MODELS AS MINDTOOLS FOR ENVIRONMENTAL EDUCATION:

HOW DO STUDENTS USE MODELS TO LEARN ABOUT A COMPLEX SOCIO-ENVIRONMENTAL SYSTEM?

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AUTHOR'S DECLARATION

This is to certify that:

this thesis comprises only my original work towards the PhD in Education

due acknowledgement has been made in the text to all other material used

the thesis does not exceed the word length for this degree.

no part of this work has been used for the award of another degree.

this thesis meets the *University of Sydney's Human Research Ethics Committee (HREC) requirements for the conduct of research.*

Signature(s): ……………………………………………………………………………………………………

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Date: ………

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PUBLICATIONS

The following publications have arisen as a direct result of the work done in this thesis:

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ABSTRACT

Environmental issues are complex and understanding them involves integration of different areas of knowledge, feedback and time delays, however strategies to cope with complexity are not often used or taught in environmental education. The aim of this thesis is to examine the benefit of three such strategies for environmental education: multiple external representations, learning from models, and collaborative learning. The socio-environmental system modelled was visitor impact in a national park in Australia. Students in Year 9 and 10 from two schools were given a text description (Text group) and either a system dynamics model (SDM group), an agent-based model (ABM group), or both models (SDM & ABM group). This experimental design allowed learning outcomes (environmental and system dynamics knowledge, and understanding of the socio-environmental system) and use of the model(s) (in terms of the proportion of time spent on each screen, activities, and strategies) to be compared in each learning environment (individual and collaborative).

Multiple external representations were the most successful strategy in the individual learning environment in terms of increases in environmental knowledge. However, students given only the system dynamics model had greater understanding of the system, and students given only the agent-based model increased environmental knowledge easily identified in the animated representation.

Prior knowledge, patterns of use, strategies for changing variables and the representational affordances of the models explained some of these differences. In particular, prior knowledge was an important indicator of how students coordinated use of the models in the SDM & ABM group.

Learning with a system dynamics model was the most successful strategy for students in the collaborative learning environment. Differences between the learning environments were detected in all groups with respect to both learning outcomes and use of the models due to prior knowledge, interrogation of the models, and the learning environments themselves.

These experiments have provided evidence that strategies for understanding complex systems provide viable methods of communicating complex ideas to school-aged students with varying levels of prior knowledge. In particular, multiple external representations provided students with flexibility in how they learned; models allowed students to experiment with a system otherwise not allowed; and a collaborative learning environment facilitated students' interpretation of a system dynamics model.

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1. INTRODUCTION

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 – there may be a delay between a cause and its effect, there may not have been a known link between the cause and its effects, or the effects may occur at a far greater scale than originally predicted. 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 educators need to focus further attention on the development of these skills.

One of the aims of environmental education is to teach environmental knowledge and provide students with the skills needed to understand other environmental problems. This thesis will build on theories of mental models in order to account for the problems that students face when learning about environmental systems. These theories relate to the role that knowledge and understanding play in such problems. Misconceptions in science are common, and studies have found that students demonstrate a lack of understanding about important environmental issues. In addition, environmental systems are usually complex systems, which are generally poorly understood. Complex systems are often described using strategies such as multiple external representations, models, or a collaborative learning environment. All of these strategies have been studied, but not together, and the results have not been conclusive with respect to the effects on learning outcomes.

The purpose of this study is to examine a range of instructional strategies aimed at enabling understanding of a *complex socio-environmental system* (a socio-environmental system is one that incorporates society's use of, or human impact on, the environment). The area of (potential) visitor impacts on a national park was selected for two reasons. The first is that empirical data exist to indicate visitor numbers in a Sydney-based national park. Secondly, the environmental issues involved in this type of system are not part of any school curriculum. This allows a study of the effects of the intervention without having to worry about pre-instructional knowledge differences. The topics and skills are relevant to the NSW Science Syllabus because they focus on the impact of humans on an ecosystem and skills involved in working scientifically.

System dynamics is a methodology designed to describe and understand complex systems. It involves the use of a computer to simulate a complex system. System dynamics models are made up of stocks (levels) and flows (rates), and the interactions between them. System dynamics is a modelling tool used not only for the environment, but also for modelling economic and social systems. Agent-based models address complex systems from the bottom-up. By defining the roles and actions that individual entities (agents) follow, system level patterns can emerge. The use and learning outcomes associated with both types of model will be examined in this study.

This study examines a number of instructional techniques to address the problems associated with understanding complex systems. 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 the systems described using system dynamics. Is system dynamics really an effective way to learn about complex systems? The first hypothesis tested is that *a system dynamics model is too abstract for high school students, and an additional representation that constrained the interpretation of the model (one that was familiar to the students, such as the animated representation included in the agent-based model) will improve interpretation, and therefore understanding*. Learning outcomes were compared from students in four groups: a control group in which students were exposed to a text-based description of visitor impacts on a national park (see Appendix 1), and three treatment groups, in which students were given a system dynamics model to examine, an agent-based model, or both of these combined.

While it has been shown that students do learn different information from different types of representations, when interactive representations are compared, the ways in which these models are used also needs to be taken into account. The second guiding research question examined is *does the type of model used have an effect on the ways in which students use the model?* Four areas are examined in relation to this research question. The first is *despite differences in the patterns of use due to the different run times of the agent-based and system dynamics models, will students be engaged and use the experiment screen more than other screens?* In addition, there has been little work that examines the preference of users when examining multiple external representations. The ways in which students interrogated the models when given both were explored in greater depth, and compared to students using single models. Examining user preference allows the first hypothesis to be confirmed: *if students used the agent-based model to constrain interpretation of the system dynamics model then this will be reflected in their use of the* *models, and students will use the system dynamics model more than the agent-based model.* The third area examined is that of the relationship between learning outcomes and the ways in which the models were used. The question of whether *the use of the model will be related to learning outcomes, particularly for those with which prior knowledge had no relationship* will also be examined*.* Finally, the effect of the strategies that students used to make changes to variables will be examined, both in relation to providing reasons for choices made, and learning outcomes associated with these strategies. Particularly, whether *the strategies used to interrogate the models will be dependent on the models used.*

Collaborative learning environments have been suggested as appropriate for learning about the environment, using multiple external representations, and learning from models. However, there has been little work that examines the effect that each of these areas has on learning outcomes. Will cooperative or collaborative learning have an effect on the skills and understanding that students gain from a system dynamics model, an agent-based model, or both? The studies carried out with regards to learning from multiple external representations and how students used the models were repeated with students in dyads. The results of these were compared in order to examine whether the differences in learning outcomes were a result of the learning environment, or of different uses of the models. The first hypothesis addressed is that *students working in a collaborative learning environment will have higher scores for all learning outcomes than students in an individual learning environment.* The second hypothesis is that *students working in a collaborative learning environment will interact more with the model than students in an individual learning environment.* The guiding hypothesis for learning from multiple representations will be applied to the collaborative learning environment: *a system dynamics model is too abstract for high school students, and an additional representation that constrained the interpretation of the model (one that was familiar to the students, such the animated representation included in the agent-based model) will improve interpretation, and therefore understanding*. Finally the effect of the learning environment on the strategies used and the way in which decisions are made will be compared between the learning environments. Particularly, whether *the strategies used to interrogate the models will be independent of the learning environment.*

While using system dynamics models and other simulations for learning has been an instructional strategy in science education for a number of years, the proposed study is innovative in a number of ways. Firstly, there is a lack of empirical data investigating learning outcomes from the use of system dynamics models (although a strong research base regarding learning outcomes from the use of agent-based models exists). Secondly, a thorough investigation of the ways in which students use agent-based and system dynamics models and any relation this may have to learning outcomes has not been done. Thirdly, the differences between individual and collaborative use of system dynamics models and agent-based models have not been examined. Besides contributions to the scholarly knowledge base on learning from system dynamics models and agent-based models in general, and on environmental education in particular, it is also hoped that this study can contribute to the practice of teaching with system dynamics models and agent-based models. It is my view that while there is a small, active international community of teachers that promotes this educational technology, the potential of system dynamics modelling, agent-based modelling, and the combination of the two deserves more widespread acceptance.

1.1 RESEARCH AIMS, CORE CONCEPTS AND THEORETICAL APPROACH

The aim of this project is to compare different ways for school-aged children to understand a complex socio-environmental system, namely the environmental impacts of recreational use of a national park. The variables to be examined relate to the representation of the socio-environmental system; the ways in which models are used, and the effect of a collaborative environment. The outcomes of the experiment include the answers to the research questions, the materials constructed for the experiments, and recommendations that can be made regarding the design of modelling software for learning environments. The research questions are:

1. What differences in understanding of a socio-environmental system can be identified in school students after they are presented with text (see Appendix 1), a system dynamics model, an agent-based model, or a combination thereof?

2. Does the representation affect how the model is used?

3. Does the way that the model is used affect what students learn from the models?

4. Does prior knowledge affect how students use models?

5. Does working in dyads affect school students' understanding of a socio-environmental system?

6. Does working in dyads affect the ways in which students use models?

The principal variables that will be examined are outlined in Table 1-1 below.

Table 1-1: Variables to be explored in the study

Independent variables	Dependent variables
Exposure to and use of an agent-based model	Environmental knowledge
Exposure to and use of a system dynamics model	System dynamics knowledge
Participation as an individual	Understanding of the socio-environmental system
Participation in a group	
School	
Strategies used to interrogate the models	

The hypotheses (H) and questions to be explored (E) are as follows:

H1: A system dynamics model is too abstract for high school students, and an additional representation that constrained the interpretation of the model (one that was familiar to the students, such the animated representation included in the agent-based model) will improve interpretation, and therefore understanding.

E1: does the type of model used have an effect on the ways in which students use the model?

There are four further questions to this:

> E1a: Despite differences in patterns of use due to the different run times of the agent-based and system dynamics models, will students be engaged and use the *experiment* screen more than other screens?
>
> E1b: If students used the agent-based model to constrain their interpretation of the system dynamics model, then this will be reflected in their use of the models, and students will use the system dynamics model more than the agent-based model.

E1c: Is the use of the models related to learning outcomes, particularly those with which prior knowledge had no relationship?

E1d: Are the strategies used to interrogate the models dependent on the models used?

Three hypotheses are related to learning in a collaborative learning environment and one exploratory question:

H2a: Students working in a collaborative learning environment will have higher scores for all learning outcomes than students in an individual learning environment.

H2b: Students working in a collaborative learning environment will interact more with the model than students in an individual learning environment.

H2c: A system dynamics model is too abstract for high school students, and an additional representation that constrained the interpretation of the model (one that was familiar to the students, such the animated representation included in the agent-based model) will improve interpretation, and therefore understanding in a collaborative learning environment.

E2a: Are the strategies used to interrogate the models independent of the learning environment?

1.2 METHOD AND RESEARCH APPROACH

This study adopts an experimental design. A random allocation of 45 students into the individual learning environment experiment (27 students) and the collaborative learning environment experiment (18 students) allowed groups to be compared with each other. In the individual learning environment, five students were given only a text description. Nine students were given the system dynamics model and the text description (SDM group), six students had access to the agent-based model and the text description (ABM group), and seven students were given both models and the text description (SDM & ABM group). In the collaborative learning environment, three students were given only a text description. Six students were given the system dynamics model and the text description (SDM group), four students had access to the agent-based model and the text description (ABM group), and five students were given both models and the text description (SDM & ABM group). The pre- and post-test design of the main instrument allowed knowledge change to be assessed. In addition, responses related to understanding of the system modelled were also collected.

Video screen shots were collected, coded, and analysed to provide information on how students used the models. These were analysed on a general use basis (proportion of time spent on each screen, frequency of activities performed) and the specific strategies used to change the variables were also analysed.

The experimental design is supported by exploratory data analysis, which allows further investigation into relationships between scores in each group, and relationships between learning outcomes and use of the models. In addition, statistical results are supported with examples of student answers.

1.3 STUDY CONTEXT

This study was carried out at two schools with students in Year 9 and Year 10 as part of a normal science class. Students were given the background questionnaire as their first task. Students were then introduced to the experiment. Students were given 20 minutes to complete the pre-test. Students were then given 20 minutes to examine the materials (text in the control group, and models in the treatment groups), and asked to complete the post-test, the final assessment and the evaluation in the remaining time.

1.4 SUMMARY OF FINDINGS, CONCLUSIONS AND CONTRIBUTIONS

Multiple external representations were the most successful strategy in the individual learning environment in terms of increases in environmental knowledge. However, students given only the system dynamics model had greater understanding of the system, and students given only the agent-based model increased environmental knowledge easily identified in the animated representation.

Prior knowledge, patterns of use, strategies for changing variables and the representational affordances of the models explained some of these differences. In particular, prior knowledge was an important indicator of how students coordinated use of the models in the SDM & ABM group.

Learning with a system dynamics model was the most successful strategy for students in the collaborative learning environment. Differences between the learning environments were detected in all groups with respect to both learning outcomes and use of the models due to prior knowledge, interrogation of the models, and the learning environments themselves.

1.5OUTLINE

The outline of this thesis is as follows. Chapter 2 provides a review of the literature on the topics presented above: mental model theory, understanding complex systems, environmental education, multiple external representations, learning with models, and collaborative learning. Chapter 3 outlines the methodology of the study, including the development of the models, and discusses the sample used. Chapter 4 is the first results chapter, addressing the hypothesis that multiple external representations will result in higher learning outcomes than single model use. The factors that may influence this finding are also explored. In Chapter 5, the use of the models is discussed in terms of the activities that students participated in, the screens that they spent their time on, and the strategies used to change the variables. This provides evidence to support the hypothesis that prior knowledge affects the use of the model, and for some learning outcomes, the specific interaction with the model is particularly important. Again a combination of experimental design and exploratory investigation is presented. The final results chapter is Chapter 6, in which the results of Chapter 4 and Chapter 5 are compared to students who used the models in dyads. The conclusions are presented in Chapter 7.

2. LITERATURE REVIEW

2.1 KEY COGNITIVE CHALLENGES

There are a number of factors that make learning about and understanding environmental systems challenging. These include issues concerned with mental model theory, the role of knowledge and understanding, and general misconceptions in understanding and managing complex/dynamic systems.

2.1.1 Learning Theory: Mental models

Mental model theory is an important theory on which this study is based. Mental models are the internal representation of a system, usually content-specific, and change as new information becomes available (1993; Halford & Andrews, 2004; 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, de Jong, & Ferguson-Hessler, 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 the 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.

Using a simulation model, such as a system dynamics model or an agent-based model can result in clearer understanding because it provides students with an example mental model (Sheehy, Wylie, McGuinness, & Orchard, 2000). Providing students with an example mental model, upon which to form their own, does not solve all the problems associated with understanding complex systems. Environmental systems are complex systems, and “forming, maintaining and manipulating a mental model of changes in a number of variables is demanding” (Sheehy et al., 2000 p. 123). The cognitive load associated with mentally simulating a dynamic system is high. Cognitive load refers to the resources used by working memory at a given point in time (Anglin, Vaez, & Cunningham, 2003). External representations affect the extraneous cognitive load associated with the task.

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. 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. They allow students to off-load the unproductive tasks, such as memorising, and instead to focus on productive tasks, such as recognising patterns (Jonassen, Carr, & Yueh, 1998). This adds to the theory of mental models by relying on tools, such as system dynamics models or agent-based models, to act as an external representation and reduce the problems associated with cognitive load and mental simulation identified in the literature.

2.1.2 Role of Knowledge/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.

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, Tekkaya, & Geban, 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 in order to understand environmental issues. 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 climate change (Daniel, Stanisstreet, & Boyes, 2004) or the carrying capacity of a population (Munson, 1994)). 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. Climate change 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 a better understanding of the system as a whole may be reached (Daniels & Walker, 2001). For example, Munson's (1994) study showed that misconceptions that relate to the carrying capacity of a population are due to students' perception that population size is independent of environmental variables. This leads to further misconceptions regarding the limits of resources and the effects of those resources on a population.

Environmental issues are based on a combination of a number of sciences, including biology, ecology, politics, and the social sciences. Ecosystems are so complex that it would be unreasonable to expect that people could accurately predict or explain the changes that would occur if one variable were altered (Munson, 1994). The focus for many environmental educators, instead, then is that changes *would* occur if one variable were altered (Munson, 1994).

2.1.3 Complex/Dynamic Systems

Systems are characterised as having components or definable elements (state variables or stocks), interactions or interrelations between them (flows of matter, energy, or information), and in open systems such as ecological and economic systems, fluxes in and out of the system boundaries (imports and exports). Systems also often behave in a dynamic manner over time (Limburg, O'Neill, Costanza, & Farber, 2002; Ossimitz, 1997). A dynamic system is one whose components are related to changes in other components in the system (Jonassen, 2000). Understanding complex systems requires that students solve problems on a number of levels, which may be ill-structured, and in order to do so, they must develop complex mental representations of the particular phenomena (Halford & Andrews, 2004; Jonassen et al., 1998).

Many people have trouble understanding complex systems even when they are illustrated using models. 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). 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. Forrester (1971) outlined four common mistakes that are often made when managing complex systems. The first is that one solution may just result in new system behaviour with unwanted outcomes. The second is that short-term “fixes” usually result in long-term problems. Thirdly, local goals often do not match up with global goals. Finally, the points in a system where intervention is conducted often have little leverage and are often where large effort may only have a small effect. 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.

Another reason that complex systems can be difficult to understand is that there can be feedback in the other direction, where aggregate level structures affect the behaviour of the elements of which they are composed (Wilensky & Reisman, 2006). In an agent-based model, the rules that apply to the agents determine the behavior of the whole system. This characteristic of agent-based models, *emergence*, is one of their main advantages. By laying down the rules for the agents and the system, behavior may *emerge* that would otherwise not have been predicted (Bousquet & Le Page, 2004; Ginot, Le Page, & Souissi, 2002; Parrott & Kok, 2001; Schieritz, 2002). A combination of both types of model may help students to understand the links between these levels of complex systems.

The system examined in this study is a socio-environmental system – visitor usage of a national park. The ecosystem of the park is a complex system, and visitor use has impacts on the system that may be unexpected on the part of the visitors, and will certainly indirectly affect other parts of the ecosystem. The recreation impact depends on the use (the type of activity, the amount of use, the behaviour of the users, the spatial distribution of the use, and the temporal distribution of the use), the environment itself, the design of the site, and the level of management (Cole, 1993). While tourist-made tracks and soil condition have been mentioned as variables that may be related to visitor impact in a national park, the most common impact that visitors themselves identified was related to the number of people at the site (Hillery, Nancarrow, Griffin, & Syme, 2001). When asked about threats to the environment of a national park 71% (of the 201 respondents) listed tourism, 28% exotic plants and animals, and 8% broader environmental issues (Hillery et al., 2001).

Recreational impacts on national parks exhibit behaviours typical of complex systems. For example Cole & Landres (1996) state that threats to these areas tend to act in combination, and the cumulative effects are synergistic rather than additive. Impacts usually exceed predictions (Cole & Landres, 1996). There is an asymptotic relationship between the amount of use and the amount of impact (Cole, 1993). If use levels are low, then a small increase in use will result in a large increase in impact. Once use levels are high, any further increase in use will have little effect on the impact. Recreational activities also change over time in response to changes in the nature of the users and the sites themselves (Duffus & Dearden, 1990). The extent of an impact is also dependent on the vulnerability of the soils, vegetation, animals, and water and its topographic features (Cole, 1993). In addition, managers of national parks have to manage the competing interests of different stakeholders (McCleave, Espiner, & Booth, 2006).

2.2 ENVIRONMENTAL EDUCATION

2.2.1 Definition

Environmental education can be enacted in schools (Ballantyne, Fien, & Packer, 2001; Caro, Borgerhoff Mulder, & Moore, 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) (Abrahamse, Steg, Vlek, & Rothengatter, 2005; Barr & Gilg, 2005; Calvert, 2004; Davies & Webber, 2004; Robottom, 2004; Volk & Cheak, 2003; Whelan, Flowers, & Roberto Guevara, 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, Garcia-Ruvalcaba, & Martinez R., 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, Kim, & Jeng, 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).

Environmental education is education *about* the environment, *for* the environment, *in* the environment (Lucas, 1979). The broadness of this definition has resulted in the variety of programs listed above, and each involves one or more of these factors. Programs incorporating education *about* the environment aim to provide information about an environment or an issue, and may contribute some information regarding skills for acquiring environmental information. Programs that focus on education *for* the environment involve skills instruction in order to influence environmentally focused behaviour in order to conserve an environment for a particular purpose.

Education *for* the environment appears to be the most controversial, with much debate occurring in the literature around the use of such education (see for example (Fien, 1993, 2000; Jickling & Spork, 1998; Thomas, 2005)). Programs that address education *in* the environment take place in an environment, such as outdoor education.

The definition of environmental education differs depending on the organisation, although most incorporate Lucas's 1979 definition, and common themes can be found. Environmental education can incorporate both formal and informal education (Environment Australia, 2000, p. 3; Sureda, Oliver, & Castells, 2004; United Nations, 1992); should focus on knowledge and skills development (Environment Australia, 2000, p. 3; NSW Council on Environmental Education, 2001; United Nations, 1992); and result in environmentally responsible behaviour (Environment Australia, 2000, p. 3; Linke, 1980; NSW Council on Environmental Education, 2001; United Nations, 1992). Definitions also emphasise the importance of the interconnectedness of the environment with itself and with other sectors such as society and the economy (Environment Australia, 2000; Fleer, 2002; NSW Council on Environmental Education, 2001; United Nations, 1992).

There are a number of methods of delivery of environmental education. These include curriculum, community education, community development, social marketing, outdoor education and cultural tourism, and other strategies such as risk minimisation, environmental monitoring, or building environmental management systems (Young, 1996).

2.2.2 Environmental education in Australia

The importance of environmental education in protecting the world's environment was officially recognised in the first intergovernmental conference on environmental education, held in 1977. The conference was organised by the United Nations Education, Scientific and Cultural Organisation (UNESCO) and the United Nations Environment Programme (UNEP). The recommendations and guidelines that were developed as a result of the conference are referred to as the *Tbilisi Declaration*. Environmental education has been included in Australia's national education goals for more than a decade (Gough, 2002). The NSW Department of Education and Training states that the aim of environmental education is to achieve "the level of competence and citizenship in all students that will enable them to contribute to the achievement of sustainable societies" (NSW Department of Education and Training, 2001 p. 9). The Department outlines the objectives of environmental education in its *Environmental Policy for Schools*, developed from recommendations made in *Agenda 21, Chapter 36* (United Nations, 1992), and outlined in Table 2-1. 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.

