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SYSTEM DYNAMICS AS A MINDTOOL FOR ENVIRONMENTAL EDUCATION

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Abstract

Concern for the environment is increasing but understanding and factual knowledge of environmental problems and systems are both low. The challenge is for school students to learn the skills needed to interpret the complex, dynamic environmental systems that even university graduates have trouble understanding. System dynamics is a modelling approach that is often used in environmental management and decision-making in order to cope with the underlying complexities. The problem is that, even though system dynamics models reduce complexity, they are still too demanding for direct use in environmental education. In the educational literature, multiple representations and learning by modelling are two techniques that have been suggested to aid in learning about complex systems. System dynamics models comprise multiple representation describing complex interactions. Studies on multiple representations have had mixed results, but under the right circumstances, may provide an effective way to teach a complex subject such as environmental education. Studies about learning by modelling have also had mixed results. While learning by modelling provides an authentic learning task for science students, the time involved in teaching students the process in addition to the domain knowledge is often lengthy. Suggestions for further research and for the design of future work in these areas of system dynamics modelling and environmental education are derived.

The challenge: Making dynamic environmental systems understandable

Humans are an integral part of environmental systems. Most of the activities in our lives affect the environment in some way, although these effects may not be immediately apparent. Environmental systems often respond in ways that are unexpected – the timeframe may be longer than expected or the effects may flow through to areas not originally thought to be related to the known system. The development of skills for understanding complex systems such as these should be an essential part of education given the global, national, and local environmental problems that exist in today’s society. Environmental education should focus some attention on the development of these skills.

The purpose of this paper is to identify instructional strategies aimed at enabling understanding of a *complex socio-environmental system* (a socio-environmental system is one that involves society’s use of the environment). Some of the issues inherent in environmental education will be discussed first. System dynamics is the modelling tool that will be used as an example in this paper, a brief overview of the use system dynamics will then be provided. The challenges involved in understanding complex environmental systems related to cognitive theories will also be summarised. Two of the techniques recommended for understanding complex systems are the use of multiple representations and using models for learning. The literature surrounding both of these techniques is inconclusive, and recommendations for the design of a study will be made.

Environmental Education

Environmental education can be enacted in schools (Ballantyne *et al*., 2001; Caro *et al*., 2003), at places of environmental significance (such as national parks or museums) (Aleixandre & Rodriguez, 2001; Darlington & Black, 1996; Orams, 1997; Powers, 2004; Siemer & Knuth, 2001), on a community-wide basis (such as large scale education campaigns) (Calvert, 2004; Davies & Webber, 2004; Robottom, 2004; Volk & Cheak, 2003; Whelan *et al*., 2004), and may involve cooperation between two of the above (Talsma, 2001). Two common goals of environmental education programs are the communication of scientific knowledge to the public (Castillo *et al*., 2002) and changes in behaviour or attitude (Corraliza & Berenguer, 2000; Pooley

& O'Connor, 2000; Vaske & Kobrin, 2001). Changing behaviours and attitudes towards the environment are regarded as important aspects of environmental education because they are seen to influence lifestyle decisions, a change in which would bring about sustainability (Commission on Sustainable Development, 2001). However, knowledge about a particular environmental issue or species does not necessarily result in higher conservation priorities with respect to management decisions (Hunter & Rinner, 2004), and the literature is inconclusive with regards to relating increased environmental knowledge with improved environmental attitudes or behaviour (Caro *et al*., 2003; Hwang *et al*., 2000). A third goal of environmental education is educating students *how* to think about the environment (Hungerford, 2002). In other words, individuals should be able to make decisions that take into account various points of view about a topic, and to think about their interactions with the environment (Simmons & Volk, 2002).

