'Even though it might take me a while, in the end, I understand it': a longitudinal case study of interactions between a conceptual change strategy and student motivation, interest and confidence

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Abstract

Although there have been many investigations of the social, motivational, and emotional aspects of conceptual change, there have been few studies investigating the intersection of these factors with cognitive aspects in the regular classroom. Using a conceptual change approach, this case study reports experiences of a student of low to average prior attainment who achieved high levels of conceptual gains in five science topics over a two-year period. Her experience in the cognitive, social and affective domains was probed through analysis of interviews, student artefacts, video recordings of classroom learning, pre/post-tests and questionnaire results. For this student, peripheral or incidental persuasion of belonging to a supportive small group initially led to greater engagement with the construction of understanding through production of multiple student-generated representations, resulting in improved self-confidence and high levels of conceptual change. Evidence of transfer from performance to mastery approach goals, adoption of positive activating emotions and increased interest in science were observed. This study highlights that adoption of a multidimensional conceptual change approach with judicious organisation of small groups to support construction of verbal, pictorial and written representations of understanding may bring about changes in motivational stance, self-confidence and emotions to maximise conceptual change.

Keywords: Motivation, Self-efficacy, Concept formation, Interpersonal relations, Emotions, Metacognition

Introduction

A vast body of literature describing and explaining the conceptual change process has been produced in studies from the realms of cognitive psychology, science education, social psychology and sociocultural aspects of learning. Each of these perspectives provide much valuable insight into conceptual change, methodologies and social constructs that support that change and learner characteristics that increase the likelihood of change occurring. Recently, evidence from each of these fields

have begun to be synthesised in order to maximise opportunities for conceptual change (Cordova, Sinatra, Jones, Taasoobshirazi, & Lombardi, 2014; Dole & Sinatra, 1998; Duit & Treagust, 2003; Tobin, 2008; Treagust & Duit, 2008; Zembylas, 2005).

What is missing from the literature is a critical evaluation of a conceptual change approach, in the regular classroom (Duit & Treagust, 2012b), in terms of the interaction between the students' cognitive/social experience in learning and their motivational stance, interest in science, self-efficacy beliefs and emotions, all of which have been shown to influence a students' intentionality

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in undergoing conceptual change (Sinatra & Mason, 2013; Sinatra & Pintrich, 2003b). Sinatra and Mason (2013) summarised the conditions under which conceptual change occurs as being 1) when students experience cognitive dissonance between their current understanding and an observed phenomenon, 2) when students are intentional in learning, and 3) when students possess activated emotions about learning.

While there have been many studies on how affective aspects, motivation, self-efficacy and interest effect students' levels of engagement and conceptual change, and suggestions of how to increase students' interest, motivation and self-efficacy, most studies were not carried out in regular classrooms but rather under controlled conditions. What is needed are studies which implement the recommendations from these studies in the classroom and which encourage students to adopt greater intentionality in learning. As suggested by Dole and Sinatra (1998), case studies of students who undergo conceptual change are needed in order to obtain a more detailed understanding of the complex interactions that occur in this process such as that of Harrison and Treagust (2001). This longitudinal case-study investigated a student's experiences learning science using a conceptual change teaching strategy called the Thinking Frames Approach (TFA) (Newberry & Gilbert, 2007; Newberry, Gilbert,, & Consortium, 2011) in Years 9 and 10. Rachel, the student chosen for this study, held performance goals, had low self-confidence and negative deactivating emotions with regards to learning science, and had low to moderate attainment in assessment tasks prior to the study. As a result of the intervention, she achieved surprisingly high conceptual gains on all pre/post scores compared to other students, developed mastery approach goals, improved interest and positive activating emotions about science, and self-confidence in her ability to understand scientific concepts. The following research question is addressed: What characteristics of the learning intervention and the social environment interacted with Rachel's learner characteristics in order to bring about change in both the cognitive and affective domains? In this study, we referred to evidence of conceptual change from both cognitive and affective dimensions shown in the Multidimensional Conceptual Change Model which is described below. To provide the basis for this research question, we review the research findings on the learning intervention social environment and learner characteristics.

Multidimensional conceptual change

Initially conceptual change studies within the field of science education focused on cognitive aspects, resulting in frameworks such as the Cognitive Change Model (Posner, Strike, Hewson, & Gertzog, 1982), Framework Theories (Vosniadou, 1994) and Ontological Category Shifts (Chi, 1992) to explain and support cognitive processes occurring. Since the 1990's there has been a focus, particularly from social psychologists, of how social aspects and affective factors such as motivation, interest, intentionality and self-efficacy support conceptual change. This recognition led to the claim that effective conceptual change strategies should be multidimensional, focusing on cognitive, social and affective aspects of that change (Duit & Treagust, 2012a; Tyson, Venville, Harrison, & Treagust, 1997).

Most studies focusing on social-affective aspects measured conceptual change in the cognitive dimension in response to those aspects (For example Eymur & Geban, 2016; Ranellucci et al., 2013; Taasoobshirazi & Sinatra, 2011), while a few studies examined the effect of a conceptual change intervention on student affect (Franke & Bogner, 2013; Lee & Byun, 2012). Similarly, few studies have looked at the effects of a conceptual change approach on affective aspects in the normal classroom (Dole & Sinatra, 1998; Murphy & Alexander, 2008). Since affective aspects clearly influence the degree of cognitive conceptual change, it seems that these affective variables also need to be explicitly addressed and developed so that they in turn undergo change (Duit & Treagust, 2012a).

Effect of social environment on conceptual change

Conceptual understanding is constructed not only cognitively and emotionally but also socially (Zembylas, 2005). Vosniadou (2013) writes of the importance of not only carefully designing students' learning progressions to address students' conceptual frameworks but also notes the benefits of constructing students' conceptual understanding and encouraging intentionality through social support. A fruitful way of supporting metacognition is through providing dialogical interactions in whole-class and small-group discussions which can lead to greater engagement with conscious reviewing of beliefs (Alexander, 2018; Duit & Treagust, 2012b; Vosniadou, 2013).

There are several benefits in being given opportunities to construct understanding in a meaningful way with peers in small groups as a community of learners. As students work towards a common task, they do not simply share ideas but 'interthink' (Mercer, 2000, 2013). Mercer (2013) suggests that interthinking occurs as students share knowledge and problem-solving strategies, argue productively to co-construct strategies and explanations, and present evidence to justify claims resulting in transformation of students' reasoning. Students who have the shared goal of persuading someone else are motivated to use evidence to support their arguments and, as they do so, scientific explanations gain in value, increasing the possibility of schemata being modified and long term conceptual change occurring (Berland &

Reiser, 2009). In addition, collaboration with peers improves understanding by: giving opportunity to act as a teacher which builds students' confidence in constructing explanations and learning independently; and strengthening students' metacognitive skills in evaluating their own and peers' explanations (Hausmann, Chi, & Roy, 2004; Sandi-Urena, Cooper, & Stevens, 2010).

In order for students to gain the social benefits of small group interactions there are many factors which must be taken into account in choosing the composition of the small group and the types of activities that they are asked to perform. Researchers suggest that the greatest collective benefit to students is when discussion occurs in mixed-ability small groups (Cohen, 1994; Lou et al., 1996). In particular, students with low prior achievement recognise the benefits of participating in mixed ability groups (Tereshchenko et al., 2018) and have been shown to benefit in recall and problem solving (Hooper & Hannafin, 1988) and higher order thinking (Tudge, 1990). Higher order thinking occurs in small group interactions when the problems chosen are ill-structured, involving conceptual learning and production of hypotheses and argumentation to find elaborated answers (Cohen, 1994; King, 2002).

