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Learning science in an integrated classroom: Finding balance through theoretical triangulation

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Abstract

The central thesis of this article is that the learning of science in integrated curricular contexts requires a broader theoretical framework than is typically adopted by researchers and teachers. The common practice of interpreting science learning in terms of conceptual and procedural understandings in such contexts is problematized through an examination of the literature. As an alternative to the traditional approach, a triangulation of three theoretical perspectives is undertaken to view the science learning in a classroom case study of integrated curriculum. A metaphor that permeates the article is that of balance and the concluding comments highlight the necessity of balance between the disciplinary forces on curriculum and the forces that better reflect the multiple dimensions of learning in the real world. The use of theoretical triangulation is demonstrated as a technique through which a balanced, and more complete, view of learning in integrated contexts can be achieved.

Learning science in an integrated classroom: Finding balance through theoretical triangulation

The integration of science in the school curriculum has been attracting attention for at least a century and has escalated in importance over the last two decades. Gehrke (1998) remarked on the popularity of curriculum integration in the 1990s and demonstrated the increased number of publications devoted to the topic in the period 1990-1997, compared with the decades of the 1970s and the 1980s (see Gehrke, 1998, tables 1 and 2). In their historical analysis of integrated curriculum during the last century, Berlin and Lee (2005) focused on science and mathematics. They recorded only two articles published in the first two decades, both in 1905, and revealed a dramatic increase in publication from the mid 1980s. From about that time, national documents have advocated approaches to curriculum that cut across the boundaries that separate disciplines such as science and mathematics. For example, the *National Science Education Standards* (National Research Council 1996) stressed the connections between science, mathematics, and technology, and the *Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics 2000) pointed to links with the content and processes of science. According to Gehrke (1998: 249), similar, 'quite carefully worded statements approving integration of other subject areas' can also be found in the standards documents in civics, geography social studies, language arts and fine arts. However, despite the apparent support for integration, or at least a cross-curricular approach, a subject-centred curriculum persists in most schools, particularly at the high school level. Perhaps this is not surprising, given that curriculum documents for most school subjects are still organized around the parent disciplines. Nearly two decades ago, Goodlad and Su (1992: 332) wrote 'although strong intellectual currents have buffeted the so-called separate subject pattern of [curriculum]

organization, it has remained the rocklike structure at the center of the stream'. There is little evidence of change.

Beane (1995: 616) argued that an integrated approach to structuring curriculum, in contrast with traditional, disciplinary-based approaches, begins not with the disciplines, but 'with the idea that sources of curriculum ought to be problems, issues, and concerns posed by life itself'. (After all, life itself is not organized into disciplines. Beane (1995: 617) reasoned that 'the issue is not whether the disciplines of knowledge are useful, but how they might be brought into the lives of young people'. There are many ways this can be achieved. In practice, curricula that are described as 'integrated' range from the synchronous teaching of concepts, such as colour in art and science, to full integration, where the organizing principle is understanding of a major problem or issue, such as providing transportation within a community, and the disciplinary boundaries of subjects brought to bear upon it become indistinguishable. Researchers and other commentators have documented various kinds of curriculum integration (for example, Fogarty 1991, Geraedts, Boersma and Eijkelhof 2006, Kysilka, 1998, Wallace, Venville and Rennie 2005), synthesised its potential benefits and barriers (Czerniak 2007, Drake, 1003, Jacobs, 1989, Koirala and Bowman 2003, Meier, Cobbs and Nicol 1998, Vars, 2001, Venville, Sheffield, Rennie and Wallace, 2008, Wallace, Sheffield, Venville and Rennie 2007), and remarked upon its equivocal outcomes (Czerniak *et al.* 1999, Vars 1991, Wallace, Rennie, Malone and Venville 2001). Clearly, curriculum integration remains contested ground, both in terms of its nature and its learning outcomes.

In this paper, we examine the contested ground of curriculum integration using a metaphorical approach to explore the notion of a balance between the disciplinary forces exerted by the traditional, disciplinary-based curriculum and the forces that better reflect the multiple dimensions of learning in the real world. Such an approach, we argue, will enable a better

understanding and representation of the learning outcomes from classrooms where an integrated curriculum is enacted. We begin by borrowing the terms ‘centripetal’ and ‘centrifugal’ from Bakhtin (1981) as the basis of our metaphor and use two examples from the literature to examine how these forces impinge on the ways learning outcomes are measured from curriculum described as integrated. We suggest that sometimes the theoretical under-pinnings of research are not in tune with the stated objectives of the curriculum itself, and that a more faithful description of learning outcomes might be obtained by employing more than one theoretical perspective. Using our own case study research into the learning outcomes from a school project in an integrated classroom, we undertake a secondary analysis of our findings using the method of theoretical triangulation. This re-analysis of our data both refines and expands our understanding of the learning outcomes, and demonstrates how a balance between disciplinary and interdisciplinary knowledge can be achieved. We conclude that a broader, more balanced view of curriculum enables educators to make more informed decisions about the quality of learning outcomes and demonstrates the advantage of a multiple perspectives approach.

The notion of balance in curriculum

Much of the contention in curriculum integration arises from tension between the traditional, subject-centred curriculum defined by firm disciplinary boundaries and the breaking down of those boundaries by a form of instruction that focuses on cross-curricular, interdisciplinary topics or issues that weaken the structure of the disciplines (Venville, Wallace, Rennie and Malone 2002). Jacobs (1989: 2) referred to the ‘Polarity problem. Traditionally’, she wrote, ‘interdisciplinarity and the discipline fields have been seen as an either/or polarity, which has promoted a range of conflicts’. Gehrke (1998: 247-8) portrayed a more dynamic situation when she wrote about a ‘continuing curricular tug-of-war. On one side pull the mighty forces of the subject-centred curriculum. . . .Tugging on the other end we find the resilient underdogs – the

indefatigable forces of the integrated curriculum'. Although colourful, the tug-of-war scenario suggests winners and losers, whereas we believe there can be mutually agreed 'middle ground'.

