Improving imagination skills in order to assist abstractive learning

Dr. Kenneth Meyer, Charles Stuart University: TAFE NSW Riverina Institute

Abstract:

As a TAFE teacher for now over fifteen years I noticed that many of my students had difficulty with abstract concepts. It was this difficulty with abstraction that I believed was affecting their learning in negative ways. The result was a project that would use positive interventions to counter this apparent learning problem. The result is this paper that emanates from a major research project that explores the use of imagination in learning with eighteen students of a full time diploma course at a large TAFE in country NSW during 2010. The purpose of the study was to significantly improve student learning in a the highly abstract domain of electricity. A narrative methodological approach was used, guided by regular self-reflective interviews. The findings of the research indicate that being metacognitive about the use of imagination does improve student learning outcomes that assist with abstractive learning. This investigation is a paradigm pioneer, standing on the edge of scientific rationalism and steps out into the substantially ignored world of imagination.

Introduction:

The prime purpose of this research has been to better facilitate how people can be encouraged and supported in using imagination to learn abstract concepts representing physical realities, for this is non-sensory nature of electrical physics. The objective of the research was to explore how imagination could be used to improve mental modelling skills which, in turn, would improve abstraction skills. The focus of the research was to amplify particular imaginative skill categories and improve these by direct and purposeful activity.

Formatted: Font color: Auto
Formatted: Font color: Auto
Formatted: Font color: Auto
Formatted: Font color: Auto

The eighteen research participants were electronics and communications students in a full-time diploma program fully supported by Airservices Australia. They were divided into three groups:

Year Twelve school leavers;
University graduates and undergraduates and
Career-changing mature age students.

The aim was to enable students to develop new learning skills from an imagination paradigm and, give them a voice to express how this may have affected their learning. So the following research question was posited, '***Will being metacognitive about imagination, individually and collectively, assist TAFE electrical engineering students in their learning and application of electrical physics?'*** as window for data and analysis.

Formatted: Font color: Auto

Although the metacognitive approach to engagement is not new, the deliberate development of imagination to improve abstraction ability, within teaching and learning electrical physics, is breaking of new ground. This required a tailored approach to the analytical method or paradigm and to the research design in order to generate the appropriate types of data.

Literature review:

Abstraction in electrical physics

Abstraction in electrical physics is unavoidable because electricity is non-sensory – that is, humans cannot directly sense electricity by sight, touch, smell, taste or sound. We can see the result of electricity as a light illuminates objects, but not the energy itself. We feel electric shock, but this is our bio-electrical system being disrupted, not used as designed to sense heat and pressure; we are not feeling electrical current flow for example. Electrical faults often have a distinctive smell, resulting from the production of ozone (0_3) as air is ionised. The

smell is the ozone gas not the electrical energy. We cannot taste electrical energy; a tingle on the tongue from a battery indicates disruption of our bio-electrical system again. Finally, sometimes the crackling sound near a high voltage substation (above 33kV) is the sound of air ionising from sharp points producing sound waves, not the electrical energy itself.
All dealings with electrical energy are abstract then by their very nature. The next level of abstraction is the modelling systems used to represent the physics, for example algebra and trigonometry. The third abstraction is the use of language and the words used to bring meaning to electrical physics in other words the jargon. An example is the use of words with historical significance, particularly in describing electrical units. 'Voltage', for example, is derived from a person's name. A fourth layer of abstraction lies in general physics concepts such as the conservation of energy: energy is neither created nor lost but may transfer from one state to another.

All levels of abstraction create problems for the learner. Examples from the literature at the first level of abstraction include:

> Many students see physics stuff, lamps, batteries etc., but do not comprehend power and current (Licht, 1991, p. 274).
>
> The fundamental reason it is difficult to teach electricity is the main domains of resistance, current and voltage are not directly observable (Arnold & Millar, 1987, p. 553).
>
> Electricity is a difficult topic for students to come to terms with. The invisible nature of what is happening makes it an abstract topic (Arnold & Millar, 1987, p. 341).

The above examples demonstrate the previous point that electricity is not directly observable and therefore learning about and within the phenomenon is immediately abstract. This builds on the non sensory premise of the thesis.