Table 2-1: Objectives of Environmental Education

Objectives of Environmental Education	
Knowledge and understanding of	The nature and function of ecosystems and how they are interrelated The impact of people on environments The role of the community, politics and market forces in environmental decision making
Development of skills in	Applying technical expertise within an environmental context Identifying and assessing environmental problems Communicating environmental problems to others Resolving environmental problems Adopting behaviours and practices that protect the environment Evaluating the success of their actions

(NSW Department of Education and Training, 2001).

There are two other bodies that address the role of environmental education specifically. The NSW Council on Environmental Education (2001) identifies a number of roles of education. These include assisting in identifying and understanding environmental issues and developing visions of sustainable futures, decision making and taking action, sustainability, and assisting in reflecting on and evaluating the consequences of actions and deciding on new courses of action. Environment Australia released a National Plan for Environmental Education in 2000. The Plan outlines five principles of environmental education (Environment Australia, 2000). Environmental education must: involve everyone; be lifelong; be holistic and about connections; be practical; and be in harmony with social and economic goals and accorded equal priority. One of the recommendations from the Plan is better communication between experts from different disciplines, and between the formal and informal education settings. Australia is currently not covered by this National Action Plan. The new National Action Plan was not approved before the Federal election took place on the 24th November 2007, and the process is on hold now that a new Federal government has been elected. The State government body concerned with environmental education is the relatively newly formed Department of Environment and Climate Change NSW (Department of Environment and Climate Change NSW, 2007). The formation of this department incorporated the other government bodies that were concerned with environmental education: the Environment Protection Authority (2003), and the Department of Environment and Conservation, NSW (2004).

2.2.3 Environmental knowledge and skills

Many studies about environmental education are focused on factors resulting in the improvement of environmental behaviour or attitudes rather than the other goals (Aleixandre & Rodriguez, 2001; Brackney & McAndrew, 2001; Campbell Bradley, Waliczek, & Zajicek, 1999; Costarelli & Colloca, 2004; Culen & Volk, 2000; Hsu, 2004; Jenkins & Pell, 2006; Jurin & Fortner, 2002; Knussen, Yule, MacKenzie, & Wells, 2004; Ma & Bateson, 1999; Milfont & Duckitt, 2004; Zelezny, 1999). There is no doubt that the interaction of motivation, cognition and behaviour is poorly understood, however there is a need for a structured approach to research about environmental education (Palmer, 1999). Issues such as “learned hopelessness” and apathy (Nagel, 2005), emotional reactions and knowledge (Borden & Schettino, 1979), and competency in environmental problem-solving skills in combination with environmental information and values (Ramsey, Hungerford, & Tomera, 1981) affect environmentally responsible behaviour.

Rickinson (2001) 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. (Leeming, Dwyer, Porter, & Cobern, 1993) also conducted a review that found that the research on the outcomes of environmental education generally exhibited weak methodologies, were unable to be compared to each other (due to unique instruments used). However, (Morgan & Soucy, 2006) point out that knowledge tests about particular locations cannot be used elsewhere. 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. Among the studies concerned with learning, studies addressed learning outcomes rather than the process of learning, students tended to be passive learners rather than active creators of their own experience, and most programs revolved around a science theme. 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. Gigliotti (1990) expressed the view that the public is emotionally charged, but lacking in basic ecological knowledge. For the public to take environmental action they need to believe that solutions to environmental problems are necessary, and fully understand the consequences to the environment and themselves of not taking action (Gigliotti, 1990). Another study found that it is perceived knowledge, rather than actual knowledge that was a barrier to responsible environmental behaviour (Simmons & Widmar, 1990).

Another issue in environmental education is how it relates to science education. In order to understand environmental issues the interplay of science, social, and economic knowledge must be understood. How best to combine these is still being discussed in the literature (Jenkins & Pell, 2006). The need to show the links between these subject areas keeps environmental education out of the science education realm. There are usually two types of question that need to be answered – an ethical, personal or social question related to the actions to take, and the second is the scientific question (Kolsto, 2006). In both cases, there is usually expert disagreement as to what action to take. There has also been debate about whether to concentrate on values education or factual, science-based education (Lundegard & Wickman, 2007). Knowledge of ecology is a prerequisite to sound decisions regarding solutions to issues even if it doesn't necessarily produce environmental behaviour (Hungerford & Volk, 1990). Knowledge and understanding are also important because they are linked to ownership of an issue (Hungerford & Volk, 1990). In fact, a recent study was able to conclude that environmentally responsible behaviour is a complex system itself, relying on the interaction of intention, moral norms, attitude, perceived behavioural control, guilt, social norm, attribution, and problem awareness (Bamberg & Moser, 2007). And in fact, the authors concluded that although the processes contributing the enactment of pro-environmental behavioural intention are not fully understood, the role of knowledge is a necessary, although not sufficient, precondition for moral norms and attitudes (Bamberg & Moser, 2007)

This thesis measured learning outcomes and had a science theme. It also measured both factual learning (with short-answer environmental knowledge questions and a combination of short-answer and multiple choice system dynamics knowledge questions) as well as understanding (using short answer questions in the final assessment task). It does not address environmentally responsible behaviour, however questions asked to assess students' understanding of the system requires them to identify decisions they *would* make.

2.2.4 Recommendations for an Environmental Education Program

General recommendations have been made regarding environmental education programs in schools (e.g. a flexible curriculum, a collaborative learning environment (May, 2000)) and for programs in the environment (e.g. achievable goals and objectives set for the visit, greater integration between schools and residential experiences (Dettmann-Easler & Pease, 1999)). Another interesting recommendation was that students should bear the consequences of their behaviours (Linke, 1980; May, 2000). The literature suggests that an effective environmental education program would give students an understanding of the issues involved in a problem, how these impact on other areas, and some idea about the steps to take to address such a problem (Fleer, 2002; Loughland, Reid, Walker, & Petocz, 2003). This is typically difficult for environmental issues because the experts are still determining the best course of action themselves.

Barriers to environmental education include conceptual barriers related to the scope and content of environmental education; logistical barriers (where and how and when); educational barriers (teachers' confidence in their own competence); and the attitudinal barriers of the teachers (Ham & Sewing, 1988; Hausbeck, Milbrath, & Enright, 1992). Because the "correct" answer is often not known in environmental issues, they may be confronting for some teachers to teach (Hausbeck et al., 1992). There are also issues involved with the decision of how to address environmental issues. With a single-issue focus, it is difficult for learners to generalise the knowledge and skill to other issues (Hungerford & Volk, 1990), and the education program may produce students who have a positive manner towards one issue, without being able to see how to apply this attitude towards their usual lives (Hungerford & Volk, 1990). The features of an effective environmental education program as outlined earlier (impart understanding of the issues, their impact, and actions to take), are difficult to achieve with adults, let alone school students. Students have difficulties with the language necessary for discussing environmental problems over time (Sheehy et al., 2000).

Critical education components include: environmentally significant ecological concepts and the environmental interrelationships that exist within and between these concepts; environmental education should be multidisciplinary; provide opportunities for learners to achieve a level of environmental sensitivity that will promote a desire to behave in appropriate ways; provide a curriculum that will result in an in-depth knowledge of issues; provide a curriculum that will teach learners the citizenship skills needed for issue analysis and investigation, and citizenship skills and the time needed for application of these; should involve hands-on contact with nature; and provide a learning environment in which learners can develop an internal focus of control (Hausbeck et al., 1992; Hungerford & Volk, 1990).

Of the methods of delivery of environmental programs, (Young, 1996), this study addresses curriculum. Education *about* the environment 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 in Table 2-1, 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 will also be examined.

This study examines three instructional strategies in environmental education with the aim of understanding how these strategies influence learning, rather than the decisions that subjects make after they have completed an environmental education program. The strategies are learning from multiple external representations, learning with models, and learning in a collaborative learning environment. The study addresses Rickinson's recommendation for deeper empirical investigation into "the *processes, experiences* and *contexts* of young people's *environmental learning*, including what kinds of conditions are helpful for which kinds of students undertaking which types of learning" (2001, p. 307).

2.2.5 A Socio-Environmental System - National Parks

This study uses the impacts of visitor use in a national park as an example of a complex system. The management aim of a national park is a mix of conservation and protection of ecosystems, natural and cultural features, landscapes, geoheritage and other phenomena, and the provision of opportunities for public appreciation, sustainable visitor use, visitor management, community health and wellbeing, and economic benefits for the community (Department of Environment and

Conservation (NSW), 2006). The model of a national park used in this study is a highly simplified version of data collected from Botany Bay National Park (BBNP), Kurnell (Davison, 2000). This piece of land has been put aside by the government because of its cultural significance, as it is Captain Cook’s landing place. As a result of the development that has occurred in the surrounding suburbs, the environmental integrity of the national park has also become important. The Park is surrounded by an oil refinery, a sand mining company and other industry. In the area are wetlands important for migrating birds. In addition to its functions as a site for cultural heritage and its environmental values, the park is important to visitors for a variety of recreational uses.

Common uses of the park are fishing, diving, picnics, going for a drive and having a look at the view, bushwalking and nature watching. Models have been used to understand visitor behaviour in natural settings (Chang, 1997; Gimblett et al., 2000a; Murdock, 2004; Romesburg, 1974; Shechter & Lucas, 1980; van Wagtendonk, 2004; Wang & Manning, 1999) although these mainly concentrate on travel and visitor contact (or carrying capacity of the park) rather than visitor impact. Models have been developed to investigate the interaction between tourism and the environment (Lacitignola, Petrosillo, Cataldi, & Zurlini, 2007), and to make informed management decisions (Bieri & Roberts, 2000; Gimblett et al., 2000a; Gimblett et al., 2000b; Roberts, Stallman, & Bieri, 2002; Schmidt, Webb, Valdez, Marzolf, & Stevens, 1998). In other parks, recreation may also include activities such as hiking, camping, horseriding, four-wheel driving, skiing, rafting and boating (Sun & Walsh, 1998). All of these uses impact on the environment in different ways. Activities such as bushwalking, even on the paths provided, can have an effect on the vegetation in a national park (Hill & Pickering, 2006). And activities that involve fires (such as in picnic grounds), or inadequate waste disposal, can introduce nutrients (such as phosphorus and nitrogen, but also others) into the soil (Arocena, Nepal, & Rutherford, 2006). A system such as this national park is a challenge to manage if funding has to be distributed between maintenance of areas for recreation, areas of cultural heritage, and environmental integrity. This is conflicting for two reasons, the first is that human contact with the environment usually impacts on that environment in some way, and natural resource managers are rarely able to control the impact that recreational users have on a national park (Cole & Hammitt, 2000). The second reason is that there is limited knowledge about the exact nature of the “natural conditions” (Cole & Hammitt, 2000).

National parks are typical complex systems in that any attempt to manage an impact may involve feedback, time delays, and unexpected consequences (Cole & Landres, 1996). Opportunities for sustainable visitor use and recreation in NSW national parks are only available in those parks where such a use is compatible with the conservation of the park's natural and cultural values.

Environmental education has been found to be effective as a conservation measure as far as the impact of recreational disturbance (Medeiros et al., 2007) and conservation behaviour (Asch & Shore, 1975), although sometimes only with particular interest groups (Morgan & Soucy, 2006). In addition, recreational experiences in national parks may be important for the development of environmental sensitivity. Environmentally sensitive people have often spent large amounts of time in natural areas engaging in recreational activities (Hungerford, 2004).

The impact of visitor use of the national park that will be the focus of this study is essentially a waste management issue. Visitors leave rubbish in the bins provided, both organic and inorganic rubbish. If this rubbish is not all collected, then it can attract feral animals as a food source, and if not eaten, then can decompose and result in the addition of nutrients to the environment, which then encourages introduced plant species. Feral animals, in particular cats, are a threat to native animals because they preferentially target young larger mammals as well as smaller mammals as prey (Short, Turner, & Risbey, 2002). While not all introduced species of plants and animals are detrimental to management of a conservation area, invasive introduced species are (Usher, Kruger, Macdonald, Loope, & Brockie, 1988), and have been shown to be a major environmental problem in countries such as Australia and the USA. Like most environmental issues, national park managers have to decide how to allocate limited resources to the control of invasive introduced species of plants and animals, and the outcomes of any decision are often uncertain (Usher et al., 1988).

Bushland in the Sydney district has evolved to take advantage of the low nutrient (particularly low phosphorus) sandy soils that are prevalent in the area (Adam, Stricker, & Anderson, 1989; Adamson & Fox, 1982; Beadle, 1954; Benson & Howell, 1990). Each species has a minimum requirement for soil phosphates in order for normal growth to occur, and if this is met, the plant survives, providing it can compete with other species (Beadle, 1954). Natural vegetation in the Sydney area is mainly grown on Hawkesbury Sandstone soils. It is a distinctive assemblage of species that are able to thrive on these poor soils, mainly sclerophyllous plants that have tough, and small or spikey leaves. This vegetation remains because of the low nutrient soils that were of no use for agriculture (Benson & Howell, 1990). Plant communities do undergo cyclic and directional changes, they are not static (Benson & Howell, 1990). Slightly different combinations of species may be favoured depending on the sequence of natural events such as fire or flood and the weather conditions thereafter, however plant communities are generally self-sustaining. Invasive introduced species of plant are able to establish themselves in a community after some type of disturbance (Benson & Howell, 1990). The seeds are dispersed into bushland via stormwater, dumped garden refuse, wind or fruit eating birds (Benson & Howell, 1990). Once nutrients are added to an ecosystem, the changes that occur are irreversible. The vegetation community is dependent on the soil type (Benson & Howell, 1990), and increases in soil nutrients encourage introduced plant species (Adamson & Fox, 1982; Morgan, 1998), have an effect on species richness and succession dynamics (Tilman, 1987), and result in the deterioration of the natural environment (Benson & Howell, 1990). This can be due to competition in terms of space, light and pollinators (Benson & Howell, 1990; Bjerknes, Totland, Hegland, & Nielsen, 2007). While litter is not the main contributor to additional nutrients in the environment (other sources include stormwater (in which phosphorus concentrations are about 50-100 times greater than those that occur in natural streams in the Sydney region), garden fertilisers, dumped refuse, sewer discharges, and pet excrement, (Adamson & Fox, 1982; Benson & Howell, 1990)) it was chosen for examination in this study because it is a common activity for visitors to a national park. Other impacts on the environment include rubbish dumping, changed fire frequency and destruction of bush for service routes and roadways (Adamson & Fox, 1982; Benson & Howell, 1990).

2.3STRATEGIES FOR UNDERSTANDING COMPLEX SYSTEMS

2.3.1 Multiple External Representations

A representation is a simplification of a phenomenon for a specific purpose (Buckley & Boulter, 1999). Zhang (1997) described external representations as “the knowledge and structure in the environment” (p. 180). This includes physical symbols, objects, dimensions of a graph, external rules, constraints, and relations embedded in physical configurations (Zhang, 1997). External representations provide information that can be perceived and used without being interpreted and formulated explicitly, they anchor cognitive behaviour, and can change the nature of tasks (Zhang & Norman, 1994). Zhang (1997) defined internal representations as “the knowledge and structure in memory” (p. 180). Cognitive processes are used to retrieve information from internal representations, and external representations can trigger this process (Zhang, 1997). The advantage of using external representations, as described earlier with reference to mental models, is that they do not need to be re-represented as an internal model in order for learners to use them for problem solving (Zhang, 1997).

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 external representations often explain their approach by stating that it is more likely to capture a learner's interest (Ainsworth, 1999b). The use of multiple external representations provides learners with an authentic learning environment because most experts, and scientists in particular, use multiple external representations to explain phenomena (Kozma, 2003; Kozma, Chin, Russell, & Marx, 2000). Presenting students with a range of representational forms gives students the opportunity to explore many aspects of the one concept (Zhang, 1997), users can use the representation of their choice, and a number of personality or cognitive factors can effect this choice (Ainsworth, 1999a). It is now easier to present multiple external representations including animations and video as well as diagrams and graphs, and to show the links between them, due to the technology that has been developed (Wisnudel Spitulnik, Stratford, Krajcik, & Soloway, 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.

Learners have four tasks when learning from multiple external representations (van der Meij & de Jong, 2006). They have to understand the syntax of each representation (novices may use representations inappropriately); they have to understand which parts of the domain are represented; they have to relate the representations to each other (this is particularly difficult because learners will have incomplete domain knowledge; and they have to translate between the representations (this is particularly difficult for novices) (Ainsworth, 1999a; van der Meij & de Jong, 2006).

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, Lowe, & Scaife, 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; Zhang, 1997). 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. Much work has been done comparing learning outcomes of students learning from text versus a diagram (see for example (Glenberg & Langston, 1992; Larkin & Simon, 1987; Moore, 1993; Schnotz & Bannert, 2003)). While system dynamics models are dynamic, they are not animated, which could explain why students often have limited understanding of systems represented by these models.

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 (Ainsworth, Bibby, & Wood, 1998; Horwitz & Christie, 1999; Seufert, Janen, & Brunken, 2007). This ability to translate the symbols inherent in the representation and the real objects is known as interpretation (Stenning, 1998). Seufert (2003) found that students who had lower prior knowledge and who received no help concentrated on memorizing facts, and invested little cognitive effort in comprehension (Seufert, 2003). Students who had medium level prior knowledge had lower scores for recall, but higher for comprehension, because they were engaged in both processes (Seufert, 2003). Learners with high levels of prior knowledge did not increase their scores to the maximum level. It was thought that this may have been due to an overestimation of their own abilities (Seufert, 2003).

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 (Ainsworth, 1999a; Ainsworth et al., 1998). Translation between representations can be facilitated by prior knowledge of the domain (semantic translation) or by direct relation of the representations themselves, without reference to the domain (syntactic translation) (Ainsworth, 1999a). 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 external representations depends on the type of test, domain, learner, and 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 (Ainsworth et al., 1998; Bodemer, Ploetzner, Feuerlein, & Spada, 2004). Integrating representations or linking them dynamically has been found to support learners, allowing them to interpret the similarities and differences of the features in each representations (van der Meij & de Jong, 2006).

There are a number of reasons for using multiple external 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 external 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 external 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 external representations may serve one of three different functions (Ainsworth, 1999b), which were later defined in a taxonomy (Figure 2-1) (Ainsworth & Van Labeke, 2002). Ainsworth (1999) suggests that the three functions are to *complement*, *constrain*, and to *construct*. When representations contain different information or cognitive requirements, the representations *complement* each other, either by processes or information (Ainsworth & Van Labeke, 2002). 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 (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). The third function is when each representation is used to help learners *construct* a deeper understanding of the learning objective (Ainsworth, 1999b). This can be by abstraction, extension or building relations between the representations (such as a system dynamics model may do for an agent-based model) (Ainsworth & Van Labeke, 2002).

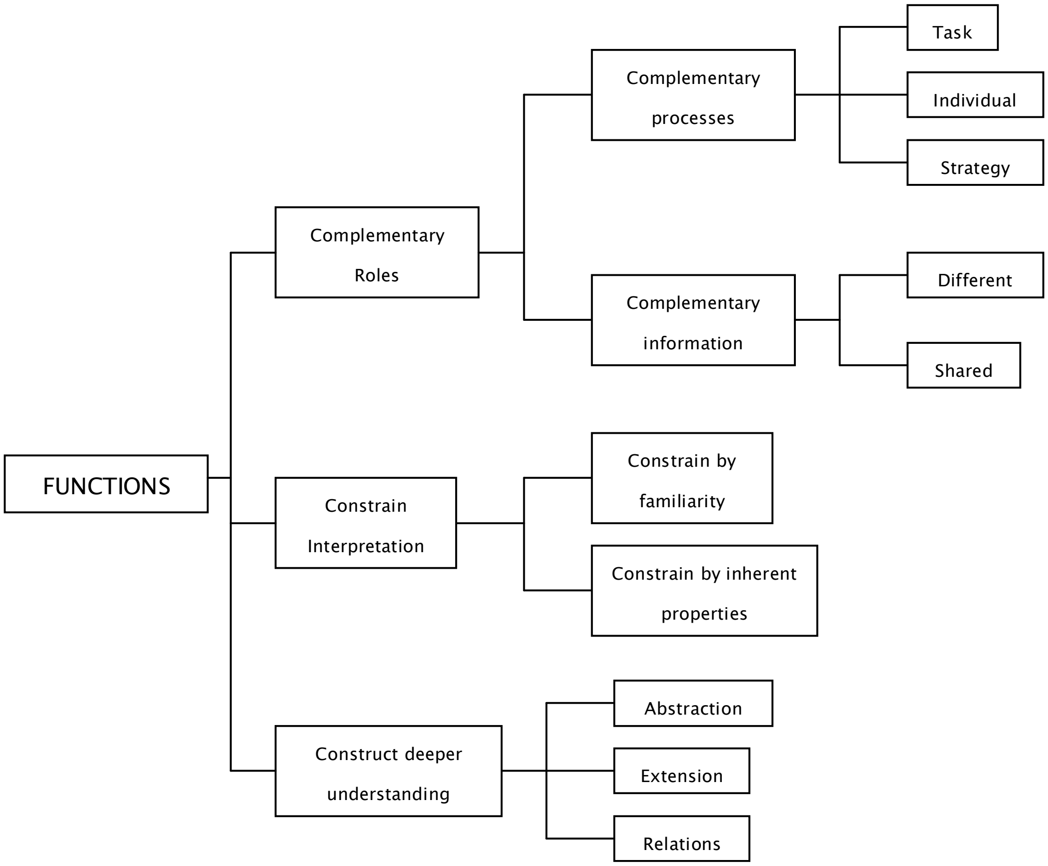


Figure 2-1: A Functional Taxonomy of Multiple Representations from (S. Ainsworth & Van Labeke, 2002)

System dynamics models and agent-based models themselves are multiple external representations. System dynamics models include a stock and flow diagram, equations, graphs, tables and text. Similarly the agent-based model is a multiple external representation with the animation, code, text, graphs and tables. Thus, all the potential issues with multiple external representations apply to learning with system dynamics and agent-based models alone, as well as together. According to this taxonomy, the functions of the multiple external representations in this study fall into several categories. Students who were given the agent-based model may have used the text to *constrain by familiarity*. In this category, it is the learner's familiarity with the constraining representation that is essential (Ainsworth, 1999a). Students who were given the system dynamics model may have used the system dynamics model to *construct deeper understanding by abstraction* of the text. In this category, it is thought that in building references between representations, the knowledge can be used to expose the structure of the domain itself (Ainsworth, 1999a). Students who were given both models and who chose the system dynamics model may have used the agent-based model to *constrain by familiarity* their understanding of the system dynamics model; or if they chose to use the agent-based model they may have used the system dynamics model to *construct deeper understanding by abstraction* or *by relations*. In any case the models provided students with complementary processes, both a complementary task, and possibly a complementary strategy to interrogate the model. The ability of the learners to understand the relationships between representations is addressed in this study.

