ANGELA E. STOTT AND PAUL A. HOBDEN

6. A BELIEF SYSTEM AT THE CORE OF LEARNING SCIENCE

A Case Study of a Critical and Creative Gifted Learner

INTRODUCTION

This chapter describes the belief system which has been interpreted by the authors to be at the core of the self-regulated learning of science undergone by an individual high achieving, gifted learner. The case reported is of a learner referred to as André. He was observed to apply a number of cognitive and metacognitive strategies in his learning of science motivated by his beliefs of what the nature of learnt meaningful knowledge should be that is precise, elegant, and transferable. Most of the cognitive strategies André was observed to use had at their core critical and creative thinking. In this chapter we describe this belief system central to André's self-regulated learning of science and describe what he understood by knowledge which is precise, elegant and transferable and illustrate how these beliefs motivated André's critical and creative thinking.

This research proposes a set of beliefs which may be beneficial for science teachers of gifted learners to nurture in their efforts to enhance self-regulated learning. Self-regulation in learning is known to enhance achievement (Al-Khatib, 2010; Zimmerman, 1990), a goal highly valued in our school systems. Understanding self-regulation in the context of gifted learning may be a key to unlocking the potential of underachieving gifted and other learners. This research also supports the view that critical and creative thinking are closely related, and as evidenced in this study, are vital components of meaningful learning.

The claims made are based on observations over a period of three years in which the first author taught André on a one-on-one basis when he was aged 13–15. During this time written work was collected and interviews and lessons recorded. Data analysis was done in a grounded fashion through iterative inductive engagement with the data. The analysis and findings reported represented here are in response to the research question "What belief system drives this high achiever's effective learning of physical science?" Validity was ensured through long term engagement and use of member checks. Ethical considerations included obtaining consent from André and his parents, and the use of a pseudonym to protect his identity.

M. K. Demetrikopoulos & J. L. Pecore (Eds.), Interplay of Creativity and Giftedness in Science, 87–103.

CONCEPTUAL FRAMEWORK

André's learning can best be characterized as that of a gifted learner striving through self-regulation to meaningfully understand scientific knowledge through his critical and creative thinking. Consequently these concepts form the core of our interpretive framework in trying to understand André's learning and are discussed below.

Self-Regulated Learning

Self-regulated learning is understood to be learning which occurs under the metacognitive control and intrinsic motivation of the learner (Schraw, Crippen, & Hartley, 2006). Learners tend to be willing to engage deeply in learning for extended periods of time, make greater use of learning strategies, and achieve better, when they are undergoing self-regulated learning (Zimmerman, Bandura, & Martinez-Pons, 1992). During self-regulated learning, learners may enter a state of flow, in which they are deeply absorbed in their work to the extent that they almost become oblivious of their environments and of the passing of time (Fredricks, Alfeld, & Eccles, 2010). Flow is considered a particularly productive and gratifying state to be in, and highly conducive to the production of new knowledge through creative thought.

Internal and external factors can contribute to the development of, and triggering of, self-regulation in learning (Sinatra & Mason, 2008). Internal factors include possession of cognitive, metacognitive, and motivational skills (Schraw et al., 2006). Motivational skills may include self-efficacy and epistemological beliefs which are beliefs about the nature of knowledge and how it is obtained (Schraw et al., 2006). Sinatra and Pintrich (2003) show that people are more likely to engage in self-regulated learning if they have a constructivist and mastery-oriented epistemology. A person holding a constructivist epistemology believes that knowledge is obtained through individual and social construction, and can therefore be contested. This is in contrast to an absolutist epistemology, according to which knowledge consists of facts to be accepted unquestioningly from an authority. A person holding a mastery-oriented epistemology believes that the purpose of obtaining knowledge is to master a domain, rather than to achieve extrinsic rewards. Therefore these two epistemological beliefs which Sinatra and Pintrich link to engagement in self-regulated learning refer to the beliefs about how knowledge is formed and learned, its contestability and the purpose of learning new knowledge. What this list lacks, however, is the ideal properties of this knowledge. It seems reasonable that the perception of what constitutes meaningful knowledge, which is most conducive to inducing engagement in self-regulated learning, may be subject-specific. Therefore, in the context of physical science learning, we ask: "What epistemological belief, about the ideal properties of knowledge, drives self-regulated learning of physical science?" It is this gap in the literature which is addressed in this study.

