entirely private and confidential. I will remove any information that identifies anyone from the surveys. The data is then stored securely in a locked facility and the research team are the only people who can access this. We will store the information for a minimum of seven years and then destroy it.

I will report what I learn from this study to the funding body, the Australian Research Council, and I will also publish my findings as a PhD research thesis.

This study has been approved under Curtin University's process for lower-risk Studies (Approval number XXX). This process complies with the National Statement on Ethical Conduct in Human Research (Chapter 5.1.7 and Chapters 5.1.18 - 5.1.21).

For further information on this study, please contact the research named above or the Curtin University Human Research Ethics Committee. c/- Office of Research and Development, Curtin University, GPO Box U1987, Perth 6845 or by telephoning +61 8 9266 9223 or by emailing hrec@curtin.edu.au. You may also contact myself (Malcolm Kirkwood) on 971561062139 or email at malcolm.kirkwood@ais.ae or Ms Annette Wilson, the principal of the Australian International School, Sharjah on 971 65589967 or by emailing annette.wilson@ais.ae.

Everyone who does research in schools must have a Working With Children Check. I have given the principal of your child's school proof that this check is current for myself as the researcher, and of course, for the regular science teachers at the school.

If you would like to discuss any aspect of this study, please contact me. If you wish to speak with an independent person about the conduct of the project, please contact my supervisor, Dr. Jill Aldridge on +61 8 9266 3592 at Curtin University's School of Education.

If you and your child are both willing for him / her to be involved, please complete the Consent Form on the following page. I have also asked your child to complete the Consent Form which is attached to his/her letter.

This project information letter is for you to keep.

Malcolm Kirkwood
Teacher
Australian International School
Sharjah, UAE.
Phone: work: +971 6 558 9967 Mob: 056 1062139
Email: malcolm.kirkwood@ais.ae

Science and mathematics Education Centre
Malcolm Kirkwood
Teacher
Australian International School, Sharjah
PO Box 43364
Sharjah, UAE
Tel: +971 6 558 9967

CONSENT FORM

- I have read and understand the information letter about the project, or I have had it explained to me in language I understand.
- I have taken up the invitation to ask any questions I may have had and am satisfied with the answers I received.
- I understand that participation in the project is entirely voluntary.
- I am willing for my child to become involved in the project, as described.
- I have discussed with my child what it means to participate in this project. He / she has clearly indicated a willingness to take part, as indicated by his / her completion of the child consent form.
- I understand that both my child and I are free to withdraw our participation at any time without affecting the family's relationship with my child's teacher or my child's school.
- I understand that data collected from my child's participation can be removed from the study at any point.
- I give permission for the contribution that my child and I make to this research to be published as a PhD thesis provided that my child or the school is not identified in any way.
- I understand that I can request a summary of findings after the research has been completed.

Name of child (printed): ______________________________

Name of parent / carer (printed): ______________________________

Signature of parent: ____________________ Date: / /

Science and mathematics Education Centre
Malcolm Kirkwood
Teacher
Australian International School, Sharjah
PO Box 43364
Sharjah, UAE
Tel: +971 6 558 9967

Dear student,

Perceived and objective indicators of success study

My name is Malcolm Kirkwood and I am from Curtin University. I am doing a study collects information that I will use to see which science textbooks work the best for your learning. This information helps your teachers choose or design the type of text that helps students best remember science information from lessons. This is for a student research (PhD) project.

I am writing to ask your permission for you to take part in the project. Your parents also have a letter from me that I hope you'll discuss with them further.

Participation in the project will require you to complete several surveys (a way for me to get information from you). The first survey is a survey of your feelings about your social standing within UAE society, and within the school community. This survey is quick to fill in, and should take approximately five minutes to complete. The second and third surveys will ask about your attitude towards science as a subject, and of your attitudes towards science books. These surveys are also quick to finish, and shouldn't take any longer than five to ten minutes per survey to complete.

Participation is voluntary and I will respect your decision to participate or not. Your decision will not affect your family's relationship with the school or your child's teacher. If you decide to participate, I need to know before the end of term 2 (week 8) for you to be included in this study. If you decide to participate, either you or your parents can change your mind at any time.

You can ask to remove information that has been collected about you at any time.

The information from the surveys is entirely private and confidential. I will remove any information that identifies anyone from the surveys. The data is then stored securely in a locked facility and the research team are the only people who can access this. We will store the information for a minimum of seven years and then destroy it.