Positive learning outcomes that have been associated with the use of multiple external representations include motivation of student learning in cases where students already liked the subject (Tsui & Treagust, 2003); visualisation, instant feedback and flexibility (Tsui & Treagust, 2003); encourage abstraction by providing a variety of representations that can then be linked to construct meaning (Ainsworth, 1999b); and positive learning outcomes if used in a complementary fashion and if used in the feedback process (Ainsworth et al., 1998). Multiple external representations may provide learners with a variety of perspectives from which to construct their own mental models. This is why learner characteristics need to be considered, and may explain some mixed results of experiments. Rohr and Reimann (1998) suggested that there is not a clear positive result with regards to static images and animations, and instead that these representations interact with subjects' beliefs. In another study, it was concluded that different representations will lead to different learning outcomes for tasks, and not that one representation is better than another (Rieber, Tzeng, & Tribble, 2004). The way in which the representations are presented may also play a role in learning outcomes. One study found that learners learn the domain better if the representations are integrated and linked (van der Meij & de Jong, 2006). This study suggested that students using a learning environment for a short period of time, in this case 38 minutes, did not explore the domain deeply, and were therefore unable to transfer their knowledge to new situations (van der Meij & de Jong, 2006). Alternatively, if the representation constrains the interpretation of another, it may be that subjects related the domain to the presented contexts too much, and were not able to transfer their knowledge.

The use of multiple external representations has been found to have negative effects on students' learning in some cases ((Tabachneck-)Schijf & Simon, 1998; Ainsworth et al., 1998; Bodemer et al., 2004; de Jong et al., 1998; Scaife & Rogers, 1996). When the purpose of the additional representation is not clear, students may change their usual problem solving processes to accommodate the representation, resulting in further errors ((Tabachneck-)Schijf & Simon, 1998). Coordination of information from different representations can be a major cost to learners of using multiple external representations (Bodemer et al., 2004; de Jong et al., 1998). This is referred to as the cognitive load associated with the task. While this is an important consideration, experimental findings show that the failure to coordinate between multiple representations is not simply a matter of cognitive load (Ainsworth et al., 1998). Even when representations are fully redundant, students have trouble coordinating between representations (Ainsworth et al., 1998). This indicates that even when the factors associated with the representations are taken into account, the characteristics of the learner still need to be considered.

One of the challenges of using multiple external representations is the cognitive load associated with translating between representations (van der Meij & de Jong, 2006). Students may have problems relating different representations due to the split-attention effect, whereby learners split their attention between the representations (Chandler & Sweller, 1992). Several studies have been carried out to investigate the many loading aspects and the best way to present multiple external representations in order to decrease the extraneous and intrinsic cognitive load, and allow students to concentrate on the integration process, given the advantages of using multiple external representations (Lee, Plass, & Homer, 2006; Seufert et al., 2007; van der Meij & de Jong, 2006). Seufert, Janen and Brunken (2007) found that both intrinsic *and* extraneous cognitive load needed to be reduced in order for advantages in learning outcomes to be recognised. In addition, the study examined the use of explanatory features, and found that they were effective when the learning environment was less complex and had fewer representations to be integrated. Lee, Plass & Homer's (2006) study investigated the design of a learning environment using multiple external representations in order to determine how best to present information to reduce the intrinsic cognitive load. They found that when the content was separated into two successive screens, the intrinsic cognitive load was reduced, however students with higher prior knowledge benefited from this more than those with lower prior knowledge. Those students who used the simulations with the content separated experienced higher levels of comprehension and transfer. The differences found between the students with the two levels of prior knowledge suggested that those with low prior knowledge experienced high cognitive load associated with establishing connections between information on the two screens. This was not unexpected because those students who already had a mental model in place would have had to use fewer resources to incorporate the new information than those without existing prior knowledge (Lee et al., 2006).

Prior knowledge of the domain is an important factor in the success of multiple external representations. Many studies have found that in the area of problem solving, novices and experts use multiple external representations in different ways. The use of multiple external representations is usually associated with expert behaviour, and thus thought to be beneficial for novices to experience in order to learn about a domain. However, novices generally find this difficult (Ainsworth, 1999a; Tabachneck-Schijf, Leonardo, & Simon, 1997), both in terms of making connections across representations and connecting representations to the real world (Kozma, 2003). Novices will often use only one representation (Ainsworth, 1999a). As novices generally lack expertise either in the domain or the representations they are using, they are unlikely to be able to recognise structural relations between representations (Ainsworth, 1999a). In addition, experts tend to successfully solve problems with abstract representations, and novices with concrete representations (Jonassen, 2003). Tabachneck-Schijf *et al.* (1997) suggest that pictorial representations may be advantageous for expert reasoning because they evoke recognition processes for the expert to access information in memory, and a dynamic construction of the picture would provide the expert with a summary of the process. The expert could therefore concentrate on the reasoning rather than on the task of maintaining an internal representation. However, this would not benefit a novice who has no prior knowledge of the topic to access. If this is the case, then is it still valuable to use strategies that are common to experts to instruct novices? It may be if it allows novices to build mental models that are more consistent with experts', which would then support appropriate cognitive processes (Cheng et al., 2001). Incorporating techniques for translating between representations as part of the instruction of novices may be necessary ((Tabachneck-)Schijf & Simon, 1998). Students with low prior knowledge have been found to have problems relating different representations to each other, and were disadvantaged because of this (Bodemer & Faust, 2006; van der Meij & de Jong, 2006). The ability of students to correctly relate multiple representations to each other was associated with familiarity of the visualizations in the learning material (Bodemer & Faust, 2006). These authors found that step-by-step integration of information can reduce extraneous cognitive load so that externally relating multiple representations can be done within working memory capacity (Bodemer & Faust, 2006).

The order in which the representations are presented may have an effect on the learning outcomes. Scaife and Rogers (1996) suggest that experience with static representations may aid in the ability to learn from dynamic representations. Whereas Schnotz (2002) suggests that the picture should be presented before the text because text can result in many different mental models, which are then confused by the picture which is more specific. This study allowed students to have free choice in terms of the order in which the representations were examined.

This study addresses the recommendation made by Buckley (2000) that further research be carried out to determine how different types of representations contribute to model-based learning. Studies have found that presenting information in two modalities can make learning more effective because it spreads processing over multiple systems (Ainsworth & Loizou, 2003). This study uses text and a system dynamics model in order to determine whether learning about a complex system is enhanced by the addition of an agent-based model. An agent-based model 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, Spector, & Davidsen, 2003). Students may also reason with multiple external representations (Cox, 1999) so, providing them with the information in a variety of forms may aid them in being able to explain it to themselves later. In this study the multiple external representations are fully redundant, that is, the same information is able to be determined from all of the representations (de Jong et al., 1998), however the processes are different. This is appropriate for the high cognitive load assumed to be involved with interpretation of new models with this level of complexity (Sweller & Chandler, 1994).

2.3.2 Learning from Models

2.3.2.1 Modelling the environment

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 valuable 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). "The purpose of a model is to capture the essence of a problem and to explore different solutions of it" (Grimm, 1999, p. 137).

A number of factors are important in constructing and using models. These include, fidelity; validation of the model (are the conclusions from the simulation similar to those reached in the real-world simulation?); verification of the model (is the model operating as it should?); level of abstraction (how embedded is the model in the domain?); how the model handles time; and the existence of an optimal solution (Feinstein & Cannon, 2002; Größler, 2004). System dynamics models and agent-based models are able to fulfil the majority of these factors, although the level of abstraction in a system dynamics model is generally high, and the existence of an optimal solution is dependent on the question that is addressed in either model. The design of interactive environments for supporting learning about complex domains should be guided by: authentic activities, construction of artefacts, collaboration, reflection, situating the context, and multi-modal interaction (Milrad, 2002). There is a trade-off between the usability and the power of a representation (Lohner & van Joolingen, 2002).

Both knowledge about the environment and the skills to interpret this information are essential in the learning outcomes of 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.

Because ecosystems are complex systems, actions that affect a single area can have unexpected repercussions elsewhere, and so modelling can be a useful tool to identify and examine such behaviour (Loiselle, Carpaneto, Hull, Waller, & Rossi, 2000). Policy makers, resource managers and engineers routinely underestimate the importance of feedback, non-linearities, time delays and changes in human behaviour as a result of policy interventions such as flood control, the use of pesticides, increasing the capacity of roads, policies for fire suppression, or security standards for water supply systems (Pahl-Wostl, 2007).

Technology can allow students to more easily collect data, present data, and understand and analyse systems (Woolsey & Bellamy, 1997). A meta-analysis conducted in 2001/2002 examining studies undertaken in the United States of America found a small positive effect for computer assisted instruction (CAI) in science (Bayraktar, 2001/2002). Some conditions promoted this positive effect more than others, including working with simulations or tutorials (rather than drill and practice), individual use of computers (rather than in groups), use of CAI as a supplement to regular instruction (rather than a substitute), and software programs that had been developed by a researcher or a teacher (rather than those commercially available) (Bayraktar, 2001/2002).

Technology can also 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 (de Hoog, de Jong, & de Vries, 1991; Gilbert & Boulter, 1998; Stylianidou, Boohan, & Ogborn, 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).

A simulation is used either for science or education, and it is used because the actual system can not be investigated directly (Rieber, 1996). Scientists use simulations to establish and refine existing theory and understanding of the system. In education, simulations are used because students can learn about a system by observing the result of actions or decisions through feedback generated over a variety of time-scales (Rieber, 1996). Despite the literature that says that learning by modelling is an important method of learning, there are few empirical studies of the success of modelling in science classrooms (see for example (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 students' understanding of the nature of modelling itself, improve learning outcomes, reduce misconceptions, increase transferability, and improve student attitude toward the class (Friedman & McMillian Culp, 2001; Gobert, Snyder, & Houghton, 2002; Kiboss, Ndirangu, & Wekesa, 2004; Kurtz dos Santos, Thielo, & Kleer, 1997; Pallant & Tinker, 2004).

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) or to investigate phenomena that occur over different time or spatial scales (Jacobson & Wilensky, 2006). Using a simulation allows students to investigate the links that occur between scales (Jacobson & Wilensky, 2006), and allows students to participate in a full inquiry-cycle in less time than they would in the real world, and thus learn better inquiry skills because they can do this more often (Murray, Winship, Bellin, & Cornell, 2001). The use of models and technology provides an authentic learning experience for the students (Jacobson & Wilensky, 2006; Kelleher, 2000). Simulations are effective particularly in science because they allow students to develop hypotheses and test them (Buckley et al., 2004; Milrad, 2002; Woolsey & Bellamy, 1997), and can provide students with scaffolds to aid in experimental design (de Jong & van Joolingen, 1998). 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). Using simulation models in education allows the learner to interact with the representation, which in turn provides the learner with feedback that can be interpreted as the basis for further interaction (Milrad, 2002).

Learning by modelling (or expressive learning activities) may result in more comprehensive long-term learning outcomes (Jonassen, 2000, 2003). Creating dynamic models allows students to combine fragmented knowledge into larger constructs by allowing them to explore that knowledge (Stratford, Krajcik, & Soloway, 1998). However, positive results have also been found in studies examining the effect of *learning with pre-built models* (Pallant & Tinker, 2004). The focus of this study will be on *learning with pre-built models*, (also defined as learning with model-based simulations) because of the greater time involved in training students in using the modelling software (Jonassen, 2000; Ossimitz, 1997), and also the large amount of time involved in students production of a working model (Haslett, 2001). For this study, the underlying model is context-based, placing the learner in a context that simulates a real situation (Milrad, 2002). Wilensky & Reisman (2006) make the point that some facts and theories need to be presented in an appropriate context in order to be integrated with existing knowledge and retained. This is certainly the recommendation made by the environmental education research. It is particularly import for students who are engaging with the experience as an isolated experience, rather than are engaged in the study of science (Wilensky & Reisman, 2006).

System dynamics modelling and agent-based modelling require higher level cognitive skills than those often addressed by computer-based learning (Jonassen, 2000). Simulation models have been used successfully in physics where improvements were found in students' achievement, problem solving skills, and overall understanding of the concepts (Jimoyiannis & Komis, 2001). However, there has not been agreement in the literature on this success (de Jong & van Joolingen, 1998; Hopson, Simms, & Knezek, 2001/2002). Reasons for poor results include: under utilisation of the features available; different types of learners not accounted for; and an inability to assess individual learners due to poor experimental design (de Jong & van Joolingen, 1998). Generally, the skills required to fully participate in discovery learning are the ability to generate a hypothesis, applying a systematic and planning process, and the use of high-quality heuristics for experimentation (de Jong & van Joolingen, 1998). Of those studies that did test individual measures, certain characteristics typified successful learning outcomes. They are direct access to domain information, students receiving assignments, and the availability of a learning environment that allows model progression (de Jong & van Joolingen, 1998).

2.3.2.2 System Dynamics Modelling

A system dynamics model will be one of the representations investigated in this study. "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 regarding negative effects on the environment that are still relevant. These include 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). Feedback is a defining element of a complex system. Forrester identifies feedback as the most important element in defining a system (Forrester, 1971). "The feedback loop is 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" (Forrester, 1971, p. 17). Feedback is also described as "the structure surrounding a decision process" (Forrester, 1968). A positive loop occurs when a change in one variable causes a change in the same direction in a second variable, which in turn causes further changes in the first. In Figure 2-2 below, the birth rate and population loop demonstrates positive feedback. An increase in the population causes an increase in the birth rate (because more of the population is able to reproduce) which causes an increase in the population, and so on. Negative loops counteract change (Sterman, 2001). In Figure 2-2, the death rate and population loop demonstrates the stabilising function of a negative feedback loop. Any increase in the population results in an increase in the death rate, which causes a decrease in the population, thereby stabilising the increase. Conventions exist for drawing causal loop diagrams, the diagrams contain variables that are linked by arrows (Sterman, 2000) (see Figure 2-2). 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).

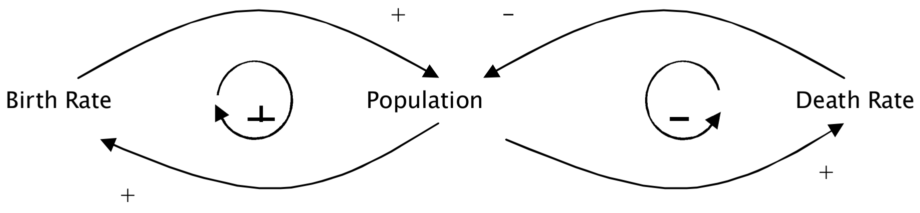


Figure 2-2: An example of a Causal Loop Diagram (Sterman, 2000, p. 138)

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 2-3). 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). “A rate of flow is controlled only by one or more of the system levels and not by other rates” (Forrester, 1971, p. 18). The clouds at the ends of the flows represent the boundaries of the system.

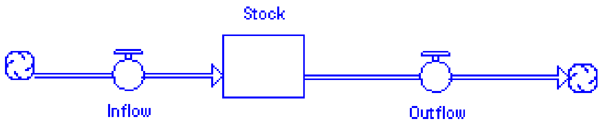


Figure 2-3: An example of a Stock and Flow Diagram (Sterman, 2000, p. 193)

System dynamics has been used to examine the dynamic complexity of perfectionist tendencies in gifted and talented children (Ramsey & Ramsey, 2002); to understand Keynes' theory of financial crisis (Harvey, 2002); to examine environmental sustainability of an agricultural development project (Saysel, Barlas, & Yenigun, 2002); the effect of exercise and diet in obesity treatment (Abdel-Hamid, 2003); to design interactive courseware (Spector & Davidsen, 1997); to understand the process of implementing technology-enhanced learning environments in higher education (Stavredes, 2001); and to understand a mine disaster in Canada (Cooke, 2003). It has been used to make policy recommendations (e.g. (Satsangi, Mishra, Gaur, Singh, & Jain, 2003; Saysel et al., 2002; Xu, 2001)), and for public participation in environmental problems (Jones, Seville, & Meadows, 2002; Stave, 2002, 2003; Walker, Greiner, McDonald, & Lyne, 1999), although using system dynamics to model stakeholders' mental models has not always been successful (Rouwette, Vennix, & Thijssen, 2000). System dynamics has been used to study a variety of situations in natural resource management (e.g. (BenDor & Metcalf, 2006; Carbonell, Ramos, Pablos, Ortiz, & Tarazona, 2000; Faust, Jackson, Ford, Earnhardt, & Thompson, 2004; Guo et al., 2001; Martinez-Fernandez, Esteve-Selma, & Calvo-Sendin, 2000; Xu, 2001)); to model socio-environmental systems (Faust et al., 2003; Martinez Fernandez & Esteve Selma, 2004; Saysel et al., 2002; Weclaw & Hudson, 2004); situations of economy versus environment (Dudley, 2004; Woodwell, 1998); and systems involving the interplay of society, economy and the environment (such as tourism (Patterson, Gulden, Cousins, & Kraev, 2004), tourist behaviour (Walker et al., 1999) and environmental sustainability (Hilty et al., 2006)).

Human impact is often left out of ecological models, even though humans may 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). 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).

STELLA™ is the system dynamics software that will be used in this study. STELLA™ is an object-oriented graphical programming language designed specifically for modelling dynamic systems (Costanza, Duplisea, & Kautsky, 1998). STELLA™ has been used in a variety of both instructional and experimental or explorational studies (e.g. (Davies, 2002; isee Systems, 2005; Patterson et al., 2004)). Icons for stocks and flows (see Figure 2-3) are placed on the screen and connections between these are made. Behind the diagrammatic representation sits the mathematical equations governing the system's behaviour (Sherwood, 2002). The diagrammatic interface allows the user to create a physical representation of their mental model and manipulate it to carry out experiments (Jonassen, 2000; Land & Hannafin, 2000), regardless of the user's understanding of the mathematics that governs the system. Outputs can be viewed as graphs or tables. STELLA™ also allows the model builder to generate a user friendly interface, for example sliders to change model parameters (Costanza et al., 1998).

Although much is written of the value of system dynamics modeling in education in schools, very little empirical data exists to confirm this (Doyle, Radzicki, & Trees, 1998; Stratford et al., 1998). Instead, case studies and anecdotal accounts from teachers who have used such models are available on the web (Guthrie & Fisher, 1999; Ragan, 1999; Verona, Ragan, Shaffer, & Trout, 2001). The Core models project was a large scale implementation of system dynamics modeling in a number of schools, and evaluation of the project, while focusing on teacher support, did find that while students did improve understanding of the scientific concepts underlying modeling, they did not improve their ability to interpret the models (Maryland Virtual High School, 2001). Studies make recommendations as to how to teach system dynamics modeling (Schaffernicht, 2006; Stuntz, 2000), or how to incorporate it into a class (Draper, 1993). 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. Other studies focus on university-aged students and examine how students mismanage systems (Moxnes, 1998), or learning about system dynamics concepts (Kainz & Ossimitz, 2002) rather than learning about the domain on which the model is based.

Students do have trouble understanding complex systems using system dynamics models. One study found that the majority of participants in four separate studies (167 subjects in total) had biased views of the dynamics of the environmental system that they were examining which suggested that they were using a static (rather than a dynamic) mental model (Moxnes, 2000). Another study found that graduate students had very poor understanding of the processes involved in climate change, 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 a structure with only one stock and two flows, feedback on decisions and allowed the opportunity to learn from past mistakes (Moxnes, 2004). This suggests that domain knowledge may not have been a factor in these subjects’ understanding of the system. While a number of studies have investigated learners’ inability to correctly model a natural resource problem (Booth Sweeney & Sterman, 2000; Diehl & Sterman, 1995; Moxnes, 2004), (Kainz & Ossimitz, 2002) determined that students did not have difficulties in determining between stocks and flows, and instead found it difficult to represent this information in a flow chat, and similarly that students were better able to interpret information from a table than from a graph. This suggests that perhaps the representational affordance of the system dynamics model, or the way in which the assessment is asked, needs to be examined.

Prior knowledge of the domain and system dynamics modeling was found to be important in *model-building* activities in high school students (Sins, Savelsbergh, & van Joolingen, 2005). Lowe (1993) states that when the display is an abstract scientific diagram (such as a system dynamics model) both domain general knowledge and domain specific knowledge are important in a learner’s construction of their mental representation. (Draper, 1993) suggests that system dynamics are an important communication tool. Doyle and Ford (1998) suggest that system dynamics models can be used to change or improve students’ mental models in order to ensure dynamic decisions are appropriate. System dynamics models allow students to test their assumptions about systems, and therefore help students to think critically about important issues (Potential, 1992). System dynamics modeling provides students with a dynamic framework in which to place detailed facts (Forrester, 1992).

This study aims to investigate the use of system dynamics as an instructional tool under different conditions. The next section outlines the literature that relates to the other instructional strategies to be tested.

2.3.2.3 Agent-based modelling

An agent-based model is the other representation that will be investigated in this study. In agent-based modelling the focus is on the interaction between the *agents*, and their *environment*. An *agent* is defined as an object that controls its own behavior, and could be individuals of a species, individuals at a particular stage in the life cycle (a cohort), or a group of individuals that can be considered identical (Ginot et al., 2002). An agent could therefore be a single plant, animal or molecule, or an entire species. Agent-based models may incorporate methods for the agents to learn, evolve or adapt to the system (such as neural networks or evolutionary algorithms) (Bonabeau, 2002a). In an agent-based model, feedback can lead agents to learn from behavior or experience (Schieritz, 2002). As discussed earlier, the rules that apply to the agents determine the behavior of the whole system, called *emergence*. By laying down the rules for the agents and the system, behavior may *emerge* that would otherwise not have been predicted (Bousquet & Le Page, 2004; Ginot et al., 2002; Parrott & Kok, 2001; Schieritz, 2002).

Agent-based models are particularly useful for modelling environmental management situations because they allow environmental models to be linked to the social systems, the interactions between different scales of decision-maker to be investigated, and the emergence of collective responses to changing environments and policies to be investigated (Hare & Deadman, 2003). Agent-based modelling has been developed from three different sources. These are individual-based modelling, which focuses on the interaction of discrete individuals that have unique characteristics; artificial life simulation, the simulation of lifelike behaviours at the macroscale through the modelling of simple interacting micro scale behaviours of components; and multi-agent systems which are composed of many autonomous, social, communicative, pro-active agents that interact with each other to solve group problems (Hare & Deadman, 2003). The benefits of agent-based modelling are: it captures emergent behaviour, it provides a natural description of a system, and it is flexible (Bonabeau, 2002b).