Many studies about environmental education are focused on factors resulting in the improvement of environmental behaviour or attitudes rather than the other goals (e.g. (Aleixandre & Rodriguez, 2001; Brackney & McAndrew, 2001; Campbell Bradley *et al*., 1999; Costarelli & Colloca, 2004; Culen & Volk, 2000; Hsu, 2004; Jurin & Fortner, 2002; Knussen *et al*., 2004; Ma & Bateson, 1999; Milfont & Duckitt, 2004; Zelezny, 1999)). Rickinson (2001) also concluded that much more evidence was found relating to the *learners* than to the actual *learning* as did Hoody (1995) who concluded that most environmental education researchers evaluate programs rather than the general educational outcomes. Even within the evidence on learners that was found in Rickinson's review study, more research was concerned with environmental ideas and perceptions than learners' educational experiences. Rickinson also found that generally, students' factual knowledge of the environment was low, and varied depending on the topic area. However, students' *understanding* of environmental issues was usually even more limited than their factual knowledge. One of the objectives of environmental education in NSW Government schools is to teach environmental knowledge and provide students with the skills to understand other environmental problems (NSW Department of Education and Training, 2001).

In NSW, environmental education is taught across all disciplines, as recommended by the United Nations (1992). This approach has been criticised in the United Kingdom because of fears that the topic would be lost amongst other subject demands, and concerns about the separation of learning about environmental values and science (Littledyke, 1997, 2000). The subject areas of science and environmental studies have been separated into different key learning areas in the national curriculum in Australia (Gough, 2004). A problem in NSW schools, and indeed worldwide, is the decreasing interest in science education, despite increasing levels of environmental concern (Gough, 2002). This suggests that perhaps Littledyke (1997, 2000) was right in his concerns regarding the separation of knowledge-based instruction and environmental values.

What is System Dynamics?

"System Dynamics is a methodology for analysing complex systems and problems with the aid of computer simulation software" (Alessi, 2000, p. 1) and includes cause and effect relationships, time delays and feedback loops. Jay Forrester described the philosophy and method of the approach of system dynamics in 1961 with the publication of *Industrial Dynamics*. In 1970, in response to the formation of the Club of Rome, the first system dynamics model related to the environment was developed (Forrester, 1971). The model addressed issues concerning population growth, and was published in a book called *World Dynamics*. Forrester and the group at the Massachusetts Institute of Technology came to a number of conclusions that are still relevant, including, the unsustainability of high standards of living and industrialisation, population pressures resulting in limited natural resources, pollution and social stresses.

Systems can be represented by *causal loop diagrams* and by *stock and flow diagrams*. Causal loop diagrams are useful for demonstrating feedback (Sterman, 2000). Forrester (Forrester, 1971) defines feedback as "the closed path that connects an action to its effect on the surrounding conditions, and these resulting conditions in turn come back as "information" to influence further action" (p. 17). A positive loop occurs when "the anticipation of a future reaction changes current behaviour" (Daniels & Walker, 2001). Negative loops counteract change (Sterman, 2001). Conventions exist for drawing causal loop diagrams, the diagrams contain variables that are linked by arrows (Sterman, 2000) (See Figure 1). The polarity of the variable is indicated by the (+) or (-) sign, and describes how the dependent variable changes in response to the independent variable (Sterman, 2000). In this example, an increase in the birth rate causes an increase in the population which then results in an increase in the birth rate. Whereas, an increase in the population causes an increase in the death rate, which then causes a decrease in the population. The loop identifier in the middle of the arrows shows the nature of the feedback, either positive (reinforcing) or negative (balancing) (Sterman, 2000).

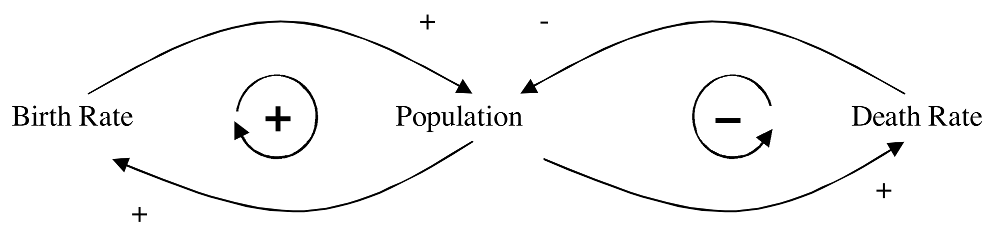

Figure 1: An example of a Causal Loop Diagram (Sterman, 2000, p. 138)