Critical and Creative Thinking

Critical thinking is closely related to creative thinking, and both of these can be linked to meaningful learning (e.g. Lipman, 1989; Paul & Elder, 2008; Schraw et al., 2006). Schraw et al. list critical thinking as one of the cognitive strategies a learner uses during self-regulated learning while Lipman argues that critical thinking involves convergent thinking during which ideas are evaluated against criteria and monitored metacognitively. According to Paul and Elder (2008), effective learning always involves a series of creative acts, which are then evaluated against criteria. Paul and Elder argue that critical and creative thinking are inseparable in practice, although describing them as if they were separate may be useful. This conflicts with authorities, such as De Bono, who believe that creative thinking requires abandonment of the logic and standards of critical thought, and that knowledge in a domain can inhibit creativity in that domain (Bailin, 1987). It appears that the views of other authors on the topic (e.g. Bailin, 1987; DeHaan, 2009; Glassner & Schwarz, 2007; Novak, 2010) fall between these two extremes, that is they view critical and creative thinking as closely related, but separate.

Creative thinking involves divergent thinking in which new ideas are generated (called fluency), thinking switches between these ideas (flexibility) as they are evaluated, and some are selected for linkage (conceptual combination), and focus (selective mental attention) (Lubart & Zenasni, 2010; Mumford, Hester, & Robledo, 2010). The kind of creativity referred to here appears to correspond to what is sometimes called “mini c creativity” (DeHaan, 2009), or “petite creativity” (Schwartz, Varma, & Martin, 2008). This refers to generation of knowledge which is new to the particular learner, although not necessarily new to the domain as a whole. Creativity is also referred to as innovation, and occurs due to transfer of knowledge from one context to another (Schwartz et al., 2008). Adaptive expertise is required to perform such knowledge transfer. Transfer can also be encouraged by use of appropriate representational tools. However, adaptive expertise requires the individual to possess a highly structured knowledge base (DeHaan, 2009), resulting from having engaged in meaningful learning for an extended period of time (Novak, 2010). In this chapter creative thinking and creativity are understood in the broad sense of generation of new ideas or artifacts. This predominantly includes generation of ideas or artifacts new only to the learner, but could also include ideas and artifacts new to the domain as a whole.

Meaningful Learning

Ausubel contrasted meaningful learning with rote learning. Whereas rote learning focuses on the recall of isolated facts, meaningful learning involves linkage and subsumption of concepts to create a hierarchical, integrated knowledge structure. This is associated with positive affect and the development of expertise in the knowledge domain (Novak, 2010). The knowledge gained from rote learning tends to be inert (non-transferable to new contexts). In contrast, knowledge gained through meaningful learning is more likely to be active, and so enable innovation to occur as knowledge is transferred to new contexts (Schwartz et al., 2008). Ausubel's term *meaningful learning* corresponds to the terms learning for understanding, effective learning, and deep learning. All of these share the criterion of conceptual linkage resulting in a hierarchical, integrated knowledge structure. Such learning is steered by critical thinking. For example, the learner makes judgments about concept selection, accuracy and relevance of linkages between concepts, and appropriateness of assignment of concepts to relative hierarchical levels, and the learner monitors learning metacognitively (Paul & Elder, 2008). This discussion again draws attention to the link between critical and creative thinking, since critical thinking is required for meaningful learning to occur, and meaningful learning is required for the development of adaptive expertise, which is required for knowledge transfer, that is creativity.

Meaningful learning refers to formation of links between concepts, and organization of these concepts relative to one another. Therefore an understanding of meaningful learning should be informed by conceptual change theory (CCT). CCT has its origins within work by Piaget. As explained by Dykstra, Boyle, and Monarch (1992), according to Piaget, learners accept new information by assimilation (acceptance without the need for major modification in mental structure) if they consider this new information to be compatible with their existing knowledge. However, learners experience feelings of disequilibration when they consider that information they are presented with is incompatible with their existing conceptual frameworks. In such cases the learners have to undergo accommodation (major modification in mental structure) before they can learn the new information. Posner, Strike, Hewson, and Gertzog (1982) used the term conceptual change to refer to accommodation, and proposed that learners make judgements about whether to undergo conceptual change or not based on their perceptions of competing concepts' intelligibility, plausibility and fruitfulness. They suggested that exposing learners to discrepant events could induce a feeling of disequilibration, also called dissonance, which might cause the learners to undergo conceptual change.

