Why are 'hands-on' science activities so effective for student learning?

By Donna Satterthwait

From effective learning research, there is a general consensus that hands-on experiences help students to learn. The question that this paper seeks to answer is what it is about these activities that fosters student learning. In a review of the literature, three factors have been identified as making a significant contribution to this strategy's success. They are peer interaction through cooperative learning, object-mediated learning and embodied experience. By taking these factors into account, teachers of Science can design lessons that explicitly utilise this knowledge.

Introduction

The experiential value of hands-on activities in science education has long been recognised as significant in engaging students. Hands-on activities represent a strategy of teaching in which the students usually work in groups, interact with peers to manipulate various objects, ask questions that focus observations, collect data and attempt to explain natural phenomena. This is actually the essence of science. Bredderman (1983) reported on the effectiveness of three of the then 'new' primary science programs developed in the United States, all of which were activity-based and showed considerable benefits to participating students because of their emphasis on the use of hands-on strategies. In a review of further research on the hands-on learning pedagogy, such activities have been shown to improve children's science learning and achievement and their attitudes towards science, increase science skill proficiency and language development (specifically reading and oral communication), and also to encourage creativity (Haury & Rillero, 1994). The potential for learning through hands-on activities is quite amazing.

Despite each having a different emphasis, seven innovative primary science curriculum projects funded and sponsored by the National Science Foundation, American Association for the Advancement of Science, or the U.S. Office of Education and various large universities (e.g. Harvard, University of California) all had the use of hands-on science activities as an essential component of their project design (Nay and Associates, 1971). However, not only do these funding organisations, educational researchers, curriculum project leaders and designers know that hands-on activities promote better student learning outcomes, but from their own classroom experiences, most teachers of Science agree. These teachers incorporate and promote a 'hands-on, minds-on' approach in their practice because they believe their students benefit from the implementation of this strategy. This style of teaching is also well supported by evidence in other subject areas (see especially the work of Boaler, 2009 in mathematics education). The pedagogy of using hands-on investigations, involving students working in groups (Treagust, 2007 pp 383-4) and manipulating objects has been recognised as a desired science teaching strategy for almost 200 years (Edgeworth & Edgeworth 1811 cited in Lunetta, Hofstein & Clough, 2007) and continues to influence science education curriculum design as seen in the more recently developed Australian Academy of Science-sponsored *Primary Connections* modules (Hackling & Prain, 2005).

Thus, a question needs to be asked – why is the teaching of Science through the provision of classroom hands-on science activities so efficacious? It is time to consider this pedagogic practice in light of new research on learning and to link this teaching strategy with some of the theoretical understandings that have emerged, especially from the domain of cognitive psychology. This literature review may help to generate discussions and hypotheses that can be investigated in science classrooms.

Understanding of Learning

The processes of learning are highly complex. To make meaning of these processes, cognitive psychologists categorise what data and evidence they have collected into various 'explanatory models' that provide a convenient way of communicating multifaceted ideas and serve to integrate concepts and research findings into systems that generate hypotheses and future applications (Spellman & Willingham, 2005). In this way, the cognitive psychologists' knowledge of human learning can be advanced and better understood. However, the considerable progress that has been made in understanding how learning takes place is rarely incorporated into classroom practice in a deliberate way, but teachers 'know' what usually works in their own classrooms; they can predict likely outcomes of their students' engagement with particular tasks. Good, experienced teachers have a deep understanding of their students' needs and attempt to address them as best they can to achieve intended outcomes.

One reason for the disjunct between knowledge about learning among cognitive psychologists and teachers' understanding of their students' learning is that there are many different cognitive models and psychological explanations of how learning occurs in individuals, and most have validity for particular instances that are often narrowly defined and contextual. What happens in the reality of the classroom is so much messier than the variable-controlled investigations of psychologists.

Straightforward explanations are difficult to apply to messy classroom contexts. The gap that occurs between the psychologist's experimental knowledge and the teacher's classroom nous is widened by the teacher's difficulty in comprehending the vocabulary of the psychologist, as well as the psychologist's lack of understanding of classroom situations. Some psychologists may have a naive view of classroom culture because of their long-held expectations of how a classroom should operate. Stereotypical classroom cultural expectations, that rarely reflect reality, also prevail throughout our society.

This gap between teachers and psychological knowledge becomes especially obvious in neurological or brain-based deficit studies, although recently there has been a deliberate attempt to bridge the divide. As more is being discovered about brain function, some neuroscientists are looking at ways in which their 'models' can inform classroom learning. The human brain appears to be highly interconnected and, like a classroom, complex and multi-dimensional. Neuroscientific studies provide enticing evidence of plasticity in cellular interactions, establishment of networks and integration of neurons and neuro-chemicals. Doidge (2007) gives examples of how different sections of the brain interact and function together and influence thinking, finding that imagining doing and actually doing both excite the same parts of the brain – *imagining one is using one's muscles actually strengthens them* (p. 205). As even more knowledge about brain function becomes available, new models about learning are likely to be proposed.