Stock and flow diagrams represent the quantitative nature of the system. A stock and flow diagram will be a representation used in the experiments in this study. A stock is defined as a "quantity of something (such as the quantity of heat in a cup of coffee)" (Alessi, 2000), and is a time-point related system variable (Ossimitz, 1997). A stock is represented by a rectangle (see Figure 2). A flow "represents the rate of change (the rate of increase and/or decrease) of a stock." (Alessi, 2000). Flows are represented by pipes into or out of a stock (Sterman, 2000). A valve can be seen on the pipe that controls the flow. They are time-interval related system variables (Ossimitz, 1997).

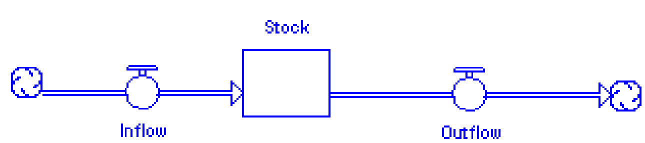

Figure 2: An example of a Stock and Flow Diagram (Sterman, 2000, p. 193)

System dynamics has been used to examine a wide range of systems (e.g. (Abdel-Hamid, 2003; Harvey, 2002; Ramsey & Ramsey, 2002; Saysel *et al*., 2002)), to make policy recommendations (e.g. (Satsangi *et al*., 2003; Saysel et al., 2002; Xu, 2001)), and for public participation in environmental problems (Jones *et al*., 2002; Stave, 2002, 2003; Walker *et al*., 1999), although using system dynamics to model stakeholders' mental models has not always been successful (Rouwette *et al*., 2000). System dynamics has been used to study a variety of situations in natural resource management (e.g. (Carbonell *et al*., 2000; Faust *et al*., 2004; Guo *et al*., 2001; Martinez-Fernandez *et al*., 2000; Xu, 2001)); to model socio-environmental systems (Martinez Fernandez & Esteve Selma, 2004; Saysel *et al*., 2002); and systems involving the interplay of society, economy and the environment (such as tourism (Patterson *et al*., 2004) and tourist behaviour (Walker *et al*., 1999)). Natural resource management is increasingly associated with complex systems as information from a variety of disciplines is incorporated (Daniels & Walker, 2001). System dynamics modelling is suited to multidisciplinary problems because it can accommodate both quantitative and qualitative data. It is fundamentally interdisciplinary (Sterman, 2001).

System dynamics models themselves are multiple representations. They include a stock and flow diagram, equations, graphs and tables. Thus, all the potential issues with multiple representations (to be discussed) apply to learning with system dynamics models.

Although much is written of the value of system dynamics modeling in education, very little empirical data exists to confirm this. Instead, case studies and anecdotal accounts from teachers who have used such models are available on the web (Ragan, 1999; Verona *et al*., 2001). Other studies have raised areas for further investigation. Studies investigating the effect of systems thinking interventions on participants' mental models (Doyle, 1997), the effect of systems modelling on the development of higher cognitive skills (Jonassen, 2003) and general learning effectiveness (Spector, 2000) are needed.

Cognitive challenges

There are a number of factors that make understanding environmental systems and the development of skills to assess outcomes challenging. These include issues to do with mental model theory, the role of knowledge and understanding, general misconceptions in science, and more specifically of complex/dynamic systems.

Mental Model Theory

Mental model theory is an important theory on which this paper is based. Mental models are the internal representation of a system, and change as new information becomes available (Halford, 1993; Norman, 1983). Mental models are based on any information the learner decides to include, and as such, may contain illogical information (Norman, 1983). Mental models are used to make sense of observations (Halford, 1993; Norman, 1983; Savelsbergh *et al*., 1998); for reasoning or making predictions (Halford, 1993; Norman, 1983; Savelsbergh *et al*., 1998; Young, 1983); and in time may become associated with a particular learning task (Savelsbergh *et al*., 1998). Learners may develop mental models intentionally to meet a learning goal, or spontaneously as a result of a given task (Buckley & Boulter, 1999). Mental models are accessed from memory if a particular representation has been associated with a situation in the past. They are either transferred directly to the new situation or a new mental model is constructed using information from the two situations.