Agent-based models, and in particular individual-based models, are used to research vegetation in ecosystems (Boulain, Simioni, & Gignoux, 2007); to describe the interaction of animal behaviour and population dynamics in order to predict the effects of agricultural practice (Wang & Grimm, 2007); population dynamics of an olive fruit fly in order to better manage the pest species' (Gilioli & Pasquali, 2007); visitor use of a national park (Gimblett et al., 2000b; Roberts & Gimblett, 2000); population dynamics in terms of resource partitioning (Uchmanski, 2000); plants and their role in an ecosystem (Parrott & Kok, 2001); residential development (Brown, Page, Riolo, & Rand, 2004). Individual-based models are important for theory and management as they allow researchers to consider variability between individuals, local interactions, complete life cycles, and individual behaviour adapting to the changing internal and external environment (Grimm et al., 2006).

The costs involved in using an agent-based model include difficulty in analysis, understanding and communication because they are more complex, and difficulty in replication of the model by others (Grimm et al., 2006). The costs involved in multi-agent systems include the lack of systematic methodology for structure and the lack of widely available industrial-strength multi-agent systems toolkits, and trust of the agents to make decisions (Sycara, 1998). Multi-agent models have been used to determine the interaction between stakeholder decision making and an ecosystem (Monticino, Acevedo, Callicott, Cogdill, & Lindquist, 2007)

When used in education, agent-based models allow students to explore the relationship between the agents' rules of behaviour and the patterns that emerge (Stieff & Wilensky, 2003). Students are able to make predictions and test them by exploring model outcomes as they manipulate variables (Stieff & Wilensky, 2003). The use of agent-based models in education "narrows the gap" between school biology and research biology (Wilensky & Reisman, 2006). The main advantage of using agent-based models is that students are able to employ their knowledge of the behaviour of individuals in the construction of theories about the behaviour of populations (Wilensky & Reisman, 2006). Agent-based models are able to be quite realistic. Using a realistic computer simulation can be motivating for students because they are entertaining and evocative (Goldstone & Son, 2005).

NetLogo is the software used in this study for the agent-based model. NetLogo is a multiagent modelling language (Stieff & Wilensky, 2003). It has its own programming language, embedded in an integrated, interactive modelling environment (Tisue & Wilensky, 2004b). NetLogo is written in

Java (Tisue & Wilensky, 2004b), and is a hybrid compiler/interpreter. It also enables users to open simulations and experiment, exploring the effects of their decisions (Tisue & Wilensky, 2004a) and was designed for use in both research and education. NetLogo has been used for education in chemistry (Levy, Kim, & Wilensky, 2004; Stieff & Wilensky, 2002, 2003), biology (Wilensky & Reisman, 2006), mathematics (Abrahamson & Wilensky, 2005), physics (Sengupta & Wilensky, 1999; Wilensky, 2003) and materials science at the undergraduate level (Bilkstein & Wilensky, 2005).

The use of agent-based models for chemistry allowed students to link multiple representations and levels in order to gain a deeper understanding of concepts and encouraged conceptual understanding rather than the memorisation of facts (Stieff & Wilensky, 2003). In a separate study, it was found that the use of NetLogo in chemistry resulted in all students understanding macroscopic concepts, a large increase in the number of students who were able to correctly describe both macroscopic and microscopic behaviour of the system, and most of the students could apply this understanding to a different context (Levy et al., 2004). However, students were not able to relate the microscopic to the macroscopic level (Levy et al., 2004). In biology, students who built models using NetLogo were able to reason about the mechanisms that underlie predator prey systems and predict future behaviour (Wilensky & Reisman, 2006). In physics, agent-based modelling helps students to make the connection between abstract and concrete concepts (Sengupta & Wilensky, 1999). In this case students were able to connect the fields of electrostatics and electricity, and to see current emerging from a moving charge, and the direction in which it was moving. Use of an agent-based model for undergraduate level students in material sciences allowed the observation of processes that were fundamental to their understanding of the concept and allowed student to make links between topics that were usually separate (Bilkstein & Wilensky, 2005).

There has been a less structured approach to the development of the field of individual and agent-based modelling than that of system dynamics modelling (Railsback, 2001). While models that have used individuals have been used in ecology since the 1970s, the use of individual-based modelling specifically only began from 1988 (Grimm, 1999). The two main advantages for ecologists using individual-based models are that they are able to represent individuals as discrete units, and the type of theory that has been generated from top-down approaches has issues (Grimm, 1999). For scientists examining natural resource management, the interaction between environmental dynamics and social dynamics needs to be examined (Bousquet & Le Page, 2004). System dynamics modelling focuses ecological theories on the system having to be in equilibrium (Bousquet & Le Page, 2004). A multi-agent system is composed of: an environment that is usually a space; a set of objects; an assembly of agents, which are specific objects, and represent the active entities in the system; an assembly of relations that link objects to one another; an assembly of operations that allow agents to manipulate objects; and operators with the task of representing the application of these operations, and the reaction of the world to this attempt at modification, that is, the laws of the universe (Bousquet & Le Page, 2004). The main issue is formalising the necessary coordination among agents and questions are related to decision making, control, and communication (Bousquet & Le Page, 2004). There is not a difference between the process of modelling itself if the two styles of modelling are compared, only in the assumptions and the tool used (Grimm, 1999).

System dynamics modelling is well suited to studying systems containing a complex web of feedback loops, and agent-based modelling is well suited to incorporating spatial and probabilistic aspects of the system (Wakeland, Macovsky, Gallaher, & Aktipis, 2004). When these authors compared the two types of models in terms of educational potential, they found that the system dynamics model was useful for conceptual understanding, whereas the agent-based model was useful because of the representation of the processes. The behaviour of individual agents is not important in system dynamics models since the dynamics of the underlying structure are dominant (Scholl, 2001). Both types of model aim to identify leverage points in complex aggregate systems, however in agent-based models these are identified in rules and agents, whereas in system dynamics models in the feedback structure of the system (Scholl, 2001). Agent-based models establish a link between the micro and macro level of the model, system dynamics models establish a link between the system structure and the system behaviour (Schieritz & Milling, 2003). These authors suggest that an integrated approach may have the advantage of helping decision makers to be able to think of the two levels that are modelled at the same time.

Students are likely to experience high cognitive load associated with either modelling style. This is thought to be related to the extent to which the elements interact with each other (Sweller & Chandler, 1994). By definition, a complex system has a number of interacting elements. In addition, at least in the case of the system dynamics model, the representation itself involves an abstract syntax. Students who are given this type of model have to learn not only the content, but also how to interpret the representation. This means that a large number of elements have to be learned simultaneously in order to be understood (Sweller & Chandler, 1994). If students had experience either with the representation, or with the domain, it would expected that their cognitive load would be smaller because some of the elements that had to be interpreted, would already be linked in their mental model (Sweller & Chandler, 1994). The agent-based model, on the other hand, allows students to understand how the interacting elements can be combined more easily. If the two representations were combined, then students will be able to understand the elements individually and in combination.

Until recently, few studies have used a combination of the two models (Schieritz & Grossler, 2003), however recently this has become more common (see for example (Martinez-Moyano, Sallah, Bragen, & Thimmapuram, 2007; Osgood, 2007; Wilensky, 2007). And a number of papers have been written that directly compare how to use the different types of model to model the same system (Borshchev & Filippov, 2004).

2.3.2.4 Learning from an animated or a static model

The agent-based model used in this study uses an animation to represent the agent-level process. Animated representations are a type of dynamic representation. Ainsworth and VanLabeke (2004) identified different types of dynamic representations. The first is time-persistent (T-P) and is similar to that seen in the output produced by both the models; the data is displayed incrementally in the form of a graph or table. 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). A T-S representation is used in the agent-based model in this study. 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). 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 (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). An example of such a case is a demonstration of germination of a plant, this occurs at a scale that learners would not normally see, and if it was related to the physical changes in the plant over a period of time, may enhance understanding of the process. 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 (see for example (Anglin et al., 2003; Byrne, Catrambone, & Stasko, 1999; Lewalter, 2003; Lowe, 2003, 2004; Rieber, 1990). 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) concluded 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 for the 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).

Factors associated with the successful use of animations are that the animation should be slow and clear so that learners can perceive any movement or changes, and the timing corresponding to the movement and changes (Tversky, Bauer Morrison, & Betrancourt, 2002); prior knowledge of the subjects (Byrne et al., 1999); and aim to reduce the cognitive load the learner is under, enabling students to store the correct model and argue about other concepts related to it (Rohr & Reimann, 1998). When learning from a model about a simple system (how an electric motor works), it has been advised that an animation should be combined with spoken rather than printed text, and that students should control the pace of the learning materials (Mayer, Dow, & Mayer, 2003). However, in this activity, there was less structure, and so it was thought to be more important that students have the freedom to interrogate the text information as often as they liked, and in the same manner as those in the Text group.

2.3.2.5 Use of the models

As mentioned earlier, the mental model that is constructed by learners will be influenced by the format in which the information is presented (Rohr & Reimann, 1998; Zhang, 1997). It is obvious that there will be a trade-off between the advantages of the representations (Lohner & van Joolingen, 2002). In addition, simulation models are thought to be important educational devices because they allow students to interact and make decisions that they would not otherwise be able to do in real life. Buckley *et al.* (2004) also suggests that use of the models, such as deciding which perceptual cues to attend to, deciding how to interact with the representation and monitoring and evaluating the results of those interactions, are important metacognitive processes that play an important part in model-based learning. If this is the case, learning outcomes would also depend on the ways in which students interrogate the simulations, as well as the representational affordances of the models themselves, although there are very few studies that investigate the use of the models when they compare learning outcomes (Kennedy & Judd, 1007, 2007; Levy et al., 2004; Moxnes, 1998).

Levy, Kim & Wilensky (2004) compared the use of an agent-based model for a high and low scaffolded learning environment. They found that students who were given less guidance spent less time exploring the model, but had similar levels of activity (Levy et al., 2004). In addition, it was noted that students performed more runs than variable changes: they were testing each set of variables more than once (Levy et al., 2004). They concluded that increasing the freedom in exploring models does not detract from the experimental spirit they expressed in the activity, however the scaffolding does increase the time in observing the model as it changes, which is crucial to finding patterns and understanding complex phenomena (Levy et al., 2004).

Levy & Wilensky (Levy & Wilensky, 2005) investigated the patterns in how students used an agent-based model to learn about Chemistry. Each action taken in the model was recorded, and the average time between actions was used to measure deliberation. The four main statistics measured were successive settings in running the model, observation time, the average time between actions, and the number of runs. Students were engaged in a relatively ‘open’ activity (only able to change one setting, but to whatever value they chose), and Levy & Wilensky were able to identify three distinct exploration patterns. The first strategy was straight to the point, which had a shorter overall observation time, but longer observation time per run; longer time between actions; and fewer runs. Levy & Wilensky identified this as an efficient mode to use the model, which may allow students to develop a deeper understanding of each state of the model. However, using a straight to the point strategy may mean that learners miss critical settings or transitions which would have been discovered by a wider range of values chosen. These critical settings are an important part of understanding a system from using a model (Lowe, 1993). The second strategy was called homing in. Students who used this strategy exhibited a shorter overall observation time, and shorter observation time per run; shorter time between actions; and more runs. These students were identified by the authors as “click happy”. The third strategy identified was called oscillating, which consisted of a longer overall observation time, but shorter observation time per run; shorter time between actions; and an intermediate number of runs. Both the homing in and oscillating strategies involved speedy model changes and short observations, which implies that students were not able to detect and generalise complex relationships between variables. However, the many states of the model means that students examined many aspects of the model’s behaviour and students were more likely to detect a critical setting. Of the two, the homing in strategy is more planned, whereas students would struggle to keep the previous state in mind for comparison when using the oscillating strategy. Similar patterns were found when students engaged in a more complicated activity where they were able to explore the model along a number of settings and a wide range of values. The authors concluded that students explored the models in a characteristic way independent of tasks or goals. There was one pattern that was noticed with respect to the goal of the learner. When there was a particular goal state for the model, students tended to gravitate towards that state; and when the range of values was informative, students used a wider range of values. It was also found that the tools made a difference when sliders and free commands were compared (Levy & Wilensky, 2005). Students who used the textual commands tended to display the oscillating strategy across a wider range of values, and in a nonlinear order, than those offered via the slider.

Strategies for interrogating models have been discussed, in some respect, in the system dynamics modelling literature. Moxnes (1998) discuses the combination of mental models and analysis. In terms of the analysis, he discusses a trial-and-error heuristic, a consistent analysis, and a gradient search, which can be loosely mapped to the oscillating, straight to the point, and homing in strategies noted by Levy and Wilensky. He suggests that the rationale behind the gradient search is that students do not have a clear idea of the importance of the particular stock in the model, and they can see no other strategy than ongoing reductions (Moxnes, 1998). None of the students had prior domain knowledge. However, there was no further investigation into the links between the strategies and the decision-making and mental model development. Moxnes (1998) also investigated the use of explanatory features such as additional information that scaffolded students in how to model the system. Students were able to utilise the extra information given about growth, but not about the stock.

Two other issues with regards to the use of the models are the user’s model preference (for the group given both models), and the role of prior knowledge in the use of models. There is little work on learners’ representational preferences. (Van Labeke & Ainsworth, 2002)’s study examined the preference for the number of representations interrogated by students (3-4) and which of those had the most requests for translation (indicated that students may start at the complicated/unknown representation and relate it back to the familiar rather than vice versa). The only study to specifically investigate the role of prior knowledge in the use of the model was the Levy & Wilensky (Levy & Wilensky, 2005) study discussed in some detail above. They suggested that prior knowledge about the domain may shorten the exploration time, resulting in a student focusing on a few key settings, such as the straight to the point strategy.

2.3.3 Collaborative Learning

Cooperative learning is an important aspect to be addressed in this study. While the use of computers is becoming more common in the classroom, environmental education generally does not cater to one computer per student, and so this style of learning should be taken into account. Other authors also suggest that it seems inadequate not to address this factor (Metz, 1998). Even fifteen years ago it was being argued that group work with computers was beneficial for learning, at even the most basic levels of data entry, as well as for problem solving exercises (Underwood & Underwood, 1990).

Cooperative learning can be contrasted to collaborative learning because “cooperation only requires that learners work together, each learner completing a part of the task, rather than negotiating with others about all aspects of the task, as is necessary in collaboration” (Beatty & Nunan, 2004, p. 166). A cooperative learning environment requires students to coordinate their efforts to complete a task (Slavin, 1983). Often, a group of students working together at a single computer encourages collaboration because not everyone can have control of their tasks (Beatty & Nunan, 2004). However, Milrad (2002) found that most of the learning seemed to occur in the discussion and not in the interactions with the simulation models.

Baker *et al*. (2001) found that, in general, students are reluctant to express disagreement when they are in groups. They suggest that when designing computer supported collaborative learning (CSCL) environments to support interaction about science, the structure should include a debatable task; cognitive preparation for debate; multiple representations of solutions; compatible partners; and a strong understanding of the topic (Baker, de Vries, Lund, & Quignard, 2001). The role of the teacher is also important. Teachers should combine the role of information giver with debate moderator for the most effective role in terms of their own development and learning outcomes of the students.

Learner perceptions play an important role in successful collaborative learning situations (Beatty & Nunan, 2004). Learners with awareness of their own ability to actively participate in a task are better able to engage in collaborative tasks. Collaborative learning requires a plan for the work process, critical thinking, and scaffolded learning. Learners need to engage in these steps to effectively use the collaborative learning environment. Determining priorities, therefore, is also an important part of the collaborative learning process. The learner’s perception of the technology is also an important component of the collaborative learning process, as learners must be scaffolded within their learning environments (Beatty & Nunan, 2004).

Cooperative learning can be an effective learning environment, although some differences have been found in the way that male and female students work in groups (Edwards, Coddington, & Caterina, 1997). Studies have found that students in cooperative learning groups out-performed individual learners in a biology subject (Singhanayok & Hooper, 1998). Cooperative learning encourages interaction with the tool (Singhanayok & Hooper, 1998); supports a range of learning styles (Wang, Hinn, & Kanfer, 2001); and allows group members to explain concepts to each other (Kramarski, 2004), which is a metacognitive strategy. Suthers and Hundhausen (2003) showed that a shared graphical representation made central characteristics of the learning object salient, which provided representational guidance to the learning discourse. A collaborative learning environment in science also provides students with an authentic learning experience because scientists work in a social work environment (Kozma, 2003). In a review of 26 studies covering almost all grades, and subjects that included social studies, science, and physical science, (Johnson & Johnson, 1985) found that 21 studies showed that cooperative learning promoted higher achievement, 2 studies had mixed results, and 3 had no differences between treatments.

While collaborative learning has been recommended in both environmental education and model-based learning, it has been specifically investigated in very few cases (Jacobson & Wilensky, 2006). Collaborative discussion-based inquiry was found to be an important process to include when using an agent-based model in a classroom situation as it allowed students to share unanticipated findings and re-interpret and reconcile these findings (Abrahamson & Wilensky, 2005). Kozma (2003) reported on a study in which a pair of students using multiple, linked representations were engaged in extended discourse to construct shared meaning out of surface features. They both achieved a scientific understanding of the domain, and replicated the discourse practice of scientists (Kozma, 2003). It is also recommended for use, along with other strategies, in Chemistry learning environments (Kozma, 2003).

Most of the current research agrees that students need to be scaffolded in their collaborative activities (Gilllies, 2003; Maloney & Simon, 2006; Manlove, Lazonder, & de Jong, 2005). In this study, collaborative learning was not scaffolded, nor was there a group goal. However, in the case of group projects without a correct answer, or solving complex problems, it may be that hearing others' thinking processes is beneficial, even if teaching does not take place (Slavin, 1996).

The collaborative learning environment in this study consisted of students in dyads sharing the learning materials. No scaffolding was used, and students had to collaborate in order to complete the task. Assessment was completed by individuals, not in groups. Interaction data was not collected and instead learning outcomes and use of the model will be compared between the two learning environments. Interaction data was not collected as part of this thesis. The purpose of this section of the thesis is to make a preliminary comparison of differences in learning outcomes and measures of use between students working alone and in dyads. This will provide directions for future research in the field of collaborative learning with system dynamics and agent-based models.

A number of authors have investigated collaboration in science education (see for example (Jeong & Chi, 2007; Oliveira & Sadler, 2007; Roschelle, 1992; Suthers & Hundhausen, 2003)). These authors identify *convergence* as the main advantage of a collaborative learning environment. Convergence occurs when students engage in collaborative inquiry learning and mutually construct understanding of the phenomenon (Roschelle, 1992). Jeong and Chi (Jeong & Chi, 2007) analysed conversations and determined that the convergence in their study could be attributed to collaborative interaction. They also found that a modest amount of convergence is typical in an unstructured, naturalistic collaborative learning situation. That suggests that in this study, which is unstructured, but in which students were randomly allocated to dyads, less convergence is expected. These authors say that convergence is due to interaction and shared input, in other words the materials.

Collaborative model-building has been examined with respect to the influence of the representation on the modelling process (van Joolingen & Lohner, 2001), and the decision-making processes involved in online collaborative model-building (Reimann, Thompson, & Weinel, 2007), however in both cases, university-aged students were used. The study by van Joolingen and Lohner suggested that the representation does influence the model-building process, however the results were preliminary.

2.4SUMMARY

The study addresses Rickinson's recommendation for deeper empirical investigation into "the *processes, experiences* and *contexts* of young people's *environmental learning*, including what kinds of conditions are helpful for which kinds of students undertaking which types of learning" (2001, p. 307). In this study, Rickinson's 'conditions' take the form of strategies commonly used to understand complex systems: multiple external representations, learning from models, and a collaborative learning environment. Learning outcomes will be compared between groups in an experimental design in order to compare the effects of these strategies. Exploratory data analysis will add information to start to answer the question of *why* particular strategies are more successful than others. The following chapter will outline the methods used in this study, including the model development, instrument development, sample, procedures and analysis. Chapter 4 will address the research question:

1. What differences in understanding of a socio-environmental system can be identified in school students after they are presented with text (see Appendix 1), a system dynamics model, an agent-based model, or a combination thereof?

Chapter 5 will address the research questions:

2. Does the representation affect how the model is used?

3. Does the way that the model is used affect what students learn from the models?

4. Does prior knowledge affect how students use models?

The following research questions will be reported on in Chapter 6:

5. Does working in dyads affect school students' understanding of a socio-environmental system?

6. Does working in dyads affect the ways in which students use models?

The conclusions will be outlined in Chapter 7.

3. METHODS

3.1 MODELLING THE SYSTEM

The system of visitor impact in a national park was chosen because of the reasons outlined in Chapter 2, namely that it is a complex system, important in terms of managing the Australian environment, and one in which human management can have an effect. The system dynamics model was built first. This allowed the structure of the system to be determined. The model went through a number of iterations. The first decision was how much to model. Data about visitor usage of the national park was available for three months (35 days), in all areas of the park (a number of picnic grounds, walking tracks and the visitor centre), and for visitors undertaking all activity types (picnicking, bushwalking, driving, cultural heritage etc) (Davison, 2000). To include all this information into the model would result in a model that was too complicated for students in Year 9 and Year 10. Of the activities, visiting the park for a picnic was thought to be a common activity that most students could relate to. In addition, the issues concerning the impact of waste management on the national park could be modelled. Because of this, of the available data, only those visitors who visited the park in order to have a picnic were included. Using knowledge gained from my honours thesis (Davison, 2000) regarding the relationship between visitors' location in the park and their activity type, only those visitors who visited three specific locations and who had selected picnic as their only activity were included.

The next stage of modelling was to develop a narrative on which the model would be based. Visitors would enter and leave the park for the purpose of having a picnic. Their impact on the park would concern the waste they left in the bins. The garbage collection person would collect a proportion of this waste, the rest of which would be left in the bin. In addition, some of the waste would be deposited in the bin after the garbage collection person had already come. This waste included organic and inorganic matter. The inorganic waste would accumulate, but the organic waste would attract introduced animal species as a food source and, if not eaten, would decompose and add nutrients to the environment. The effects of increased nutrients in the environment would be to make the environment more suited to introduced plant species, which would then out-compete the native species of vegetation. This same structure would be repeated at the three picnic areas, each with their own pattern of visitor use over 35 days.

The model was constructed in Stella™. It was examined, and decided that this was too much information to give to Year 10 school students. The model was cut back to one picnic area, without the flow on effect from the introduction of nutrients to the environment, and the timeframe was reduced to ten days in the park. The days were selected based on the highest number of visitors (for the equations associated with this model, see Appendix 2).