We have chosen to borrow the terms 'centripetal' and 'centrifugal' from Bakhtin's (1981) analysis of language to characterise the contrasting forces underlying disciplinary and integrated approaches to curriculum. Bakhtin (1981: 272-273) wrote of 'the unifying, centralizing, centripetal forces' and 'decentralizing, centrifugal forces' working in opposition in any form of language. He argued that 'every utterance of a speaking subject serves as a point where centrifugal as well as centripetal forces are brought to bear. The processes of centralization and decentralization, of unification and disunification, intersect in the utterance' (1981: 272). The notion of these two opposing forces, familiar to us as science educators, appealed as a metaphorical means of examining the unifying and disunifying pressures on the nature of the discipline in school curriculum. We are not the first to use this metaphor to deal with educational and curriculum matters. For example, in the context of anthropology, González (2004: 18) sought to

situate culture within a consideration of centripetal and centrifugal forces...

Centripetal forces impel us toward a centralizing and unification of theory, while centrifugal forces hurtle toward heteroglossia and multiplicities.

In terms of this metaphor, centripetal forces pull students inward, toward a central unifying location within a particular discipline such as science. This means that students are forced to look inwards, focussing on the orderliness of the discipline, with their learning maintaining both the content and practices of that discipline. The arguments behind this approach to curriculum flow from the notion that disciplines, such as science, provide specialised knowledge and ways of looking at the world that enable rigorous explanation of various phenomena. In this way, disciplines provide students with the skills and cognitive tools required

to solve focused, discipline-based problems (Beane 1995, Gardner and Boix-Mansilla 1994, González 2004, Schoenfeld 2004). In opposition to centripetal forces, centrifugal forces push students outward, towards diversity, disunity, and multiplicity, and define learning and teaching in ways that are multifaceted (Leonardo 2004). This outward-focused approach results in an integrated curriculum that disregards, or breaks down, strict disciplinary boundaries and enables teachers and students to participate in curriculum and instruction that respond to issues that may be more immediately relevant and motivating to young people because their multiple dimensions and interdisciplinary nature better reflect the realities of their experiences outside school.

We find the metaphor of centripetal and centrifugal forces useful for exploring the tensions between disciplinary and integrated approaches to curriculum, particularly in regard to how science education researchers view learning. The looking-inward, looking-outward nature of this metaphor avoids the pitfalls of metaphors that put these curricular approaches at the opposite ends of a continuum or in mutually exclusive camps (for example, Fogarty 1991). The metaphor enables us to visualise tension between the opposing forces and, more importantly, provides the possibility of a place where balance between these forces can exist and be represented. It also draws attention to the importance of theoretical frameworks in looking at the outcomes of curricula, because an exploration of learning outcomes in terms of the inwardly focused, discipline-based curriculum requires a different theoretical perspective than an exploration of learning outcomes in terms of the outwardly focused, integrated curriculum.

Before presenting specific examples of the consequences for educational research of the tension between these opposing forces, we acknowledge the recent writings of Roberts (2007a, b). In his analysis of the terms science literacy/scientific literacy, Roberts (2007a: 730) put forward two visions: ‘Vision I gives meaning to SL [scientific literacy/science literacy] by looking inward to the canon of orthodox natural science, that is the products and processes of

science itself', whereas 'Vision II derives its meaning from the character of situations with a scientific component, situations that students are likely to encounter as citizens'. Roberts' description of these visions for scientific literacy parallel the approach we have taken to the broader curriculum context with our metaphoric use of centripetal and centrifugal forces. We argue for a place of balance between these forces, a place where both the disciplinary and integrated approaches to the curriculum subject can exist. Roberts (2007a: 768) has pointed out that his 'Vision II subsumes Vision I, but the converse is not necessarily so'. Thus he also sees a place for the disciplinary content of science in terms of understanding the broader, social situations encountered by citizens. This is not surprising. As Jacobs (1989: 9) pointed out, 'students cannot fully benefit from interdisciplinary studies until they acquire a solid grounding in the various disciplines that interdisciplinarity attempts to bridge'.

Illustrations of the consequences of the tension between centripetal and centrifugal forces on curriculum in regard to educational research can be found through an examination of the literature. For example, Davis (2004) investigated the ways in which project-based instructional practices influenced students' science learning and attitudes about science when they were involved in an integrated investigation of a local pond. The conceptual framework described in the study clearly represented the centrifugal push towards an integrated curriculum through reference to the work of Brickhouse and her colleagues (e.g. Brickhouse, Lowery and Schultz 2000) by arguing that 'understanding students' learning is more than the measurement of their acquisition of facts and skills. Understanding student learning involves having a sense of students' development of identity' (Davis 2004: 5). The notion of 'students' development of identity' is clearly not part of a traditional, science discipline-based framework for understanding student learning. In contrast to the stated theoretical framework, however, the findings presented in the paper report on students' learning as science content knowledge, use of science inquiry

skills, and understanding nature of science. Students' attitudes to science were considered, with the majority of students viewing the project positively, but in the conclusion of this article, the change in students' attitudes was given less importance. This is evident in statements such as, 'this study describes the ways in which students' explorations of a local pond resulted in their learning of science content, inquiry, and the nature of science' (Davis 2004, 22), that make no reference to the students' attitudes or their development of identity.

In another study that demonstrated the effects of tension between centrifugal and centripetal forces on curriculum, Enyedy and Goldberg (2004) investigated how two teachers implemented a school-wide environmental education program designed to integrate technology across the curriculum. The purpose of the research was to look at how 'differences in the classroom communities influence student learning' (p. 912). The theoretical framework of this study referred to literature on communities of practice that 'suggests a shift away from an exclusively individualistic, psychological view on learning toward a perspective of learning involving participation in social interactions within the context of a community' (Enyedy and Goldberg 2004: 906). The authors referred to the work of Cobb in mathematics education and how he made connections between levels of social organization and how students grow into their classroom culture or community. In this sense, the theoretical framework reflected centrifugal forces on curriculum because the learning was described in terms of social interactions within the context of a community and problems that were relevant to the students' lives. While Enyedy and Goldberg (2004: 914) claimed that their 'assessments of student learning reflect these theoretical orientations and assumptions', we view the study in different terms. The individually administered, pre- and post-tests used to assess the students' 'scientific understanding of the domain and their understanding of the tools and procedures of inquiry' (p. 915, including graphing, reading maps and measurement error), are more representative of the discipline-

focused, centripetal forces on the curriculum than the socially-connected, centrifugal forces in integrated approaches. Moreover, we are not surprised by this inconsistency. There is enormous pressure on researchers and teachers to define learning in discipline-based terms of conceptual and procedural understanding of science and, in contrast, little support for those who might be creative and brave enough to explore what learning science might look like in other ways, for example, in terms of growing into their classroom culture or community.