More recent research, as reviewed by Vosniadou (2008), has provided some support for the role of dissonance in conceptual learning, particularly amongst gifted learners, but has also shown that learners often respond to dissonance by avoidance behavior, rather than by undergoing conceptual change. The social, contextual and motivational aspects of conceptual learning have also received greater attention in recent research. Sinatra and Mason (2008), and Sinatra and Pintrich (2003) are some of the leaders in this so-called warming movement of conceptual change. They focus on intentional conceptual change, which is a subcategory of self-directed learning, since both share the characteristics of being under the metacognitive and motivational control of the learner. Epistemological beliefs therefore drive the choices a learner makes during intentional conceptual change, as is the case in all self-directed learning. They also drive the choices the learner makes of whether to engage in intentional conceptual change or not, including whether to embrace or avoid dissonance. Other work on conceptual learning within a sociocultural perspective includes that by Tytler and colleagues on use of representations to socialize learners into a discipline (e.g. Hubber, Tytler, & Haslam, 2010), as well as work on use of analogical thinking in conceptual learning (e.g. Clement, 2008).

It is the authors' view that all learning, particularly meaningful learning, is constructivist in nature and is limited by the capacity of working memory. According to constructivist learning theory, learning cannot occur by passive absorption of knowledge, but only through active sense-making activity on the part of the learner (Dirks, 1998). According to the Information Processing Model (IPM) of learning, the small capacity of working memory is the greatest limitation to human learning (Jonassen, 2009). Working memory consists of whatever one is thinking about at a particular moment. The more individual items a learner tries to think about simultaneously, the greater discomfort, called cognitive load, the learner experiences. Both critical and creative thought present significant cognitive load to the learner, since they require the learner to think of multiple pieces of information simultaneously. The hierarchical, integrated knowledge structure of experts enables them to chunk knowledge elements. In this way they can represent more information in working memory within fewer individual items, thus reducing the limitations of cognitive load (Kirschner, 2009). Motivation appears to expand the size of working memory somewhat, and also make learners more prepared to persevere with their learning despite the discomfort afforded by cognitive load (Niaz & Logie, 1993). When intrinsic motivation is high, learners may engage passionately with their learning and be more disposed to engage in critical and creative learning.

Summary

Based on the above discussion of the core concepts, the following framework was used in the interpretation of André's learning. At times a learner may enter a state of self-regulated learning in which metacognitive control and intrinsic motivation play vital roles. During self-regulated learning, learners may become so intensely engaged in learning as to become almost unaware of their surroundings and the passing of time. Self-regulated learning, particularly when undergone in a state of flow, is very creative, is associated with strongly positive feelings, and is associated with high achievement. It is our view that gifted learners enter such states more frequently than other learners. Unfortunately, underachievement is well known amongst gifted learners and seen by some as very complex and an enigma (Reis & McCoach, 2000). Since self-regulation is known to improve achievement, and since gifted learners are known to be likely to benefit from instruction in learning strategies and styles, understanding beliefs that drive gifted learners may empower teachers to help underachieving gifted learners to reach their potential.

During self-regulation, learners make use of cognitive and metacognitive strategies under the control of their belief systems. One of the cognitive strategies learners engage in is critical thinking. This is closely related to creative thinking. Critical and creative thinking are therefore important components of self-regulated learning or for that matter any kind of meaningful learning. The learner's belief system includes epistemological beliefs which are beliefs about the nature of knowledge and how it should be acquired. Some belief systems are more conducive to promoting self-regulation in learning than others are. However, little is known about the particular beliefs of what constitutes meaningful knowledge in particular domains, such as school science and which promote self-regulated learning in that domain. These beliefs are the focus of this chapter.