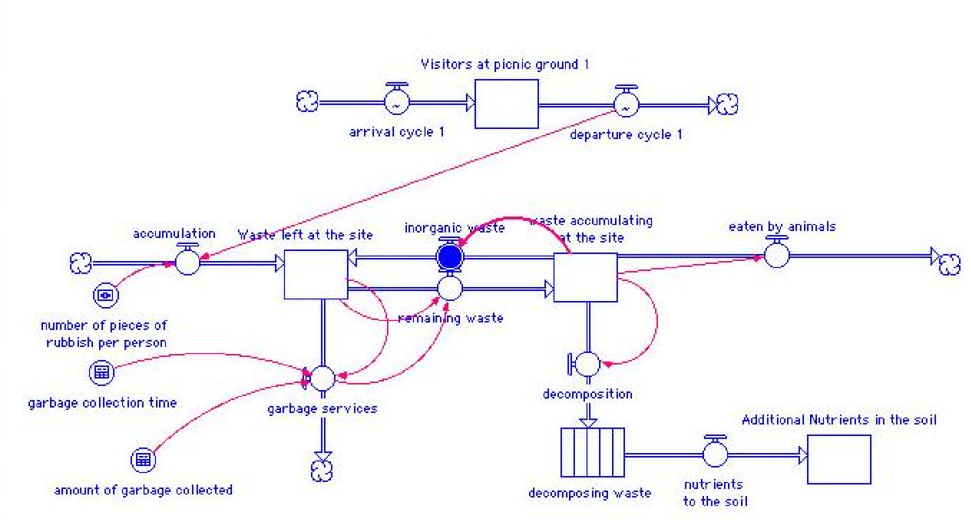
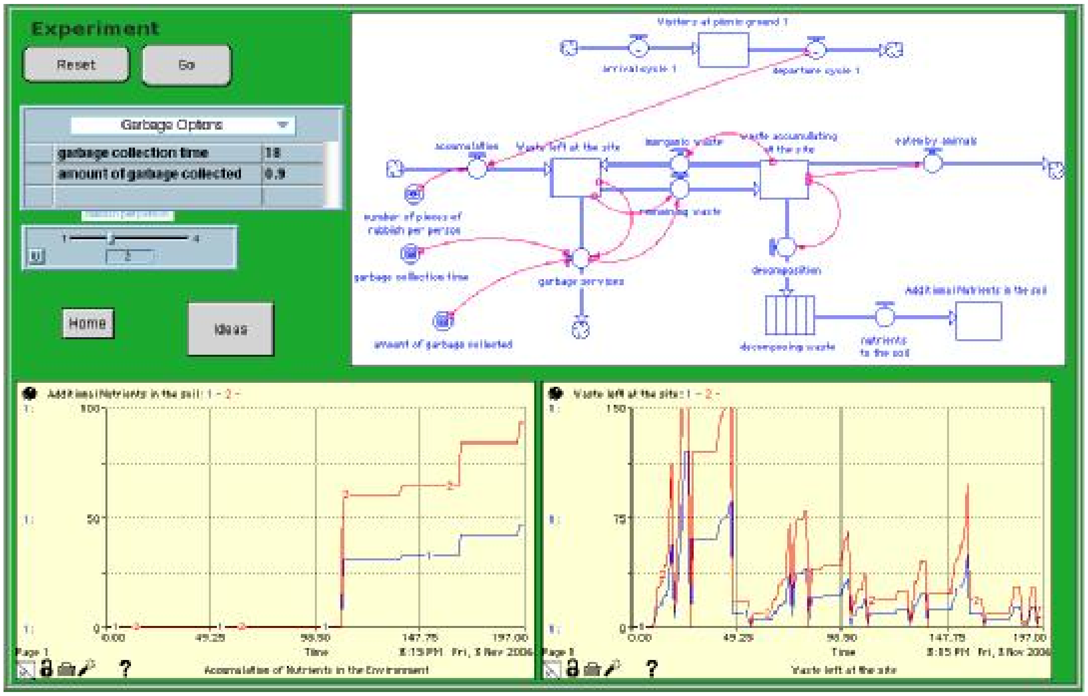


Figure 3-1: System dynamics model of visitor impact on a national park

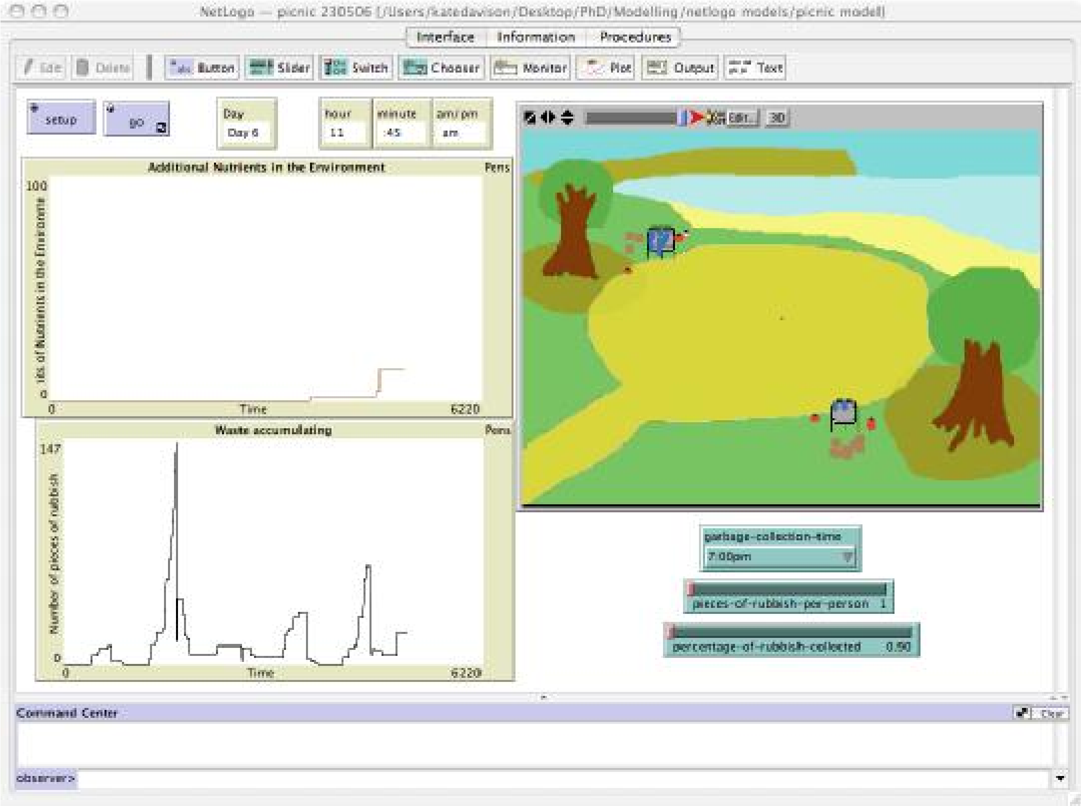
The user interface was also designed, and a number of screens were added to the Stella™ model. These included a *home* screen, which was an introduction to the model and contained directions with regards to the other screens. The second screen was the *information* screen, containing the text information describing the system (Appendix 1). The third screen was the *explore* screen, which allowed students to explore the model "step-by-step" using Stella's™ storytelling feature (isee Systems, 2007), or in full which provided students with the entire model as seen in Figure 3-1. The final screen was the *experiment* screen, in which students could interact with the model (Figure 3-2). The *experiment* screen contained a slider and two items in a table allowing students to input values for variables. The variables were the number of pieces of rubbish, the time that the person came to collect the garbage, and the proportion of rubbish that was collected. Changing the number of pieces of rubbish allowed students to examine the extremes of what could happen in the system. The other two variables were decisions that a park manager could make. Students were not able to manipulate the number of people who arrived or their arrival or departure cycles, because these are not variables that a park manager could control. There was a (pulse) withdrawal of garbage each day by the garbage services function, depending on the garbage collection time and the proportion of garbage collection. Fifty percent of the waste left at the site was organic, and the other fifty percent was inorganic. Inorganic waste adds to the waste left at the site stock, while organic waste can either be eaten by introduced animal species' or decompose (with a time delay), adding nutrients to the environment. Students were also able to see the stock and flow diagram, and two graphs. These graphs showed the amount of nutrients added to the environment and the total waste accumulated. By observing these two graphs, students could see how the accumulated waste was increasing and decreasing as a result of their interaction and could see the time delay involved in the corresponding change to nutrients in the environment. Students selected 'go' to run the model, and 'reset' which set the values back to their original values. On the system dynamics model there was also an 'ideas' option, which repeated information given at the end of the text description, reminding students of the available values to which the variables could be changed.



garbage collection time	18
amount of garbage collected	0.9

Figure 3-2: System dynamics model *Experiment* screen

The next stage with regards to model-building activities was to build the agent-based model; this was done using NetLogo™. While the structure and narrative had been decided on using the system dynamics model, the decisions made in the agent-based model revolved around how exactly to represent these processes visually. What would the picnic ground look like? How could the process of decomposition be represented in an animation? It was decided that the graphics did not have to look too realistic. A number of authors (see for example (Lowe, 2004)) have found that animations can be *underwhelming* if they simply run with no obvious need for students to interpret what they see).



Day: Day 6
hour: 11
minute: :45
am/pm: am
garbage-collection-time: 7:00pm
pieces-of-rubbish-per-person: 1
percentage-of-rubbish-collected: 0.90

Figure 3-3: Agent-based model *Experiment* screen

In NetLogo, the screen on which students can interact with the model is called the *Interface* screen. For the purposes of comparison with the system dynamics model, this screen will be referred to as the *Experiment* screen for the remainder of the thesis. The combination of features seen in Figure 3-4 is typical for a NetLogo model with a graphics window, plotting window and sliders and buttons that students can manipulate (Stieff & Wilensky, 2003). One advantage of the agent-based model is that it allows students to make links between the agents' behaviour (graphics window) and the macro-level (plotting window) of the system occurs in the *experiment* screen.

In terms of using this software in order to build the model, the rules for the basic elements are written (see Appendix 3). The individual elements are referred to as "turtles" (Wilensky & Reisman, 2006). Turtles move around a two dimension grid, each cell of which is referred to as a "patch" (Wilensky & Reisman, 2006). Patches can also execute instructions and interact with turtles and other patches (Wilensky & Reisman, 2006). Turtles can be used to represent agents on a number of different levels, in this case the visitors, waste products, introduced animal species, and additional nutrients were all turtles. Patches represent the medium in which they interact (Wilensky & Reisman, 2006), in this case the national park picnic ground. As the agent-based model was developed, and it was determined what could be represented using this method, the system dynamics model was modified slightly, so that the two models were aligned.

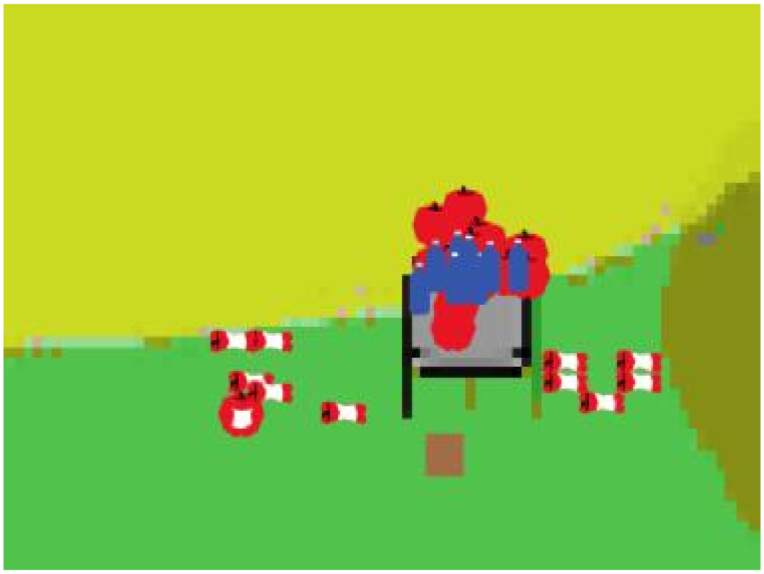


Figure 3-4: Waste represented in the agent-based model

The organic waste was represented by an apple. For the process of decomposition, the apple then went through a number of stages: deflated, an apple core, an apple core on its side, and then when the process was complete, a brown square was used to represent additional nutrients. Students were given a key to interpret this information. It was decided that for the purpose of the model, the process of decomposition would take three days; this allowed a time delay (an important concept). This was represented in the usual way in the system dynamics model (see Figure 3-1). This is a much shorter timeframe than reality, however if the real times had been used, the model would have to run for too long before the students ‘saw’ anything in the agent-based model.

The models were tested for usability and speed in the first pilot study (discussed below). The other modification that was made to the models following the pilot study was a further reduction in the time represented in the model (to allow for more experimentation to occur). This reduced the simulated time from ten days to seven days. Further details were also added to the two graphs, including labels on the x-axis of both graphs indicating the day (rather than the number of minutes).

3.2 DEVELOPMENT OF THE INSTRUMENTS

The five instruments that were developed for this study are: the background questionnaire; the environmental knowledge test; the system dynamics knowledge test; the final assessment task; and the evaluation.

3.2.1 Background questionnaire

The background questionnaire contained a number of questions including general information, experience with computers, attitudes toward science, and attitudes toward the environment. The questionnaire can be found in Appendix 4.

3.2.2 Environmental knowledge test

Both the environmental knowledge and system dynamics knowledge tests were given to students in a pre-test / post-test design. Students received their pre-test answers and space was provided for students to either change their original answer or to write 'as above'. This design was decided upon given the time and effort involved in the knowledge tests. There was only a short amount of time between the pre- and post-tests, and students were given three assessments to complete after the activity. In order to reduce students' boredom, and to save them from composing the lengthy answers that may have been the same as their pre-test answers, it was decided that students would be given the option of having access to their original answers and either altering these answers or not. As the assessment was not testing recall of facts, it was not thought that there would be negative repercussions for the learning outcome analyses. On examination of the answers that students provided, students did change their answers in the post-test answers. The other potential risk was that students would not provide answers to the questions in the post-test, this did not occur.

The environmental knowledge test was worth 32 marks, and contained seven questions, four of which were analysed in the overall environmental knowledge score, and three of which were analysed individually for this thesis. Negative marking was not used. The entire knowledge test can be found in Appendix 5, including the first three questions. The questions included in the overall score were:

4. Choose one effect of the loss of vegetation on soil (1 mark), water run-off (1 mark), and the whole ecosystem (1 mark). (*Total 3 marks*).

5. Have a think about introduced species of animals (such as cats, rats or mice)

    a. Please circle any of the following activities that you think would cause an increase in the number of introduced species of animals: **bushwalking, fishing, having a picnic**, going for a drive, **horseriding**, **walking a dog**, **littering**, **collecting fire wood, collecting shells**. (8 marks)

    b. Name one effect of introduced animals on the environment (1 mark). (*Total 9 marks*)

6. Now think about introduced species of vegetation

    a. Please circle any of the following activities that you think would cause an increase in the number of introduced species of vegetation: **bushwalking,** fishing**, having a picnic, going for a drive, horseriding, walking a dog, littering, collecting fire wood,** collecting shells. (7 marks)

    b. Name one effect of the introduction of non-native vegetation on native vegetation (1 mark). (*Total 8 marks*)

7. Now imagine you are in an ecosystem that is not a national park, for example a beach, a mangrove swamp, or a local creek. Please complete the following table. For each activity listed identify one effect on the ecosystem, choose one possible further effect and indicate how long these effects would take to occur.

    a. Building a road. What is the initial impact on an ecosystem (1 mark)? What is the timescale (tick one): same day, 1 week, 1 year, more than 1 year (1 mark)? What are the further effects on the ecosystem (1 mark)? What is the timescale (tick one): same day, 1 week, 1 year, more than 1 year (1 mark)?

    b. Littering. What is the initial impact on an ecosystem (1 mark)? What is the timescale (tick one): same day, 1 week, 1 year, more than 1 year (1 mark)? What are the further effects on the ecosystem (1 mark)? What is the timescale (tick one): same day, 1 week, 1 year, more than 1 year (1 mark)?

    c. Bushwalking. What is the initial impact on an ecosystem (1 mark)? What is the timescale (tick one): same day, 1 week, 1 year, more than 1 year (1 mark)? What are the further effects on the ecosystem (1 mark)? What is the timescale (tick one): same day, 1 week, 1 year, more than 1 year (1 mark)? (*Total 12 marks*)

Questions 5 and 6 are directly related to the learning materials. The purpose of asking students these questions is to determine whether they learned the main message in the materials. Questions 4 and 7 required students to apply the knowledge that was available in the learning materials to other ecosystems. Question 4 was not analysed separately as students had high pre-test scores, and as it was only worth 3 marks, there was little change in the scores.

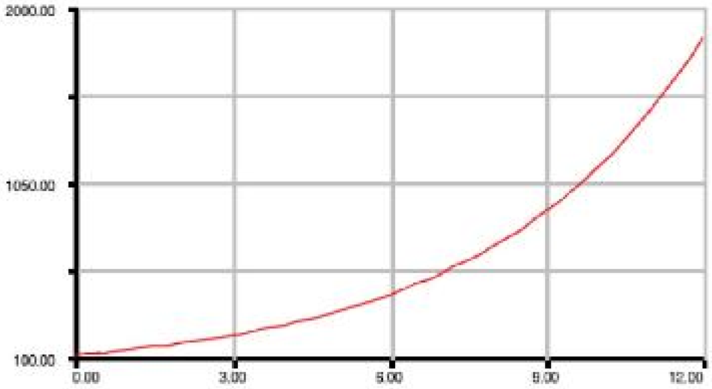
3.2.3 System dynamics knowledge test

The system dynamics knowledge test was worth 12 marks, and contained eight questions, all of which are analysed for this thesis (see Appendix 5). The questions included in the overall system dynamics knowledge score were:

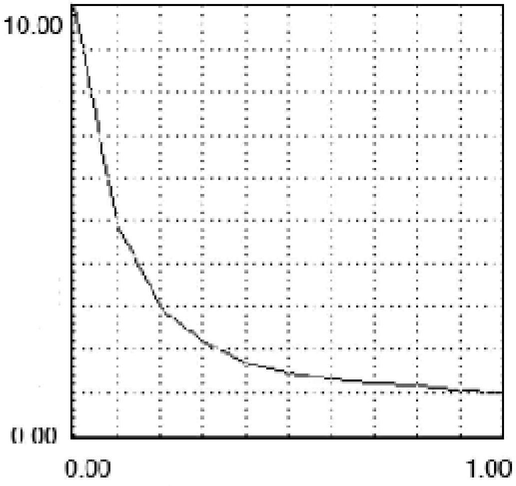
8. Please choose the definition of *time delay* that best fits your understanding of the term with respect to system dynamics: a) when the cause and effect are separated by time (1 mark), b) when you are running late for an appointment, c) when something scheduled is late, d) when something is postponed, e) I do not know.
9. Identify one environmental impact that involves a *time delay* from any that you have discussed so far (1 mark) and indicate the approximate length of time involved (short term or long term) (1 mark). (total 2 marks)
10. Which of the following describes the term *reinforcing feedback* as it relates to system dynamics? a) the two variables change in the same direction (1 mark), b) the two variables change in opposite directions, c) positive information that a teacher gives you about your work, d) a loop that exists between an audio input and an audio output, e) I do not know.
11. Which of the following is an example of *reinforcing feedback* as it relates to system dynamics? a) interest added to a bank account (1 mark), b) lake shrinking due to evaporation, c) "your assignment was good, though your spelling needs some work", d) when a microphone is placed in the general direction of the output speakers resulting in a high-pitched squealing, e) I do not know
12. Which of the following describes the term *balancing feedback* as it relates to system dynamics? a) the two variables change in opposite directions (1 mark), b) the two variables change in the same direction, c) negative information that a teacher gives you about your work, d) a loop that exists between an audio input and an audio output, e) I do not know.

13. Which of the following is an example of *balancing feedback* as it relates to system dynamics? a) lake shrinking due to evaporation (1 mark), b) interest in a bank account, c) “your assignment was terrible, you didn’t try at all”, d) when a microphone is placed in the general direction of the output speakers resulting in a high-pitched squealing , e) I do not know.

14. How would you describe the behaviour of the variables of the two graphs below:



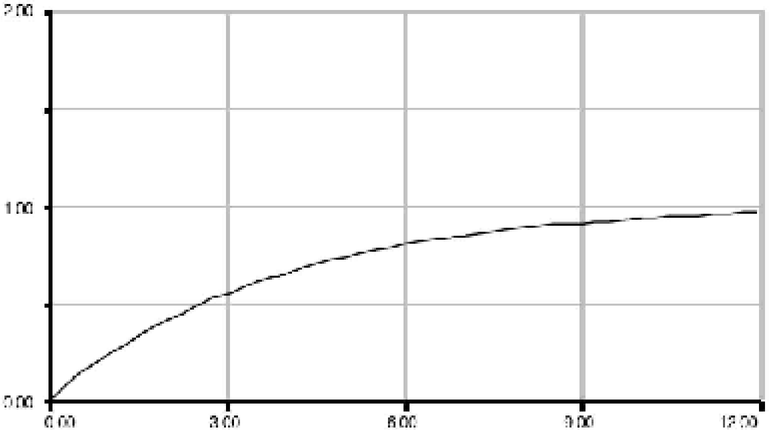
(i)



(ii)

a) (i) exponential growth and (ii) exponential decay (1 mark), b) (i) exponential decay and (ii) exponential growth, c) (i) equilibrium and (ii) exponential decay, d) (i) oscillation and (ii) equilibrium, e) I do not know

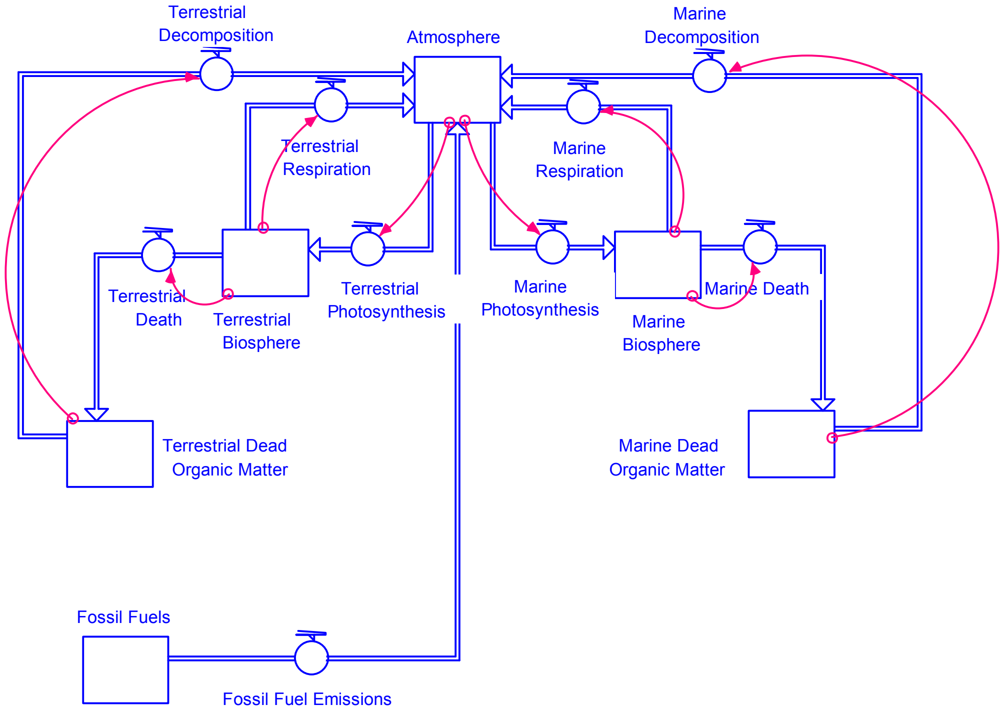
15. How would you describe the system represented by the graph below?



a) equilibrium (1 mark), b) exponential growth, c) exponential decay, d) oscillation, e) I do not know.