Cases from the literature that demonstrate the second level of mental modelling as abstractive include:

> However, we have found that the use of model building as an instructional strategy is usually not sufficient (Shafer & McDermott, 1992, p. 1008).
>
> Instruction of Ohm's law from electricity theory serves as an example domain. All of the instruction discussed below can be supported with one simple model (Figure 5-10), a circuit whose behaviour is expressed in a rule that applies Ohm's law: current (I) equals potential (E) divided by resistance (R), different presentations can either be made from copies of this basic model, or they can be constructed as overlays upon it (Gregson & Little, 1998, p. 143).

Here the research indicates that to deal with the first level of abstraction a second layer needs to be added using existing models, particularly the model of algebra.

Instances from the literature that focus on the abstractive levels of language include:

> The classroom context led her to bring up her "physics class" model, Newton's third law, but common-speech wording of the question led her to bring up a common sense response, larger objects exert larger force (Redish & Steinberg, 1999, para. 45).
>
> Certain words in a particular culture are difficult to encode because they have varying meanings (Carspecken & Walford, 2001, p. 18).

The third facet of abstraction is that of the use of language. In particular technical languages, as words like 'current' have multiple meanings in different contexts.

This group of illustrations from the literature demonstrates the final level of abstraction that is inherent in the electrical physics concepts.

> Problems with abstract frameworks when dealing with energy and its conservation (Sencar & Eryilmaz, 2004, p. 462).
>
> Turning to the specific point, it has been implied strongly that the differentiation of ideas of electric "current" and "energy" is crucial for further development of understanding (Sencar & Eryilmaz, 2004, p. 562).

This final abstractive level is with reference to the actual concepts embedded in electrical physics. The concept of current expended over time as energy is an abstractive relationship concept as an example from just above. The project's intent was to explore deeply these levels of abstraction in relation to learning using imagination skills to assist with learning.

These multiple levels of abstraction create ever deepening dimensions of complexity in the learning of electrical physics.

Conceptualisation and abstraction in electrical physics

Reasoning in science, and so reasoning in electricity, requires reasoning in the abstract (Osborne & Freiberg, 1985, p. 55).

For the purposes of this study, I have defined a conceptualisation as an abstract and simplified idea of the world that we wish to represent apart from or removed from its context (Lesgold, 2001, p. 6). When abstraction is thought of as separate from concrete realities or specific objects, an abstract idea or concept is produced.

Abstract conceptualisation attempts to make meaning when meaning is not obvious from concrete reality. This is the focus of the project as students are encouraged to explore this aspect through the use of measurement instruments during circuit construction and testing. Another example of this is concept-mapping or mind-mapping. This is the process of systematically mapping the relational connections and so bringing meaning to those connections or 'making sense' (Sencar & Eryilmaz, 2004, p. 1080; Smith, 2006, p. 63). Many studies in the literature examine misconception, which again is about meaning and is about the production of incorrect meaning (Bull, Jackson, & Lancaster, 2010; Garnett & Treagust, 1992; Linke & Venz, 1997; McDermott, 1998; Smith, DiSessa, & Roschelle, 2006; Smith, 2006, p. 73). At its centre, meaning creation comes through problem-solving and reflection as Quinn explains.

> At its core, individual learning is about engagement in activity encountering a problem and reflecting to create an abstract conception, and then testing that conception through more activity in an ongoing cycle. (Quinn, 2005, p. 24)

Abstraction is strongly associated with complexity. Progress and vertical movement are characterised by higher and higher levels of difficulty (Gott, 1988, p. 125). So, as conceptions become more abstract, the more involved they tend to be. The outcome is that electrical physics is a series of highly abstract concepts and so it becomes very complex (Guzzetti, 2000, p. 93).

The most common method to deal with abstraction is analogy (Chiu & Lin, 2005, p. 459). Analogy is an attempt to use a system or process that is similar to the abstract concept but based in observable physical reality. The analogy of water in pipes is often used in electrical physics when first learning about Direct Current. Millar and Burton (1994) claim that the visual aspect encourages abstract reasoning. Unfortunately, the analogy quickly breaks down in its attempt to make the abstract concrete and is totally ineffective for AC (Alternating Current).

Analogy is not the only way of connecting the abstract to the concrete in an attempt to bring understanding and meaning. In electrical physics, the use of animated simulation or visual metaphor is often used (Gibbs, 1999, p. 220; Tang, 2003, p. 1). This is effective because abstraction and the concrete are both parallel continuums. Not every concept is completely abstract or completely concrete (Smith, 2006, p. 26). Metaphor in the form of animation often finds or explains, even bridges, the abstract and concrete thus sense is made (Tang, 2003, July, p. 2).