RESEARCH DESIGN

The first author has known André since he was a baby, and became aware of his intellectual giftedness, particularly in the sciences, when he was very young, since he grew up in an isolated rural mission community in which the author also lived at the time. Although unrelated to André, the author did encounter him on a regular basis as a member of the mission community and as a teacher at the mission school that André attended. André, while still in primary school, would often visit the science laboratory as the author prepared demonstrations for lessons, or as he worked on his science fair projects. These encounters, together with reports from his teachers, confirmed and intensified impressions of André's giftedness and creative ability. His giftedness was confirmed by subsequent events. During his schooling, André won regional science fairs and the national science fair. In most of his projects he created electronic devices, such as a sonar positioning system and a soccer-playing robot. André also received numerous awards for science, mathematics and computer Olympiads on regional and national levels, and scored ten As in the grade 12 national examination. These subsequent achievements supported the idea that André exemplified a case of a gifted and creative learner from whom we could learn.

During André's grades 8 to 10 (age 13–15), the first author engaged in a case study on how André learned science, and the belief system which drove this learning (Stott, 2002). The author taught André science in an enriched and accelerated individual program when he first entered secondary school in grade 8. Detailed records of his learning were begun at this time. This formed the basis of a detailed case study (Yin, 2003) where the case was selected for its intrinsic interest (Stake, 1994), and for its potential to suggest ways in which less successful learners may be helped to improve their learning by observing the learning of more successful learners (Baron, 1987). This is similar to expert-novice research, in which the differences between experts and novices are examined in order to propose ways to help novices improve (see, for example, Kirschner, 2009). Within the context of studies on gifted education, this is also consistent with findings that the learning of lower-achieving gifted learners can be enhanced by explicit instruction in learning strategies observed in higher-achieving gifted learners (e.g. Lee, 2004; Scruggs, 1985; Sternberg, 1987).

Data collection occurred through participant observation, since a human instrument was considered best able to sense and examine the complexities of the case, and thus generate a rich, holistic description from which naturalistic interpretations and generalizations could be made (Merriam, 2009). By the end of the three-year study the data corpus was considerable and consisted of 35 detailed lesson reports, 21 detailed notes of critical incidents, 17 full audio-recorded one-on-one lessons, 12 interviews with André probing his learning, and 27 self-report notes written by André as he was going about learning. Data collection and analysis were focused by the research questions, such as "What belief system drives this high achiever's effective learning of physical science?" As patterns began to emerge in the data, these patterns were summarized in categories, which were used to code the data. Analysis of the data using these codes resulted in emergence of more patterns. This inductive, iterative process resulted in the creation, testing and refinement of an explanatory model, grounded in the data (Taber, 2000), to answer the research questions.

André and his parents gave consent for the conduction of this research and the publication of its results, under the chosen pseudonym. Long-term observation and multiple data sources were used to ensure validity (Merriam, 2009). Relevant sections of the research findings were shown to the people to which they refer, and appropriate adjustments were made to ensure valid representation. In all cases this only required minor changes. Rich descriptions have been given in Stott (2002), enabling readers to form interpretations and generalizations of their own, thus enhancing the validity of the study (Stake, 1994). The first author has maintained contact with André and his family to the present. Recent discussions with André, as well as André's confirmation of the contents of this chapter, provide additional support for the validity of the work presented here.

A CASE STUDY: ANDRÉ'S LEARNING

The authors interpret André's self-regulated learning of science as being motivated and directed by beliefs that meaningful scientific knowledge should be precise, elegant, and transferable. Therefore, André uses the criteria of precision, elegance, and transferability to test whether the scientific knowledge he possesses is acceptable, or whether he needs to continue to apply critical and creative thinking to transform the knowledge further until it does meet these criteria. The beliefs are defined, and their roles in André's use of the cognitive strategies of critical and creative thinking during learning are illustrated below.

Precision

The belief that meaningful scientific knowledge should be "precise" is defined to mean that the learner believes that conceptual boundaries and characteristics for conceptual abstraction must be clearly defined and logically coherent, so that they can be applied in an exact, consistent manner. This is illustrated by remarks and drawings André made (Figure 1) in response to the question, “How does a pendulum’s length affect its frequency?” He said that if length determines a pendulum’s frequency, then the two pendulums he drew in Part 1 of Figure 1 should have significantly different frequencies because their lengths are significantly different. But he doubted that this would be so. He said that adding a string of negligible mass below a pendulum bob would not change the position of the centre of mass significantly even though it would alter the length significantly. He reasoned that if it was the pendulum’s length to centre of mass, rather than its length, that determined frequency, then the two pendulums drawn in Part 1 would swing with negligibly different frequencies. While asking whether this is universally applicable, he drew Part 2 and considered the effect of this situation on pendulum frequency. He said he intended the length to centre of mass to be the same as for the first pendulum, but the absolute length to differ in a different way to the middle picture (Field notes, 31/01/01).

