Creativity, Complexity and Physics Education

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Abstract

When examining the creative insights of some of the great scientists of our past, I am compelled by curiosity to investigate the thought processes that influenced their discoveries and how understanding those processes can influence the teaching of physics. In the following paper I put forth that a creative idea may be classified simply as a conceptual change. When viewed through the lens of complexity thinking, conceptual changes bear intriguing similarities to the behaviours of complex phenomena. I then use this insight to discuss how both existing literature on creativity and education as well as complexity thinking and education are not only very similar but also provide an ideal framework to encourage creativity within the high school physics classroom.

It was my first day of teaching. The grade 11 physics students piled into the classroom and assumed a respectful and alert demeanour. I turned on a kettle full of cold tap water and told them to listen carefully. The previous class had been rough. They were a talkative grade 9 group who had been fully aware that I was a new teacher. All I wanted was a bit of silence. After the water started to boil I poured it out of the kettle, refilled it with cold water and told the grade 11's to listen to the process again, but *more* carefully.

To be quite honest, I really did not know where I was going with the demonstration; only that I had planned it out well in advance and it had seemed, at the time, to be a good introduction to the sound unit. Suddenly a student blurted out, "That's amazing!" A few others nodded appreciatively and I started out of my reveries in a panic that I had missed out on something. "What do you hear?" I asked, quite genuinely. Together we began to analyze the assortment of sounds we heard as the

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water came to a boil. We then began to brainstorm the reasons why those particular sounds had been emitted based on our pre-existing scientific knowledge.

At that point of my life I had not yet thought about the peculiarities of water. I had not pondered over the behaviour of heated liquids as they experience a phase transition and, reaching a critical point, self-organize into a gas. I had not even been aware of the concept of phase transitions as it is described in complexity thinking. It would not be until two years later that I could apply complexity thinking to the educational environment through the frameworks of Doll (1993) and Davis and Sumara (2006). All I understood at that point was that the students were becoming aware of something more; that the substance they had taken for granted all their life was unveiling a new insightful dimension. My students were experiencing conceptual change.

Rezaei and Katz (2002) describe the process of conceptual change in four phases. The first and second phases involve a systematic analysis of preconceptions using various cognitive strategies such as concept maps and analogies. These serve to provide a bridge between prior knowledge and the new concepts to be learned. In the third phase dissatisfaction with existing preconceptions in light of newly apprehended phenomenon leads to an exploration of plausible alternatives. The fourth phase allows for time to verify the choice alternative. In essence, the process may cycle over and over again but always beginning from a new starting point.

A conceptual change, in my view, is equivalent to a type of creative idea. To be considered creative, a product or idea must be thought of as original and appropriate to the individual creator (Starko, 2005). When a student considers a concept in light of new phenomena and, as a result, gains a novel understanding (novel to the student) then the student has not only undergone conceptual change, but has been creative. In this manner, the realm of creative possibilities within the physics classroom opens up as a student may undergo a series of conceptual changes during a lesson. They may, for example, occur while considering a physical "law" and juxtaposing it with everyday experiences or while manipulating laboratory data and equipment in novel ways.

Before delving further into the complexities of creativity and conceptual changes and how the work of Doll (1993) and Davis and Sumara (2006) may help to underscore the importance of creativity within the classroom, it is worth investigating the habits of mind and actions of our late and famous predecessors in science. It is their stories of great scientific discoveries which have been scrutinized with the hopes of finding the secret to creative success, yielding helpful hints.

Galileo, Einstein, and Feynman

As Goodstein (1985) tells the story, Galileo Galilei (1564 – 1642) was sitting one morning in his church pew feeling, perhaps, a bit bored and searching for a distraction. Above the pulpit there happened to be a long, hanging candelabra which had begun to swing back and forth due to a sudden gust of wind that blew in through the open windows. Galileo began timing the swings. He did not have a stop watch. In his day, sundials and hour glasses were accurate time pieces. Instead Galileo used his own pulse to time the swings. He found that no matter how small the distance traversed by the candelabra became, the length of time it took to make the journey remained constant. He then made the further leap that perhaps this phenomenon could be used to build a better time piece than his own pulse. What followed was his invention of the pendulum clock.