One of the main abstractions used in electrical physics is text. Text, or written language, is an abstraction of spoken language. The particular textual abstraction in electrical physics is the use of jargon (Olsen, 2002, p. 566). Many of the terms in electrical physics only find their meaning in the context of electrical physics.

The final aspect of conceptualisation and abstraction is generalisation. The more often a phenomenon is repeated, the greater the likelihood of generalisation and this is a short step to abstraction (Jarvis, 2006, p. 21). Electrical physics, the phenomenon, is repeatable anywhere in the universe, such is its nature, and the result is abstract generalisation (Licht, 1991, p. 341). An example of generalisation is Ohm's law (Osbourne & Gilbert, 1979, p. 86) a law that can be applied successfully in all situations.

Research paradigms:

The research question has driven the selection of the approach in this research; rather than a preferred methodology driving the type of question being asked. The research question again is: ***Will being metacognitive about imagination, individually and collectively, assist TAFE electrical engineering students in their learning and application of electrical physics?***
Answering this research question has required a blended research approach based on both action and narrative. Therefore, principles and processes from a number of different, yet related research approaches and methodologies have been drawn upon.

One of these research characteristics offered by the theory and process of participatory action research was selected due to the metacognitive requirement of the research question. This approach encourages the students to be direct and expected participation in the process. Such an approach provides narrative data.

In addition, in order to ascertain if the metacognitive approach to imagination has affected the participants' learning of electrical physics, their stories of the imagination activity process are collected. These two sets of narrative data provide the rationale for drawing on narrative research methods and approaches. Overall the research approach is ethnographic and essentially a blending of participatory action and narrative research.

Participatory action research (PAR)

Action research has an inherent cyclic dimension that is qualitative in nature (Gay & Airasian, 2003, p. 166; Kemmis & McTaggart, 2003, p. 4). Action research is also ethnographic as the cyclic process most often involves a defined group of people (Compte & Goetz, 1982, p. 35). In this study the group of people is a class cohort of eighteen full-time Diploma of Electronics and Communication students and their teachers.

Participatory Action Research (PAR) has all the hallmarks of action research with two additional dimensions. The first is that the participants are equally involved with, and as, researchers in the process (Kemmis & McTaggart, 2003, p. 345). The second dimension lies in what constitutes the activity in the spiral/cycle. PAR begins with planning change with respect to the problem or practice that has been identified. This step is often more interactive than in action research. In PAR, there is already an idea of what is happening and how it may be changed. The second stage involves enacting and observing the process and the consequences of the change. This stage is more than a single act; it includes reacting. The acting and observing are inter-related, producing some analysis in the process. The third stage is the formal reflection about the process and its consequences. The result is then re-planning, acting and observing, reflecting, and so on (Kemmis & McTaggart, 2003, p. 381).

Student participation operates at several levels. The first is through understanding of the research, its process and its purpose. The next level is to interact and engage purposefully with the research. The third level involves the students' individual reflections on the research to make changes at a micro level and suggestions at the macro-level. For participants to be able to thus engage effectively, they will need an understanding of learning including learning cycles (Engeström, 2000, p. 970; Marek, Eubanks, & Gallaher, 2006, p. 189) and learning theory (Brown et al., 1989, p. 40; Illeris, 2002, p. 84). They also need insight into 'interview of instance' (Osbourne & Gilbert, 1979, p. 91), and related techniques used in physics education enquiry (Schwandt, 2003, p. 144).

A significant reason for selecting this approach is that PAR assists with grounding theory in practice, a significant aspect of this study. This methodology has seven key features that make it appropriate (see Kemmis & McTaggart, 2003, p. 384). PAR is social as it deliberately explores relationships between the realms of the individual and the social. PAR engages people in examining their knowledge and their interpretive categories. PAR is practical and collaborative as it engages people in examining social practices that link them to others. PAR helps people recover, and release themselves, from the constraints of social structure that limit their self-development. PAR encourages critiquing the very culture of language, social media and modes of work. PAR is recursive, helping people to investigate reality with the purpose of change. PAR aims to be transformative of both theory and practice.

Narrative research

Narrative is a primary way humans make sense of our world and deal with its complexities (Marshall, 2005, p. 52; Moen, 2006, p. 9). It therefore follows that narrative research is an appropriate approach to investigating sense-making (Lieblich, Tuval-Mashiach, & Ziber, 1998, p. 5). Fielding (2007) asserts that narrative is concerned with communicating the human experience (p. 386). Narrative research is an appropriate approach for this project as it investigates students' experiences of learning electrical physics.