Affective dimensions
Since Pintrich, Marx, and Boyle's (1993) influential article was published, which turned attention to the affective aspects of conceptual change, researchers have investigated the influence of motivational, and other affective characteristics of the learner on the degree to which they undergo conceptual change. Even though students may have similar background knowledge or hold a similar conceptual ecology they possess differing learning goals, intentions to learn, motivations, feelings of self-efficacy and interest (Sinatra & Mason, 2008). These affective factors play an important role in whether a student will adopt a scientific understanding of a phenomenon by encouraging more active engagement with learning (Sinatra & Mason, 2008) and are strong indicators for success and persistence in studying science (Ting, Sam, Khor, & Ho, 2014). In order to understand the conceptual change process, it is necessary to investigate the interaction between learner characteristics and the cognitive aspects of conceptual change (Sinatra & Mason, 2008).

Intentionality in conceptual change
Sinatra and Pintrich (2003b, p. 6) defined intentional conceptual change as 'goal-directed and conscious initiation and regulation of cognitive, metacognitive, and motivational processes to bring about a change in knowledge'. Intentional learning is student directed and initiated and underpinned by the students' goal orientation.

Students intentionally regulate their own learning, are aware of metacognitive strategies, are motivated to focus on the task and are willing to restructure their understanding (Limon Luque, 2003), rather than just being at the mercy of their previously held knowledge or being controlled by the level of difficulty of the task (Sinatra & Pintrich, 2003a). Conceptual change involves the restructuring of conceptual frameworks (Chi, 1992; Dole & Sinatra, 1998; Vosniadou, 1994) and hence engaging students on an intentional level may be essential for effective and long-lasting change as they encounter discrepant events, and construct new frameworks based on their plausibility and fruitfulness (Sinatra & Pintrich, 2003a; Sinatra & Taasoobshirazi, 2011).

However, the most common form of conceptual change in classrooms may be unintentional, as students are often unaware of the change that is taking place in their conceptual understanding (Vosniadou, 2003). Since unintentional change does not involve a conscious understanding of the conceptual change that has taken place the persistence of such changes have been questioned (Hatano & Inagaki, 2003; Sinatra & Pintrich, 2003a). However, Hatano and Inagaki (2003) suggest that, because intentional conceptual change requires a lot of effort, it may only occur when students feel that, in order to understand a phenomenon there is no other choice but to intentionally engage in recognising the differences between their prior conceptions and scientific conceptions.

The importance of persuasion, via central and/or peripheral routes, as suggested in the Cognitive Reconstruction of Knowledge Model (CRKM) (Dole & Sinatra, 1998), in encouraging intentional consideration of the plausibility one's own conceptions versus the intelligibility and plausibility of the scientific ideas provided is suggested through extensive research on attitude change (Hynd, 2003). The central route to persuasion occurs as a result of engaging directly with scientific concepts and arguments challenging alternative conceptions. The peripheral route to persuasion involves non-cognitive factors, such as admiration of peers, for instance popular girls (Fisher, 2019) or students who are generally respected as high achievers, which leads to adoption of those peers' explanations.

Achievement goals
Achievement goals are the motivation behind why a student does or does not engage in learning a particular topic (Elliott & Dweck, 1988) and consideration of these goals is necessary to support conceptual change (Linnenbrink & Pintrich, 2003).

There are two broad categories of achievement goals: mastery and performance goals (Sinatra & Mason, 2008). A student who has mastery goals is intrinsically interested in learning deeply and gaining mastery of skills.

Rather than giving up when they encounter difficulties, they persist, learning to overcome them. They have also been shown to use more self-regulation strategies and undergo greater levels of cognitive change (Pintrich, 2000; Pintrich & Schrauben, 1992). A study of Ranellucci et al. (2013), based on the CRKM of Dole and Sinatra (1998), showed that a mastery goal approach was linked with use of both deep and shallow processing strategies and engagement in these strategies, particularly deep processing strategies, led to conceptual change. Deep processing strategies involve summarizing and elaboration of ideas, integration of new ideas into existing knowledge schemata and meta-cognitive strategies, while shallow processing involves memorization or activation of previously acquired knowledge with little metacognition.

Students with performance goals, however, are more focused on themselves, results and their appearance as learners to others (Pintrich, 2000; Pintrich & Schrauben, 1992). Their goal is to show others that they are competent learners, and their self-worth is tied up with being able to show that they are good students (performance approach) or avoid showing others that they are not good students (performance avoidance). These students do not persist when they make errors, they avoid challenging tasks as they may not feel adequate when addressing them, they engage less deeply with tasks and have fewer control strategies (Pintrich, 2000; Pintrich & Schrauben, 1992). Possessing high performance approach or avoidance goals and low mastery goals appears to mitigate against conceptual change since they are focused on appearing to be 'good students' or not appearing to be 'poor students' to others rather than on using mistakes as learning experiences (Ranellucci et al., 2013).

Epistemic motivation
Sinatra and Mason (2008) identified another form of motivation: epistemic motivation which focuses on motivation to obtain new knowledge and understanding, and restructure knowledge. There are two types of epistemic motivation –seeking closure and avoiding closure (Kruglanski, 1989). The goal of seeking closure is to get definitive knowledge about a topic in order to avoid uncertainty or because there are time constraints. This can lead to students quickly making decisions without truly restructuring their understanding (Kruglanski, 1989). Conversely, epistemic motivation avoiding closure is associated with a disposition which continues to search for further clarification and new hypotheses, allowing for greater conceptual change (Sinatra & Mason, 2013). Hatano and Inagaki (2003) suggest that a motivational disposition, which avoids closure when confronted with discrepant events, leads to students being willing to consider different explanations, particularly when this takes place in a social environment through classroom dialogues which review and discuss different possible explanations.

Interest
Students' level of interest, like achievement goals, has the power to direct students' attention towards the concepts being learned as well as being a motivator for conceptual change (Sinatra & Mason, 2008). Individual interest seems to be a stable factor related to a student's long-held attitude towards a subject (Murphy & Alexander, 2008). In contrast, situational interest can be induced (Schraw & Lehman, 2001). For instance, teaching through presentation of alternative conceptions about gene technology resulted in students developing greater interest when alternative conceptions were made visible and those students with greater interest adopted more scientific conceptions (Franke & Bogner, 2013). However, more studies investigating the effects of conceptual change strategies on student interest are needed (Sinatra & Mason, 2013).

Self-efficacy
A student who feels greater self-efficacy is more confident in their abilities to successfully learn (Schunk & Zimmerman, 2006). Bandura suggests that students' self-efficacy is a major motivating factor for what students will be willing to expend their effort on (Bandura, Barbaranelli, Caprara, & Pastorelli, 1996). The greater this feeling of self-efficacy the more likely students are to persist with a task, even when they find it difficult (Schraw, Cripen, & Hartley, 2006). High levels of self-efficacy result in less stress about tasks and greater confidence that difficult concepts can be learned resulting in greater engagement in self-regulatory processes (Pajares, 2002) and higher levels of intentional conceptual change (Sinatra & Mason, 2008). Provision of informational feedback on tasks has been shown to improve feelings of self-efficacy (Hattie & Timperley, 2007) particularly when the students attribute improvements to their own efforts (Schunk, 1987).