I will report what I learn from this study to the funding body, the Australian Research Council, and I will also publish my findings as a PhD research thesis.

This study has been approved under Curtin University's process for lower-risk Studies (Approval number XXX). This process complies with the National Statement on Ethical Conduct in Human Research (Chapter 5.1.7 and Chapters 5.1.18 - 5.1.21).

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Everyone who does research in schools must have a Working With Children Check. I have given the principal of your school proof that this check is current for myself as the researcher, and of course, for your regular science teacher at school.

If you would like to discuss any aspect of this study, please contact me. If you wish to speak with an independent person about the conduct of the project, please contact my supervisor, Dr. Jill Aldridge on +61 8 9266 3592 at Curtin University's School of Education.

If you and your parents are both willing for you to be involved, please complete the Consent Form on the following page. I have also asked your parents to complete the Consent Form which is attached to their letter.

This project information letter is for you to keep.

Malcolm Kirkwood
Teacher
Australian International School
Sharjah, UAE.
Phone: work: +971 6 558 9967 Mob: 056 1062139
Email: malcolm.kirkwood@ais.ae

Science and mathematics Education Centre
Malcolm Kirkwood
Teacher
Australian International School, Sharjah
PO Box 43364
Sharjah, UAE
Tel: +971 6 558 9967

Dear science teacher,

Perceived and objective indicators of success study

My name is Malcolm Kirkwood and I am from Curtin University. I am doing a study that involves the collection of information that I will use to see which science textbooks work the best for student learning. This information allows teachers to choose or design the type of text that helps students best remember science information from lessons.

I am writing to ask your permission for you as a science teacher at Sharjah English School to take part in the project. A major focus of the study is for me as the researcher to be as non-invasive as possible, to avoid any disruption to classes, and on an absolute minimal amount of commitment required from teaching staff in the completion of the project. Your role and requirements are discussed below.

Participation in the project will require your classes to complete several surveys. The first survey is a survey of student feelings about his or her social standing within UAE society, and within the school community. This survey is quick to fill in, and should take approximately five minutes to complete. I also have a parent version of this survey. This survey asks questions about the family's social standing, and includes questions relating to income, home ownership, and employment. The second and third surveys ask of students' attitudes towards science as a subject, and of attitudes towards science texts. These surveys are also quick to finish, and shouldn't take any longer than five to ten minutes per survey for students to complete.

As a science teacher at Sharjah English School, I will ask you to distribute several learning texts, in addition to the surveys listed above, at specified times to students during term three. I will administer before and after testing to students to assess their learning from the form of text used. Prior to commencing the study, I will also ask for a brief interview with you to go over the intent, procedures, and anticipated outcomes of the study.

Participation is voluntary and I will respect your decision to participate or not. If you decide to participate, I need to know before the end of week 1 (term 3) for you to be included in this study. If you decide to participate, you can change your mind at any time.

The information from the surveys is entirely private and confidential. I will remove any information that identifies anyone from the surveys. The data is then stored securely in a locked facility and the research team are the only people who can access this. We will store the information for a minimum of seven years and then destroy it.

I will report what I learn from this study to the funding body, the Australian Research Council, and I will also publish my findings as a PhD research thesis.

This study has been approved under Curtin University's process for lower-risk Studies (Approval number 477654). This process complies with the National Statement on Ethical Conduct in Human Research (Chapter 5.1.7 and Chapters 5.1.18 - 5.1.21).

For further information on this study, please contact the research named above or the Curtin University Human Research Ethics Committee. c/- Office of Research and Development, Curtin University, GPO Box U1987, Perth 6845 or by telephoning +61 8 9266 9223 or by emailing hrec@curtin.edu.au. You may also contact Ms Annette Wilson, the principal of the Australian International School, Sharjah on 971 65589967 or by email annette.wilson@ais.ae.

Everyone who does research in schools must have a Working With Children Check. I have given the principal of your school proof that this check is current for myself as the researcher.

If you would like to discuss any aspect of this study, please contact me. If you wish to speak with an independent person about the conduct of the project, please contact my supervisor, Dr. Jill Aldridge on +61 8 9266 3592 at Curtin University's School of Education.

If you are willing to be involved, please complete the Consent Form on the following page. I have also asked your head of department to read and acknowledge these information and consent forms attached to this letter.

This project information letter is for you to keep.

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