The reporting of these two studies demonstrates that even when the teachers, students, and approaches used in the classrooms under investigation had moved beyond the strictures of a discipline-based curriculum, the standards by which researchers judged student learning remained the standards supported and promulgated by the discipline, in these cases science content knowledge, inquiry skills and understanding of nature of science. In other words, the assessment of outcomes was shaped by the inward, disciplinary-focused centripetal forces, even when the framework of the study was reflective of the outward, centrifugal forces. It is unfortunate that more inspired ways of documenting and describing learning, for example, a more explicit exploration of the students' development of sense of identity, were not included. We do not suggest that this inconsistency is an idiosyncratic concern, confined to the two studies in question, or even to studies in science education, but rather an issue that the education research community as a whole needs to consider. The problem from an educational perspective is that disciplinary-based knowledge has been valued as the major indicator of student learning for so long that we, in the field, are lacking the methods and explanatory frameworks to capture and enable the analysis of learning outcomes that are not strictly discipline-based.

We argue that it is important for the science education community to look beyond a traditional view of what it is to understand and learn science. Parallel arguments can be made for most other school subjects. It is just as important, from a research perspective, to ensure that what

is measured is consistent with the theoretical perspective that guided the implemented curriculum in the first place. This point is not new. It was made by Goodland and Su (1992: 340) who contended that curriculum evaluations ‘must conform to the educational goals established in the first place, not be determined on the basis of other criteria simply because they are easily measured’. Similarly, McNeil (1992: 278) pointed out that empirical studies of curriculum organization lacked consistent terminology and adequate theory. He noted ‘signs that curriculum organization . . . is becoming more consistent with views of an unpredictable and indeterministic world and a systemic view that will address real-world problems’. McNeil recommended that research efforts should ‘describe, appreciate, interpret, and explain’. We suggest that this requires multiple ways of examining the outcomes of curriculum innovation, and that more than one theoretical framework could prove useful in understanding more fully what happens in curriculum integration and describing more faithfully its learning outcomes.

In the next section of this article, we open to discussion and critique the use of theoretical triangulation as a methodological tool that allows researchers to examine classrooms from multiple perspectives, incorporating both disciplinary and integrated learning. Using more than one theoretical perspective enables students’ knowledge to be represented as grounded in their experiences, relationships and contexts, and drawing from, but not bounded by the constraints of, the traditional disciplines. It allows integrated, disciplinary, and other curricular perspectives to be considered together, in an overlapping rather than a mutually exclusive way and therefore to reflect a more holistic view of learning outcomes.

Method

The methodological approach we use to allow this multifaceted scrutiny is theoretical triangulation, which, according to Denzin (1989: 237) ‘consists of using multiple rather than single perspectives in relation to the same set of objects’. Of course, the data collected are always

inflected by the theoretical perspective used to collect them, a point Denzin (1989: 241) took into account when he stated

If facts are determined by theory, then theoretical triangulation is best seen as a method of widening one's theoretical framework as empirical materials are interpreted. The recommended procedure is to use all the interpretations that could conceivably be applied to a given area.

This position moves away from earlier conceptions in the social sciences of triangulation as a way of establishing validity, a conception derived from a navigational technique to locate a desired point by the convergence of data. Instead, as Mathison (1988) pointed out, social researchers often find that there is not only convergence, but also inconsistencies and contradictions in their data. Further, as researchers, we wish to use all of our findings as we work to construct explanations of the social phenomena we study. According to Mathison (1988: 15; original emphasis), '[t]he value of triangulation is not as a technological solution to a data collection and analysis problem, it is as a technique which provides more and better evidence from which researchers can *construct meaningful propositions* about the social world'.

Moran-Ellis *et al.* (2006: 48) put it bluntly: 'This view [of triangulation] replaces the idea that different results suggest flawed measurement with the idea that different results reflect different aspects of a phenomenon'. Fielding and Fielding (1986: 33), in an oft quoted paragraph, noted:

Theoretical triangulation does not necessarily reduce bias, nor does methodological triangulation necessarily increase validity. Theories are generally the product of quite different traditions, so when they are combined one may get a fuller picture, but not a more 'objective' one. Similarly, different methods have emerged as a product of different theoretical traditions, and therefore combining

them can add range and depth, but not accuracy. ... We should combine theories and methods carefully and purposefully with the intention of adding breadth or depth to our analysis, but not for the purpose of pursuing objective truth.

Perhaps surprisingly, theoretical triangulation has been used and discussed more commonly in nursing research than in educational research. Banik (1993: 47), for example, noted the advantages of using triangulation 'if more than one theoretical framework seem essential in explaining important aspects of a phenomenon or if the research design requires multiple types of data'. Hinds and Young (1987) provided an example in a study of wellness, where the theoretical framework construed wellness as a multidimensional and dynamic phenomenon. As we have shown, curriculum integration may also be construed as multidimensional and dynamic, and so may its outcomes.

We illustrate the use of theoretical triangulation through our study of integrated teaching and learning in a school with the pseudonym Eagleton High School. The integrated project under investigation was the design and construction of a solar-powered boat by Grade 9 (13- and 14-year-old) academic extension students. We describe how the conduct of the study impacted on our thinking and how the process of elucidating the theoretical frameworks influenced the way we viewed and analysed the detailed and complex data collected from the case study. Our analyses resulted in three published articles, each of which reflected critical steps in our own learning journey and the progression in our thinking. Each article focused on different aspects of the raw data set and described the selection and analysis of the data from one of three different theoretical perspectives, described here as an integrated perspective (Venville, Wallace, Rennie and Malone 2000), a discipline-based perspective (Venville, Rennie and Wallace 2003), and a sources-of-knowledge perspective (Venville, Rennie and Wallace 2004). Using a retrospective theoretical triangulation, we reflect further on the findings of these three articles to add breadth

and depth to our earlier analyses, allowing us to better understand how the different theoretical perspectives resulted in different ways of understanding the learning outcomes for the participants in the case study.