The development of these new 'brain learning' models, when added to previously proposed cognitive models of learning, make the time right to re-examine cognition models and classroom practices to gain more insight and attempt to better understand why particular teaching strategies 'work'. A good place to start this process is to call attention to one such pedagogy, the 'hands-on activity', a well-regarded science teaching strategy and examine why this strategy seems to cause students to learn.

Although there may be many attributes that contribute to the apparent success of student learning within this way of teaching, for the purpose of this paper three factors have been identified that play a significant role in the hands-on practice. The three factors presented in this paper are:

1. The influence of cooperative learning and social constructivist understandings;
2. Mediated learning through the use of objects; and
3. Embodiment as a way of students gaining understanding and making meaning of their experiences (see Figure 1).

The question becomes how each factor contributes to the whole – that is, the students' learning of Science. In this paper, these three factors will be defined and then discussed in light of recent literature from research studies in cognitive psychology.

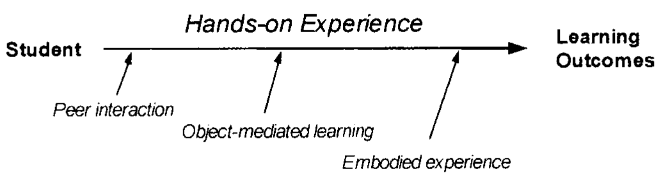

Figure 1: Factors that contribute to efficacious science learning

1. Peer Interaction Through Cooperative Learning

Social constructivism theory informs the teacher of the importance of cooperative group work for learning to occur among students. Effective understanding is closely associated with cooperative learning pedagogies (Walberg, 1999). As stated by Hattie (2009, p. 212),

> *...cooperative learning has a prime effect on enhancing interest and problem solving, provided it is set up with high levels of peer involvement.*

The sharing of knowledge, observations and beliefs among peers through dialogue is at the core of social constructivism. As a translator of theory into classroom practice, Lemke (1990) advocates that students be given an opportunity to engage in 'side conversations', especially those that,

> *...describe, compare or discuss real objects or events using the scientific terms in a flexible way appropriate to the situation* (p. 169).

Shifts in understanding need group discussions and/or arguments to enhance the creation of new meaning, so the provision of peer interactions in the classroom seems to be an especially important prerequisite for establishing thought-provoking conversations. Numerous studies and reviews have been undertaken and published that demonstrate the key conceptual principle that humans make meaning of their encounters through the comparison of the current with the previous, that humans need to make sense of what they experience and that they share knowledge by exchanging information through interactions with each other, usually in dialogue. Notions of prior understanding and the discrepant event have greatly influenced how science lessons and units are planned and implemented. Social constructivism theory informs the teacher that if an individual student's ideas are to be changed, new experiences that challenge prior knowledge need to be provided. The teacher of Science provides opportunities to challenge pseudo-scientific beliefs through hands-on group work; research has demonstrated that the creation of cognitive dissonance can promote considerable knowledge transformation (Guzzetti, Glass , Sayden & Gamas. 1993) to address and challenge misunderstandings.

2. Object–Mediated Learning

Some of the most productive, and common, science activities are those that involve the manipulation of objects. This factor plays a significant role in motivating and focusing our students on the learning of Science through the use of objects in an activity in which they are to be engaged. Lev Vygotsky, the educationalist often identified with social constructivism, viewed tools ('technical tools' in terms of objects, or 'psychological tools' as symbols or signs) as defining and shaping human activity, not merely facilitating it (Wertsch, 1990). Similarly, object- mediated learning contributes to students' learning by causing them to question or seek explanations of the effects of an object's use in particular contexts to bring about results, which at times are surprising. It seems as if the objects themselves possess attributes that by their very nature implicitly 'instruct' their usage: what is it about the object that contributes to how it is used and what is learnt through its usage? Children have been observed to alternate between playing with objects and learning from objects, alternating between 'what can I do with this object?' and 'what does this object do?' (Hutt, 1981, p. 284). Manipulations of three-dimensional things deliver an event reality that is in itself intriguing and triggers curiosity among the students. It is this physical connection to the object and the characteristics of the object that allow manipulation, and thus learning, to occur. Often, during lab activities, students 'play' with equipment in ways that are testing the object's design, construction or purpose!