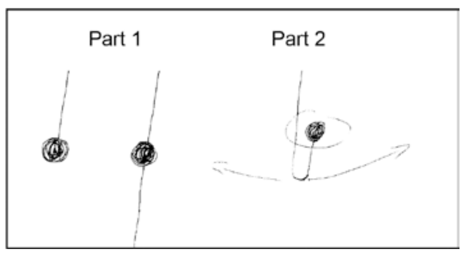

Figure 1. Pendulum variations André drew while exploring factors affecting pendulum frequency

André’s behavior is interpreted here as searching for and testing a sharp (i.e. precise) conceptual line between a factor which determines pendulum frequency and a factor which does not. Notice that this searching and testing involved both critical and creative thinking. It involved creative thinking as André generated appropriate alternatives for testing his hypothesis, and it involved critical thinking as he made substantiated judgments about these alternatives. In another incident, André’s comment that concepts must be mutually exclusive to prevent inappropriate generalization (Personal communication, 1/11/02), further supports the view that he values conceptual precision very highly for ensuring scientifically sound learning. In a more recent personal communication (04/12), André remarked that he thought that people’s science learning could be improved if they could be shown that meaningful scientific knowledge is precise and well structured.

Learners experience a feeling of disequilibrium, also called dissonance, when new information is presented which they perceive not to fit satisfactorily into their existing knowledge structures, and this feeling may encourage them to undergo conceptual change (Posner et al., 1982). From this it follows that the more stringent a learner's requirements for the fit between knowledge elements to be acceptable, the more likely that discrepant information will challenge understandings and misconceptions, and possibly encourage the learner to undergo conceptual change when necessary. André's high regard for precision in knowledge causes him to set very stringent criteria for information to acceptably fit into his existing knowledge structure. This reduces the likelihood that he would undergo sloppy assimilation of incompatible information into his knowledge structure. It increases the likelihood that he is self-regulated to undergo conceptual change towards more scientifically accurate understandings whenever his existing knowledge structure differs even only slightly from a more scientifically acceptable structure. As pointed out by Howard (1987), the categorization of borderline instances puts conceptual boundaries to the test, thus clarifying the rules of conceptualization. Also, engagement with hypothetico-predictive reasoning helps learners to make predictions based on their hypotheses and test the validity of their understanding (Lavoie, 1995). However, it seems reasonable to expect that unless a learner values knowledge precision the activities of borderline categorization and hypothetico-predictive reasoning could be engaged in with little improvement in the learners' conceptual understanding.

Elegance

A belief that meaningful scientific knowledge should be elegant refers to a value for simple, compressed order in the organization of information. André defines information elegance as "explaining the most cases or the most observations, or thoughts, or whatever, in the least number of facts. Compressed data." (Interview, 09/10/02). André says that if an elegant outcome can be reached, then it is worth working at something beyond the point of understanding or functionality (Diary entry, 19/02/02).

André says he dislikes verbosity. He communicates minimalistically. He was frequently observed to search for patterns within information and to generate graphs and equations to aid communication and to consolidate learning. For example, Figure 2 shows a reproduction of André's summary of the effect of object distance from a lens on the position of the resultant image. This was an outcome of a lesson (Field notes, 06/03/01) in which he was taught about five discreet set-ups: the object being beyond 2F, at 2F, between 2F and F, at F, and between F and O, of the lens. At the start of the lesson he could not answer questions about where the image would be formed in each case, and no graph was drawn or referred to by the author during the lesson. It appears that André developed the graph to summarize learning which occurred in that lesson, rather than merely repeating something he had seen elsewhere. André produced the graph towards the end of the lesson in response to an instruction to repeat what he had been taught. His preference for drawing the graph over repeating the outcome of each of the five individual set-ups is interpreted as being due to a high regard for the graph's elegance.