Whereas Galileo's thinking seemed to be influenced by perceiving a real world phenomenon and making connections to his existing understandings, Albert Einstein (1879 – 1955) thought in terms of images and "thought experiments" and strove to translate the images into words and equations that could be understood by others (Grosz, 2005). In one example of such a thought experiment, at the age of 16, Einstein imagined that he was chasing a light beam until he was running beside it (Hirsch, 2003). This type of insight led him to look at the concept in terms of measurement instead of matter (Goldberg, 1983). The final result was the proposition of his famous special theory of relativity at the age of 26 (Hirsch, 2003).

A final story can be drawn from an experience of Richard Feynman (1918-1988) who had been, at the time of his discovery, working on a problem in quantum electrodynamics. He was eating lunch in a cafeteria when a student threw up a plate containing a blue Cornell medallion. As the plate came down, it wobbled and to Feynman, it seemed that the blue medallion went around faster than the wobble. He started playing around with equations of motion of rotating things which led him to think about the spin of electrons and quantum electrodynamics. It was for this work that Feynman later won a Nobel Prize in physics (National, 1999).

From the above stories, one can construe that a sudden "flash of creative insight" led each one to the tantalizing spoils of scientific fame. Plato would have described these incidents nothing short of inspirations from the Gods themselves (Starko, 2005). In fact, the "Aha!" moment, the moment of conceptual change, felt by all of these scientists is similar to "Aha!" moments experienced daily by the students in our classrooms. There is an air of mystery surrounding such a moment and it is here that the existing literature on creativity can join hands with complexity thinking to inform how we, as teachers, can make the topic of physics as rich an arena for our students as it was for Galileo, Einstein, and Feynman.

Creativity and Complexity

Contrary to the popular "flash-of-genius" belief, creative people have prepared minds and, as put forth by Louis Pasteur, "chance favours only the prepared mind" (Austin, 1975, p. 74). At the time of his discovery Galileo had been spending countless hours devising experiments to understand the phenomenon of gravity (Goodstein, 1985). He spent countless hours timing falling bodies. Einstein had been working as a patent clerk; a position which he enjoyed because it allowed him to practice "sizing up a physical system at a glance and seizing its essence…to understand how it was supposed to operate and whether it would" (Panek, 2004, p. 84). This type of experience would help him size up his own thought experiments. Feynman, as mentioned, had already been hard at work trying to disseminate the field of quantum electrodynamics.

Along with having a prepared mind, these scientists also were able to consciously compare, contrast and connect seemingly unrelated bits of information. One prime way that this is often done is through metaphors and analogies. Galileo compared his own pulse with the regularity of the swing of the pendulum which convinced him of the pendulum's superior accuracy. Einstein used visual metaphors to contrast his understandings between pre-existing scientific and logical arguments. Feynman connected the motion of an object in a twirling bowl, a fairly common everyday experience, to the spin of electrons.

In Davis and Sumara's (2006) framework, the above internal dialogues fall in the realm of neighbourly interactions; in this case, relationships created between sensory data received and pre-existing individual knowledge. Doll (1993) reminds us that these relationships are ongoing and cultural as conditions and situations to which one is exposed are always changing. In fact, the internal diversity with which one enters a problem is what makes the process of drawing relationships unique to each individual. Added to this is Doll's (1993) concept of recursion. Recursion involves the looping of thoughts upon thoughts which compels one to continuously reflect upon one's own knowledge in light of continually received sensory data.

In the literature of creativity, the above ideas fall under the process of incubation (Ghiselin, 1975). It is a period in which the creative individual focuses on irregularities and apparent disorders with the intention of creating a new order (Barron, 1975). Metaphors and analogies are simply tools that we use to create order for ourselves. It is a process which describes a "commitment to a complex personal synthesis" (Barron, 1975, p. 158); much like the cultural manifestations of recursive thought. Incubation is then terminated by the appearance of spontaneous insight (Ghiselin, 1975). What we have here is a period of disordered thoughts derived from continuously received sensory inputs (as we ourselves are systems open to the world), mingling with existing data and then suddenly reaching a critical point after which the system changes and reaches a new order. In other words, what we have here is an example of a non-equilibrium system going through a phase transition and, at a critical point, achieving a new order. Creativity, a conceptual change, is a complex phenomenon.