Narrative provides the audience with access to the world of the storyteller that other approaches cannot offer (Fielding, 2007, p. 385) and allows access to the storyteller's thinking, both conscious and unconscious (Lieblich et al., 1998, p. 9). Its diversity and depth provides useful information for analysis. In bringing meaning, narrative also brings context. The contextual aspect is bi-directional and recursive. Narrative not only brings context but also has a context of its own (Daniels, 2008, p. 103). Narrative is 'therefore' never neutral (Taylor, 2009, p. 3) and, as narratives are produced, collected and analysed, these contextual dimensions must be taken into account.

Constructing reality

Storytelling, narrative, is wired into us as humans. We tell stories in a social context as this enables us to make sense of reality (Brown & Duguid, 2000, p. 106). This is what is known as narrative in academics. Storytelling in the social context is about relationships and our place within these relationships (Down, 2006, p. 153). From childhood right through to adulthood, narrative is how we learn to put the world together (Marchall, 2005, p. 46). Narrative builds or constructs by creating tension and then releasing the tension. The narrative releases the tension by then providing the answer or at least a strong signpost to the answer (Quinn, 2005, p. 44). This tension plays directly into the human imagination via curiosity.

Finding meaning

There is a connection between narrative and meaning that leads to action (Atkinson, 1990, p. 41; Jarvis, 2006, p. 64; Pink, 2005, p. 26). If the narrative engenders action, change in thinking and behaviour, then meaning has been established. Meaning is also created as the mind builds connections or schemas (Clancy & Lowrie, 2010, p. 44; Daniels, 2008, p. 99; Koestler, 1964). Meaning is also equivalent to the interpretation of the narrative which consequently yields value. External narratives come loaded with meaning received from outside the senses. Internal narratives are created from within one's own thinking process (Stevenson, 2003, p. 19).

Research design basis

The rationale of using PAR is two-fold. The first element is to encourage the participants' involvement in improving the learning of electrical physics through actively participating in imaginative skills activities and exercises. The second is to provide participants with formal points at which to stop and reflect on their practice in learning electrical physics, and how this may have been influenced by the imaginative skills engagement. This then produces the content of the students' narratives.

The narrative research, operating in parallel with action research, encouraged participants to record their stories by means of semi-structured interviews. At the middle and end of an action research cycle, participants were given open questions to assist their reflection about imagination and learning electrical physics. Participants had two or three days to reflect on the questions before video interview. This was repeated for each action research cycle. Other data or parts of the participants' stories were collected incidentally in response to significant incidents as part of the overall narrative. In addition written responses were collected when appropriate.

Findings and discussion:

Even though the larger project investigated many faces of imagination and learning the focus of this paper is imagination and abstraction. The full project developed eight definitions with regard to imagination. The following findings and discussion focus on only three of these definitions as a framework for explanation here.

Definition 1

The first definition is the ability to, and process of, forming mental models or images of things not actually detectable by the senses. The dimension of imagination is highly significant in learning electrical physics. Since no aspect of the phenomenon of electricity is present to the senses, this necessitates mental modelling and abstraction skills as a starting point.

Non-sensory mental modelling is required in all electrical physics, but is most challenging in sub-atomic theories, magnetism, creation/storage of charge and current flow. Chemistry, too, would benefit from imagination and mental modelling skills since it deals with matter at a sub-atomic level that cannot be directly sensed.

In this non-sensory domain, the predominant skills for mental modelling are analogy, diagrams (illustration) and reasoning. Similarly the main skills of abstraction are metaphor, reproduction, reasoning, elaboration and risk. This is not to say that the skills align perfectly. Rather, the skills cross-connect and I have separated them for reasons of clarity and descriptive order.

The skill of reasoning is applicable to most imagination definitions and categories of imagination. One of the important applications of this skill is the ability to recognise gaps in understanding and or logic, and to make accurate perception of when and how to move between different representations.

The skill of reproduction is being able to give physical reality to mental models, perhaps in a circuit diagram or by connecting an electrical circuit. Both are representational reproductions, representational because there are often many valid ways to draw or connect a circuit.

The imaginative skills of elaboration are significant in mental modelling. As students observe the effects of electricity with all their senses, they need to make reasoned guesses (elaboration) and with them adjust and confirm their mental models.