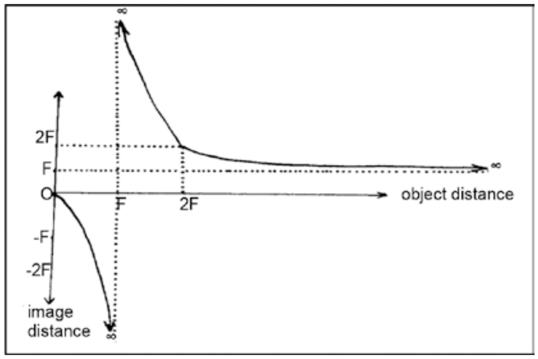

Figure 2. A reproduction of a graph André drew to summarize the relationship between object and image positions relative to a lens

André's value for elegance often motivated him to engage with information for a longer period than he would have otherwise, as he created successively more elegant representations. Therefore his value for elegance drove him to undergo creative thought as he generated representations, and critical thought as he evaluated these representations, particularly against the criterion of elegance. André is not alone in his high regard for elegance and the motivating influence this has on his creative activity. For example, Gooding (1982) maintains that Michael Faraday's belief in the elegance of nature drove his theory creation. Amongst more recent creative geniuses, Steve Jobs' love for elegance largely drove his product designs (Isaacson, 2011).

A learner can only link two concepts when both concepts are represented simultaneously in working memory, which is of very limited capacity (Jonassen, 2009). Greater knowledge elegance can be expected to result in lower cognitive load, despite representation of a larger amount of information in the working memory. Therefore it is reasonable that knowledge elegance should increase the likelihood that a learner can undergo beneficial and complex link formation. This is consistent with Bruner's view that effective learning must involve theory formation in order to avoid mental clutter (Bruner, 1971), since "Knowledge, to be useful, must be compact, accessible, and manipulative" (p. 106). It is also consistent with the finding that experts within a particular knowledge domain possess hierarchically organized and highly linked knowledge base, which includes abstracted levels of knowledge, all of which are necessary for elegant representation (Novak, 2010).

André's value for conceptualizing and representing knowledge elegantly drove him to self-direct extended engagement in creation and evaluation of representations. The contribution of this extended engagement with representations to André's effective learning can be understood in terms of dynamic transfer and the role representations play in coordinating aspects of conceptual understanding. According to theories of dynamic transfer, representations empower a learner to transfer learning to a new context through a series of steps (Schwartz et al., 2008). In other words, representations serve as tools to augment working memory. According to Pierce's triadic model, conceptual understanding involves coordination between a concept, its representation, and its referents (i.e. phenomena to which both the concept and representation refer) (Hubber et al., 2010). Creation, critical evaluation, and recreation of representations refine a learner's understanding of the coordination between these three elements, resulting in effective conceptual learning.

Transferability

By a belief that meaningful scientific knowledge should be transferable, we refer to the learner's value for aspects of understanding which enable knowledge to be used in new contexts, i.e. which make knowledge utilizable, manipulable and flexible (Bruner, 1971). André's value for being able to work something out rather than being limited to what has been learnt by repeated practice, in other words his high regard for the ability to transfer knowledge to new contexts, is shown in the way he works out formulae. This is illustrated in his learning of the formula $F = ma$. Every time André was observed to use this formula within a year of being introduced to it, he derived it from first principles. He would do this by slowly reasoning aloud through the direct and inverse relationships between the concepts. Once this verbal reasoning ceased to be observed he was asked if he was now recalling the formula from memory. He said this was how he was arriving at it:

> I think of a body that's decelerating because of a net force acting in the opposite direction to motion…. and obviously it will lose momentum, and the rate at which – momentum is actually force stored – and the rate at which it loses momentum is equal to the force it exerts on the resisting. (Interview, 29/01/02)

During another interview he remarked that thinking about the relationships between concepts was how he remembered most equations. When asked why this was so despite the fact that reproducing a memorized equation was less time consuming, he replied:

> In an application you're not going to get: "Here's this formula and now work that out". If you're working something out in a practical application, you need to work it out logically because it's not the same problem over and over." (Interview, 09/10/02)

In both these methods of deriving the formula, André is making use of links between concepts. He justifies using these conceptual links to derive the formula, rather than merely recalling the memorized equation, by saying that the derivation is more likely to be useful in a non-routine problem, that is, it is more transferable. This is consistent with work on knowledge transfer, such as that by Schwartz et al. (2008), which shows that multiple links between knowledge elements ensure flexibility and improves knowledge transferability. It is also consistent with expert-novice research, which lists the highly linked nature of an expert's knowledge system as a major reason why experts are able to apply knowledge to new contexts (Kirschner, 2009). The effectiveness of André's physical science learning, and his creative ability, can partially be understood as a result of the formation of multiple conceptual linkages in a manner which aids transfer between contexts. This is driven by the satisfaction André gets from knowledge linked in this way being utilizable in various contexts.