(*Total Questions 8-15 12 marks)*

16. Case study



What environmental issue is this model describing? (1 mark)

What element of the system is not in balance? (1 mark)

What are the potential issues if the system is not balanced? (1 mark). (*Total 3 marks).*

The purpose of Questions 8-15 was to assess general system dynamics concept knowledge. These concepts are important in the field of system dynamics, and prior knowledge may influence interpretation of a system dynamics model. In addition, assessment of these concepts after the treatment would also be useful to determine whether simple exposure would help to improve knowledge of these areas.

The purpose of Question 16 was to assess whether students could identify a system from a static diagram of a stock and flow diagram. The system is one that should be familiar to students, the carbon cycle, and addresses an important scientific issue: that of climate change. Once again, determining whether students already had this skill before the treatment will help to determine real results.

3.2.4 Final Assessment Task

The final assessment task focuses on *understanding* of an environmental system. Originally it consisted of one open ended question asking students to explain the environmental system to someone who had never seen it. The second page was blank, asking students to draw a visual representation of the environmental system. This was originally going to be a concept map. The form of questioning was altered after the pilot study to provide more structure for the students in terms of their interrogation of the model, and ability to answer the questions.

The final assessment contained five questions that allow students to assume the role of a national park manager (see Appendix 6). The questions are:

1. What variables did you alter? What happened to the system when you altered the variables? (You can include graphs or diagrams)

2. What are the management issues that are involved in looking after this area of the National Park?

3. What decisions would you make if you were the manager of this park?

4. If this description (the model/s and the text) of the National Park was more detailed, what do you think would happen next? What are the possible problems that could occur for the environment?

5. Imagine **you are** the manager of this National Park, and you have to write a report for your boss who has never been to the park before. Describe the park, what happens in the park, what the main issues are, and the consequences of the different management options.

These questions were grouped into sections. The first section was called the *Use of the Model.* This section included all of Question 1. The section *Describe* included the answers to two parts of Question 5: describe the park and what happens in the park. The *Issues* section included answers to Question 2 and a part of Question 5: what the main issues are. The *Higher Level Thinking* section included Question 3, Question 4, and the final part of Question 5: what are the consequences of the management options? The purpose of these questions was to assess understanding of the system itself, rather than more general environmental knowledge.

3.2.5 Evaluation

The evaluation is an evaluation of the experience. This consists of ten statements with a likert scale regarding general features of the experience, for example, whether the students could visualise the real situation, whether they liked being in the national park or not, etc. Following this are 4 open ended questions focusing on what students liked the best, the least, what they would change if they could, and any other comments. The results of these questions are not presented in this thesis (see Appendix 7).

3.3 USE OF THE MODEL

The use of three screens were analysed in the system dynamics model: the *information* screen, the *explore the model* screen, and the *experiment* screen. The agent-based model had two screens that were analysed, the *information* screen and the *experiment* screen. The proportion of time spent *off task* was also calculated for each model. The activities that were analysed were the frequency of changes made to each variable, the number of times the model was run, and the total activity was recorded. The variables that could be changed were the *number of pieces of rubbish* each person left (Npr), the *proportion of rubbish collected* by the garbage collection person (Prc), and the *garbage collection time* (Gct). Others that are reported on from the system dynamics model relate to the *explore the model* screen: explore the model step by step (SbS) and explore the model in full (IF). There was also an “ideas” option available on the system dynamics model. The total activity included all of the above, as well as other activities not discussed in these results. An example of the way that the video was coded can be found in Appendix 8.

To make sense of the patterns of use in this study, they were classified according to Levy and Wilensky's (2005) strategies.

Table 3-1: Patterns found in Levy and Wilensky's (2005) study

	Strategy		
Name	Straight to the point	Homing in	Oscillating
Description	The most informative state is accessed directly	The most informative state is gradually approached through decreasing increments	The model oscillates between two regimes, back and forth between high and low values
Overall observation time	Lower	Lower	Higher
Observation time per run	Higher	Lower	Lower
Time between actions	Higher	Lower	Lower
Runs	Lower	Higher	Medium

3.4 LIMITATIONS

This study had three main limitations:

Small sample size

This is common in educational research, and in all relevant instances in this study, effect sizes were reported which take sample size into account.

The sample size limits the generalisability of the study, and conclusions are limited to these experiments.

Short treatment time

20 minutes is a short amount of time during which to expect learning to occur. For practical reasons, it was necessary for this study. However, the results will show that increases in

knowledge scores and understanding can be achieved in a short amount of time. This is relevant for environmental educators who often have time restrictions in their programs.

No interaction data for the collaborative learning environment

The literature agrees that the benefits that a collaborative learning environment brings to learners are related to the interaction between learners. For practical reasons, this data was not collected in this study. However, the investigation of differences in use of learning outcomes will suggest specific areas for further research and provide information about general patterns of use of agent-based and system dynamics models and associated learning outcomes.

3.5ETHICS

The principle ethical issue for this project was that the subjects were children, so the parent's/guardian's permission was required. All students were given an information sheets and a consent form to take home, and could return the consent form to their teachers, directly to myself, and were given stamped envelopes with my university address already printed, which they could also use. In all cases, contact was made with the Principal, the Head Science Teacher, and the classroom teacher, and information sheets were given to all involved. Of the 18 students involved in the pilot study, six returned consent forms, and of the 121 students involved in the main study, 49 returned consent forms.

Other ethical issues to be considered were confidentiality and anonymity. The results are used collectively, and identifiers have been used rather than names in all cases where individual data is reported. The schools that participated have not been identified. Data storage is another ethical issue. Hardcopies of all data are kept in a locked filing cabinet, and will be destroyed after seven years. Electronic copies of all data with students' names are password protected. Ethical approval was sought from the University of Sydney and the Department of Education and Training, NSW. The letters of approval can be found in Appendices 9 and 10.

3.6PILOT STUDY

3.6.1 Aim

The aim of the pilot study was to trial the models, the instruments and the procedure before undertaking the main study.

3.6.2 Sample

The pilot study was conducted in a Year 10 science class at an independent co-educational high school in Sydney. Six students returned their permission slips. Video screen shots were collected and coded from two students.

3.6.3 Design

A class list was provided before I went into the classroom, and students were randomly allocated to groups. The information presented to students in the models and the text is redundant, it is just the process that differs. Two students were given only a text description. Five students were given the system dynamics model and the text description (SDM group), five students had access to the agent-based model and the text description (ABM group), and five students were given both models and the text description (SDM & ABM group). However, due to the number of permission slips that were returned, the following sample sizes were obtained: Text group (1 student), SDM group (2 students), ABM group (3 students) and SDM & ABM group (0 students).

This experimental design addressed the recommendations made by Doyle et al. (1998) who state that measuring changes in mental models in response to system dynamics models should include an experimental control, collect data from individuals, and measure actual change (rather than perceived change).

3.6.4 Procedure

Students were given the background questionnaire as their first task and then introduced to the experiment (for the script used, see Appendix 11). Students were then given 20 minutes to complete the pre-test followed by a break for recess. When they returned, they were given 20 minutes to examine the materials (the text for the control group, and models for the treatment groups). They were then asked to complete the post-test, the final assessment and the evaluation.

Video screen shots were collected and coded in this study. Users were classified using the same parameters as Levy and Wilensky, and some additional parameters are suggested. Video screen shots were collected and coded with respect to times, activities and screens (see for example Appendix 8).

3.6.5 Outcomes

As a result of the pilot study a number of changes were made. The main change was that the duration of time modelled was shortened (reduced from ten consecutive days to seven). This served the purpose of reducing the runtime of the agent-based model, and provided students in the ABM group and the SDM & ABM group with more opportunities to use the model to experiment. The original open-ended format to questions in the final assessment task was also adjusted to reflect the style of questions outlined earlier. The procedure itself was found to be adequate, and the times allocated for answering the questions was retained.

3.7 MAIN STUDY

3.7.1 Design

Two experiments were carried out for the main study. The first experiment was in an individual learning environment. A class list was provided before I went into the classroom, and students were randomly allocated to groups. The information presented to students in the models and the text is redundant, it is just the process that differs. 18 students were given only a text description. 19 students were given the system dynamics model and the text description (SDM group), 19 students had access to the agent-based model and the text description (ABM group), and 19 students were given both models and the text description (SDM & ABM group). However, due to the number of permission slips that were returned, the following sample sizes were obtained: Text group (5 students), SDM group (9 students), ABM group (6 students) and SDM & ABM group (7 students).

The second experiment was carried out in a collaborative learning environment. Students interrogated the materials in dyads, and assessment was carried out on an individual basis. A class list was provided before I went into the classroom, and students were randomly allocated to groups. 10 students were given only a text description. 12 students were given the system dynamics model and the text description (SDM group), 12 students had access to the agent-based model and the text description (ABM group), and 12 students were given both models and the text description (SDM & ABM group). However, due to the number of permission slips that were returned, the following sample sizes were obtained: Text group (3 students), SDM group (6 students), ABM group (4 students) and SDM & ABM group (5 students).

3.7.2 Sample

Schools were selected for contact based on their proximity to the University of Sydney, prior contact with science teachers, and their interest in the use of technology in Science. These were a mixture of both Government and Independent schools. Schools were given the option of whether Year 9 or Year 10 students were nominated to participate. Schools were contacted through the contact person, and after that Information Sheets were sent to the Principal and Head Science teacher. Follow up phone calls and emails were used to determine participation.

Altogether there were 27 students from two schools who returned their permission slips, and whose responses were analysed in the individual learning environment. There were 18 students from School 1 whose responses were analysed in the collaborative learning environment. Four students returned their consent forms and were absent on the day of the study.

The first school, School 1, was an academically selective girls high school; students who participated from this school were in Year 10. The second school, School 2, was a girls 7-10 middle school; students who participated from this school were in Year 9.

Students were novices with respect to both system dynamics and visitor use of national parks. This eliminated potential complications due to misconceptions about impacts in a national park. The exercise was incorporated into normal class work, and the experiments performed in the schools. This design may be limited in its generalisability; however it was practical in terms of logistics and acquiring an appropriate sample. Depending on the representativeness of the sample, this generalisation may be able to be expanded upon.

3.7.3 Procedures

Students in both schools were given an introduction to the purpose of the experiment and a brief introduction outlining how the model would look, how students could interact with the materials, and expectations regarding their work (see Appendix 11).

Students were given the background questionnaire as their first task (20 minutes) then given 20 minutes to complete the pre-test. Students were then introduced to the experiment (10 minutes).

Students examined the materials for 20 minutes. They were then asked to complete the post-test (15 minutes), the final assessment task and the evaluation (15 minutes).

Video screen shots were collected and coded in this study. Video screen shots were collected and coded with respect to times, activities and screens. Users were classified using the same parameters as Levy and Wilensky, and some additional parameters are suggested.

3.8 ANALYSIS

The results of the background questionnaire data and the evaluation are not presented for the purposes of this thesis. Analyses indicated that differences between the control group and the treatment groups in both learning environments were not relevant for the research questions outlined.

In order to use parametric statistical tests, the data have to be normally distributed, the variance must be homogeneous, the data should be interval-level data, and the data should be independent ((Field, 2005)). In order to check the normality of the distribution, the *skewness* and *kurtosis* of the data should be examined, and a Kolmogorov-Smirnov test should be carried out (Field, 2005). Skewness and kurtosis are significant at $p < .05$ when the z-score is > 1.96, significant at $p <.01$ when the z-score is > 2.58, and at the $p < .001$ when z-score > 3.29. In small samples the $p < .01$ should be used (Field, 2005). Kolmogorov-Smirnov tests were also carried out on all variables, and a significant $p < .05$ result indicates a deviation from a normal distribution. The results of the *skewness* and *kurtosis* and Kolmogorov-Smirnov tests can be found in Appendix 12 for each learning outcome compared in the following results chapters, and in Appendix 13 for the measures of use of the models.

The measures of skewness and kurtosis and the results of the Kolmogorov-Smirnov tests indicated that some data were distributed non-normally. The normal distribution of the data could not be assumed for these variables. Transformations were unsuccessful; however given the small sample size this was expected. The small sample size also meant that the tests for a normal distribution for each group were unable to be carried out. It was decided that regardless of the variable, non-parametric statistical tests would be used for consistency. Non-parametric tests will have an increased chance of a Type II error *if* the data are normally distributed. A Type II error occurs when the results of statistical tests show that there is no effect in the population when really there is (Field, 2005).

Medians and ranges are reported on instead of means and standard deviations because of the non-parametric nature of the data. The proportion of students who scored more than 50% and the proportion of students who increased their score are also reported to get a sense of students' performance. Kruskal-Wallis tests were carried out to compare independent data with more than two groups (such as learning outcomes between the four groups). Mann-Whitney tests were used to compare data between two conditions with different participants, and as post-hoc tests in combination with Kruskal-Wallis tests (Field, 2005). Due to the already small sample size, and the exploratory nature of the research, it was decided that corrections for multiple analyses (such as a Bonferroni correction) would not be required in these cases. Any significant differences found in these post-hoc tests are treated cautiously, and further investigation of the results is carried out. Friedman's ANOVA was used to compare the use of the model within each group (frequency of changes of the three variables, proportion of time spent on each screen). The Wilcoxon signed-rank test is used when there are two sets of scores that come from the same population (Field, 2005). This was used to test the differences between the pre- and post-tests for environmental knowledge and system dynamics knowledge, and as a post-hoc test for Friedman's ANOVA.

The relationships between the learning outcomes were compared using correlations for each group. Correlations identify linear relationships between variables (Field, 2005). While generally this does not allow conclusions about causality to be made, in the cases where the order of events is known – for example pre-tests were completed, students used the model, and post-tests and the final assessment task were then completed; some implications can be seen. Spearman's correlation coefficient (r_s) was calculated due to the non-parametric nature of the data. A correlation of 1.00 indicates that the ranks of the marks in the pre- and post-test (of the same question) were identical. In this case, because students were not required to re-answer the question if they were satisfied with their pre-test answer, it indicates no change in their ranking. A high, significant correlation indicates some deviation in rankings, and therefore from previous answers. When noted *in combination* with a significant increase in the scores (as was reported in the discussion sections throughout the thesis), it indicates that students added to their previous knowledge in order to answer the post-test questions and simply supports the findings of the Wilcoxon Signed-ranks tests. If, however, the value of the correlation was non-significant, then that indicates an area for further investigation, because the ranks in the pre- and post-test are markedly different. In all cases this was used only to indicate areas that may require further inquiry. A large, significant correlation between the pre-test score of one question, and the post-test score of another indicates that a relationship exists between the two. In the case of these occurrences, I discuss the possibility of such a relationship indicating that students who had higher scores in the pre-test were also able to score highly in the post-test in this other question.

Due to the small sample size, large effect sizes were taken into account in addition to significance, and are noted throughout the results sections. Pearson's correlation coefficient r was used (Field, 2005), and calculated by dividing the z score by the square root of n. Field identifies the following parameters: $r = .10$ is a small effect size, $r = .30$ is a medium effect size, $r = .50$ is a large effect size. Only large effect sizes are reported in this thesis.

In Chapter 4 (Multiple External Representations), the overall scores for the environmental knowledge test, the system dynamics knowledge test, and the final assessment task were analysed first. This involved the comparison of the scores between groups using the Kruskal-Wallis test (and Mann-Whitney test post-hoc if required). The Wilcoxon signed-rank test was used to compare pre- and post-test scores for each group. For these tests, significance is reported at the $p < .10$ level because of the small sample size. Effect sizes are calculated where appropriate, and large effect sizes, $r > | .50 |$ are noted. Spearman's *rho* was used to explore the relationships between learning outcomes. The significance level reported for correlations is $p < .05$. This pattern was repeated for individual test scores. References to the actual answers to items in the final assessment task are also used to support relationships found between learning outcomes. The answers can be found in Appendix 14.

In Chapter 5 (Use of the Models), the use of the model was also compared between groups using the Kruskal-Wallis test (and Mann-Whitney tests post-hoc if required). Friedman's ANOVA was used to compare the proportion of time spent on each screen within each group, and the frequency of changes made to each of the three variables (with Wilcoxon signed-rank tests post-hoc if required). Spearman's *rho* was used to explore the relationships between the measures of the use of the model, and between these measures and learning outcomes. Kruskal-Wallis tests were used to compare the use of the model between students who used different strategies to change the variables (with Mann-Whitney tests post-hoc if required), and similarly for learning outcomes. When the strategies were analysed, the amount of time as well as the proportion of time spent on screens was compared between strategies. Significance levels for all tests are as reported above. The sample size used in Chapter 5 is less than that reported in Chapter 4; the collection of some video screenshots was unsuccessful. In the ABM group $n = 5$, in the SDM group $n = 7$, and in the SDM & ABM group $n = 6$.

In Chapter 6 (Collaborative Learning Environment), Mann-Whitney tests were carried out on pre-test and post-test scores to compare the individual and collaborative learning environments in all cases. The remaining analysis was performed as outlined for both Chapter 4 and Chapter 5. The sample size used for the section examining the use of the models is less than that reported in the first half of the chapter; the collection of some video screenshots was unsuccessful. . In the collaborative learning environment, for the ABM group $n = 2$, for the SDM group $n = 4$, and for the SDM & ABM group $n = 2$.

The experimental design has been outlined and the analysis presented here. The following three chapters will present the results of these analyses.

4. MULTIPLE EXTERNAL REPRESENTATIONS

4.1 RATIONALE

Providing or generating multiple external representations are well-researched strategies for understanding complex systems. Advantages include capturing the learners' interest and providing an authentic learning environment for students (1999b; Kozma, Chin, Russell, & Marx, 2000). 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, de Jong, & Ferguson-Hessler, 1998). There are challenges involved with using multiple external representations. These include students changing their usual problem solving processes to accommodate the representation, resulting in further errors ((Tabachneck-)Schijf & Simon, 1998); and the high cognitive load associated with the coordination of information from different representations can be a major cost to learners using multiple representations (Bodemer, Ploetzner, Feuerlein, & Spada, 2004; de Jong et al., 1998). Regardless of cognitive load, some students still fail to coordinate between multiple representations (Ainsworth, Bibby, & Wood, 1998).

In this study, both the agent-based model and the system dynamics model give students the benefits of multiple representations using graphs, text and the representation of the model itself (animation in the case of the agent-based model and a stock and flow diagram for the system dynamics model). Rohr and Reimann (1998) said that 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. 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, Spector, & Davidsen, 2003). Stock and flow diagrams, however, are abstract scientific diagrams, and Lowe (1993) states that both domain general knowledge and domain specific knowledge are important. Providing students with both models should provide them with benefits associated with multiple representations such as the safety net discussed above. Using both models may help students to be able to think of the two levels that are modelled at the same time (Schieritz & Milling, 2003). The addition of the alternate model may also overcome problems observed with learning with both types of model – such as making links between levels in the agent-based model and interpreting a new representation in the system dynamics model. The multiple representations of the models should *constrain* students' understanding by providing a combination of a familiar representation and an authentic, scientific system view representation.

4.2 HYPOTHESIS AND BRIEF INTRODUCTION TO THE CHAPTER

The guiding hypothesis is that: *a system dynamics model is too abstract for high school students, and an additional representation that constrained the interpretation of the model (one that was familiar to the students, such as the animated representation included in the agent-based model) will improve interpretation, and therefore understanding.*

The experiment compared the learning outcomes from students randomly allocated to four groups: a control group (Text group, $n = 5$) in which students were exposed to a text-based description of visitor impacts on a national park (see Appendix 1), and three treatment groups, in which students were either given a system dynamics model to examine (SDM group, $n = 9$), an agent-based model of the system (ABM group, $n = 6$), or both of these combined (SDM & ABM group, $n = 7$).

For a full discussion of the analyses performed, refer to Chapter 3. In brief, the results of analyses carried out on the overall environmental knowledge and system dynamics knowledge test scores and the final assessment task score will be reported on first. The second section provides a focus on a number of key questions and sections within the overall scores. Each section has the following structure:

- Comparison of pre-test and post-test scores between groups, and comparison of pre-test and post-test scores within each group,
- Comparison of the change in knowledge scores between the groups,
- Comparison of the final assessment task scores between the groups, and
- Exploratory analysis of relationships between learning outcomes.

4.3 LEARNING OUTCOMES: ENVIRONMENTAL KNOWLEDGE, SYSTEM DYNAMICS KNOWLEDGE, AND UNDERSTANDING

4.3.1 Results

As outlined above, this section reports on the results of the analyses performed on overall test scores. Pre-test and post-test knowledge test scores will be compared between the groups using Kruskal-Wallis tests. Pre- and post-test scores will be compared for each group using Wilcoxon signed ranks tests. The results of Kruskal-Wallis tests comparing the change in knowledge test scores between groups will then be reported. Final assessment task scores will also be compared between groups using Kruskal-Wallis tests. Due to the small sample size, large effect sizes were taken into account in addition to significance, and are noted where appropriate. Finally an exploratory analysis of the correlational relationships between learning outcomes will be described using Spearman's *rho*. The meaning of these results in terms of the hypothesis will then be discussed.

4.3.1.1 Pre- and post-test environmental and system dynamics knowledge scores

Students in each group completed two knowledge tests in a pre- and post-test design. Pre-tests were administered before interaction with the materials. Post-tests were completed by students after the treatment, and students were given the opportunity to change their original answer, or to keep it (for a full discussion of this, please see Chapter 3). The environmental knowledge test was worth 32 marks, and contained items that related specifically to the materials and items that required application of this knowledge to other systems. The system dynamics knowledge test was worth 12 marks, and also contained general system dynamics knowledge questions and an applied question.