This type of connection is not new to complexity thinking. Chris Langton, in Waldrop's (1996) account of the emergence of complexity, toyed with the idea of extending the notion of phase transitions from matter and cellular automata to the origins of life. Ball (2006) has reported several investigations of critical points within the phase transitions of magnetic material as it becomes demagnetized, of traffic when it becomes congested from freely flowing, and even to speculating upon the nature and structure of social networks (just to name a few). In light of this new way of viewing creativity, the question which remains to be asked is, how does this connection between creativity and complexity help inform educators?

The answer to this question becomes clearer if we touch upon one more piece of information and that is the connection between mind and matter; the "matter" in this case, being the brain. The process which is essential for the creation of meaning occurs when information is converted from working memory via electrical signals to long-term storage regions. In this process, which can take days to months, the brain constantly checks information relayed to working memory and compares it to stored experiences. In other words, "whenever new learning moves into working memory, long-term memory simultaneously searches long-term storage sites for any past learnings similar to, or associated with, the new learning" (Sousa, 2006, p. 135). It is precisely this type of recursive behaviour that leads to the creation of analogies and metaphors and connections. When one consciously engages in this process, at some critical point, there will be an "aha!" moment when one undergoes conceptual change.

This process is essential in understanding why, if the conditions are not right, students may find it hard to experience moments of conceptual change in the classroom (as will be explained shortly). The balance of this paper focuses on how the remainder of Davis and Sumara (2006) and Doll's (1993) ideas on complexity thinking as applied to education allows for the emergence of creativity within the classroom setting.

When Conditions are Not Ideal

Laboratory experiments, when I was in high school, were always terrifying experiences. It seemed that we had a set amount of time to get the "right" results and then we would have to write it up for marks. I always just *had* to get the right answers. The night before science labs I used to pray that luck would be with me so that I would be able to figure out the "right answers." Many of those labs just passed me by. I don't remember the majority of them except the ones in chemistry. My chemistry teacher believed that we would always make mistakes. As such, he would allow us the opportunity to spend as much time as we needed figuring out the labs. We rarely needed the extra time – perhaps just knowing that it was available had a calming effect. Rather than coveting the "right answer" he would guide us whenever we had problems. As a result, I began to think of his labs as being opportunities to gain further insight into the phenomenon about which we were reading instead of as a vehicle for marks.

I believe that many students still face the laboratory scene with the same apprehension. The top three blocks to creativity within society and the classroom, according to Cropley (1992), are success orientation, sanctions against questioning, and external evaluations. Starko (2005) adds the factors of surveillance, competition and lack of choice. These blocks lead to stress and negative emotions. Sousa (2006) explains that when students feel stressed, a certain hormone, which activates defence behaviours in the body, is released. Brain activity is reduced to focusing on the cause of stress and how to deal with it instead of encouraging recursive thought. This hormone also interferes with the recall of emotional memories. In effect this inhibits, physiologically, the process of meaning making and creativity. In contrast, Sousa also describes how the use of humour in the classroom and experiencing laughter not only provides more oxygen to the brain (oxygen and glucose fuel the brain – the more challenging a task, the more fuel it consumes) but also causes an endorphin surge which gives a feeling of euphoria accompanied by increased focus and attentiveness.

Starko (2005) emphasizes the importance of assuring psychological safety and maintains that a teacher should encourage independence, autonomy and self-evaluation within their students. She further explains that she views a creativity-friendly classroom as a problem-friendly classroom (one which encourages problem "finding"). In a classroom setting where control is decentralized and not residing chiefly within the teacher, a state of "organized randomness," as characterized by Davis and Sumara (2006), can be facilitated. Here a thought provoking problem is released into the classroom and it takes shape and direction through neighbourly interactions. Students, constrained only by the boundaries of the problem are free to think independently. Doll (1993) further elaborates that the problem must be rich enough to allow for several burgeoning avenues of exploration and that a sense of rigour should be encouraged within the students so that they persist in pursuing their questions as they come up along the way. Creative ideas, and conceptual changes, then, become part of the learning spiral contributing to Barron's (1975) idea of a "complex personal synthesis" which is a state of continual transformation.

Figure 1 depicts a series of three charts which outline the connections between creativity and complexity thinking in education. If we begin with approaches taken within the classroom which block creativity, we can focus on the opposite approaches as those which encourage creativity. Creativity encouragers happen to phrase, in an alternative way, the basic tenets of complexity thinking in education as described by Doll (1993) and Davis and Sumara (2006).