André would often test the transferability of his newly gained knowledge by using it to design various types of machines. This was usually done in a "playful" manner, and was accompanied by a lot of speaking to himself about "if this then that", and a general attitude of obvious enjoyment. This again illustrates André's use of both creative and critical thought to drive his deep learning style. André underwent creative thinking as he generated these designs, and critical thinking as he evaluated the transferability of his knowledge, based on his ability to use this knowledge flexibly within the new situations he had created.

CONCLUSION

Discussion

It appears that André's learning of science is driven by a motivating epistemological belief about the nature of meaningful science knowledge, namely that it should be precise, elegant, and transferable. This belief system drives André to undergo both critical and creative thinking during his self-regulated learning, in which he often enters a state of flow. A value for precision drives André to create test-cases and to stringently evaluate inclusion and exclusion of items into a conceptual category. This provides André with intrinsic motivation to undergo deep conceptual learning resulting in development of a highly accurate conceptual knowledge base. A value for elegance drives André to manipulate his knowledge as he creates and evaluates representations of this knowledge. He continues this manipulation and representation process until his representations are sufficiently concise, interlinked, structured and generalized to meet his criterion of knowledge elegance. This provides André with intrinsic motivation to undergo self-regulated learning resulting in a well-structured, integrated, hierarchical knowledge base, and also to develop powerful representational tools. A value for transferability of knowledge motivates André to manipulate his knowledge by applying it creatively to new contexts, linking memory elements within and between concepts, and so evaluating the compatibility of new learning with his existing knowledge.

These beliefs are powerful in motivating the gifted learner to engage in creative and critical thought in a self-regulated manner. It is not surprising to find that beliefs can so strongly influence learning. For example, Gooding (1982), in a study of the learning and creative process of the experimental and creative genius, Michael Faraday, also found epistemological beliefs, including a high value for elegance of knowledge, to drive Faraday's thinking. Also, Sternberg (1987) suggested that the most effective way to improve learning effectiveness, and even intelligence, is to alter a learner's belief system.

The value of a belief that meaningful scientific knowledge is precise can be understood in terms of conceptual change theory (Posner et al., 1982). A value for precision increases the learner's likelihood of undergoing dissonance and consequent conceptual change towards a more scientifically acceptable conception when exposed to appropriate discrepant events. The value for knowledge precision drove the learner to create test-cases and perform thought experiments, which contributed to him suspending judgment about his conceptions for a while. This was followed by him making conceptual decisions, using critical thinking, during which he underwent conceptual change. This is consistent with interpretations made by Gooding (1982) about Michael Faraday's process of conceptual change using thought experiments.

Much work on conceptual learning suggests that most learners do not experience conceptual learning as a revolutionary, gestalt-change, sudden, process in which a new conception suddenly clicks into place, mentally, immediately enabling the learner to apply it across contexts (e.g. Tao & Gunstone, 1999). Instead, learners tend to vacillate between variations of conceptions, and need explicit help in transferring newly obtained conceptions to new contexts (Schwartz et al., 2008). Interestingly, though, André describes his conceptual learning as involving a series of revolutionary "*clicks into place*", rather than an evolutionary process, and was surprised that this is not so for most people (Personal communication, 04/12). A possible explanation for this is that André's belief system drives him to undergo revolutionary conceptual change to a greater extent than most learners who lack such a belief system.

The value of a belief that meaningful scientific knowledge is elegant can be understood in terms of the information processing model of learning, and in the motivation this belief creates for representation production. Representation production can enable a learner to undergo dynamic transfer and can improve the quality of a learner's conceptual learning process. Greater knowledge elegance is accompanied by chunking, abstraction and hierarchical organisation of knowledge. These processes result in the formation of a knowledge structure characteristic of an expert. Such a knowledge structure enhances learning, problem solving and creativity by enabling more information to be represented and linked in working memory for a particular amount of cognitive load (Kirschner, 2009). Representation production aids the process of dynamic transfer, since representations serve as tools to augment the size of working memory (Schwartz et al., 2008). This enhances a learner's ability to undergo innovation, in other words creative thinking. Creation and evaluation of representations also enhance conceptual learning as learners coordinate their understandings of concepts, their representations and their referents (Hubber et al., 2010).