The design of the original research was a case study (Yin 2003) of the participants in a single classroom in a suburban high school engaged in teaching and learning an integrated topic about the design and construction of a solar-powered boat. During first term, the class teachers of science, mathematics, and technology synchronized their teaching of a series of science and mathematics concepts integral to the design, building, and testing of the boat as a technology project. The culmination of the term's work was evaluating the performance of students' solar-powered boats. Data collection occurred over an intensive, 10-week period. A total of 26, 40-minute lessons was observed and field notes compiled. Data were collected from students and teachers using semi-structured interviews which were audiotaped and fully transcribed. Students worked in groups of two or three, documenting their work using portfolios and making a videotape of significant milestones in their progress. The portfolios were examined and the videotapes viewed. Data triangulation enabled the collection and analysis of a comprehensive and credible body of data to explore students' and teachers' participation in the integrated unit of work and the learning outcomes that resulted.

According to Yin (1989), the exemplary case study must consider alternative perspectives that seriously challenge the design of the study. The perspectives might be alternative cultural views, different theories, or other different contrasts. During the course of this case study, and during the writing of the three articles, we selected different theories to develop what Yin referred to as 'rival propositions' on which to base the data analysis. It was this process of selecting rival propositions that allowed us to perform a theoretical triangulation. Clarke (2001: 14) argued that 'the practice of any researcher enacts a theory of learning (and of knowledge) that

structures the data that is [sic] collected and affords certain interpretations of that data while constraining other possible interpretations'. In the re-examination of our case study, we attempted to break free from the 'methodological monism or myopia' that Clarke referred to by embracing three different theoretical positions to analyse the data in a complementary way. Thus, we do not seek to reject the alternative perspectives based on empirical evidence as suggested by Yin (1989), but to reconcile alternative meanings in order to utilise the richness of the original database to reflect better the learning in a legitimate (in the sense of being non-interventionist), integrated classroom setting. Such an approach is consistent with Clarke's (2001: 29--30) view that 'complementary accounts have the potential to be mutually informing and to constitute in combination a richer portrayal of classroom learning than would be possible by the consideration of either account separately'.

The data to be analysed here are not the raw data collected from the original classroom, but the 'refined' data that were generated in our previously published articles in terms of the methods, models and theoretical perspectives presented therein. Yin (2003) explained that one strategy for analysing case study evidence is to rely on the theoretical propositions that led to the case study. The original purpose and design of a case study are based on such propositions and are reflected in the research questions, the literature review, and new insights. These aspects formed the basis of the re-analysis of the case study data that is presented here. We began by returning to our three published articles and distilling from each the original purpose, research questions, the focus of the literature review, the underpinning theory, the main forms of data representation used as evidence, and the insights drawn from that particular theoretical perspective. A summary of the outcome is presented in table 1, which provides an overview of the refined data for each of the three articles.

Insert table 1 about here

The present article required a two-stage analysis. In the first stage, we asked a series of ‘what’ questions about our refined case study data that enabled us to provide descriptions of the learning outcomes from the three theoretical approaches. We asked:

1. What did each theoretical perspective value as ‘learning’ for the students?
2. What sources and representations of data were used as evidence for assessing the nature of learning from each perspective?
3. What were the results and conclusions made about learning outcomes in an integrated context from each of the theoretical perspectives?

In the second stage of analysis, we reviewed the findings of Stage One, and explored plausible explanations for what was observed. To focus our exploration, we searched for findings which converged, and findings which did not, but were inconsistent or contradictory. This enabled us to construct a more complete theoretical understanding of the learning outcomes from the integrated classroom than was possible from each perspective separately.

Stage one: Analysis of three theoretical perspectives

In the following paragraphs we provide a précis of each of the three articles in terms of the theoretical perspective adopted. Each précis is structured around the three questions referring to what was valued as learning, the nature of the data used as evidence, and the conclusions reached about learning outcomes.

1. An integrated perspective

What was valued as learning outcomes for students? In the first article, we adopted an integrated perspective. We focused on what students learned in integrated settings that they could

not learn in disciplinary-based settings and our research questions (see table 1) examined the broad learning implications of an integrated curriculum involving a science component. This perspective was underpinned by an epistemological analysis of curriculum by Rogers (1997). Rogers described ‘disciplinary’ ways of knowing (in contrast with subjects) as modes of thinking, conceptual tools used by experts, or student experts, when addressing complex problems. Rogers claimed that the dynamic experience of building and using knowledge with students engaged in problem solving and active inquiry is often neglected and undervalued in traditional approaches to curriculum where the focus is often on the factual information that the students are able to memorise. A more practical manifestation of this perspective is described in a very detailed case study labelled a ‘design experiment’ by Roth (1998: 76), who found that much of the students’ learning in an engineering unit was not of the type traditionally valued in schools – ‘the “knowing that” type’ of knowledge. Rather, he found that children developed many competent practices that could be described as “know how to do” a variety of things’. This ‘knowing how to do’ knowledge discussed by Roth is an example of the kind of learning that became the focus of the theoretical perspective used in this article and consequently the results obtained reflected knowledge about ‘knowing how to do’.

What representations of data were used as evidence in this perspective? Data in this article were represented by three learning episodes, each about a pair of students working together on their solar boat. A learning episode consisted of one of a series of more or less discrete events that made up the entire learning experience of the students. We constructed each episode using data from field notes of classroom observations, photocopied records of the students’ assessment portfolios and transcripts of open-ended interviews with the focus students. For example, one learning episode was about Sharon and Cynthia and how they made decisions about the best solar cell circuit for their boat and how to attach it to their boat to maximise exposure to the sun. The

learning episode documents that, through testing and recording the results of various combinations of their cells in series and in parallel, Sharon and Cynthia were able to gain the practical knowledge that connecting the cells in series would increase the voltage reading and connecting them in parallel would increase the current reading. They also learned that a combination of the current and voltage determined the power and hence the performance of their boat. The practical application of the students' understanding of Ohm's Law confounded the students because they were unable to take into consideration the influence of a load on the circuit, so they resorted to more pragmatic methods of finding out 'how to do' the circuit by asking other students. This learning episode also described how knowledge gained from their mathematics class about how to read a sun chart, and mathematical knowledge of trigonometry, enabled Sharon and Cynthia to work out the optimum angle to mount the solar panels on their boat for the time of year and the time of day that the final testing took place.