Students have difficulties with the language necessary for discussing environmental problems over time (Sheehy *et al*., 2000). In addition, "forming, maintaining and manipulating a mental model of changes in a number of variables is demanding" (Sheehy *et al*., 2000 p. 123). Using a simulation model, such as a system dynamics model can result in clearer understanding because it removes the need for complex language, and provides students with an example mental model (Sheehy *et al*., 2000). Doyle and Ford (1998) state that one of the goals of system dynamics, when used for educational purposes, is to "change or improve mental models in order to improve the quality of dynamic decisions" (pp. 3-4).

The Role of Understanding

Halford (1993) discusses a number of properties that understanding should entail. In order for understanding to occur, the subject should have a mental model that represents the structure of the concept; these mental models should be generalisable and therefore able to be transferred from one situation to another; and the models should be able to generate predictions or inferences outside of the basic information given (Halford, 1993; Wild & Quinn, 1998). In addition, understanding should result in certain outcomes including the further development of problem-solving skills and strategies and the further organisation of information to determine relations between representations.

Misconceptions in Science

When learners construct their own models of concepts they do not start with a blank slate. Learners' pre-existing models will affect further understanding of a topic presented to them (Duit, 1995). Misconceptions in science can be particularly difficult to overcome, even after directed instruction in a specific area (Ozkan *et al*., 2004). Understanding of scientific phenomena are often based on every day experiences which are often deeply held beliefs and are difficult to overcome (Duit, 1995). Misconceptions of scientific phenomena may lead to confusion about environmental problems (Alerby, 2000).

It is important that students have a clear understanding of the concepts involved in science. Misconceptions in science are difficult to change in both common scientific phenomena (such as how bodies work (Cumming, 1998)) and complex environmental problems (such as global warming (Daniel *et al*., 2004)). A number of theories have been discussed to explain why misconceptions in science are so difficult to change. Buckley (2000) says that understanding biology is challenging because it is an interactive system that exists at a range of scales. Alternatively, or in addition, many misconceptions are formed at a young age (by the time the student is four) which could explain older students' resistance to altering their understanding of scientific concepts (Cumming, 1998). However, complex environmental problems, about which opinions may not have been formed at a young age, also confuse students. Global warming is one such environmental issue. Misconceptions have been identified that showed limited understanding of the links between different environmental issues as well as poor understanding of the nature of the issue itself (Daniel *et al*., 2004). One of the most telling misconceptions was that about half the students, typically older students, thought that burying waste rather than burning it would reduce global warming, when in fact both processes will produce greenhouse gases (Daniel *et al*., 2004). The ability to utilize systems thinking would mean that people would not attempt to compartmentalize these systems, and better understanding of the system as a whole may be reached (Daniels & Walker, 2001).

Understanding Complex Systems

Many people have trouble understanding complex systems even when illustrated using causal loop diagrams or stock flow diagrams. Dynamic systems are typically too complicated for school students to understand using traditional methods of modelling (Woolsey & Bellamy, 1997), but even highly educated university students have trouble with concepts such as stocks, flows and feedback (Booth Sweeney & Sterman, 2000; Diehl & Sterman, 1995; Moxnes, 2004). One study found that every participant in four separate studies (167 subjects in total) had a biased view of the dynamics of the environmental system that they were examining in the direction of a static mental model (Moxnes, 2000). Another study found that graduate students had very poor understanding of the processes involved in global warming, a common misconception was that stabilising emissions would "fix the problem", showing a poor understanding of dynamic processes (Sterman & Booth Sweeny, 2002). Unfortunately, the management strategies employed by Moxnes' (2004) students that mismanaged a system to collapse are strategies that have been observed in natural resource managers in districts similar to the ones in at least one of the studies. This mismanagement was even observed when the subjects were given feedback on decisions and allowed the opportunity to learn from past mistakes (Moxnes, 2004). Diehl and Sterman (1995) found that subjects were unable to take into account the effects of feedback and time delays. They suggested two reasons for this. Firstly people's mental representations of complex tasks tend to be simplified and therefore overlook side effects, feedback processes, and delays (Diehl & Sterman, 1995). The second reason suggested was that even when people know about these elements, their ability to correctly infer the behaviour of such a system is poor. They conclude that the first reason can be overcome by training, and the second reason can be overcome by computer simulation modelling. Moxnes (2004) concluded that subjects lacked dynamic mental models, and that this could contribute to the inability to manage the system to equilibrium. Therefore it is very important to educate students in the skills necessary to understand system dynamics.