Risk as an imagination skill pervades all learning, particularly within electrical physics. The research is clear that anecdotal models are very resistant to change. Students need to become 'risk-takers' with regard to their learning as those mental models are challenged.

In order to improve the students' imaginative skills a number of activities were used. One that has special relevance to mental modelling is white-board Pictionary.

Whiteboard Pictionary is the Pictionary board game modified. Students had to create visual metaphors and analogies to express abstract concepts. Again pressure is introduced as sides compete with each other or against time. The game encourages participants to stretch their imaginative skills of connection and mental modelling using drawing, metaphor and analogy.

Mal's appreciation of the introduction of imaginative skills to improve mental modelling is indicative of most students.

> When it comes to Term 4, as an example I can say the subject Datacom [Data of communications]. We learn only theory things; apart from a couple there were no practicals. So it's a matter of modelling of the imagination because it's like that video tape of warriors of the Internet. It helps me understand how the data packets flow around a network. It's very helpful for me. So, even though it's not real, but when you make a model and imagine it that way, then it's very helpful to understand how it works inside the network. Actually, I use it a lot of times in amplifiers when we draw the AC equivalent circuits [Thevin's] or high frequency equivalence. It's not actually there so we have to imagine the presence of the components.

Definition 5

This definition uses imagination as the capacity to solve difficulties resourcefully in a non-linear manner. The major elements involved in lateral or imaginatively problem-solving are: aims/goals/focus, procedural knowledge, reasoning/logic, ways of knowing, elaboration, risk, innovation, and creativity.

Imaginative skills for aims/goals/focus incorporate the ability to perceive what the actual problem is in a critically focussed way and then use this insight to search for non-traditional or non-standard solutions. Imaginative problem-solving requires the skill of unpacking procedural knowledge through critical reflection. It also requires the ability to de-automate the blindingly obvious and use this as part of new solutions. Logical reasoning uses imagination skill in so far as it requires a combination of reflection and connections to find applicable solutions.

Elaboration is an imaginative skill that takes associations of the past, views them in a new light and re-works them in new associations and relationships. The process is not static but dynamic, is reflexive and investigative. It results in improved ways of solving problems.

Derived from lateral approaches to knowing and elaboration, the skill of risk taking is important to imaginative problem-solving (Brookfield, 1987, p. 71). Acting outside the relevant norms entails risks and, therefore, imaginative problem-solving is inherently risky. The resulting solutions are considered innovative if they are effective – aesthetically, ergonomically, or in reducing energy use. The imaginative skill of innovation or creativity is more than a collage of randomly associated ideas; creativity is an interactive, flexible framework representing a way of knowing, explaining and communicating.

Many aspects of electrical physics require imaginative problem solving – most prominently are those of design, application, and protection. Design requires imaginative skills in all the processes from problem perception through to algebraic representation and finding solutions. These solutions may then become part of the physical outworking of further problems as designing circuits is intended to lead the production of circuits. Imaginative skills in the electrical domain move from abstraction to physical application through many aspects of problem-solving. By way of illustration the earth leakage circuit-breaker developed twenty years ago and mandated some five years later, protects human life.

Dillon's comment provides his perception of the world of electricity and adult learning.

> When it comes to activities to help imaginative skills, I think problem-solving skills. I love problem-solving so much and I think being able to constantly problem-solve, solve problems, just means later on you can solve a problem quicker because you know how to approach a problem easier... The spatial and psycho-motor skills as well because they are applicable to everything we ever do. Those three problems are my favourites.

In the course of the study, many problem-solving activities were used. One activity whose primary purpose was to stimulate imaginative problem-solving was 'PCB to circuit'. In the first of these, students received a complete small electronics project (sound generator). However, the circuit diagram was withheld. From the circuit written description for operation and construction, the component list and printed circuit board lay-out, the circuit was to be re-created. This activity stretched their abstraction skill by their having to work backwards. Their spatial and psycho-motor skills were important as their diagrams often had to be re-worked. Students' mental modelling was challenged as they had to deconstruct and re-construct concepts.

Definition 7

This definition is the capability to create new images from former experiences, pictorially and or linguistically. This facet relates to the way we construct mental images and/or schema to represent concepts and our ability to construct, adjust and reconstruct these constructs. The skills that support the production of new images or ideas in memory are underpinning knowledge, finding relational links, risk, novelty, innovation and abstraction.