What were the results and conclusions made about learning outcomes? Using the lens of the integrated perspective, we found that the curriculum enacted by these teachers with these students bridged the compartmentalised knowledge that is usually presented in discrete subject disciplines. The vignette about Sharon and Cynthia exemplified this bridging of knowledge because the students were able to use the language from science and from mathematics and apply their understandings from these disciplines to help them establish maximum power for their boat. We found that through this 'bridged knowledge', the integrated technology project provided a point of application, meaning, context, and relevance for the concepts and skills the students studied in the three learning areas of science, mathematics and technology. The problem solving required for the solar boat project was the driving force behind most of what the students did in each of the subjects. The students were engaged in active inquiry because concepts were being used to address complex problems (Rogers 1997). Our use of an integrated perspective in this

article showed that students' learning was enhanced as a consequence of the bridged knowledge and the applied nature of the integrated project. The whole, we concluded, was greater than the sum of the parts.

The analysis of the data in this first article drew our attention to two additional theoretical perspectives. The second perspective came from our observation that even though the students in this class could apply some conceptual understandings to solve some of the practical problems that faced them, they were likely to have poor conceptual understandings of other science concepts usually regarded as important in discipline-based curriculum. The third perspective came from our observation that students were very pragmatic about finding solutions to their problems from various sources of information. These two new perspectives resulted in the two further articles described below.

2. A discipline-based perspective

What was valued as learning outcomes for students? In the second article we adopted the familiar, discipline-based perspective whereby robust understandings of important phenomena and concepts within the discipline of science were the focus of learning (Fensham, Gunstone and White 1994, Hand and Prain 1995). The research questions in this article (see table 1) focused on the students' conceptual understandings of science and how they applied those understandings to the solar boat project. We looked particularly at the concepts *circuit* and *current* because of the existence of previous research into students' understanding of these concepts (Cosgrove 1995, Driver *et al.* 1994, Osborne and Freyberg 1985). The theoretical framework (see table 1) was primarily drawn from constructivism, both individual constructivism (Fensham, *et al.* 1994, Hand and Prain 1995) and social constructivism (Driver *et al.* 1994), and referred to the process of conceptual change (Cosgrove 1995) as a way of describing and analysing learning.

What representations of data were used as evidence in this perspective? In this article, we presented our findings as narrative style anecdotes documenting the conceptions held by each individual student about circuit and current. The data were obtained through multiple choice (forced-response) individual interview questions about circuits and current (based on Osborne and Freyberg 1985), followed by open-ended interview questions that further probed the students' understanding and reasoning. Field notes of classroom observations and student portfolio data were used to build the narratives about the application of those concepts to the process of building the solar powered boat.

What were the results and conclusions made about learning outcomes? We found that students had a clear, scientifically appropriate awareness that a closed circuit was required for current to flow. Without this understanding the students would not have been able to build a working solar boat. However, we were surprised to find that all interviewed students had a consumption (non-scientific) view of electric current. For example, one student, Kevin, held a consumption view of electric current so strongly that he was sure that tests would indicate that the current would be reduced once it 'had been past the light bulb'.

From the discipline-based perspective, there was evidence to suggest that the students had a good understanding of some aspects of electricity, such as the concept of circuit. There also was clear evidence that their understanding of the concept of current was inconsistent with the accepted scientific view. The consumption view of electrical current held by the students was likely reinforced by the practical, applied nature of the technology project. It would seem that the students were able to solve problems with limited scientific conceptual tools. Rather like the electrical tradesperson who routinely solves practical electrical problems without sophisticated theoretical knowledge, these students constructed their boats with naïve understandings of electricity.

3. *A sources-of-knowledge perspective*

What was valued as learning outcomes for students? In the third article, we adopted a sources-of-knowledge perspective, focussing on the process of decision making and investigating how students sought and used knowledge to make key decisions about the solar boat project. We were also interested in how science and mathematics content knowledge was used or valued by the students as they carried out their projects.

In developing this framework, we drew on Reiss and Tunnicliffe's (1999) and Roth's (1998) findings that people outside the classroom, such as family and community members, as well as other classroom participants, like teachers and classmates, are sources of knowledge that can be, and are, used in the classroom. These authors suggested that the origins of knowledge and the value that students place on different sources of knowledge may be critical to the outcome of the learning exercise. Similarly, Newman and Schwager (1992) examined why, and under what conditions, certain children feel confident and comfortable seeking assistance from teachers and classmates, whereas other children do not. The process of seeking assistance is referred to by Newman and Schwager (1992: 125) as 'adaptive help-seeking', and they define it as a strategy of self-regulated learning. They explain this process as the strategic posing of direct, verbal questions for the purpose of obtaining information required for the successful completion of school tasks.

What representations of data were used as evidence in this perspective? We presented the data in this third article in the form of three embedded, narrative cases describing students' critical decisions about hull design, circuit design and solar cell mount design. Each case consisted of a lesson précis constructed from field notes of classroom observations, a vignette of the students' decision making process constructed from field notes of classroom observation and transcripts of student interviews, and a diagrammatic representation of sources of information

used by the pairs of students to make the decisions. The diagrammatic representations were constructed from the vignettes and cross-checked with the raw field notes and transcripts. The diagrammatic representations provided an indication of the chronology of the decision making process and when the various sources of knowledge were used.

What were the results and conclusions made about learning outcomes? We found that the students used several sources of knowledge to make key project decisions about the solar-powered boat. These sources included the content knowledge taught in science and mathematics lessons, the classroom teachers, data from trials and tests performed by the students during lessons, students from within the class, and students and other people, like family members, from outside the classroom. The extent to which the students relied on various sources of information also seemed to be linked directly with the degree of open-endedness of the problem that the students were attempting to address (Venville *et al.* 2004). We observed that the students tended to have a pragmatic approach to sourcing information, seeking out ways of obtaining potentially 'good,' or workable, solutions to their problem.