Strategy 1: Multiple Representations

A representation is a simplification of a phenomenon for a specific purpose (Buckley & Boulter, 1999). Most teachers will use more than one representation when explaining a concept to their students. This may be in the form of a verbal description followed by a diagram, or a map, or a graph. Teachers who use multiple representations often explain their approach by stating that it is more likely to capture a learner's interest (S. Ainsworth, 1999). Another advantage of using multiple representations is that they provide an authentic learning environment because most experts, and scientists in particular, use multiple representations to explain phenomena (Kozma *et al*., 2000). Studies have found that presenting information in two modalities can make learning more effective because it spreads processing over multiple systems (S. Ainsworth & Loizou, 2003). It is now easier to present multiple representations including animations and video as well as diagrams and graphs, and show the links between them, due to the technology that has been developed (Wisnudel Spitulnik *et al*., 1998). However, studies have been inconclusive with regard to their effect on learning outcomes (Scaife & Rogers, 1996). Factors relating to the individual representations, and to the coordination of multiple representations may explain the variance in results.

The nature of the representation (propositional, diagrammatic, animation, etc.) may have an effect on learning outcomes. There is little empirical evidence to suggest that animations are better than pictorial representations, or that pictorial representations are better than verbal or text based representations. In fact, representations are not simply diagrammatic or animated or propositional (Cheng *et al*., 2001). For example, most diagrams have some text or propositional statements included in them. The mental model that is constructed by learners will be influenced by the format in which the information is presented (Rohr & Reimann, 1998). For example, text based representations will usually result in a propositional representation, a graphical representation will mainly result in a mental image or combination, and an animation will produce a dynamic mental model.

The learner's prior knowledge, in terms of both domain knowledge and representation knowledge, may also have an effect on learning outcomes. If learners are already familiar with either the domain or the representation, then there should be an increased ability to recognise the connection between the representation and the phenomenon represented (S. E. Ainsworth *et al*., 1998; Horwitz & Christie, 1999). This ability to translate the symbols inherent in the representation and the real objects is known as interpretation (Stenning, 1998).

The ability of the learner to translate *between* representations is necessary for the successful use of multiple representations (Halford, 1993; Roth & Bowen, 1999). Translation is dependent on a number of factors. The first is the nature of the representation. This includes the modality of the representation (propositional versus graphical), level of abstraction (abstract symbolic values are used in a model to explain a phenomenon (de Jong *et al*., 1998)), degree of redundancy (Boshuizen & (Tabachneck-)Schijf, 1998), strategies encouraged, and differences in labeling and symbols. In addition, translation is dependent on the tasks and domain values, and learner characteristics (S. E. Ainsworth et al., 1998). In order for the representation to assist interpretation, it should present information at different levels of abstraction, and reveal the nature of the connections; show the factors that make a concept unique and how it relates to other concepts; and support the integration of different perspectives on the domain (Cheng, 1999). The successful use of multiple representations depends on the type of test, the type of domain, the type of learner, and the type of support (de Jong *et al*., 1998). It is also a result of learners successfully learning how to interpret each representation; understanding the relationship between the representation and the domain (Scaife & Rogers, 1996); and finally the coordination of representations (S. E. Ainsworth et al., 1998; Bodemer *et al*., 2004).