Consciously or subconsciously, new images and ideas are developed from the substrate of previous learning or underpinning knowledge, as was mentioned by Piaget (1993, p. 5). Imagination is used to recognise this basis and to use it to learn widely. Since the imaginative connections are not obvious, a broad general knowledge and positive attitude to life-long learning will provide the nutrients for new images and ideas. Learning requires the imaginative skills of risk-taking in areas whose value may not become apparent to others until much later. Mediating the risk is the imaginative skill of novelty: making initial superficial links in anticipation of exploring them later. In subsequent exploration, new links are found and explored. As new images and ideas arise, they are often abstract. Abstraction skills allow the memory to make links using experimentation and elaboration. This occurs as abstraction is taken to the concrete, back to the abstract again and into the concrete in a continuous cycle. To have use and meaning, abstraction must have an outworking.

Because of its non-sensory nature most concepts in electrical physics are abstract and the connections between them are therefore neither obvious nor simple. This can result in the construction of strong anecdotal misconceptions. Imaginative skills, by producing new images and ideas in memory, allow students to discover new ways electrical concepts will operate together. 'Road Runner Rules' was used to help students gain imaginative skills involved in producing new images or ideas in memory.

In 'Road Runner Rules', students view several episodes of the well-known cartoon series. After a few episodes, students describe or define some of the cartoons' nine basic 'rules' – for example, the coyote never wins or the Road Runner can transcend the laws of physics. Then the students view further episodes until all nine 'rules' are defined. In a very engaging way, the activity requires viewers to make the same imaginative links that the cartoonists have made. Imagination has been used to transcend the physical world into a metaphysical world of humour.

Josh enjoyed the game activities and understood its strategic nature but did not have the level of imaginative skills required. Further use of this tool would have probably remedied this.

> The board games we played this time were completely new ones. We played the one where you had to chase the guy around the city [Scotland Yard]. That was an entirely different skill set to what I am used to, to play a game. The strategies we were using to try and track him down were not working at all. They seemed that you should-but not a chance. He was always two or three steps ahead.

Conclusion:

The implications for abstract learning arising from the research are the need for change in attitudes to the use of imagination in learning; strategic learning activities involving imagination; the role of imagination in reconceptualising poorly understood aspects; and enhancing reflection on learning using imagination.

Need for change in attitudes to using imagination in learning

At the start of the study the attitude of most students to using imagination in learning, particularly learning electrical physics, was negative. Most of the students agreed to participate in the study despite their cultural preconceptions about using imagination in 'real' learning. The proceedings of the research indicated that the cultural negativity to learning using imagination was pervasive in all students' attitudes to learning. As the research continued, the attitudes of all the students moved toward acceptance. The research demonstrated that changing attitudes with regard to using imagination improves learning outcomes.

Strategic learning activities involving imagination

The action research nature of the research meant that a series of learning activities were introduced to test the hypothesis of the research question; that is, would improving the student's imaginative skills result in an improvement in their learning? The research found that the students responded positively to the imagination activities. Developing strategic learning activities using imaginative skills does impact on the efficacy of problem-solving, narrative and metacognition. All three of these require a commitment to life-long learning and appropriate risk-taking in learning.

Problem-solving is assisted through imaginative skills by recognising the learning options and possibilities that are not obviously apparent. The most common problem-solving assumption challenged by imagination was the tendency to try and find a mathematical solution. Imaginative skill building provided students with increased mental modelling, conceptualisation and schema construction which provided alternate ways to problem-solve.

Narrative, and therefore meaning making, is enhanced using imaginative skills, as these skills improved students' ability to reflect in multiple ways. Imaginative skills assist in memory reflection of the past, concept reflection in the present and future possibilities that could produce meaning. Narrative also provides connection between experience, knowledge and possibility to further ask the question 'what if...?' and 'may be we could...?'.

Role of imagination in reconceptualising poorly understood aspects

The non-sensory nature of the phenomenon of electricity often results in simplistic anecdotal misconceptions. These misconceptions develop early in childhood and over time become well embedded, and so are very difficult to change. The study repeatedly demonstrates through the student narratives that misconceptions are difficult to change.

The imaginative skill building and its application to learning produces a dissonance 'space' to consider and create a variety of mental models and so allows the student to re-create a concept. This imaginative re-creating involves alternative concepts or ideas that they can compare and contrast. It is important that students recognise the non-permanency of explanations. Our explanations are constructed on our experience, knowledge and perception at the time of their construction. Conceptions are built over time and experience and it is imagination that provides a safe space for the learner to play with ideas, adjust them accordingly and so learn.