Shifting the focus to cooperation and collaboration from success orientation and competition allows for opportunities where students can dialogue with each other through neighbour interactions and build an understanding of the material through recursion, metaphors and analogies. This, as discussed, is a natural process that occurs in the brain as it tries to create relationships between new phenomenon presented and existing phenomenon stored from past experiences. Studies support the positive effects of allowing for discussion, cooperation and collaboration within the physics classroom (Tao, 1999; Kelly and Chen, 1999; Tao, 2001b; Kneser and Ploetzner, 2001; Roald, 2002).

Allowing for questions and for choice instead of placing sanctions against them requires an attention to creating conditions within a classroom that encourages such behaviour. This can be achieved through creating a state of organized randomness (Davis and Sumara, 2006) where a rich problem provides the seed for propelling discoveries and offering the opportunity of experiencing rigour, the conditioning of discipline (Doll, 1993). Studies done in the physics classroom encourage not only

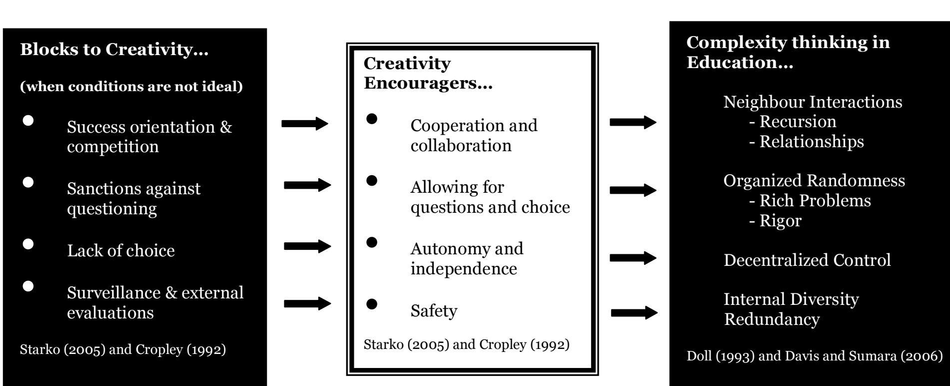

FIGURE 1. Connections between creativity and complexity thinking in education.

inquiry-based teaching which begin with unveiling rich problems but also environments which stimulate discussion to the extent of even allowing for debates and controversy (Tao, 2001a; van Zee, Iwasyk, Kurose, Simpson and Wild, 2001; Niaz and Rodriguez, 2002; Bartholomew, Carpenter and Owens, 2003; Peters, 2005). By assuming the role of a facilitator within the classroom, a teacher can provide students with a degree of autonomy and independence.

Creating the conditions of safety within the classroom means that a teacher should have a sense of the internal diversities and redundancies existing within it. This includes knowledge of individual student differences, common cultural experiences, existing power relations between social groups, and so on. Studies have been done within the physics classroom examining the such issues including the importance of appreciating student context and achievement within class and student sensitivity to feedback (Geelan, Wildy, Louden and Wallace, 2004; Ziegler, Finsterwald and Grassinger, 2005). Observing and monitoring for issues such as the ones mentioned above allows for the facilitation of a safe classroom community; safe enough to allow students to make mistakes and to take risks.

It is for all of the above reasons, including those that have been drawn from literature in the fields of creativity and complexity thinking, which I believe complexity thinking in education allows for creativity within the classroom. The point however, with which I would like to end, concerns the issue of taking risks within the classroom. Great scientists like Galileo, Einstein and Feynman invested years, sometimes decades in investigating phenomenon for which they felt passionate. Dedicating years to a particular study involves a substantial amount of risk in itself but when it diverges from the path taken by the contemporary bandwagon, it represents an even greater risk.

Similarly, when a student in our class takes a chance and offers an understanding that runs the risk of exposing misconceptions, we must recognize that as an opportunity for students to elucidate their understandings in view of their prior understandings and encourage their efforts. Complexity thinking allows for a way of looking at the world. Complexity thinking in education supplies a framework by which to experience that view. Creativity, or conceptual changes, outlines the cognitive processes undertaken to provide that view all the while hinting at why it can be so enjoyable. As educators we can encourage this sense of joy and passion. And perhaps, if we choose to be creative in our own pedagogical approach and understanding, we may also experience this sense of joy and passion along the way.

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