Table 4-1: Median, range of scores and proportion of students who scored more than 50% for the knowledge pre- and post-test scores, for each group and the results of the Wilcoxon signed-ranks test comparing the pre- and post-test scores.

	Pre-test				Post-test				
		Range		More than 50% score		Range		More than 50% score	Pre-test vs. Post-test (*T*)
Group	*Mdn*	Lower	Upper	(%)	*Mdn*	Lower	Upper	(%)	
ABM									
EK	16.25	0	25	50	15.75	5.5	28	50	**2.5**[a]
SDK	3.5	0	10	33	6.5	0	10	50	**0.0**
SDM									
EK	11.5	2	31	33	15.5	3	24	33	17.0
SDK	1	0	7	11	2	0	7	11	8.0
SDM & ABM									
EK	14.5	2	20.5	43	17	10	22.5	57	**0.0****
SDK	3.5	0	7	14	5	1.5	8.5	29	**1.0**
Text									
EK	14	7	27	40	19	12	27	80	**0.0**[a]
SDK	1	0	7.5	20	5	2	7.5	20	**0.0**[a]

Note. EK = environmental knowledge test (maximum score 32 marks). SDK = system dynamics knowledge test (maximum score 12 marks). Bold typeface indicates large effect size ($r > | .50 |$).

[a] $p < .10$. * $p < .05$.

Table 4-1 shows that the ABM group had the highest median pre-test environmental knowledge score and the Text group had the highest median post-test environmental knowledge score. The ABM group also had the highest proportion of students who scored more than 50% in the pre-test. The Text group had the highest proportion in the post-test. Kruskal-Wallis tests showed that the difference between the groups with respect to pre-test scores was non-significant ($H(3) = 0.30$, $p = .96$), as was the difference with respect to post-test scores ($H(3) = 2.34$, $p = .51$).

The ABM and SDM & ABM groups shared the highest median pre-test system dynamics knowledge score, and the ABM group had the highest median post-test system dynamics knowledge score.

Only 33% of students scored more than 50% in the pre-test in the ABM group, but 50% scored more than 50% in the post-test. The difference between pre-test scores was non-significant ($H(3) = 2.93$, $p = .40$), as was the difference between groups in terms of post-test scores ($H(3) = 2.16$, $p = .54$) for the system dynamics knowledge test.

Wilcoxon signed-rank tests showed that students in the Text group ($p < .10$) and the SDM & ABM group ($p < .05$) significantly increased their environmental knowledge score between the pre- and post-tests and large effect sizes were associated with each. There was a significant ($p < .10$) difference between the pre- and post-test scores in the ABM group, and a large effect size was associated with this. The range of scores for this group decreased between the pre-test and post-test, and the lower range of the scores was higher in the post-test than the pre-test. The difference between pre- and post-test scores in the SDM group was non-significant and the effect size was small.

Comparison of system dynamics knowledge scores showed that the Text group experienced a significant ($p < .10$) increase between the pre- and post-tests and a large effect size was associated with this. There were large effect sizes associated with increases in system dynamics knowledge test scores in the ABM and SDM & ABM groups, however the differences were non-significant. In the SDM group, the difference between pre- and post-test scores was also non-significant and the effect size was medium.

4.3.1.2 The change in the environmental and system dynamics knowledge scores

The change in the knowledge scores was calculated by subtracting the pre-test score from the post-test score. The purpose of comparing these changes is to determine whether the treatments had an effect on the size of the difference between the scores.

Table 4-2: Median changes, the range of the change, and the proportion of students that increased their scores for the knowledge tests, for each group

Group	*Mdn*	Range		Increased score (%)
		Lower	Upper	
ABM				
EK_{change}	3.5	-3	6	83
SDK_{change}	0	0	5	33
SDM				
EK_{change}	1	-16	8	67
SDK_{change}	1	-2	7	67
SDM & ABM				
EK_{change}	2.5	0	14	86
SDK_{change}	0	-1	4	43
Text				
EK_{change}	3	0	9	80
SDK_{change}	2	0	6	80

Note. EK = the environmental knowledge test (maximum score is 32). SDK = the system dynamics knowledge test (maximum score is 12). $_{change}$ = the change in the score between the pre-test and post-test.

As can be seen in Table 4-2, the median change in the environmental knowledge score between the pre- and post-test scores for each group varied between 1 and 3.5. In addition, a high proportion of each group increased their environmental knowledge score, although the SDM group had the lowest proportion. A non-significant difference was calculated in the change in environmental knowledge scores between the groups ($H(3) = 1.24$, $p = .74$).

The median change in the system dynamics knowledge score varied between 0 and 2, some students in the SDM and SDM & ABM groups experienced a decrease in their score, and the Text group had the largest proportion of students increase their score. There was a non-significant difference in the change in system dynamics knowledge scores between the groups ($H(3) = 2.53$, $p = .47$).

4.3.1.3 Understanding of the system: Final assessment task scores

The final assessment was worth 91 marks and contained five questions that allowed students to assume the role of a national park manager. Questions addressed areas such as self-reported interrogation of the materials, description of the system, environmental and management issues raised by the materials, and decisions, predictions and consequences of the decisions suggested. The purpose of these questions was to assess understanding of the system itself, rather than more general environmental knowledge.

Table 4-3: Median and range of scores in the final assessment task, for each group

		Range		
Group	*Mdn*	Lower	Upper	Score > 50% (%)
ABM	17	13	36	0
SDM	20.5	7	27	0
SDM & ABM	20	8	34	0
Text	26	2	37	0

Note. The maximum score is 91.

The highest median score for the final assessment task was found in the Text group, as can be seen in Table 4-3. Students in the ABM group had the lowest median score. There was a non-significant difference between the groups when this learning outcome was compared ($H(3) = 0.70$, $p = .87$).

4.3.1.4 Correlations between learning outcomes

Spearman's *rho* was used to determine the relationships between learning outcomes in each group due to the non-parametric nature of the data. A correlation of 1.00 indicates that the ranks of the marks in the pre- and post-test (of the same question) were identical. In this case, because students were not required to re-answer the question if they were satisfied with their pre-test answer, it indicates no change in their ranking. A high, significant correlation indicates some deviation in rankings, and therefore from previous answers. When noted *in combination* with a significant increase in the scores (as was reported in the discussion sections throughout the thesis), it indicates that students added to their previous knowledge in order to answer the post-test questions and simply supports the findings of the Wilcoxon Signed-ranks tests. If, however, the value of the correlation was non-significant, then that indicates an area for further investigation, because the ranks in the pre- and post-test are markedly different. In all cases this was used only to indicate areas that may require further inquiry. A large, significant correlation between the pre-test score of one question, and the post-test score of another indicates that a relationship exists between the two. In the case of these occurrences, I discuss the possibility of such a relationship indicating that students who had higher scores in the pre-test were also able to score highly in the post-test in this other question.

Table 4-4: Correlations between learning outcomes in the ABM group using Spearman's *rho*

	Pre-test environmental and system dynamics knowledge scores		Learning outcomes				
	EK_{pre}	SDK_{pre}	EK_{post}	EK_{change}	SDK_{post}	SDK_{change}	FAT
Pre-test environmental and system dynamics knowledge scores							
EK_{pre}	--						
SDK_{pre}	.60	--					
Learning outcomes							
EK_{post}	.89*	.43	--				
EK_{change}	-.26	-.55	-.12	--			
SDK_{post}	.83*	.83*	.60	-.64	--		
SDK_{change}	.51	-.03	.68	-.38	.27	--	
FAT	.81*	.84*	.58	-.18	.81*	-.05	--

Note. EK = environmental knowledge score. SDK = system dynamics knowledge score. FAT = final assessment task score. $_{pre}$ = pre-test score. $_{post}$ = post-test score. $_{change}$ = change in the score between the pre-test and post-test.

n = 6.

$^{*}p < .05$.

Table 4-4 shows that in the ABM group, students who had a higher pre-test environment knowledge score also had higher post-test scores for the environmental knowledge and system dynamics knowledge tests; and a higher final assessment task score. Similarly, students who had a higher pre-test system dynamics knowledge score had a higher score for the system dynamics knowledge post-test and the final assessment task. The system dynamics knowledge post-test score was also positively, significantly correlated with the final assessment task.

Table 4-5: Correlations between learning outcomes in the SDM group using Spearman's *rho*

	Pre-test environmental and system dynamics knowledge scores		Learning outcomes				
	EK_{pre}	SDK_{pre}	EK_{post}	$\text{EK}_{\text{change}}$	SDK_{post}	$\text{SDK}_{\text{change}}$	FAT
Pre-test environmental and system dynamics knowledge scores							
EK_{pre}	--						
SDK_{pre}	-.29	--					
Learning outcomes							
EK_{post}	.47	.36	--				
$\text{EK}_{\text{change}}$	-.46	.27	.43	--			
SDK_{post}	-.16	.14	-.21	-.10	--		
$\text{SDK}_{\text{change}}$	-.24	-.45	-.36	.03	$.70^{*}$	--	
FAT	.01	.31	.47	.16	.25	.20	--

Note. EK = environmental knowledge score. SDK = system dynamics knowledge score. FAT = final assessment task score. $_{\text{pre}}$ = pre-test score. $_{\text{post}}$ = post-test score. $_{\text{change}}$ = change in the score between the pre-test and post-test.

$n = 9$.

$^{*}p < .05$.

Table 4-5 shows that in the SDM group, pre-test scores were not significantly correlated with learning outcomes. Students who had a higher post-test score for system dynamics knowledge also had a larger change in their system dynamics knowledge score.

Table 4-6: Correlations between learning outcomes in the SDM & ABM group using Spearman's *rho*

	Pre-test environmental and system dynamics knowledge score		Learning outcomes				
	EK$_{pre}$	SDK$_{pre}$	EK$_{post}$	EK$_{change}$	SDK$_{post}$	SDK$_{change}$	FAT
Pre-test environmental and system dynamics knowledge score							
EK$_{pre}$	--						
SDK$_{pre}$	.79*	--					
Learning outcomes							
EK$_{post}$	.93**	.60	--				
EK$_{change}$	-.86**	-.86*	-.75	--			
SDK$_{post}$	.78*	.74	.76*	-.96**	--		
SDK$_{change}$	.04	-.22	.25	-.26	.49	--	
FAT	.93**	.68	.93**	-.86*	.85*	.30	--

Note. EK = environmental knowledge score. SDK = system dynamics knowledge score. FAT = final assessment task score. $_{pre}$ = pre-test score. $_{post}$ = post-test score. $_{change}$ = change in the score between the pre-test and post-test.

$n = 7$.

$^{*}p < .05$; $^{**}p < .01$.

In the SDM & ABM group, students who had a higher pre-test environmental knowledge score also had a higher pre-test system dynamics knowledge score. Students who had a higher pre-test environmental knowledge score had a higher post-test score for the environmental knowledge test, for the system dynamics knowledge test, and for the final assessment task. Higher pre-test environmental knowledge scores were negatively and significantly correlated with the change in the environmental knowledge score. Students who had a higher pre-test system dynamics knowledge score also had a smaller change in their environmental knowledge score.

Students who had a higher post-test environmental knowledge score also had a higher system dynamics knowledge post-test score and a higher final assessment task score. The change in the environmental knowledge score was negatively and significantly correlated with the system dynamics knowledge post-test score and the final assessment task score. Students who had a higher system dynamics knowledge post-test score also had a higher final assessment task score.

Table 4-7: Correlations between learning outcomes in the Text group using Spearman's *rho*

	Pre-test environmental and system dynamics knowledge scores		Learning outcomes				
	EK_{pre}	SDK_{pre}	EK_{post}	EK_{change}	SDK_{post}	SDK_{change}	FAT
Pre-test environmental and system dynamics knowledge scores							
EK_{pre}	--						
SDK_{pre}	$.98^{**}$	--					
Learning outcomes							
EK_{post}	.70	.56	--				
EK_{change}	$-.90^{*}$	$-.98^{**}$	-.40	--			
SDK_{post}	.70	.56	1.00^{**}	-.40	--		
SDK_{change}	-.41	-.55	-.05	.67	-.05	--	
FAT	1.00^{**}	$.98^{**}$	.70	$-.90^{*}$	.70	-.41	--

Note. EK = environmental knowledge score. SDK = system dynamics knowledge score. FAT = final assessment task score. $_{pre}$ = pre-test score. $_{post}$ = post-test score. $_{change}$ = change in the score between the pre-test and post-test.

$n = 5$.

$^{*}p < .05$; $^{**}p < .01$.

Table 4-7 shows that in the Text group, students who had a higher pre-test environmental knowledge score had a higher pre-test system dynamics knowledge score. The students who had a higher pre-test environmental knowledge score had a lower change in their environmental knowledge score and a higher final assessment task score. Pre-test system dynamics knowledge scores were negatively and significantly correlated with the change in the environmental knowledge score, and positively and significantly correlated with the final assessment task. Students who had a higher environmental knowledge post-test score also had a higher system dynamics knowledge post-test score. Those who had a higher change in their environmental knowledge score had a lower final assessment task score.

4.3.2 Discussion

The guiding hypothesis was that: *a system dynamics model is too abstract for high school students, and an additional representation that constrained the interpretation of the model (one that was familiar to the students, such as the animated representation included in the agent-based model) will improve interpretation, and therefore understanding.*

If this hypothesis holds true, students in the SDM group would have few increases in knowledge scores, students in the ABM group would be able to increase knowledge scores, most probably those that are related to the representational affordance of the animation provided, and the SDM & ABM group will allow students to have the benefits of both, and provide an environment in which students can link the two representations. This is because the stock and flow diagram should provide students with a greater understanding of the macro level of the system than the graphs in the agent-based model, and the animation should provide students with a greater understanding of the micro-level as the animation provides a high level of detail. The control group is important in this discussion, but only briefly. The remainder of the discussion focuses on whether students increased knowledge scores, and whether there were significant differences when groups were compared for learning outcomes. Each of the above areas will now be addressed separately: the control group, the affordances of the system dynamics model, the affordances of the agent-based model, and the use of multiple representations.

4.3.1.5 The control group

Students in the control group increased both knowledge scores between the pre- and post-test, and had a similar final assessment task score to students in the treatment groups. Students in all groups were given a text description, and due to the experimental design, it can be assumed that results calculated for treatment groups that differ from the control group, may be a result of the treatment. Non-significant correlations between pre-test scores and learning outcomes indicated that the treatment had an effect on learning outcomes. Seufert (2003) found that students who had lower prior knowledge and who received no help, concentrated on memorizing facts, and invested little cognitive effort in comprehension. The results for the Text group support this finding. In the Text group, a positive significant correlation between the pre-test environmental knowledge and system dynamics knowledge scores and the final assessment task score and negative, significant correlations between pre-test scores and the change in the environmental knowledge score suggested that students with lower prior environmental and system dynamics knowledge concentrated on improving their knowledge of those areas, whereas students who had higher prior knowledge in these areas were able to concentrate on understanding the system overall.

4.3.1.6 Learning from an agent-based model

Agent-based models have been shown to be successful in allowing students to link multiple representations and levels to gain a deeper understanding of concepts, and is suited to representation of a process or a dynamic system due to the animation involved as part of the model (Milrad et al., 2003; Rohr & Reimann, 1998; Savelsbergh et al., 1998; Stieff & Wilensky, 2003; Wakeland, Macovsky, Gallaher, & Aktipis, 2004). However, with these advantages comes a high cognitive load related to the extent to which the elements interact with each other (Sweller & Chandler, 1994), which may prevent links between the levels from being made by students. In the ABM group, increases in both knowledge test scores were reported. The results of the correlations support those of Ainsworth et al. (1998) and Horowitz & Christie (1999) who suggested that if learners are already familiar with either the domain or the representation, then there will be an increased ability to recognize the connection between the representation and the phenomenon represented. In the ABM group, students who had higher pre-test scores for environmental knowledge and system dynamics knowledge were able to score highly on the post-test questions and the final assessment task (which assessed understanding). It may be that the prior knowledge facilitated students' exploration of the model so that students who had this knowledge were better able to understand the system, and improve their environmental and system dynamics knowledge scores. Due to the lack of significant correlations between these learning outcomes and the change in the scores, no conclusions can be made with regards to the large effect sizes associated with increases in the knowledge scores. To explain these results the environmental knowledge score, system dynamics knowledge score, and final assessment task will be investigated in the following sections.

4.3.1.7 Learning from a system dynamics model

System dynamics models are useful for conceptual understanding (Wakeland et al., 2004), they establish a link between the system structure and the system behaviour (Schieritz & Milling, 2003). Students have been shown to improve understanding of the scientific concepts underlying modelling, rather than their ability to interpret the models after a long-term intervention (Maryland Virtual High School, 2001). However, the high cognitive load involved in interpreting the abstract, scientific diagram may result in small learning gains (Lowe, 1993; Sweller & Chandler, 1994). In the SDM group, there was a non-significant difference between the pre- and post-test environmental knowledge test scores, and the system dynamics knowledge test scores for students in the SDM group. These results and those of the correlations indicate that the treatment had an effect on learning outcomes. Students who had high pre-test environmental knowledge and system dynamics knowledge scores did not have high post-test scores for these tests. However, students had similar levels of understanding to other groups. These support the findings outlined above in that students were able to understand the system conceptually, however were not able to apply other knowledge to this understanding.

4.3.1.8 Learning from multiple representations

As has been explained, one advantage of using multiple representations is that this 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). In addition, the using both models may help students to be able to think of the two levels that are modelled at the same time (Schieritz & Milling, 2003), and may overcome the challenges involved with learning with both types of model – such as making links between levels in the agent-based model and interpreting a new representation in the system dynamics model. The multiple representations of the models should *constrain* students' understanding by providing a combination of a familiar representation and an authentic, scientific system view representation. However, challenges such as the high cognitive load associated with the coordination of information from different representations can be a major cost to learners of using multiple representations (Bodemer et al., 2004; de Jong et al., 1998). Regardless of cognitive load, some students still fail to coordinate between multiple representations (Ainsworth et al., 1998).

Students in the SDM & ABM group significantly increased their environmental knowledge score ($p < .05$). Significant increases were also noted in both the control group and the ABM group. By comparison with the lack of change in the SDM group previously discussed, the increased score in the SDM & ABM group indicates that for students given a system dynamics model, the addition of an agent-based model provided students with an advantage with respect to environmental knowledge scores. Significant correlations between the pre-test environmental knowledge score and the post-test score indicated that students used prior knowledge in addition to the representation, as was suggested for students in the ABM group. Additionally, correlations between learning outcomes suggested that students were able to learn about all three areas (environmental knowledge, system dynamics knowledge, and understanding of the system). A number of authors suggest that learners who are already familiar with either the domain or the representation, should have an increased ability to recognise the connection between the representation and the phenomenon represented (Ainsworth et al., 1998; Horwitz & Christie, 1999; Seufert, Janen, & Brunken, 2007). Seufert (2003) found that students who had lower prior knowledge and who received no help concentrated on memorizing facts, and invested little cognitive effort in comprehension. Negative correlations were calculated between the change in the environmental knowledge score and prior environmental and system dynamics knowledge. In terms of the relationship with learning outcomes, students who had greater changes in their environmental knowledge scores had lower scores for the system dynamics post-test and the final assessment task. The correlations suggest that students who already had higher prior knowledge of the environment may have been able to concentrate their efforts on translating between the two models, and so had a greater understanding of the system; whereas students with lower prior knowledge focused their attention on increasing their knowledge of these areas.

A large effect size was associated with an increase in the system dynamics knowledge score for students in the SDM & ABM group, and also in the control group and the ABM group. Comparison with the non-significant change in the median system dynamics knowledge score in the SDM group indicates that for students given a system dynamics model, the addition of the agent-based model provided students with an advantage in terms of system dynamics knowledge scores. Correlations between knowledge scores suggested that the treatment may have had an effect on this score. It may be that students with higher prior environmental knowledge were able to concentrate on learning about areas not related to environmental knowledge (such as system dynamics concepts) covered by the materials.

The comparison of the final assessment task scores showed a non-significant difference between the groups. However, the relationships between the final assessment task score and knowledge tests scores were different in each group. In the SDM & ABM group, correlations suggested that students who were able to score highly on the knowledge tests were also able to score well in the test assessing their understanding of the system because they included the knowledge that they gained from the treatment in their answers.

Of those groups that were given a model, the SDM & ABM group was the most successful, in terms of a greater increase in their environmental knowledge score, a similar increase in their system dynamics knowledge score to those in the ABM group, and a similar final assessment task score to all other groups. These results support the findings of many authors who suggest that using multiple external representations is a useful strategy for learning about a complex system (Ainsworth, 1999b; Kozma et al., 2000; Savelsbergh et al., 1998).

4.3.2 Conclusions

The most effective treatment (in terms of an increase in knowledge scores between the pre- and post-test), was the group that was given the multiple external representations (SDM & ABM group). When students with access to a system dynamics model were provided with the additional process level information of the agent-based model, students increased their environmental knowledge test score more so than students in other groups. However, correlations suggested that a large change in this score was at the expense of understanding the system, and increasing system dynamics knowledge scores.

The most effective treatment for the system dynamics knowledge test was the Text group. Students from this group had the greatest increase in their system dynamics knowledge test score between the pre- and post-test, however correlations between learning outcomes did not help to explain the finding. It may be that the representation itself had an effect on this outcome, and further analysis of the learning outcomes is necessary to explain this further. This has implications for system dynamics instruction. If students are learning systems concepts it should not be in conjunction with a new representation.

There was a non-significant difference between the groups when understanding the system (final assessment task) was analysed. This has implications for both the system dynamics community and environmental educators. The treatment did not affect the overall understanding of the system, but it did affect what students learned about environmental knowledge questions and system dynamics knowledge questions. Given that there were different relationships between the learning outcomes, there may be a difference between the groups in terms of *what* was understood about the system. Further analysis in the following section may help to explain this finding.

Research on expert and novice use of representations for problem-solving may be relevant in explaining some of these results. It has been suggested that experts use pictorial and dynamic representations to evoke a recognition process allowing them to reason with the external representation rather than maintain the internal representation (Tabachneck-Schijf, Leonardo, & Simon, 1997). The domain ‘experts’ in this study were able to use the multiple representations more successfully than the domain ‘novices’. This difference in the use of single and multiple representations may indicate the difference between using the models to reason with, or as a mindtool, and to build mental models. Students with lower domain knowledge learned about particular areas, improving their mental model in one section. When given two models, these domain novices were able to use them, and were able to arrive at a similar level of knowledge of all three learning outcomes, but particularly improved knowledge about the environment. The domain experts may have been more successful in the final assessment task because they were able to link these areas together. This has implications for both environmental educators and system dynamics educators. The SDM & ABM group and the Text group provided a learning environment in which students with any level of prior knowledge could improve their knowledge about the environment.