Emotions
Pekrun, Goetz, Titz, and Perry (2002) classified emotions into positive or negative, both of which can have activating or deactivating effects on learning. For instance, emotions such as enjoyment or pride are classified as positive activating emotions and have positive influences on learning by improving motivation, use of metacognitive strategies and by encouraging greater elaboration and critical thinking (Taasoobshirazi, Heddy, Bailey, & Farley, 2016). In comparison, negative deactivating emotions such as boredom and hopelessness undermine motivation, turn student attention away from the task and

reduce opportunities for conceptual change (Liu, Hou, Chiu, & Treagust, 2014; Sinatra & Mason, 2013).

It is clear from the literature that social, emotional and motivational aspects of learning strongly influence students' intentionality in undergoing conceptual change in the cognitive domain. However, Fortus' study (2014) showed an under-representation of publications in major science education journals addressing these affective aspects of teaching and learning science. Even less is known about the ways in which a student's learning experience can positively influence learner characteristics such as motivational stance and intentionality.

Methods and analysis
Research design
This case study was part of a larger two-year explanatory sequential mixed-methods (Creswell, 2014) research investigating the effects of the TFA as implemented in the teaching of a variety of science topics. It presents a longitudinal explanatory case study (Yin, 2009) of one student's experience of the TFA prior to and over that 2 year period. Both quantitative and qualitative data were collected. A case study design is warranted since it provides opportunity for a detailed analysis of a student's experience learning with the TFA in a classroom context. It also takes into account the contextual conditions that may influence a student's experience through consideration of multiple sources of evidence in order to develop an explanation of the resultant conceptual change in terms of the interplay between the student's social, emotional and cognitive experiences.

Context
The research was conducted in Years 9–10 (15–16 year old, $N = 30$) in a moderate-fee paying co-educational private school in Australia. Classes were of mixed ability and the majority of students had a mid-range socioeconomic status for the region, according to government statistics. The study commenced when ethics approval was granted and informed consent was obtained from all participants.

The teacher in both years was a teacher-researcher with 10 years' experience. Rachel, the student chosen for this case study, was placed in a mixed ability small group of four students chosen by the teacher. Care was taken in choosing the group members to ensure that students had positive views of their group members and included at least two girls (Webb, 1984). Group members worked together for the entire year. Although this group appeared to be functioning well, a second group was formed in the second year of the study in order to overcome some challenges with group dynamics in other groups. Roles were not designated and all group members were encouraged to participate in group discussions as they were able.

The thinking frames approach
Each TFA lesson was made up of the following steps:

1. Presentation of a scenario or demonstration designed to challenge students' alternative conceptions. Students predict what will happen and why in small group discussions and present their ideas to the class. After the teacher carries out the demonstration, students work in their small groups to construct another explanation consistent with their observations. Each group presents their revised explanation to the whole class. This is similar to an expanded Predict-Observe-Explain process, Predict-Discuss-Explain-Observe-Discuss-Explain (PDEODE) (Savander-Ranne & Kolari, 2003; White & Gunstone, 1992).
2. The teacher uses questioning strategies to encourage further elaboration of explanations, and to direct student thinking towards the scientific model.
3. Students then choose keywords that they believe will be essential to explain their observations and work in their small groups to construct individual pictorial and written explanations of the phenomenon (Treagust, Won, & McLure, 2018). The teacher moves from group to group using questioning to challenge alternative conceptions as they arise and to encourage deeper elaboration of explanations.
4. In order to encourage meta-cognitive engagement students use a rubric known as the Levels Mountain (LM) (Newberry, Gilbert, & Hardcastle, 2005) to evaluate their own written explanations. Levels 1 and 2 of the LM represent simple and more detailed descriptions of students' observations. Level 3 represents a simple causal explanation. Level 4 represents a more detailed explanation, aspects of the scientific model and scientific vocabulary while Level 5 is a more complex and persuasive explanation explicitly linking evidence to the scientific model.
5. Finally, the teacher evaluates students' explanations based on the LM and provides constructive feedback about ways in which to improve these on students' worksheets (Hattie & Timperley, 2007). In each unit a series of TFA lessons was designed to build understanding of different aspects of the underlying ontological model and specifically address common alternative conceptions.

As an example of a TFA lesson to address understanding of Newton's third law, students were asked to

explain why a skateboard moves backwards as the rider steps off. After PDEODE discussions the teacher used questioning to engage student thinking with Newton's third law and encourage elaboration of explanations. Students then produced pictorial explanations of their observations. Students were encouraged to avoid drawing 'what happened' but to tell a scientific story of 'why it happened'. They then organised their ideas into summary dot points, followed by production of an elaborated written explanation linking their observations with the underlying laws to provide a causal explanation. Further details about TFA lessons are described by McLure, Won, and Treagust (2020b), and McLure, Won, & Treagust, (2020c).

Analysis of conceptual change

Topics prescribed in the Australian Curriculum (ACARA, 2013) were taught during this period and students' conceptual understanding before and after learning was measured using a variety of conceptual inventories (Table 1). In two cases, delayed post-tests were also administered 6 months after the teaching period.

Results of using the TFA over a two-year period with Year 9–10 students in a number of different science domains were analyzed from a cognitive conceptual gain perspective. Evidence obtained from pre and post-test results from previously validated tests designed to understand students' alternative conceptions and whether students had adopted scientific conceptions, showed that the TFA did lead to significant conceptual gains in biology, chemistry and physics topics and these gains were, on the whole, significantly greater compared to comparison groups (McLure, Won, & Treagust, 2020a). The effect was evident for high and low achieving students.

Data collection and analysis

The first author had taught this class science during Year 8 and data from tests, assignments and classroom observations were available to describe her learning experience prior to learning with the TFA. Lessons were captured using video and/or audio recordings and classroom interactions were documented. Half of the students were interviewed about their experiences at the end of semesters 1 and 2 in Year 9 and at the end of the

year in Year 10, using a semi-structured protocol. Interviews were transcribed and coded for themes based on learner characteristics and social interactions. Further triangulation of these themes were obtained from teacher observations recorded in journal entries and video/audio recordings of lessons.

An attitudes and self-efficacy questionnaire adapted from Kind, Jones, and Barmby (2007) and Bandura (1990, 2006; Bandura et al., 1996) based on a five point Likert scale ranging from strongly disagree (1) to strongly agree (5) was completed by all students prior to learning with the TFA in Year 9, at the end of Year 9 and Year 10. Responses to groups of questions with a common theme, such as attitude to learning science in school, were found to have high internal validity (Cronbach's alpha of 0.77–0.92). Rasch Winsteps software (Linacre, 2012) was used to compute person measures of each member of the class based on these scales and the initial linear logit scale was transformed to one ranging from 0 to 100.

Evidence of conceptual gains were obtained after teaching with the TFA by administration of pre and post-tests in each topic shown in Table 1. Further evidence of conceptual change was obtained by analysis of TFA worksheets collected at the end of each lesson. Written explanations were initially evaluated by the first author using the Levels Mountain (LM) rubric. All LM scores were checked again at the end of the 2 year intervention for consistency by the first author and by another researcher.