Why use multiple representations?

There are a number of reasons for using multiple representations. Specific information may best be conveyed in a particular type of representation (de Jong *et al*., 1998) and so to convey a range of information, a number of different representations may be needed. Learning material that contains a variety of information may require the combination of different representations; the coordination of multiple representations may be seen as an indicator of expertise (see below); and presentation of representations in a particular sequence may be the best way to learn about the subject (de Jong *et al*., 1998). In addition, using multiple representations provides a safety net in case the student's reasoning process comes to a halt for some reason with a single representation (Savelsbergh *et al*., 1998).

Multiple representations may serve one of three different functions (S. Ainsworth, 1999), which were later defined in a taxonomy (S. Ainsworth & Van Labeke, 2002). Ainsworth (1999) suggests that the three functions are to *complement*, *constrain*, and to *construct*. In the *constraining* function, one representation is used to constrain any misinterpretations that may result from the other. This may be done by using something familiar to the learner (such as an animated representation) or by the inherent properties of the representation (S. Ainsworth & Van Labeke, 2002). This function is often used in physics to make the problem more tractable (Savelsbergh *et al*., 1998), and has been reported as the reason that graphical representations are successful (Scaife & Rogers, 1996). According to this taxonomy, the function of the multiple representations in this case fall into the *constrain by familiarity* category. This function occurs when one representation is used to constrain understanding of another by using a familiar representation, such as animation (S. Ainsworth & Van Labeke, 2002). The ability of the learners to understand the relationships between representations is addressed in this study, as learners will be able to access the animated representation as a way of explaining the diagram.

Animation – will it help students to understand system dynamics models?

Animated representations are a type of dynamic representation. Ainsworth and VanLabeke (S. Ainsworth & VanLabeke, 2004) identified different types of dynamic representations. The first is time-persistent (T-P), the data is displayed incrementally in the form of a graph or table (S. Ainsworth & VanLabeke, 2004). This representation "displays the current value and any other ones that have been computed" (p. 244). The second type of dynamic representation is a time implicit (T-I) representation. When static, these representations show values but not the time that the values occurred, if dynamic then the representation adjusts as the learner is watching. In this case the dynamic representation does add information in terms of the sense of time. The third type of representation is time-singular (T-S) and "displays one or more variables at a single instant of time" (p. 246). T-S representations are often used when communicating complex information, but because they are so complex, the external representation contains limited information and therefore puts greater strain on internal processing (or cognitive load) (S. Ainsworth & VanLabeke, 2004). This is because learners have to keep the system's previous states in their head to compare them to the current state. They suggest that the *constrain by familiarity* function (mentioned earlier) may be most commonly met by using a T-S representation to help learners interpret T-P or T-I representations. Lowe (Lowe, 2003) identifies three different types of animated representations: *transformations* (changes in form – colour, shape etc.); *translations* (changes in the positions of entities); and *transitions* (appearance or disappearance of entities) (Lowe, 2003). Lowe's definitions most commonly apply to Ainsworth and VanLabeke's *T-I* and *T-S* representations.

The main benefit of using animated representations is their ability to depict temporal change (Lowe, 2003). Animation may enhance understanding in cases where events are shown at a scale otherwise unable to be seen by the learner, and especially if the animation then shows how these events show themselves at a different scale (Rohr & Reimann, 1998). This kind of process is difficult to explain and understand in words. The components that are not accessible to perception and conceptual aspects may not be readily understandable unless a dynamic representation is used (Savelsbergh *et al*., 1998). Animated representations may help students to construct a useful mental model (Rohr & Reimann, 1998; Savelsbergh *et al*., 1998) and further, overcome difficulties in using their model for reasoning about the domain.