Our findings from this third perspective confirmed those of Reiss and Tunnicliffe (1999) and Roth (1998) that people outside the classroom, such as family members, as well as teachers and classmates, are valued and regularly used sources of knowledge. Further, we found evidence of adaptive help-seeking strategies (Newman and Schwager 1992) being used by the students in this project. The integrated solar-powered boat project provided a context where the students were academically challenged because they didn't know all of the answers and hence sought knowledge from a range of sources to find solutions. Moreover, the students showed sufficient curiosity and interest in their work that they were motivated to seek information from those sources of knowledge. According to Newman and Schwager this practice indicates that they were striving for independent mastery, that is, they wanted to learn in order to master a task or solve

the problem at hand, rather than for some extrinsic reason, for example, to satisfy the teacher or get good grades.

Stage two: Synthesis and discussion

In the previous section, we summarized the outcomes of our analysis from each of three theoretical perspectives. In this section, we re-examine those findings, searching not only for convergence but for inconsistencies and contradictions that enable us to construct a more complete understanding of what was observed in terms of the theoretical perspectives underpinning each of the three articles. We are, in Denzin's (1989: 242) words, 'making the widest possible use of [our] set of observations', in order to better understand the learning outcomes occurring in this integrated classroom. We found two major organising themes: what it means to learn science, and how learning is assessed.

What it means to learn science

One contradiction that leaps from this juxtaposition of the three theoretical perspectives is, why is it that from an integrated perspective, student learning was seen to be enhanced beyond what they would learn in the individual subjects, but from a disciplinary perspective learning was seen to be limited because none of the students understood the concept of current? Judging by the amount of research that has been conducted on teaching and learning of current, it is a concept highly valued by the science education community. It is commonly found in science curriculum documents around the world. From a science discipline perspective the concept of current is worth knowing and understanding.

Paradoxically, however, this concept was of little value in helping the students to construct and race their solar-powered boat. We speculate that the inclusion of the concept of electrical current in this teaching and learning program was a relic of a curriculum motivated and supported by a science discipline-based approach, reflecting the centripetal forces which place

value on the concepts and principles traditionally supported and taught by science teachers. Moreover, our choice to research about the concept of current was a relic of our own discipline-based interests and backgrounds and something which seemed important to us at the time. When viewing this classroom from a discipline perspective, our concerns, like those of many other researchers and teachers, were focused on the need for students to learn and understand what are considered to be important, traditional science concepts, such as circuit and current.

An integrated perspective problematizes the role of discipline-based knowledge. For example, could it be that concepts, such as the nature of electric current, that do not serve or support the outcome of building and racing a solar-powered boat have little legitimacy or grounds for inclusion in an integrated curriculum? Czerniak *et al.* (1999: 428) argued that ‘integration can be justified only if the understanding of content is enhanced and if integration is the best way to teach concepts’. If we adopt the view of those authors, the integrated approach to curriculum described in this case study can not be justified because it did not enhance the understanding of important scientific concepts such as current. This seems to us to be a limited view because from other perspectives, such as an integrated perspective and a sources-of-knowledge perspective, learning can take place even when conceptual learning is not optimal.

In a related example of contradiction, Brantlinger and Majd-Jabbari (1998) reported that while middle class parents supported the notion of an integrated curriculum, their narratives revealed a preference for conservative, factual, subject-bound curricula in which their children have traditionally performed well. This contradiction may have arisen because learning is more often viewed and reported to parents from a single, disciplinary view of knowledge and learning. We suggest that a similar underlying preference and history of experience with science-based knowledge influenced the teachers who created the curriculum for this case study and also influenced us as researchers. Although school subjects, such as science, do not map directly onto

their parent disciplines, at the school level each discipline carries with it traditions of teaching, learning, and assessment (Deng 2008, Shulman and Sherin 2004), so the nature of the discipline has consequences for the ways that teachers teach and assess. This history is not easily cast aside by teachers or researchers as they grapple with what it means to deliver or examine and understand an integrated approach to curriculum. Rogers (1997) claimed that school subjects have traditionally presented knowledge as ‘finished products’ rather than as modes of thinking and conceptual tools that can be used to address complex problems. This case study revealed that for the teachers and for us as researchers (but perhaps not the students) the notion of electric current as a ‘finished product’ was more prevalent than as a ‘mode of thinking or a conceptual tool’.

Interestingly, in an example of convergence of our findings, all three alternative perspectives demonstrated that students were involved in active inquiry and application of concepts in meaningful, relevant contexts. They were intrinsically motivated and pursued adaptive help-seeking strategies to learn from various sources of knowledge in order to master the task of building a solar powered boat.

The assessment of learning in science

In comparing the three perspectives, we reconsidered the ways that we selected and presented the data in order to answer the research questions. While the data were selected from the same database, each data presentation painted a different picture of the same classroom because it drew from a different theoretical perspective. One exception is that only the analysis from the disciplinary perspective drew from the forced-response interview data. These closed questions directed students to select a particular response from a set of four alternatives representing common conceptions of circuits and of current. In contrast, the data used for the

integrated perspective and the sources-of-knowledge perspective were selected primarily from classroom field notes, open-ended interview responses and student portfolios.

This inconsistency derives from the long, established research history of evaluating learning about science concepts using diagnostic tests. Learning from the other two perspectives does not have such a well-established bank of supporting instruments for diagnosing learning and understanding. Researchers and teachers, therefore, are inclined to use more descriptive and less prescriptive methods of collecting and presenting data to show learning from other, non discipline-based perspectives. This observation highlights the difficulty faced by educators in recognising and describing the learning that occurs in integrated classrooms, particularly the learning that is not of the traditional ‘knowing that’ kind (Roth 1998). Moving from the more traditional approaches to researching science learning in integrated contexts – such as those attempted by Davis (2004) and Enyedy and Goldberg (2004) – towards exploring more innovative and lateral aspects of learning, means moving to a realm where the research is less supported by traditions, there are few standard instruments, and few clear definitions of what it is that researchers should be looking for to assess learning outcomes. This makes the documentation of learning outcomes in these contexts very difficult to describe using traditional, discipline-based terms and explanations. When these research factors are taken into consideration, it is not surprising that even though Davis (2004) was interested in elucidating the ‘students’ development of identity,’ in the end, she resorted to the conventionally acceptable option of describing students’ science content knowledge, inquiry skills and their understanding of nature of science. Similarly, it is not surprising that Enyedy and Goldberg (2004), while suggesting an exploration of how students ‘grow into their science classroom culture or community’, used cognitive pre- and post-tests to assess the students’ scientific understanding of the domain and their understanding of inquiry. This historically validated approach to measure learning in science

owes much to the centripetal forces that assign value and status to the concepts and pull teachers and students towards the centrality of the discipline.