Case study selection

After analysis of the pre/post tests and of the interview data for themes, benefits of this approach in terms of conceptual gains and improved attitudes towards learning science and self-efficacy, was observed for many students (McLure et al., 2020a). The study also showed that conceptual gains for students learning with the TFA approach were significantly greater than for those in a comparison class who were learning with more traditional methods (McLure et al., 2020a). In order to further understand these changes this study focuses on one student, Rachel, who displayed moderate to high conceptual gains in all topics taught using the TFA. Rachel's case stood out as she had been a low achiever on higher

Table 1 Topics taught and instruments used to measure conceptual change

Topic (Grade; No of TFA lessons)	Instrument	Source
Thermal Energy (9; 6)	Thermal Concept Evaluation (TCE)	(Yeo & Zadnik, 2001)
Electricity (9; 3)	Evidence Based Practice in Science Education (Set 2) (EPSE-Set2)	(Millar, 2002)
Newton's Laws (10; 6)	Force Concept Inventory (FCI)	(Hestenes, Wells, & Swackhamer, 1992)
Genetics (10; 7)	Scientific Reasoning in Genetics (SRG)	(Tsui & Treagust, 2010)
Natural Selection (10; 3)	Concept Inventory of Natural Selection (CINS)	(Anderson, Fisher, & Norman, 2002)

order tests yet showed much higher than expected gains compared to other students of similar ability. She had also expressed negative feelings about science learning and had low feelings of self-efficacy at the beginning of the study yet developed positive emotions related to studying science. The first researcher had also taught Rachel in the year prior to this study which allowed further comparisons between her prior learning experience and observations throughout the 2 years of the TFA intervention. Rachel had also been willing to elaborate on her experiences during interviews which allowed for greater understanding of her perspective. It should be noted that Rachel did not receive any extra attention compared to others in her cohort during this study.

Results and discussion

In order to understand the conceptual change that Rachel experienced, her learning experience and learner characteristics prior to the intervention must first be understood. Evidence of conceptual change is then presented in the form of pre/post test results and progressions of written explanations over the two-year period. An explanation for these changes is sought through analysis of Rachel's own perspective, provided through interview and questionnaire data, about her learning experience with the TFA. Teacher observations collected throughout the teaching and data collection period were used to confirm or negate Rachel's perspective.

Rachel's initial learner characteristics

Prior to the TFA intervention, Rachel was a quiet, diligent student who displayed feelings of very low self-confidence in science. During Year 8, Rachel always completed work thoroughly and in a timely manner. Since she was diligent and took care to address marking criteria in assignments which often involved presentation of knowledge rather than analysis, she gained a B grade for this work. However, her test scores were relatively low and her standardised National Assessment Program – Literacy and Numeracy scores (NAPLAN), completed by all Australian students in Years 7 and 9, were in the lowest one third of the class. In informal discussions with Rachel she noted that she tried to meet her parents' expectations of hard work suggestive of a motivational goal based on performance rather than mastery in order to please them. It was observed that she mainly used shallow processing strategies, such as memorisation or focused on completing superficial tasks, such as presenting work in the right format for assignments, rather than deeply engaging in metacognitive strategies. As a result, she generally received lower grades on tests that involved higher order thinking questions or interpretation of data. She did not participate in class discussions, never volunteering answers or explanations and

reluctantly answered direct questions, often saying 'I don't know', consistent with holding high performance avoidance goals (Pintrich, 2000) as she was fearful of giving the 'wrong' answer in front of peers. Holding performance goals, particularly performance avoidance goals has been shown to mitigate against conceptual change (Ranellucci et al., 2013). Although she completed tasks as thoroughly as possible her goal in completing tasks was to find the 'right' answer so that she could get the task done – evidence of epistemic motivation seeking closure (Kruglanski, 1989) which may also restrict development of deeper conceptual understanding (Alexander & Sinatra, 2007). She frequently expressed a lack of confidence in understanding concepts and negative emotions about science and school, learner characteristics which reduce intentional conceptual change (Sinatra & Mason, 2008) and result in a student giving up in the face of challenges (Schraw et al., 2006). Rachel had a wide circle of friends, worked on weekends and some evenings and was interested in training as a hairdresser. From her perspective, science had a low utility value for her life goals.

Rachel's negative attitudes towards learning science and her self-efficacy beliefs are illustrated by her Rasch person measures for questionnaire scales given at the beginning of Year 9, before learning using the TFA (Table 2). Her attitude to learning science in school was ambivalent (Person measure 48.5; Mean Likert score 3) as was her attitude to school (Person measure 46.8; Mean Likert score 2.5). She had a lower self-efficacy in science than most of the class (Person measure 36.4; Mean Likert score 2.3) and held the most negative feelings about future participation in science of all students in the class (Person Measure 0.1; Mean Likert score 1).

Rachel mentioned several times in interviews that prior to learning with the TFA her predominant emotion towards science lessons was the deactivating emotion, worry, possibly related to her high performance goals. Combined with low feelings of self-efficacy this caused her to adopt an epistemic motivation seeking closure. Rachel's initial learner characteristics prior to learning with the TFA are summarised in Fig. 1.

Rachel's progression in and communication of her conceptual understanding

Comparison of Rachel's pre- and post-test results (Table 3) describe the conceptual gains that Rachel made over 2 years learning with the TFA. These are compared to the mean class results for each conceptual test. Compared to the class means for post-test results, Rachel achieved higher scores in the topics of thermal physics, electricity and natural selection, a similar post-test score for genetics and a lower post-test score for the topic of Newton's laws. However, the delayed post-test

Table 2 Rachel's Rasch person measures for attitudes and self-efficacy questionnaire scales

Questionnaire scales/items (No. of items)	Rasch Person Measures (Scale 0–100)		
	Feb Grade 9	Dec Grade 9	Dec Grade 10
Attitude to learning science in school (6)	48.5	54.4	70.8
Attitude to future participation in science (5)	0.1	54.9	54.9
Importance of science (5)	49.2	53.4	57.6
Attitude to school (7)	46.8	46.8	48.9
Self-efficacy in science (6)	36.4	50.4	50.4

score for this topic was similar to the class mean. Rachel obtained moderate normalised conceptual gains in all conceptual tests except for the FCI. Conceptual gains achieved in the Thermal Concept Evaluation (38.5% to 69.2%) were sustained over a six-month period as shown by her delayed post-test results (61.5%) Her post-test results put her in the top 25% of the class. Although Rachel began with a very limited understanding of force concepts as shown in the FCI pre-test results (6.9%), at the end of the unit, she had gained some understanding (24.1%), which appeared to improve over the following six-month period (37.9%) despite no further teaching on the topic. Likewise, Rachel showed considerable improvement in conceptual understanding of genetics (27.3% to 54.5%). In the topic of natural selection, she achieved a surprisingly high mark on the pre-test (75%)

which increased to 85% on the post-test, putting her amongst the top 3 students in the class in that topic.

Rachel's written explanation in the first TFA lesson was a simple, but incomplete, description which did not link evidence with claims or use any reasoning. For example, in the first TFA question Rachel reproduced some of the drawings that she had seen in videos but she did not relate these drawings to explanations of these observations in her written explanation (see Fig. 2).