Overall the research has successfully demonstrated that developing and using imaginative skills improves the effectiveness of learning, and especially abstract learning. Shifts in attitudes to using imagination, requires committed teachers. The development of a strong understanding of metacognition by the students also is required if this is to occur. The research has shown this can be achieved by using strategic activities particularly in the areas of problem-solving, narrative and self monitoring of learning. The study also indicated strongly that imagination assisted with student mental modelling skills by producing space for options and possibilities that would challenge strongly held simplistic conceptions. Linked to this is the skill of reflection, that has been enhanced by the development of imaginative skills, thus making room for learning that is beyond just the facts.

References

Arnold, M., & Millar, R. (1987). Being constructive: An alternative approach to the teaching of introductory ideas in electricity. *International Journal of Scientific Education, 9*(5), 553–563.

Atkinson, P. (1990). *The ethnographic imagination: Textual construction of reality*. London: Routledge.

Brookfield, S. (1987). *Developing critical thinkers*. San Francisco: Jossey-Bass.

Brown, J., Collins, S., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32–42.

Brown, J. S., & Duguid, P. (2000). *The social life of information*. Boston: Harvard Business School Press.

Bull, S., Jackson, T. J., & Lancaster, M. J. (2010). Students' interest in their misconceptions in first-year electrical circuits and mathematics courses. *International Journal of Electrical Engineering Education, 47*(3), 307–318.

Carspecken, P. F., & Walford, G. (2001). *Critical ethnography and education*. Oxford: Elsevier Science.

Chiu, M., & Lin, J. (2005). Promoting fourth graders' conceptual change of their understanding of electric current via multiple analogies. *Journal of Research in Science Teaching, 42*(4), 429–464.

Clancy, S., & Lowrie, T. (2003). Pokemon meanings: Narrative constructions from multimodal text. *International Journal of Learning, 10*.

Compte, M. D. L., & Goetz, J. P. (1982). Problems of reliability and validity in ethnographic research. *Review of Educational Research, 52*(1), 31–60.

Daniels, J. (2008). Negotiating learning through stories: Mature women, VET and narrative inquiry. *Australian Journal of Adult Learning, 48*(1), 93–107.

Down, C. M. (2006). *Situalted Learning: Perceptions of training practitioners on the transfer of competence across workplace contexts.* RMIT University, Melbourne.

Engeström, Y. (2000). Activity theory as a framwork for analyzing and redesigning work. *Erngonomics, 43*(7), 960-974.

Fielding, N. (2007). Computer applications in qualitative research. In P. Atkinson, A. Coffey, S. Delamont, J. Lufland & L. Lofland (Eds.), *Handbook of ethnography*. London: Sage.