Measuring learning outcomes from a non-disciplinary perspective requires a different and multifaceted approach. Our work in this field, and our review of literature about integrated curriculum, leads us to propose the need for a vision that is broader and more encompassing than the narrow, science discipline-based perspective, to understand and evaluate what students learn about science in integrated settings. Such a vision would encompass what Davis (2004) found with regard to children learning science content knowledge, their use of science inquiry skills and their understanding of nature of science. More importantly, it might have given Davis a broader framework within which to explore in a more meaningful way the notion of ‘students’ development of identity’ and Enyedy and Goldberg’s (2004) notion of ‘growing into their classroom culture or community’.

An important advantage of finding a balance between the centripetal, discipline-focused and centrifugal, integrating forces that shape curriculum is that disciplinary knowledge can be seen and evaluated in an applied, real world context by students, teachers and researchers alike. For example, we observed that science concepts like circuit, current, Ohm’s Law and Archimedes’ Principle may or may not be useful in terms of the real world problem of building and racing a solar powered boat. The concept of circuit was useful in the sense that students could construct a working circuit on their boat. This concept, as learned in their science class, had its limitations, however, and students needed to go to other sources of knowledge to find out what combination of solar cells, in series or parallel, would give them the best power output. Ohm’s Law helped students to understand that in series the voltage would increase and in parallel the current would increase, but it was only the practical, applied nature of the project that helped the students to realise and understand that the power output was complicated by the load. The

simplicity of Ohm's Law did not help them with an accurate calculation of power output in their solar boat. In the construction of the hull, students could use Archimedes' Principle to calculate scientifically whether their planned hull would sink or float, but to investigate the more subtle nuances, such as stability and the degree to which the hull would float above the water line, they had to explore alternative sources of knowledge. They needed to test hull shapes, do trials, and ask other people, including the teacher, to find a successful approach.

Towards a more balanced approach to curriculum

We began this article by using the metaphor of centrifugal and centripetal forces to describe the tensions between discipline-based and integrated curricula. We finish with a proposal about how these seemingly opposing forces may be reconciled or balanced within an understanding of school curriculum. The centripetal forces push students inward towards a unified discipline, such as science, and maintain the content and process of that discipline. Similar forces work to maintain the unity and boundaries of other disciplines, such as mathematics. In such a system, students learn science, mathematics and subjects derived from other disciplines as separate and disconnected. In contrast, centrifugal forces impel students outward towards multiple dimensions that better reflect real world experiences. These experiences are shaped by issues, concerns and problems that decentralize and disunify the disciplines, blending knowledge without regard to subject boundaries. Somewhere between these opposing forces there has to be a balance, a position that can serve the need for discipline knowledge and the need to understand the interdisciplinary nature of the issues and problems posed by the world outside of school. Within a balanced curriculum, students can be encouraged to reflect on and critique subject-specific knowledge, understand the limitations of that knowledge, particularly in applied situations, and recognise when creativity, lateral thinking, adaptive help-seeking, and trial and error play a role in the knowledge building process. This

broader, more balanced view of curriculum allows students, teachers, and researchers to value disciplinary knowledge and to utilise the cognitive and practical tools that the discipline may offer. At the same time, it allows students, teachers, and researchers to look outward to engage in relevant, exciting, and motivating real world problems and issues, and to explore how disciplinary knowledge can be useful in understanding, addressing and solving those problems and issues. Moreover, it allows students and teachers to realise the limitations of disciplinary knowledge in specific contexts and to explore other avenues and sources of knowledge that may be more practical, expedient, informative, or simply more social or fun, than allowed by the rigorous rules and rigid processes of the discipline.

In contrast with the Davis (2004) and Enyedy and Goldberg (2004) studies described earlier in this article, Hargreaves and Moore (2000) examined what a group of leading-edge teachers made of curriculum integration in their classes. Their study set out to build an understanding of what integration actually looked like in the teachers' classrooms from the bottom up, rather than imposing a predetermined, discipline-based framework for analysis. They found that one of the common themes that characterised the integrated practice was that of relevance. Distinct forms of relevance revealed by their analysis included relevance to employment, relevance to personal development and relationships, and relevance to social and political contexts. The researchers used each of these forms of relevance as a lens through which the teaching practice could be critically appraised. For example, through the lens of social and political relevance, drawing on current events in the community was a particularly effective way of simulating current affairs in classroom activities. The authors also acknowledged the problems teachers faced when facilitating students' examination of issues of social and political relevance. The issues were usually somewhat distant in time and space from the societies in which the students lived. In this respect, Hargreaves and Moore (2000: 7) found that the integrated

curriculum, 'while bold and critical in making connections with society, also appeared to be silent on many of the most controversial social and political issues of today that were relevant to students' present and future lives'. The authors concluded that, at best, the integrated approaches observed in their study advanced the rigour of classroom learning and made learning more applied, more critical, more inventive, and more meaningful for students.

There is a critical difference between the Davis (2004) and Enyedy and Goldberg (2004) studies and the Hargreaves and Moore (2000) study. The former two studies were focused on students' science learning whereas the latter explored the manifestation of an integrated curriculum unbounded by the constraints of a particular discipline. We contend that the science discipline context of the former two articles acted in a centripetal way, forcing the researchers to focus on the content, methods and nature of science. In contrast, the unbounded research of Hargreaves and Moore acted in a more balanced way, enabling the researchers to be influenced by both the centrifugal and centripetal aspects of the curriculum and to analyse the multiplicities of learning that lie beyond the learning of discipline-based content and processes. In a similar way, our article that examined curriculum integration from a disciplinary perspective (Venville *et al.* 2000) focused our findings in a centripetal sense on the traditional forms of science learning. The process of theoretical triangulation, however, has given us a broader and more meaningful understanding, not only about what happened within a particular case study, but of the nature of the learning outcomes in more general terms.