Rachel wrote the following paragraph explaining how we know about the structure of the atom:

> Rachel (TFA1): John Dalton believed that all things are made up of atoms, someone discovered that atoms have electrons that are negative. Thompson
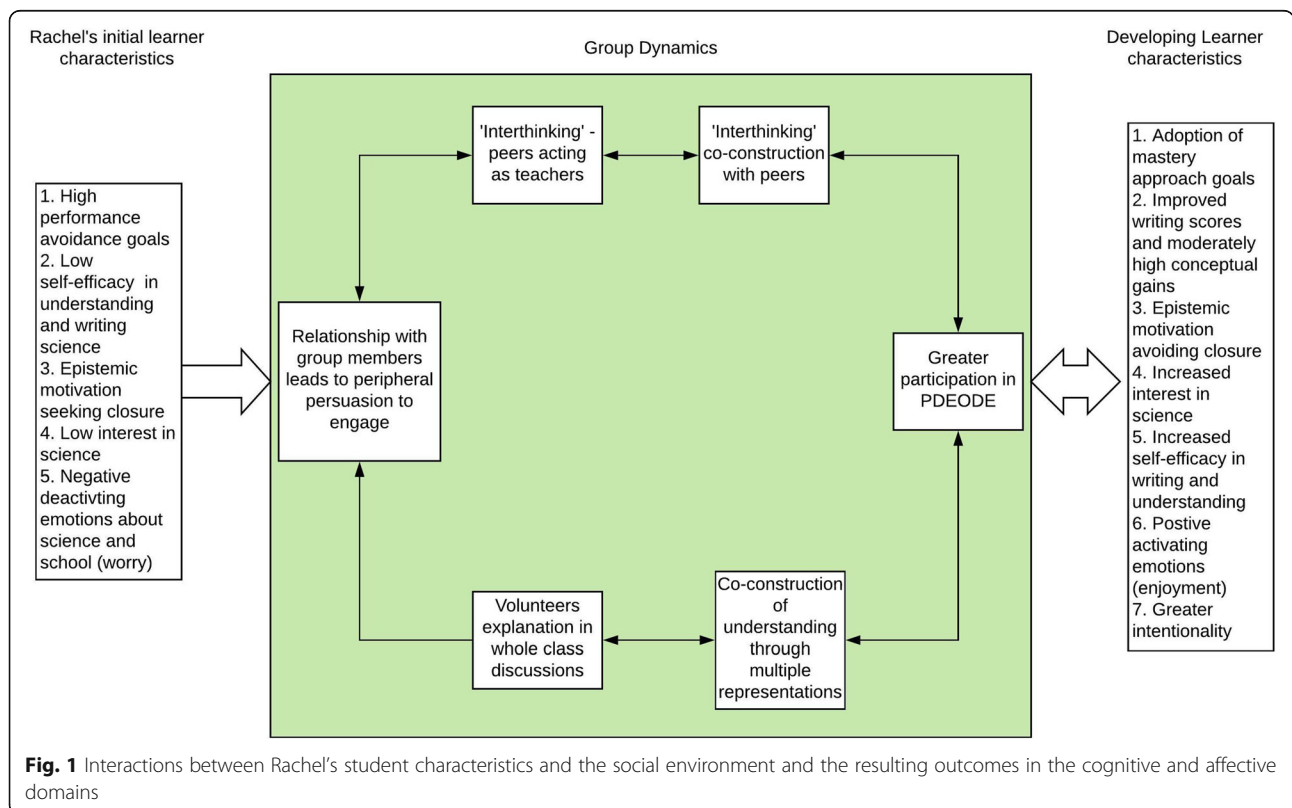
Fig. 1 Interactions between Rachel's student characteristics and the social environment and the resulting outcomes in the cognitive and affective domains

Table 3 Conceptual Test Results (pre-, post- and delayed post-tests) for class and Rachel

Conceptual Test	Participant	Pre-test (%)	Post-test (%)	Delayed post-test (%)	Normalised Gain <g>
TCE (thermal physics) (Rachel)	Rachel	38.5	69.2	61.5	0.50
	Class mean (SD)	25.3 (10.5)	45.7 (15.1)	47.7 (17.7)	0.27
EPSE Set 2 (electricity)	Rachel	30.0	70.0		0.50
	Class mean (SD)	27.0 (21.6)	49.6 (31.1)		0.31
FCI (Newton's laws)	Rachel	6.9	24.1	37.9	0.19
	Class mean (SD)	26.3 (10.2)	41.5 (14.5)	43.3 (15.7)	0.21
SRG (genetics)	Rachel	27.3	54.5		0.38
	Class mean (SD)	20.5 (17.4)	54.9 (18.8)		0.43
CINS (natural selection)	Rachel	75.0	85.0		0.40
	Class mean (SD)	43.3 (14.5)	60.2 (18.5)		0.42

believed that atoms have some positive parts and negative like a plum pudding. Rutherford did an experiment where he shot positive alpha particles at gold foil. (LM 1)

This explanation was a simple incomplete description (LM1) of the Thomson model and did not describe the Rutherford model at all, even though she had drawn out an explanation of what the Rutherford experiment showed. She gave her own work a level 3 which suggests that she was unaware that she was not relating cause and effect in her explanation.

By the second semester of Year 9, Rachel was growing in confidence in using the TFA and her LM scores regularly reflected that she paid careful attention to linking cause and effect and using scientific language. Rachel began to participate in whole-class discussions, volunteering explanations. An example of the improvement in her written explanations by the end of Year 9 can be seen in her paragraph explaining why a paper cup without water burns when placed over a Bunsen burner while one with water in it doesn't burn:

Rachel (TFA14): The paper cup with water doesn't burn because the thermal energy from the Bunsen burner went to the cup which the water absorbed, and because of thermal equilibrium (two objects have thermal energy balance, therefore, the water will have the same temperature as the cup). The boiling point of water is 100 °C therefore the cups ignition temperature will be higher and it will never reach it. The paper cup without water reaches its ignition temperature faster because it doesn't have the water to balance the thermal energy (thermal equilibrium). (LM 4)

Rachel used the terminology 'thermal equilibrium' incorrectly in her explanation. In previous lessons she learned that thermal equilibrium was reached when two objects are in contact and transfer of energy occurs through collisions of molecules. Even though the term is
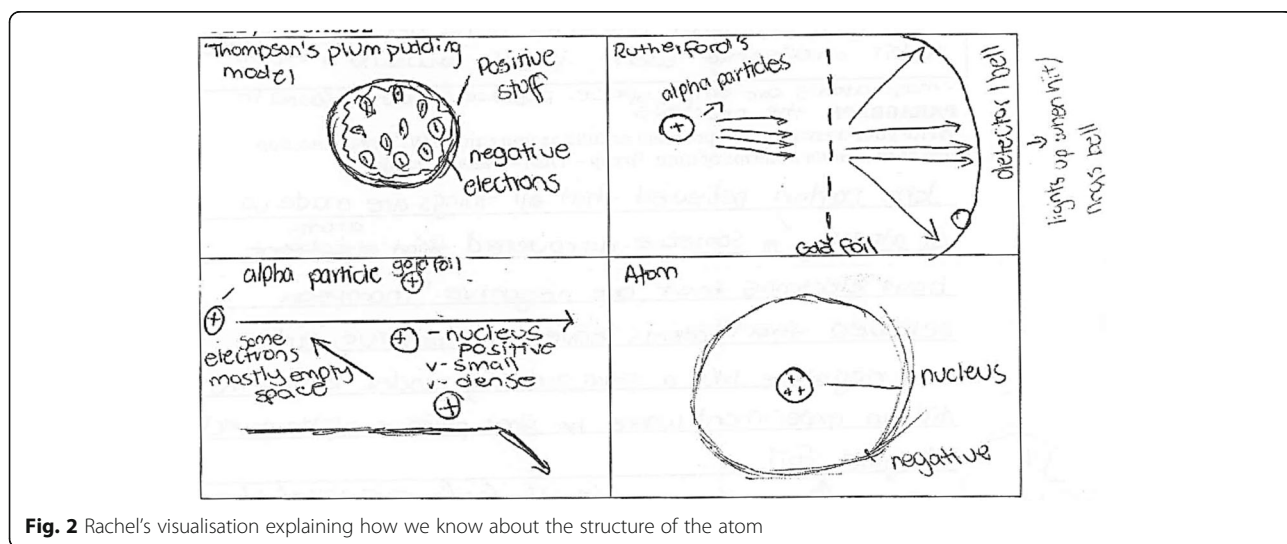
Fig. 2 Rachel's visualisation explaining how we know about the structure of the atom

not strictly correct her explanation implies an understanding that thermal energy is transferred through contact and that this fact led to the temperature of the cup remaining below the ignition temperature. She did not, however, explain why the temperature of the water never exceeds 100 °C nor did she mention the high thermal heat capacity of water.