The value of a belief that meaningful scientific knowledge is transferable can be understood in terms of the motivation this provides for link formation between knowledge elements, and the flexibility and activation of a highly linked knowledge base (Lavoie, 1995). Experts are known to possess highly linked knowledge structures (Kirschner, 2009). In contrast, the knowledge of novices is often inert (cannot be activated within new contexts) due to the sparseness of links between novices' knowledge elements.

The belief system described in this chapter steers André's creative and critical thinking in effective ways. The high levels of motivation observed to propel André's self-directed learning are clearly closely linked to the opportunity for undergoing creative thinking. For example, participation in the national annual science fair particularly propelled his learning by providing a platform for his creative work. Undergoing self-directed learning driven by the motivation which creativity provided him, clearly enthused and invigorated him to learn science. André wrote that participation in the science fair "taught me to accept problems as part of any undertaking…. it imposed an annual rhythm of creative activity on me without which I would have probably run to a boring halt" (Written comment, 09/02). More recently, André remarked about the idea of flow and that he thinks that "almost 100% of real progress is made in that [flow] state, and the rest of the time is spent trying to reach it" (Written communication, 27/05/2011).

Limitations

The findings discussed above arose from a case study of a single gifted learner, who was learning Physical Science individually in a one-on-one relationship with a teacher, and who already possessed a belief system which steered his self-directed learning towards critical and creative thought. No claim can be made that these findings can be generalized to all gifted and creative learners. For a learner to undergo this form of self-regulated learning, a number of interacting internal and external factors are necessary. For example, it is widely accepted that optimal learning occurs with a mix of individual and social learning opportunities (Glassner & Schwarz, 2007). The context of the study described here did not allow observation of the influence of social contexts on the gifted learner's learning, and consequently this has not been addressed in this chapter. This does not mean, however, that socio-cultural perspectives on learning were seen as unimportant. This chapter has focused on the role of ontological and epistemological beliefs on critical and creative thought, and self-regulated learning. The gifted learner under study clearly possessed highly developed cognitive and metacognitive skills and high levels of self-efficacy. His learning also occurred within a stimulating and supportive environment. Clearly these factors are important, and without them it is unlikely that cultivation of the belief system described here would be possible, let alone effective. In addition the full study (Stott, 2002) described the learning strategies this gifted learner was observed to use, as well as the teaching strategies found to be effective in stimulating and supporting engagement with self-directed learning. Arising from the study it was suggested that teachers of gifted learners explicitly teach such learning strategies while nurturing, or encouraging the development of the belief system described here.

Implications

Despite the limitations discussed above, the insights gained from this study have implications for physical science education, particularly of gifted learners. It would be interesting to investigate the extent to which giftedness in the domain of physical science is linked to possession of this, or a similar, belief system, and what the effects of nurturing such a belief system amongst gifted learners would be. As Sternberg (1987) points out, altering a person's belief system is extremely difficult, and may, indeed, not even be possible. However, it is possible that many learners who are gifted in the sciences may naturally possess similar belief systems which need to be nurtured, possibly increasing the likelihood of their uptake of these principles. This study suggests that science teachers should value, model, and nurture an epistemological belief system which values knowledge which is precise, elegant, and transferable. For example, teachers should prompt learners to give more precise, rather than vague answers, encourage learners to refine representations to make them more concise and generic, and encourage learners to apply their knowledge to new contexts, and form links between memory elements and between concepts. The findings of this study suggest that such activity might encourage learners to become self-regulated as they use both creative and critical thinking to undergo effective learning. This should enhance the affective experience of learning, as well as enhance achievement levels (Novak, 2010). This study also reinforces our understanding that critical and creative thinking are very closely linked to one another and are at the core of meaningful and self-regulated learning.

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Angela E. Stott
Schools Partnership Project
University of the Free State
South Africa

Paul A. Hobden
School of Education
University of KwaZulu-Natal
South Africa