The educational implications of this study are potentially profound for teachers, curriculum developers and researchers. We suggest that it is possible to find some balance between the centripetal forces creating unity of their discipline and the centrifugal forces and interdisciplinarity that reflect the multiple dimensions of reality. Of course, the place where balance may be found will vary depending on the objectives and desired outcomes of a particular

curriculum. In terms of science, such a balanced approach enables educators to examine the learning of science in integrated classroom settings in ways other than, but in concert with, the learning of the content, processes and nature of science, enabling a more holistic evaluation of the learning that occurs in integrated curricular settings. It is also an approach that resonates with Roberts' (2007a) Vision II for science/scientific literacy.

In this study, the problems associated with viewing a learning situation through one theoretical lens were acknowledged and compensated for by the use of a framework that accommodates multiple theoretical perspectives. Our findings show how triangulation of these theoretical perspectives exposed student learning in integrated contexts in a way that has previously been elusive because of a singular theoretical perspective that has restricted a more comprehensive vision. This balanced approach can assist teachers, curriculum developers, and researchers to make more informed decisions about the implications of curricular approaches for students and their learning.

In conclusion we suggest that the learning of science in integrated settings can and should be examined through frameworks other than (as well as) those traditionally used by science educators. We call this approach a worldly, interpretive framework (Venville *et al.* 2002). As committed science educators it has taken us some time, considerable research effort, and a quiet conceptual revolution to come to this position. We have come to understand that the centripetal and centrifugal forces described above, act not only on curriculum and those enacting the curriculum, but these same forces act on us as researchers and influence the questions about curriculum that we ask, the methods we use, the theoretical frameworks we develop and consequently, the way that we are able to see and analyse the world around us. What we have attempted to represent in this article is the research journey that has brought us to this position.

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Table Caption

Table 1. A summary of the three perspectives used in articles based on the case study of Eagleton High School.

Perspectives	Purpose:	Research questions:	Major focus of literature review:	Underpinning theory:	Main form of data representation used as evidence:	Insights:
1. Integrated perspective Venville, Wallace, Rennie and Malone (2000)	To examine potential educational gains for students studying in integrated settings by exploring the nature of student learning.	1. How can integrated teaching/learning in science, mathematics and technology be described when it is implemented in a traditional, discipline-based school environment? 2. What happens to student learning as a result of an integrated approach to teaching?	<ul style="list-style-type: none"> The applied nature of learning in integrated settings (e.g. Roth, 1998, Ritchie and Hampson 1996) Motivation (Wicklein and Schell 1997, Clark and Clark 1994, Henderson and Landesman 1995) Teachers' concerns (Venville, Wallace, Rennie and Malone 1998) 	<ul style="list-style-type: none"> Teaching for deep understanding (Perkins 1991) Disciplinary ways of knowing as modes of thinking or conceptual tools (Rogers 1997) 	Three narrative learning episodes about three pairs of focus students. 1. The boat that tipped over and sank 2. Rigging up the solar cells 3. The boat that did not work. Data sourced primarily from classroom observation and open-ended interview questions.	<ul style="list-style-type: none"> Teachers with specific subject-related knowledge and skills could provide an integrated environment with application, meaning, context and relevance. Student learning was enhanced beyond the learning that occurred in the separate disciplines. Thinking and learning bridged traditionally compartmentalised knowledge, i.e. learning that occurred in science was applied to problems in technology.
2. Discipline-based perspective Venville, Rennie and Wallace (2003)	To examine science understanding and application in the context of an integrated teaching module.	1. What conceptions do students have of 'circuit' and 'current'? 2. How do students apply their understandings of electricity while they	Learning about electricity (Driver, Squires, Rushworth, and Wood-Robinson 1994, Cosgrove 1995, Osborne and Freyberg 1985, Shipstone 1985)	<ul style="list-style-type: none"> Individual constructivism (Fensham, Gunstone, and White 1994, Hand and Prain 1995) Social constructivism (Driver <i>et al.</i> 1994) 	Anecdotes were constructed about each student's understanding of the concepts circuit and current based on forced- response and open-ended interview questions. Information about application	<ul style="list-style-type: none"> The concept of circuit was applied to the integrated project and this helped to enhance its relevance. Learning reflected the idea of 'knowing how to do' a variety of things (Roth 1998). All students had a 'consumption' (non-scientific) view of electric current.

		are working on an integrated, technology-based project?			collected from open-ended interview questions and classroom observation.	• Learning in integrated contexts was not the 'knowing that' type of knowledge traditionally valued in schools.
3. Sources of knowledge perspective Venville, Rennie and Wallace (2004)	To investigate how students sought and used knowledge to make key decisions that significantly affected the outcomes of the technology-based solar boat project.	1. How useful are the facts, information and concepts learnt in science and mathematics to students who are trying to complete technology-based projects or solve engineering problems? 2. In what ways are sources of information such as the teacher, other students and people outside the classroom preferred sources of knowledge?	• Students' conceptions of knowledge (Rogers 1997, O'Loughlin 1994) • Learning communities and sources of knowledge (Roth 1998, Reiss and Tunnicliffe 1999) • Adaptive help seeking (Newman and Schwager 1992)	• Integrated knowledge (Beane 1995) • Children's conceptions of knowledge (O'Loughlin 1994)	Data are presented as three, narrative style, embedded case studies based on critical decisions that the students had to make about: 1. hull design, 2. circuit design, and 3. solar cell mount design. Data mainly from classroom observation, informal interviews and open-ended interview questions.	• Students used several sources of knowledge to make key decisions, including discipline knowledge, student-performed tests and trials, the teacher, family members and other students. • Students had a pragmatic approach to selecting their sources of knowledge. • Adaptive help-seeking strategies were demonstrated by students.