As well, students are more likely to remember things that elicit a positive emotional response (Willingham, 2009). Students enjoy laboratory activities (Lunetta, Holstein & Clough, 2007); they enjoy manipulating equipment and observing the changes that they cause. Students of Chemistry ranked interest in chemistry classroom investigations over demonstrations, films, discussion or lectures (Ben-Zvi, Hofstein, Samuel & Kempa, 1977), and students had even more positive attitudes towards Chemistry when they participated in genuine inquiry activities, rather than more traditional 'recipe' practicals (Kipnis & Hofstein, 2005; Palmer, 2009).

3. Embodiment

The third factor, embodiment, is closely linked to object-mediated learning since object manipulation requires movement of the human body. Embodied learning can be defined as how we humans make sense of our perceptions and actions as we negotiate our journey through our surroundings. By being present, interacting with others and using equipment, an experience is created and understood through this physicality. For example, recent data indicate that the brain is modified by the use of tools:

> *...that the use of tools can change the pattern of movement because the body schema has changed (1).*

This comment was based on a study which provided direct evidence that using tools changes the way in which the brain detects our body parts (Cardinali, Frassinetti, Brozzoli, Roy & Farne, 2009).

The mind and the body are not separate entities, as had been thought by many philosophers, most famously Descartes (Johnson, 2008). Rather the mind and body work synergistically to build a repository of understandings expressed in brain structure and abstract ideas. The structure and function of the body is represented within the neural networks of the brain, and the formation of these networks is a prerequisite to being able to remember and imagine experiences. From our varied experiences, our ability to create and imagine develops and grows as the neural network in our brain develops. Strick, Dum and Fiez (2009) discuss neurological data that show how the cerebral cortex, the part of the brain that has long been associated with thinking processes, links with the cerebellum, the recognised area of motor regulation. They conclude that,

> *...the cerebellum plays a functionally important role in human cognition and affect' (p. 426).*

It appears that the brain's anatomy and function are interconnected to all human endeavours, including learning, thinking and moving (Roser & Gazzaniga, 2004).

Perception has been shown to be intimately linked to culture. Nisbett and Masuda (2003) showed that cognitive differences exist in how East Asians and Westerners, Additionally, this is expressed in commonly-used phrases which influence how we conceptualise ideas. Language usage is indicative of the close association between understanding, experiences and brain development (Doidge, 2007). How humans move is how humans learn is how humans experience.

Implications for the Science Classroom

How then can we as teachers of Science incorporate these research findings into our classroom practice to enhance our students' learning experiences? Listed below are a few possible ideas that can readily be implemented with science hands-on activities. These suggestions are not necessarily new to the practise of science teaching, but they are those practices that have been shown to enhance learning:

- Find out what students know before the lesson sequence begins, especially to identify any misunderstandings they might have and then attempt to address these through cooperative learning group science activities.
- Foster conversations among the students that involve asking and responding to good, thought-provoking questions; set up situations where the students can play the devil's advocate. As well, you could write a different question on a slip of paper for each science activity group. The group discusses it and then presents their response to the class. Other students would then be invited to agree or disagree with the response.
- Require students to manipulate objects in usual and unusual ways and to collect this information as part of their investigation. Perhaps include the students' ideas on how the equipment should be arranged and used, and let them try their own ideas rather than giving them a pre-determined diagram or procedure.
- Attempt to include lessons in which exploration is promoted. When safe and appropriate, encourage students to 'play' with the materials to help them identify properties (or limitations) of the objects for themselves. Think of other ways in which we could see (or imagine) what would happen if the objects were used differently.

Summary

All three of these factors, cooperative learning, object manipulation and embodiment, contribute to the underlying efficacy of hands-on activities in science education. New ideas about how neural networks interact and integrate the totality of human experiences in the gaining of knowledge call for teachers to plan for the learning experience as a whole, rather than as smaller parts. Teachers of Science have evolved a powerful teaching strategy, the hands-on activity, which characterises this more holistic model of learning. Typical hands-on activities incorporate dialogue through cooperative group work, the manipulation of objects and the collection of embodied sensory inputs in conjunction with the neurobiology and aesthetics of the mind, all of which create opportunities for students to make meaning of the natural world. Further analysis of hands-on science group work may result in a better understanding of how teachers can sustain engagement and learning among our students.

Science educators should recognise their contribution towards enhanced learning through the implementation of the hands-on strategy. Becoming explicitly aware of factors that characterise hands-on teaching and their potential to cause student learning, teachers of Science can make explicit decisions that enhance and strengthen such learning opportunities. These factors, along with teachers' observations of students' actions in information collection and processing, allow teachers of Science to make meaning of their pedagogy and to design even more productive learning activities within which our students can engage in Science.

(1) Comment by Angelo Maravita, a cognitive neuroscientist at the University of Milan-Bicocca, Italy on study published in *Current Biology* 19(12). This study provided direct evidence that using tools changes the way in which the brain detects our body parts. Downloaded on 23 June 2009, from http://www.thescientist.com/blog/print/55771. This entry was posted on 22 June 2009.

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