In the second year of learning using the TFA, Rachel worked hard to understand concepts in the topic of Newton's laws and write detailed explanations. She mostly attained LM scores of 4 or greater, as scored by the teacher/first author, although, like many other students, she initially found writing about Newton's third law more difficult (LM 3.5). By the end of the unit, however, she was able to write quite sophisticated elaborated causal explanations. In explanation of why two balls of 1 kg and 2 kg thrown at the same horizontal velocity from a cliff reach the ground at the same time and place she synthesised her knowledge of Newton's first and second laws to explain the problem, linking these to explain why both objects accelerate at the same rate despite having different masses. She also recognises that they both travel at the same velocity in the horizontal direction, obeying Newton's 1st law and so landing at the same distance away from the cliff. She successfully uses some scientific language by identifying the appropriate laws involved, correctly using terminology about gravitational pull as the only force acting on the mass and gave a detailed explanation using mathematical reasoning. However, she uses anthropomorphic language suggesting that the ball has agency when she says that it 'wants to stay in a straight line' (LM5).

> Rachel (TFA 6): The reason why two balls of mass 1 kg and 2 kg thrown from a cliff at the same velocity hit the ground at the same time and same place is due to Newton's first and second laws. The reason why Newton's first law applies to this scenario is because when the balls are thrown they want to stay in a straight line and at a constant velocity. But the earth's gravitational pull wants to pull the balls towards the earth (downwards) and the bigger ball has a greater mass meaning double the force [compared to] the mass of the small ball. So for the big ball $a = 2F/2m$ which equals to a, and for the small ball $a = 1F/1m$ which equals to a. So therefore the acceleration must be the same. Thus meaning the balls fall at the same time and the same place. [Rachel's accompanying diagram showed the balls hitting the ground at the same point]

Seeking explanations for Rachel's engagement with scientific concepts

A number of themes arose from Rachel's interview responses over the 2 year period of the intervention. These themes remained consistent from the end of Semester 1, Year 9, after the TFA was introduced, until the final interview at the end of Year 10. Rachel was aware of her improvement in conceptual understanding over the period and she was able to articulate many aspects of her experience learning through the TFA which positively influenced that understanding. The main themes that arose were those of the supportiveness of the small group experience, the benefits of constructing deeper understanding through production of multiple representations, the benefits of practicing application of the ontological model in different contexts and the resultant gains in feelings of self-efficacy in each topic.

One significant aspect of Rachel's experience, that was evident from her interview responses and class observations, was her initial and sustained decision to engage with the processes presented in the TFA in order to undergo intentional conceptual change. As Sinatra and colleagues note (Sinatra & Pintrich, 2003a; Sinatra & Taasoobshirazi, 2011), it is this decision to participate fully in construction of understanding and implement self-regulatory strategies that may result in more significant conceptual change. However, the initial motivation to engage can depend on external factors, or peripheral persuasion, such as a desire to fit in with the group or admiration of a group member (Dole & Sinatra, 1998). During interviews with Rachel, it was evident that both central and peripheral routes of persuasion were activating factors for her engagement in TFA lessons.

Small group interactions

Over the 2 years of the study, Rachel benefited greatly from small group interactions with peers while learning with the TFA. The TFA necessitates students producing an initial group prediction of what will happen in the demonstration followed by an explanation of their observations presented to the class. Both mixed ability groups that Rachel was placed in included a higher achieving student who she admired and low to moderate achieving students with whom she had positive relationships, all of whom Rachel looked to for support. Her group was usually on task, discussing the question in hand and presented evidence of co-constructing explanations through interthinking.

The supportiveness of Rachel's group interactions was evident from class observations as well as being a recurring theme in interviews with Rachel. Due to her low self-efficacy and performance goals coupled with an epistemic motivation seeking closure, Rachel initially felt the need for higher achieving 'explainers' as she did not have the self-confidence to independently build her own conceptual understanding. When students first began learning using the TFA, the feeling of belonging within the group appeared to act as a motivation which

constrained Rachel to engage with the process of constructing explanations in order to preserve the group's positive identity within the class (cf. Korpershoek, Canrinus, Fokkens-Bruinsma, & de Boer, 2019). For instance, Rachel expressed that she was committed to her group as she respected them and so wanted them to present 'good explanations' to the class. As a consequence she wanted to play her part in improving their explanations by understanding the phenomena presented. This peripheral route of persuasion, commitment to the group cause, led to greater initial engagement with construction of understanding.

By the end of Year 9, after 1 year learning with the TFA, Rachel described her interactions in the TFA small group as follows:

> Rachel: I would say me and Melissa are probably the ones who don't understand as much, but then Simon and Mathilde, they're really good at picking out the ideas easily. And then without them giving you the answer, we just talk about it, and then you get an idea. 'Oh, I actually understand now.' And so, then you can write your ideas down.

Although Rachel began by relying on the other students in her group to explain to her, by the end of Year 9, although she was still clearly receiving support in constructing explanations, she was taking an active role in that construction. As she says, she was not just given the answers but was led towards deeper understanding of concepts so that she could form her own explanations. This suggests a shift from peripheral routes of persuasion to engagement with the central route of persuasion, namely engagement with the discrepant events that were being presented and with her group to construct understanding of the phenomenon.

Additionally, Rachel explained that she, Mathilde and another Year 9 student, Patricia, often met outside of class to continue their TFA discussions.

> Rachel: If we can't catch up in person, we have a group message, us three on iMessage and we'll talk about our ideas, about what we had for our thinking frames and stuff. It's like you're going to your teacher.

This proactive engagement with social construction highlights the benefits that Rachel found in working together to construct understanding. Although Patricia was not in Rachel's group, she was a high-achieving student who she admired and who gave Rachel further support in reaching a deeper understanding of concepts. As Hattie and Timperley (2007) note, seeking out feedback on the process of developing and writing an explanation is a very powerful self-regulation strategy to develop.

In the second year of learning using the TFA, Rachel continued to enthusiastically participate in small group discussions. The teacher noted that Rachel began putting forward her own ideas in class discussions, an interaction that had never been observed prior to learning with the TFA. At the end of Year10 Rachel was interviewed once again and she again emphasised the importance of small group discussions in construction of understanding.

> Rachel: I was lucky to have people who you could have a conversation with about different ideas, so that was helpful. And they were pretty on track most of the time. I had Bahardir, Kip and Eliza. We kind of all worked together. No-one really took charge. No-one said 'this is how you do it'. They would explain it rather than say, 'just write this down'. They explained how it works, which was good.

Bahardir was a well-respected, high achieving student who willingly contributed his ideas and helped other students by explaining to them. This Year 10 group that Rachel was in was just as supportive as the Year 9 group, but once again Rachel highlights that this did not mean that others were doing the thinking for her. It appears, from her reflections about her small group experience that she was actively pursuing mastery goals as she built her own understanding throughout their discussions.