There have been mixed results with regards to the effect of animation on learning. Byrne *et al*. (Byrne *et al*., 1999) found that the use of animation does not automatically enhance learning. They could not distinguish between the effect of animation and the effect of simply a good visual representation, with or without animation effects (Byrne *et al*., 1999). The authors hypothesised that animation may affect the speed at which a student learns (or the motivational factors) rather than the amount learnt, however this was not examined in their study. Lowe (2003) has investigated the effects of using animation in learning about meteorological effects, and has generally found that animation is not effective in this domain. Subjects tend to be attracted to the information generated by the features in the animation that actually change in a contrasted manner to the rest of the display (Lowe, 2003, 2004). Lowe (2003) concludes that even when interaction and user control are provided, and the animated representation is accurate, simply presenting the representation may not be enough to allow learners to build accurate mental models of the phenomena.

One explanation associated with negative effects of learning from animations is the high cognitive load associated with interpreting the animation, and mentally simulating the model in order to reason with it later (Rohr & Reimann, 1998). A method suggested to overcome the cognitive load associated with the interpretation was to present learners with a static version of the dynamic representation before the dynamic representation was shown (Bodemer *et al*., 2004). Another suggestion is for increased direction when presenting novices with animated representations of phenomena (Lowe, 2004).

Modelling as a Mindtool

Providing students with an example mental model, upon which to form their own, does not solve all the problems associated with understanding complex systems. The cognitive load associated with mentally simulating a dynamic system is high. External representations decrease the cognitive load. A Mindtool is a term defined by Jonassen (2000) as “an intellectual toolkit for engaging learners in constructive, critical thinking about whatever they are learning…Mindtools provide a set of computer-mediated activities that foster thinking.” (p. v). He argues that students cannot use applications such as modelling without engaging the mind (Jonassen, 2000). Mindtools allow learners to represent, manipulate, and reflect on their knowledge (Jonassen, 2000). Jonassen (2003) also suggests that the ability to externally represent problem formations using tools or formalisms is another way for novices to construct representations that allow them to engage in expert problem solving behaviour. Mindtools give external representations a role beyond providing an example mental model for students to adopt. This adds to the theory of mental models by relying on tools, such as system dynamics models or animations, to act as an external representation and reduce the problems associated with cognitive load and mental simulation identified in the literature.

Using models to understand environmental systems is common practice, system dynamics modelling is one of a number of tools designed to address environmental issues. Human impact is often left out of ecological models, even though humans often have a large impact on the real systems (Alberti *et al*., 2003). Environmental problems usually involve interdisciplinary collaboration, which may be difficult due to different disciplines, models and parameters (Benda *et al*., 2002). System dynamics is useful because it is designed for this sort of interaction. A common problem concerning the management of complex systems is that one or two influences are identified, assumed to be the factors responsible for the outcomes observed, and this results in the implementation of simple policies to address complex problems (Alessi, 2000).

Models are representations of ideas, objects, events, processes or systems (Gilbert & Boulter, 1998), and are generally simplifications of reality (Coyle, 2000; Jonassen, 2000). Computer-based models allow complex systems to be represented efficiently and constructed in a relatively short amount of time. The level of detail in any model involves a trade off between fidelity and communication (Avni, 1999; Bellinger, 2003; Feinstein & Cannon, 2002). A computer-based model may be a better tool for learning because the assumptions of the system must be stated explicitly, allowing these assumptions to be criticised and compared (Forrester, 1971). In addition, parts of the system are able to be more easily visualized when using a model (Gilbert & Boulter, 1998).

Models used in science education have two main roles. The first is an analytic role, when models are used to simplify complex structures and the model is applied directly to a situation (Harre, 1999). The second role is an explanatory one, where models are used as representations for anything that cannot be observed naturally, such as theories (Harre, 1999). In either case, the use of models and technology provides an authentic learning experience for the students (Kelleher, 2000). Simulations are effective particularly in science because they allow students to develop hypotheses and test them (Woolsey & Bellamy, 1997). Once a model is created, it can be used as a trigger to explain behaviour or identify how the system relates to a larger system (Coyle, 2000).