Garnett, P. J., & Treagust, D. F. (1992). Conceptual difficulties experienced by senior high school students of electrochemistry: Electrochemical (galvanic) and electrolytic cells. *Journal of Research in Science Teaching, 29*(10), 1079–1099.
Gay, L. R., & Airasian, P. (2003). *Educational Research* (7th ed.). Upper Saddle River, NJ: Macmillan.
Gibbs, R. W. (1999). Mental imagery in interpreting poetic metaphor. *Metaphor and Symbol, 14*(1), 37–44.
Gott, S. (1988). Apprenticeship instruction for real world tasks: The coordination of procedures, mental models and strategies. In E. Z. Rothkopf (Ed.), *Review of research in education 15* (pp. 97–169). Washington DC: American Educational Research Association.
Gregson, P. H., & Little, T. A. (1998). Designing contests for teaching electrical engineering design. *Institutional Journal Engineering Education, 14*(5), 367–374.
Guzzetti, B. J. (2000). Learning counter-intuitive science concepts: What have we learned from over a decade of research? *Reading & Writing Quarterly: Overcoming Learning Difficulties, 16*(2), 89–98.
Illeris, K. (2002). *The three dimensions of learning: Contemporary learning theory in the field between the cognitive, the emotional and the social* (D. Reader & M. Malone, Trans.). Frederiksberg, Denmark: Roskilde University Press.
Jarvis, P. (2006). *Towards a comprehensive theory of human learning: Lifelong learning and the learning Society*. London, England: Routledge.
Kemmis, S., & McTaggart, R. (2003). Participatory action research. In N. Denzin & Y. Lincoln (Eds.), *Strategies of qualitative inquiry* (pp. 336–396). London, England: Sage.
Koestler, A. (1964). *The art of creation*. London, England: Hutchinson.
Lesgold, A. (2001). The nature and methods of learning by doing. *American Psychologist, 56*(11), 964–937.
Licht, P. (1991). Teaching electrical energy, voltage and current. *Physics Education, 26*(5), 272–277.
Lieblich, A., Tuval-Mashiach, R., & Ziber, T. (1998). *Narrative research: Reading, analysis and interpretation*. London, England: Sage.
Linke, R. D., & Venz, M. I. (1997). Misconceptions in physical science among non-science background students. *Research in Science Education, 9*, 103–109.
Marek, E. A., Eubanks, C., & Gallaher, T. H. (2006). Teachers' understanding and the use of the learning cycle. *Journal of Research in Science Teaching, 27*(9), 821–834.
Marshall, S. A. (2005). *What's it like being us: Stories of young New Zealanders who experience difficulty learning.* Unpublished masters thesis, Auckland University of Technology, Auckland, New Zealand.
McDermott, L. C. (1998). Comments on: Learning and understanding key concepts of electricity. In A. Tiberghien & E. Jossem (Eds.), *Connecting research in physics education with teacher education* (pp. 1–6): International Commission on Physics Education.
Miller, H., & Burton, J. (1994). Images and imagery theory. In D. Moore & F. Dwyer (Eds.), *Visual literacy: A spectrum of visual learning* (pp. 65–84). Engelwood Cliffs, NJ: Educational Technology
Moen, T. (2006). Reflections on the narrative research approach. *International Journal of Qualitative Methods, 5*(4), 1–11.
Olsen, R. V. (2002). Introducing quantum mechanics in the upper secondary school: A study in Norway. *International Journal of Science Education, 24*(6), 565–574.
Osborne, R., & Freyberg, P. (1985). *Learning in science: The implications of children's science*. Auckland, New Zealand: Heinemann.
Osbourne, R. J., & Gilbert, J. K. (1979). Investigating student understanding of basic physics concepts using an interview-about-instance technique. *Research in Science Education, 9*, 85–93.

Piaget, J. (1993). Jan Amos Comenius. *UNESCO, International Bureau of Education, 23*(1/2), 173–196.
Pink, D. H. (2005). *A whole new mind*. Crows Nest, Australia: Allen & Unwin.
Quinn, C. N. (2005). *Engaging learning: Designing e-learning simulation games*. San Francisco: Pfieffer.
Ralston-Saul, J. (2001). *On equilibrium*. Camberwell, Australia: Penguin Books.
Redish, E. F., & Steinberg, R. N. (1999). Teaching physics: Figuring out what works. *Physics Today*, *52*, 24–30.
Schwandt, T. A. (2003). Three epistemological stances for qualitative inquiry: Interpretivism, hermeneutics and social constructionism. In N. K. Denzin & Y. S. Lincoln (Eds.), *The landscape of qualitative research: Theories and issues* (pp. 292–331). Thousand Oaks,CA: Sage.
Sencar, S., & Eryilmaz, A. (2004). Factors mediating the effect of gender on ninth-grade Turkish students' misconceptions concerning electric circuits. *Journal of Research in Science Teaching*, *41*(6), 603–616.
Shafer, P. S., & McDermott, L. C. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part II. *American Journal of Physics, 60*(11), 1003–1013.
Smith, J. P., DiSessa, A. A., & Roschelle, J. (2006). *Misconceptions reconceived: A constructivist analysis of knowledge in transition*. Berkeley, CA: Computers and Education.
Smith, P. J. (2006). Identifying learning preferences in vocational education and training classroom settings. *Journal of Vocational Education and Training*, *58*(3), 257–270.
Stevenson, J. (2003). Expertise for the workplace. In J. Stevenson (Ed.), *Developing vocational expertise: Principles and issues in vocational education* (pp. 3–25). Crown Nest, NSW, Australia: Allen & Unwin.
Tang, K. C. (2003, July). *Imagination in teaching and learning of direct numbers: Two Chinese examples.* Paper presented at the International conference on Imagination and Education, Vancouver, Canada.
Taylor, E. W. (2009). Fostering transformative learning. In J. Mezirow & E. W. Taylor (Eds.), *Transformative learning in practice*. San Francisco: Jossey-Bass.