The figurative representation of Rachel's experience in Fig. 1 depicts her initial learner characteristics, the influence of her small group experience on her engagement with cognitive aspects of the TFA. It illustrates how peripheral routes to persuasion, activated due to positive relationships with peers, commitment to the group and the presence of respected 'explainers' within the small group setting, were mediators for Rachel's initial engagement with learning. In Year 9 she identified Simon, Mathilde and Patricia as students with higher ability than herself who could support her in understanding difficult concepts. However, by Year 10 she seemed to be no longer looking for a higher achiever to explain as she notes that all group members were equally involved in co-constructing understanding.

Social construction through interthinking

Elements of Mercer's (2000, 2013) 'interthinking' were evident from Rachel's interview responses about her small group interactions. Firstly, group members had the shared goal of producing a persuasive explanation to present to the class based on the evidence presented for the observed phenomenon (cf. Deutsch, 1962). As they worked together towards this goal, Rachel's group collaborated by *sharing their knowledge* (Mercer, 2013).

Rachel noted the benefits in having higher ability peers explain their understanding. The small group arrangement also gave Rachel confidence to ask more questions than she would have done if the discussions had only been held with the whole class (Fig. 1).

Another aspect of 'interthinking', *co-constructing understanding* (Mercer, 2013), was particularly evident in Rachel's small group where they worked both inside and outside class to produce and refine their explanations. Over the first year, as she became more confident in her understanding, she was observed to participate more proactively in the construction process by putting forward her own suggestions and explanations within both the small group and the larger class. She also expanded the TFA small group situation by using social media to discuss and extend her understanding through interactions outside of class. Rachel was observed and reported engaging in the important skill of argumentation within her small group. The opportunity to persuade peers during the small group PDEODE discourse, encouraged presentation of supporting evidence for arguments and raised the possibility of conceptual schemata being modified (Berland & Reiser, 2009).

Rachel's engagement with cognitive and metacognitive strategies of the TFA

Opportunities to engage with the central route of persuasion (Dole & Sinatra, 1998) were presented in the PDEODE part of the TFA lesson, where students' alternative conceptions were revealed as being insufficient to explain their observations. As Petty and Cacioppo (1986) note, the greater the level of engagement with the central route to persuasion due to interest, relevance and characteristics of the learner, the more persistent its effects in terms of conceptual change. Rachel's initial engagement with the TFA process due to the peripheral persuasion in order to fulfil her commitment to her group members led to greater motivation and intentionality to engage with the PDEODE process and to produce representations of her understanding, particularly verbal and written explanations, (see Fig. 1). This, in turn, led to greater conceptual change.

> Rachel: I really like when we had the classroom discussions [PDEODE] … you get everyone's idea of what they're thinking. And then we might go into our groups and then talk about it further. You separate the key words, and then you get to actually draw out what you think, even if it's really hard to draw, but you get to put it on paper what you think. You remember the picture that you drew instead of one you just looked at in the textbook. I find it helpful when you write the end statement thing - you look at your drawing and then you get an idea

on what to put in your conclusion. You don't just forget it. It's not just note taking.

Together with the support of the dialogic interactions in small group and whole class discussions during the TFA lesson, Rachel emphasised the importance of stepwise scaffolding of understanding through production of multiple representations of understanding. She developed a set of self-regulatory strategies that supported her in deeply processing understanding, particularly through drawing, which allowed her to form a mental representation of the concept that stayed with her for longer. By combining the ideas that she had developed while discussing these concepts with her small group, and which were consolidated by producing pictorial representations of her understanding, with key scientific words that she had selected, she was able to more confidently write an explanatory paragraph. The steps of the TFA appear to have resulted in her developing mastery goals resulting in greater intentionality in engaging with the TFA process.

Changes in Rachel's learner characteristics
Addressing motivational and affective barriers to conceptual change

Although students may experience the same cognitive processes in the classroom, whether conceptual change occurs has much to do with the student's motivation to learn (Pintrich et al., 1993). According to Heywood and Parker (2009, 24), motivation is 'influenced by students' self-efficacy, goals, intentions, beliefs, expectations and needs'. By positively influencing these characteristics students can become more motivated to participate in constructing conceptual understanding through deep and 'elaborated' engagement (Petty & Cacioppo, 1986). Rachel's case gives an insight into how learning with the TFA addressed these motivational-affective barriers.

Increased self-confidence and self-efficacy

A prominent benefit of the small-group discussions and 'interthinking' was the increase in Rachel's confidence in expressing her ideas (see Fig. 1). She had greater opportunity and was less intimidated when participating in discussions within the small group than she was in whole-class discussions in front of the teacher and all her peers. Previously she had rarely, if ever, been willing to express her ideas within class discussions. However, as she gained confidence through the co-construction process, lesson transcripts provided evidence that she began to volunteer her opinions within the whole-class discussions as well. Where previously she would never put up her hand in class, she began doing so and gave explanations without being prompted to do so.

Rachel's increasing Rasch person measures for attitude to science and self-efficacy in science (Table 2) and her interview responses showed that she had become much more confident in understanding and writing scientific explanations since learning with the TFA. In the interview at the end of Year 10, Rachel confirmed that she felt a lot more confident in writing explanations and credited this change to small group interactions and the way in which a series of TFA lessons built on the onto-logical model which supported her conceptual understanding.

> Rachel: I feel like I have got a lot better at writing my explanations. I think it is due to understanding better and the group dynamic. When we were doing a thinking frame it would be like one little topic, but the next lesson it would be something that linked on to that. So that if you could understand the topic from the lesson before, you would be able to understand the next day. It kind of all linked together.

Rachel also indicated that she felt more confident in understanding science in general, in understanding experiments and that the TFA had helped her remember concepts for tests. She still didn't have a very high self-concept in her ability in science but she believed that there had been a marked improvement. When asked to rate her confidence in understanding science at the end of Year 8, she gave a 3 or 4 out of 10 while she said that her present confidence level was 7 out of 10. In place of her low self-efficacy Rachel now believed that she could understand difficult concepts if she persisted which is a characteristic of a student who is undergoing intentional conceptual change (Sinatra & Pintrich, 2003a).

> Rachel: I think that I understand a lot better, even though it might take me a while. In the end, I understand it.

TFA lessons provide short-term goals with immediate and frequent feedback which Bandura and Schunk (Bandura & Schunk, 1981; Schunk, 1983, 1987) claim improve self-efficacy by showing students whether they have gained mastery of these tasks. Since Rachel effectively used the strategies of the TFA, such as discussing in her small group and production of multiple representations of her understanding, she attributed her improvement to her own efforts and this further improved her feelings of self-efficacy (Schunk, 1987).

Increase in positive, activating emotions
Changes from deactivating to activating emotions were also observed in Rachel's case. Prior to this study, she frequently expressed negative, deactivating emotions regarding learning science. These included hopelessness (a feeling that she would never be able to understand science) and worry. These deactivating emotions undermine conceptual change by reducing motivation and distracting students from engaging in tasks (Liu et al., 2014; Sinatra & Mason, 2013). Reduction in deactivating emotions, such as anxiety or hopelessness, and increased positive, activating emotions were seen in Rachel's case. Her Rasch person measures for the scale of 'attitude to science in school' (Table 2) showed a considerable improvement from 48.5 to 70.8 over the 2 years. In comparison, her responses to the general attitude to school scale remained constant, and ambivalent over the 2 years of the study (Table 2). In interviews, she reported finding science enjoyable and looking forward to science lessons which had the effect of further increasing motivation to intentionally use self-regulatory strategies, develop critical thinking and elaboration of explanations (cf. Taasoobshirazi et al., 2016).