Technology can be used for learning by modelling (Rohr & Reimann, 1998; Woolsey & Bellamy, 1997) and learning with models (Milrad *et al*., 2003) to allow improved understanding of complex, dynamic systems. Many authors (Gilbert & Boulter, 1998; Stylianidou *et al*., 2004) refer to these types of learning as *exploratory learning activities* (students are able to explore pre-existing models) and *expressive learning activities* (students create their own models). A further step is for students to critique other students' models (Gobert & Pallant, 2004). Understanding scientific models is quite different from the ability to reason with scientific models (Gobert & Pallant, 2004).

Learning by modelling (or expressive learning activities) may result in more comprehensive long-term learning outcomes (Jonassen, 2000, 2003). However, positive results have also been found in studies examining the effect of *learning with pre-built models* (Pallant & Tinker, 2004). The focus here is on *learning with prebuilt models* because the time involved in training students in using the modelling software (Jonassen, 2000; Ossimitz, 1997), and also the time involved in students' production of a working model (Haslett, 2001) are not practical for an environmental education scenario.

Despite the literature that says that learning by modelling is an important method of learning, there are few empirical studies of the effects of modelling in science classrooms (Stylianidou *et al*., 2004). Davies (2002) found that the features of a simulation that were important for student engagement were the complexity of the situation, the learning environment as a whole, navigational opacity, allowing sufficient time for engagement to develop, and allowing for cooperative learning. Some studies have shown that both model building exercises and learning with models can promote systems thinking, improve learning outcomes and student attitude toward the class (Friedman & McMillian Culp, 2001; Kiboss *et al*., 2004; Kurtz dos Santos *et al*., 1997).

Both knowledge about the environment and the skills to interpret this information are essential in environmental education if the goal of responsible citizenship is to be achieved. As such, access to information in science is the first part of the process (Buckley & Boulter, 1999), and the other is constructing models and testing hypotheses.

Conclusion

Even though system dynamics has been reported in the literature as an effective tool for modelling complex systems, both experts and novices have trouble understanding complex systems described using system dynamics. Is system dynamics really an effective way to learn about complex systems? We suggest that it is necessary to go beyond presenting system dynamics models, however both existing options – multiple representations and learning by modelling – introduce their own challenges. Empirical research investigating the effects of multiple representations on learning with models (Buckley, 2000), and the effects of learning by modelling have been suggested in the literature, but are yet to be conducted.

We are conducting an empirical study to examine the effects of multiple representations on learning using system dynamics models and animation. The hypothesis tested is that a system dynamics model is too abstract for students, and an additional representation that constrained the understanding of the model (one that was familiar to the students, such as animation) will improve understanding. An animated representation may be useful when learning about a complex system because keeping a dynamic system in mind when resolving a localised problem can be challenging (Milrad *et al*., 2003). Students may also reason with multiple representations (Cox, 1999) so perhaps, providing them with the information in a variety of forms will aid them in being able to explain it to themselves later. In this study the multiple representations are fully redundant, that is, the same information is able to be determined from all of the representations (de Jong *et al*., 1998). In this study, education *about* the environment (Lucas, 1979) is addressed in that it concentrates on environmental knowledge about the potential visitor impacts in a national park and the skills involved in understanding a complex system. A number of the recommendations outlined by the NSW Policy on Environmental Education and others identified by the NSW Council on Environmental Education and Environment Australia are addressed in this study. It aims to examine strategies leading to the acquisition of knowledge and understanding in the areas of the nature and function of ecosystems, how they are related, and the impact of people on environments. These strategies may also develop skills in identifying and assessing environmental problems, and applying technical expertise within an environmental context. In addition, the ability to reflect on and evaluate the consequences of actions, and better communication between formal and informal education settings will also be examined.

While using system dynamics models and other simulations for learning has been an instructional strategy in science education for a number of years, our study is innovative because there is a lack of empirical data investigating learning outcomes from the use of system dynamics models. Besides contributions to the scholarly knowledge base on learning from system dynamics models in general, and on environmental education in particular, it is also hoped that the study can contribute to the practice of teaching with system dynamics models. It is our view that while there is a small, active international community of teachers that promotes this educational technology, the potential of system dynamics modelling deserves more widespread acceptance.

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