Changes in motivation
As noted in the literature (Bandura et al., 1996; Pajares, 2002; Schraw et al., 2006; Sinatra & Mason, 2008), higher levels of self-efficacy act as motivating factors for increasing intentionality to engage with meta-cognitive strategies and persist when students encounter difficult tasks. Rachel's increased self-efficacy, combined with cognitive processes within the TFA lesson, seem to have resulted in the establishment of a positive feedback loop between affective, social and cognitive factors resulting in significant conceptual change (see Fig. 1).

An important student characteristic, which underpins student engagement with conceptual change and determines how consciously a student attends to cognitive and meta-cognitive strategies, is the type of achievement goals that they possess (Linnenbrink & Pintrich, 2003). In Rachel's case, it is clear that a change in achievement goals occurred over the period of learning with TFA. Prior to learning with the TFA, Rachel had possessed performance avoidance goals as evidenced by her unwillingness to give any responses to questions in class. She did work hard, but this was based on her desire to please her parents who had expectations that she did her best, rather than a desire for mastery of a topic. These performance goals led to her engaging in shallow rather than deep processing (Ranellucci et al., 2013), particularly since her epistemic motivation was one of closure (Kruglanski, 1989).

Rachel's case study suggests that combining the strategies of the TFA with the social support of judicially chosen small groups may support a student in developing mastery approach goals to learning, leading to deeper processing strategies (Ranellucci et al., 2013) and

more self-regulation (Pintrich, 2000). Rachel showed evidence of increased intentionality in her approach to TFA lessons as she actively participated in presenting ideas and using cognitive and self-regulatory strategies available in the TFA, particularly production of multiple representations of understanding (compare written explanations for TFA 6 & 14 with TFA 1). This increased intentionality seemed to be as a direct result of the peer support that she received during and after TFA lessons. Rachel noted that the TFA lessons required a deeper level of attention and understanding than she usually gave to other types of lessons where she would simply copy material or read from texts. As a result of the peripheral persuasion due to her commitment to her small group members, she expressed that she felt constrained to engage on a much deeper level with TFA lessons in order to complete them to her satisfaction. This agrees with Hatano and Inagaki's (2003) observation that truly intentional conceptual change may only occur when there is no other choice, as a lot of effort is required. Social commitment to her small group meant that she felt there was no other choice than to be intentional about her learning.

> Rachel: Science, I used to, it's not that I didn't enjoy it, but I just, I didn't understand it a lot. I always worried about tests and exams. I find that the thinking frames are more helpful. I remember thinking back to the thinking frame and what we talked about in class. Then I knew what to write about. I find that it's easier to remember than what you would've read off a textbook. Whereas if you have a classroom discussion, you're involved, you're forced to be involved in the conversation, so you're more likely to remember what you talked about than when you're drowsy reading when you're just not really focusing. I don't feel really good at science, but I feel I enjoy science more and I understand it more now than I did before.

As Rachel's small group supported her in constructing multiple representations of her understanding, the greater self-efficacy that she experienced due to improved writing and LM levels led to her adopting mastery goals and becoming more intentional in utilizing the metacognitive strategies that the TFA provided - actively engaging in small group and whole-class discourse and self-regulation to improve representations, particularly her written explanations. Consequently, her level of conceptual understanding increased significantly and she displayed unexpectedly high overall conceptual gains which reinforced the positive activating emotion of enjoyment. All of these factors had the effect of further improving her feelings of self-efficacy and gave her the confidence to persevere in mastering her understanding of difficult concepts (see Fig. 1).

Changes in interest in science
Rachel rated her interest level in science at the beginning of Year 9 as 3 or 4 out of 10 compared to 7 out of 10 at the end of Year 10 – particularly for genetics and chemistry. This was confirmed by the marked improvement in Rasch person measures for attitude towards future participation in science on the questionnaire over the 2 year period (Table 2). She began Year 9 with a very negative attitude towards continuing to learn science in later years (0.05) but ended Year 10 with much more positive attitude towards future participation (54.9). This appears to not just be a change in situational interest but a deeper change in personal interest which is usually resistant to change (Murphy & Alexander, 2008). Rachel noted that she had increased personal interest in science in response to greater understanding attained through the TFA, combined with a change in self-concept – evolving from a student who saw herself as not good at science to one who could understand and explain scientific concepts. Observations in this study are compatible with Franke and Bogner's study (2013) which showed that students learning with a conceptual change approach that challenged alternative conceptions developed greater interest as a result, leading to greater conceptual change.

Before learning using the TFA Rachel said that she definitely didn't want to pursue any science in Years 11 and 12. However, after learning with the TFA, she chose to study General Science in senior high school. She returned to our school several times and asked to join the science classes for the day. She said that she missed the learning that she had experienced in the TFA classes.

Limitations
This study was carried out by the first author as teacher-researcher in a private, fee-paying school. As a result there may be limitations in terms of the students' willingness to fully express negative experiences due to a power imbalance between interviewer and interviewee. Rachel was encouraged to be as objective as possible and it was emphasised to her that there would be no negative consequences for giving critical feedback and that, in fact, this would be welcomed and helpful in order to improve the TFA process. Although the socio-economic status of students was similar to nearby government schools in the area, as members of a private, fee-paying school, Rachel may have been under pressure from her parents to work hard and gain improved scores. It should be noted, however, that one third of students in Australia attend private schools (Australian Bureau of

Statistics, 2019) and the school in this study had relatively low fees compared to many other private schools. Further studies in government schools and in areas with lower socio-economic status may extend understanding of the generalisability of this approach.

Conclusions and recommendations

In conclusion, in Rachel's case, the interaction between cognitive aspects of the TFA lessons (PDEODE, cognitive conflict strategies and production of student-generated multiple representations) and the small group interactions resulted in both central and peripheral routes to persuasion being activated and supported conceptual change. Detailed analysis of Rachel's interactions with the TFA process over the long-term demonstrates the importance of carefully choosing the small group environment to provide social support for the conceptual change process. A student with performance avoidance goals, epistemic motivation seeking closure and low self-efficacy needs the initial support of students in their small group who they look up to as capable of explaining and supporting them in constructing understanding. The peripheral persuasion of working with respected peers can positively influence a student's intentional engagement with cognitive processes, even so far as to make the student feel that there is no other alternative than to be engaged with the conceptual change approach. In Rachel's case implementation of the TFA conceptual change strategy combining presentation of discrepant events, small group and whole class discussions and the affordances of constructing a series of explanations in different modes, interacted positively to bring about changes in motivational stance and resulted in increased conceptual change. As Rachel recognised the benefits to her understanding and hence her achievement, over the longer term she adopted mastery approach goals. A commensurate change from negative deactivating to positive activating emotion and negative to positive self-efficacy beliefs resulted as she continued to reap the benefits in terms of increased conceptual understanding, achievement on post-test scores and on LM scores for written explanations. Changes in Rachel's learner characteristics, in turn, led to even greater cognitive engagement with the TFA process, creating a positive feedback loop (see Fig. 2) which resulted in significant and persistent conceptual change. Finally, Rachel's personal interest in science and in future participation in science was positively influenced by the success achieved.

This study highlights the powerful impact of a multidimensional conceptual change approach such as the TFA on a students' conceptual understanding. Since the role of the small group in providing peripheral persuasion for initial engagement with the strategy and for support in co-construction of understanding through interthinking is central to such an approach, the teacher's role in carefully arranging the small group environment is crucial. Understanding a students' learner characteristics, particularly their underlying motivations for learning and emotions about learning is essential when choosing members of a group.

Authors' informations
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