At this point, the hypothesis has been supported, and students who had both the system dynamics model and the agent-based model had a greater increase in their environmental knowledge score than the other groups. However, the Text group also increased their system dynamics knowledge tests scores more than students in the other groups, and students in both the ABM group and the Text group increased their environmental knowledge scores (although to a lesser extent). These results do not provide any explanation of whether students were using the agent-based model to *constrain by familiarity* their understanding of the system dynamics model, or using the system dynamics model to *construct deeper understanding by abstraction* or *by relations* of the agent-based model. Examination of these differences will be discussed later in this Chapter, with analysis of key sections of the tests, and in Chapter 5, with analysis of the ways in which the models were used.

4.4INDIVIDUAL QUESTIONS

The guiding hypothesis also applies to this section of the chapter: *a system dynamics model is too abstract for high school students, and an additional representation that constrained the interpretation of the model (one that was familiar to the students, such as the animated representation included in the agent-based model) will improve understanding.*

Key items and sections of the environmental knowledge test will be compared between pre- and post-tests for each group. Each pre-test, post-test, change in knowledge test and final assessment task score for these sections will be compared between the groups. Relationships between the key items will then be explored using correlations.

4.4.1 Results of the analysis of key items

As outlined above, this section reports on the results of the analyses performed on overall test scores. Pre-test and post-test knowledge test scores will be compared between the groups using Kruskal-Wallis tests. Pre- and post-test scores will be compared for each group using Wilcoxon signed ranks tests. The results of Kruskal-Wallis tests comparing the change in knowledge test scores between groups will then be reported. Final assessment task scores will also be compared between groups using Kruskal-Wallis tests. Due to the small sample size, large effect sizes were taken into account in addition to significance, and are noted where appropriate. Finally an exploratory analysis of the correlational relationships between learning outcomes will be described using Spearman's *rho*. The meaning of these results in terms of the hypothesis will then be discussed.

4.4.1.1 Pre- and post-test environmental and system dynamics knowledge scores

Three questions were analysed as part of the environmental knowledge tests. Question 5 (9 marks) questioned students about the types of activities that could cause an increase in the number of introduced animal species, and asked them to name one effect of such an increase. Question 6 (8 marks) asked students to identify the types of activities that could cause an increase in the number of introduced plant species, and what the effects of such an increase might be. Question 7 (12 marks) asked students to describe the impact of building a road, littering and bushwalking in terms of the initial impact, the time scale involved in that impact, any further impacts, and their associated time scales. Question 7 allowed students to apply the system-specific knowledge assessed in Questions 5 and 6 to another system.

Table 4-8: Median, range of scores and proportion of students who scored more than 50% for key questions in the environmental knowledge pre-test and post-test for each group and the results of the Wilcoxon signed-ranks test comparing the pre- and post-test scores.

	Pre-test				Post-test				
		Range		Score > 50%		Range		Score > 50%	Pre-test vs. post-test
Question	*Mdn*	Lower	Upper	(%)	*Mdn*	Lower	Upper	(%)	(*T*)
ABM									
Q5	2	0	6	17	4	1	7	33	**0.0***
Q6	2.25	0	4	0	2.75	0	6	50	**0.0**^{a}
Q7	9	0	12	67	6.5	1.5	12	50	4.0
SDM									
Q5	2	0.5	8	33	3	0.5	7	44	7.5
Q6	1	0	8	22	2	0	7	33	7.0
Q7	8	0	12	56	8	0	10	67	4.5
SDM & ABM									
Q5	2	1	5	14	3	2	6	14	**0.0***
Q6	2	0	4.5	14	2	1	5.5	14	**0.0**
Q7	7.5	0	11	71	9	3.5	12	86	**2.0**^{a}
Text									
Q5	3	0.5	5.5	40	4	3	9	40	**1.5**
Q6	3	0	7	40	5	1	8	60	2.5
Q7	5	0	12	40	6	5.5	12	40	**0.0**

Note. Q5 = knowledge about introduced animal species (Maximum score is 9). Q6 = knowledge about introduced plant species (Maximum score is 8). Q7 = knowledge about the impact of humans on the environment and associated timescales (Maximum score is 12). Bold typeface indicates large effect size ($r > | .50 |$).

$^{a}p < .10$. $^{*}p < .05$.

Table 4-8 shows that median scores assessing knowledge about introduced animal species (Question 5) were between 2 and 3 for the pre-test and between 3 and 4 for the post-test. Kruskal-Wallis tests showed that the differences between pre-test scores ($H(3) = 0.70$, $p = .87$), and post-test scores ($H(3) = 2.09$, $p = .55$) were non-significant. Question 6 assessed knowledge about introduced plant species, and median scores were between 1 and 3 for the pre-test and between 2 and 5 for the post-test. There was a non-significant difference between the groups with respect to pre-test scores ($H(3) = 1.31$, $p = .73$), and the post-test scores ($H(3) = 1.79$, $p = .62$). The final environmental knowledge score examined was Question 7 assessing knowledge about human impacts on an ecosystem and associated timescales. Median pre-test scores ranged from 5 to 9; and median post-test scores from 6 to 9. Comparisons of pre-test scores ($H(3) = 0.12$, $p = .99$) and post-test scores ($H(3) = 1.99$, $p = .57$) between the groups indicated that the differences were non-significant.

The results of the Wilcoxon signed-ranks tests were also reported in Table 4-8. Students in the ABM group significantly increased the score associated with knowledge of introduced animal species (Question 5) ($p < .05$) and the score associated with knowledge of introduced plant species (Question 6) ($p < .10$), and large effect sizes were associated with both.

In the SDM group there were negligible to medium effect sizes were associated with non-significant changes in the three environmental knowledge scores.

Significant increases were observed in the score associated with knowledge of introduced animal species (Question 5) and with the score assessing knowledge of human impacts of the environment and associated timescales (Question 7) in the SDM & ABM group, and large effect sizes were associated with both. Large effect sizes were also associated with increases in the score associated with knowledge of introduced plant species (Question 6).

In the Text group, large effect sizes were associated with increases in all environmental knowledge scores except that associated with knowledge of introduced plant species (Question 6), for which a medium effect size was calculated.

4.4.1.2 The change in the environmental and system dynamics knowledge scores

The change in the knowledge scores was calculated by subtracting the pre-test score from the post-test score. The purpose of comparing these changes is to determine whether the treatments had an effect on the size of the difference between the scores.

Table 4-9: Median, range of the change in scores, and the proportion of students that increased their score for each question in the environmental knowledge tests, for each group

		Range		
Question	*Mdn*	Lower	Upper	Increased score (%)
ABM				
$Q5_{change}$	1	1	5	100
$Q6_{change}$	1	0	2	67
$Q7_{change}$	0.5	-5	3	50
SDM				
$Q5_{change}$	0	-7	4	44
$Q6_{change}$	1	-7	4	67
$Q7_{change}$	0	-9	3	22
SDM & ABM				
$Q5_{change}$	1	0	2	86
$Q6_{change}$	0	0	2	43
$Q7_{change}$	1	-1	10	71
Text				
$Q5_{change}$	2	-1	3.5	80
$Q6_{change}$	1	-2	3	60
$Q7_{change}$	1	0	5.5	60

Note. Q5 = knowledge about introduced animal species (Maximum score is 9). Q6 = knowledge about introduced plant species (Maximum score is 8). Q7 = knowledge about the impact of humans on the environment and associated timescales (Maximum score is 12). $_{change}$ = change in the score between the pre- and post-test.

Table 4-9 shows that the median change in the scores assessing knowledge about introduced animal species (Question 5) ranged between 0 and 2. A Kruskal-Wallis test showed that the difference between the groups for the change in Question 5 was non-significant ($H(3) = 2.59$, $p = .46$). The median change between the pre- and post-test scores assessing knowledge of introduced plant species (Question 6) was between 0 and 1.There was a non-significant difference between the groups associated with the change in the Question 6 score ($H(3) = 1.00$, $p = .80$). Question 7 assessed knowledge about human impacts on an ecosystem and associated timescales. The median change between the pre- and post-test scores varied between 0 and 1. The difference between the groups for the change in this score was non-significant ($H(3) = 2.79$, $p = .43$).

4.4.1.3 Understanding of the system – key outcomes

Individual questions in the final assessment task were grouped into three sections. The first section assessed students' abilities to describe what they saw in the model (*Describe*, 8 marks). The second section addressed students' abilities to identify the issues that were raised by the materials (*Issues*, 16 marks), and the third assessed students' abilities to make decisions, predictions, and identify the consequences of their decisions (*Higher Level Thinking*, 24 marks).

Table 4-10: Median, range of scores and proportion of students who scored more than 50% for each section for key sections of the final assessment task for each group

		Range		
Question	*Mdn*	Lower	Upper	More than 50% (%)
ABM				
Describe	2.5	0	5	17
Issues	3.5	1	9	17
HLT	4.5	2	8	0
SDM				
Describe	4	0	5	33
Issues	5	2	7	0
HLT	3	1	7	0
SDM & ABM				
Describe	1	0	4	0
Issues	3	1	9	14
HLT	4	2	10	0
Text				
Describe	0	0	6	20
Issues	8	2	9	20
HLT	6	0	11	0

Note. Describe = *Describe* section of the final assessment task (Maximum score is 8). Issues = *Issues* section of the final assessment task (Maximum score is 16). HLT = *Higher Level Thinking* section of the final assessment task (Maximum score is 24).

Comparison of the key sections of the final assessment task showed that there was a non-significant difference between the groups with respect to the *Describe* section (H (3) = 3.27, p = .35). The difference between the groups with respect to the Issues section (H (3) = 1.45, p = .70) was also non-significant. Finally, there was a non-significant difference between the groups when the scores for the *Higher Order Thinking* section were compared (H (3) = 1.89, p = .60).

4.4.1.4 Correlations between learning outcomes

Spearman's *rho* was used to determine the relationships between learning outcomes in each group due to the non-parametric nature of the data. A correlation of 1.00 indicates that the ranks of the marks in the pre- and post-test (of the same question) were identical. In this case, because students were not required to re-answer the question if they were satisfied with their pre-test answer, it indicates no change in their ranking. A high, significant correlation indicates some deviation in rankings, and therefore from previous answers. When noted *in combination* with a significant increase in the scores (as was reported in the discussion sections throughout the thesis), it indicates that students added to their previous knowledge in order to answer the post-test questions and simply supports the findings of the Wilcoxon Signed-ranks tests. If, however, the value of the correlation was non-significant, then that indicates an area for further investigation, because the ranks in the pre- and post-test are markedly different. In all cases this was used only to indicate areas that may require further inquiry. A large, significant correlation between the pre-test score of one question, and the post-test score of another indicates that a relationship exists between the two. In the case of these occurrences, I discuss the possibility of such a relationship indicating that students who had higher scores in the pre-test were also able to score highly in the post-test in this other question.

Table 4-11: Results of correlations between pre-test scores and learning outcomes in the ABM group

	Environmental and system dynamics pre-test knowledge scores			
	Q5$_{pre}$	Q6$_{pre}$	Q7$_{pre}$	SDK$_{pre}$
Environmental and system dynamics pre-test knowledge scores				
Q5$_{pre}$	--			
Q6$_{pre}$	.73	--		
Q7$_{pre}$	.99**	.74	--	
SDK$_{pre}$	.46	.65	.44	--
Learning outcomes				
Q5$_{post}$	.67	.74	.61	.27
Q5$_{change}$	−.26	.14	−.35	.10
Q6$_{post}$	.65	.94**	.70	.46
Q6$_{change}$	.31	.65	.40	.09
Q7$_{post}$	.93**	.77	.97**	.37
Q7$_{change}$	−.60	−.81	−.58	−.90*
SDK$_{post}$	.05	.09	.04	.83*
SDK$_{change}$	−.13	−.13	.02	−.03
Describe	.49	.73	.50	.88*
Issues	.50	.90*	.51	.87*
HLT	.24	.37	.24	.93**

Note. Q5 = knowledge about introduced animal species. Q6 = knowledge about introduced plant species. Q7 = knowledge about human impacts on an ecosystem and associated timescales. SDK = system dynamics knowledge Describe = *Describe* section of the final assessment task. Issues = *Issues* section of the final assessment task. HLT = *Higher Level Thinking* section of the final assessment task. $_{pre}$ = pre-test score. $_{post}$ = post-test score. $_{change}$ = change in the score between the pre-test and the post-test.

$n = 6$.

$^{*}p < .05$; $^{**}p < .01$.

In the ABM group, students who had a higher pre-test score assessing knowledge about introduced animal species (Question 5) also had a higher pre- and post-test score assessing knowledge of human impacts on the environment and associated timescales (Question 7). Pre-test Question 6 scores (assessing knowledge about introduced plant species) were positively and significantly correlated with: post-test scores for this question; and the *Issues* section of the final assessment task. Similarly, students who had a higher pre-test score assessing knowledge about human impacts on the environment and associated timescales (Question 7) had higher post-test scores for this question.

Pre-test scores assessing knowledge about system dynamics concepts were significantly negatively correlated with the change in the score assessing knowledge of human impacts on the environment and associated timescales (Question 7), and significantly and positively correlated with the post-test score for system dynamics knowledge, and with the three sections of the final assessment task.

Table 4-12: Results of the correlations between learning outcomes in the ABM group

	Learning outcomes										
	$Q5_{post}$	$Q5_{change}$	$Q6_{post}$	$Q6_{change}$	$Q7_{post}$	$Q7_{change}$	SDK_{post}	SDK_{change}	Describe	Issues	HLT
Learning outcomes											
$Q5_{post}$	--										
$Q5_{change}$	.49	--									
$Q6_{post}$	.58	-.07	--								
$Q6_{change}$	.25	-.24	.86*	--							
$Q7_{post}$	.62	-.30	.75	.46	--						
$Q7_{change}$	-.39	.02	-.71	-.44	-.49	--					
SDK_{post}	.38	-.14	.73	.49	.54	-.99**	--				
SDK_{change}	.49	-.48	.43	.27	.85*	-.15	.70*	--			
Describe	.46	.26	.54	.10	.53	-.72	.62	.05	--		
Issues	.52	.26	.78	.45	.52	-.88*	.81*	.03	.90*	--	
HLT	-.06	-.02	.20	-.12	.19	-.71	.62	-.20	.81	.69	--

Note. Q5 = knowledge about introduced animal species. Q6 = knowledge about introduced plant species. Q7 = knowledge about human impacts on an ecosystem and associated timescales. SDK = system dynamics knowledge. Describe = *Describe* section of the final assessment task. Issues = *Issues* section of the final assessment task. HLT = *Higher Level Thinking* section of the final assessment task. $_{\text{post}}$ = post-test score. $_{\text{change}}$ = change in the score between the pre-test and the post-test.

$n = 6$.

$^{*}p < .05$; $^{**}p < .01$.

In the ABM group, students who had a higher post-test score assessing knowledge of introduced plant species (Question 6) had a greater change in this score. The change in the Question 7 score was negatively and significantly correlated with the score for the *Issues* section of the final assessment task.

Students who had a higher post-test score for system dynamics knowledge had a higher change in that score. Students who had a higher score for the *Describe* section of the final assessment task also had a higher score for the *Issues* section.

Table 4-13: Results of correlations between pre-test scores and learning outcomes in the SDM group

	Environmental and system dynamics pre-test knowledge scores			
	$Q5_{pre}$	$Q6_{pre}$	$Q7_{pre}$	SDK_{pre}
Environmental and system dynamics pre-test knowledge scores				
$Q5_{pre}$	--			
$Q6_{pre}$	.84**	--		
$Q7_{pre}$	.41	.55	--	
SDK_{pre}	-.07	-.02	-.32	--
Learning outcomes				
$Q5_{post}$	.40	.34	-.14	.43
$Q5_{change}$	-.40	-.35	-.45	.33
$Q6_{post}$	.20	.57	.29	.21
$Q6_{change}$	-.46	-.10	.09	.25
$Q7_{post}$	.11	.33	.59	-.40
$Q7_{change}$	-.32	-.30	-.64	.21
SDK_{post}	.05	.09	.04	.14
SDK_{change}	-.13	-.13	.02	-.45
Describe	.31	-.04	-.10	-.16
Issues	.20	-.07	.08	.51
HLT	-.05	.01	.39	-.17

Note. Q5 = knowledge about introduced animal species. Q6 = knowledge about introduced plant species. Q7 = knowledge about human impacts on an ecosystem and associated timescales. SDK = system dynamics knowledge. Describe = *Describe* section of the final assessment task. Issues = *Issues* section of the final assessment task. HLT = *Higher Level Thinking* section of the final assessment task. $_{\text{pre}}$ = pre-test score. $_{\text{post}}$ = post-test score. $_{\text{change}}$ = change in the score between the pre-test and the post-test.

$n = 9$.

$^{*}p < .05$; $^{**}p < .01$.

In the SDM group, pre-test scores assessing knowledge about introduced animal and plant species were significantly and positively correlated.

Table 4-14: Results of the correlations between learning outcomes in the SDM group

	Learning outcomes										
	$Q5_{post}$	$Q5_{change}$	$Q6_{post}$	$Q6_{change}$	$Q7_{post}$	$Q7_{change}$	SDK_{post}	SDK_{change}	Describe	Issues	HLT
Learning outcomes											
$Q5_{post}$	--										
$Q5_{change}$	.60	--									
$Q6_{post}$	.47	.08	--								
$Q6_{change}$	.20	.35	$.70^{*}$	--							
$Q7_{post}$	-.32	-.20	.02	-.22	--						
$Q7_{change}$	.30	.61	-.04	-.07	.07	--					
SDK_{post}	-.31	-.08	-.46	-.45	.33	-.14	--				
SDK_{change}	-.34	.10	-.54	-.34	.30	-.45	$.70^{*}$	--			
Describe	.14	.16	-.65	-.61	-.13	-.15	.50	.65	--		
Issues	.51	.34	-.15	.00	-.39	-.20	.07	-.12	.49	--	
HLT	-.03	.15	-.07	.22	.03	-.61	.39	.64	.44	.33	--

Note. Q5 = knowledge about introduced animal species. Q6 = knowledge about introduced plant species. Q7 = knowledge about human impacts on an ecosystem and associated timescales. SDK = system dynamics knowledge. Describe = *Describe* section of the final assessment task. Issues = *Issues* section of the final assessment task. HLT = *Higher Level Thinking* section of the final assessment task. $_{\text{post}}$ = post-test score. $_{\text{change}}$ = change in the score between the pre-test and the post-test.

$n = 9$.

$^{*}p < .05$; $^{**}p < .01$.

In the SDM group, students who had a higher post-test score assessing knowledge of introduced plant species (Question 6) also had a larger change in the score for this question. The change in the system dynamics knowledge score was positively and significantly correlated with the post-test score for this section.

Table 4-15: Results of the correlations between pre-test scores and learning outcomes in the SDM & ABM group

	Environmental and system dynamics pre-test knowledge scores			
	Q5$_{pre}$	Q6$_{pre}$	Q7$_{pre}$	SDK$_{pre}$
Environmental and system dynamics pre-test knowledge scores				
Q5$_{pre}$	--			
Q6$_{pre}$	.67	--		
Q7$_{pre}$	.82*	.75	--	
SDK$_{pre}$	.84*	.54	.86*	--
Learning outcomes				
Q5$_{post}$	.86*	.67	.58	.73
Q5$_{change}$	-.49	-.13	-.67	-.54
Q6$_{post}$	.49	.89*	.48	.22
Q6$_{change}$	-.15	-.22	-.45	-.49
Q7$_{post}$	.38	-.02	.44	.22
Q7$_{change}$	-.69	-.85*	-.67	-.62
SDK$_{post}$	.68	.69	.83*	.74
SDK$_{change}$	-.14	.22	.04	-.22
Describe	.81*	.85*	.93**	.90*
Issues	.68	.76*	.67	.79*
HLT	.86*	.71	.92**	.68

Note. Q5 = knowledge about introduced animal species. Q6 = knowledge about introduced plant species. Q7 = knowledge about human impacts on an ecosystem and associated timescales. SDK = system dynamics knowledge. Describe = *Describe* section of the final assessment task. Issues = *Issues* section of the final assessment task. HLT = *Higher Level Thinking* section of the final assessment task. $_{pre}$ = pre-test score. $_{post}$ = post-test score. $_{change}$ = change in the score between the pre-test and the post-test.

n = 7.

$^{*}p < .05$; $^{**}p < .01$.

Table 4-15 shows that in the SDM & ABM group, pre-test scores assessing knowledge about introduced animal species (Question 5) were significantly and positively correlated with the pre-test score assessing knowledge about human impacts on an ecosystem and associated timescales (Questions 7), and with the pre-test score assessing system dynamics knowledge. Students who had a higher Question 5 pre-test score also had a higher post-test score for this question, and higher scores for the *Describe* and *Higher Level Thinking* sections of the final assessment task. Pre-test scores assessing knowledge of introduced plant species (Question 6) were significantly and positively correlated with the post-test score for this question and the *Describe* and *Issues* sections of the final assessment task; and negatively and significantly correlated with the change in the Question 7 score. Students who had a higher Question 7 pre-test score also had a higher pre-test score assessing system dynamics knowledge, a higher system dynamics post-test score, and higher scores for the *Describe* and *Higher Level Thinking* sections of the final assessment task.

The pre-test score assessing knowledge of system dynamics concepts was positively and significantly correlated with the *Describe* and *Issues* sections of the final assessment task.

Table 4-16: Results of the correlations between learning outcomes in the SDM & ABM group

	Learning outcomes										
	Q5$_{post}$	Q5$_{change}$	Q6$_{post}$	Q6$_{change}$	Q7$_{post}$	Q7$_{change}$	SDK$_{post}$	SDK$_{change}$	Describe	Issues	HLT
Learning outcomes											
Q5$_{post}$	--										
Q5$_{change}$	.00	--									
Q6$_{post}$	.51	.00	--								
Q6$_{change}$	−.03	.37	.14	--							
Q7$_{post}$	−.08	−.82*	.00	.18	--						
Q7$_{change}$	−.83*	.00	−.71	.21	.22	--					
SDK$_{post}$	.43	−.67	.52	−.59	.26	−.62	--				
SDK$_{change}$	−.35	−.28	.39	−.27	.04	.08	.49	--			
Describe	.61	−.58	.72	−.30	.35	−.78*	.90*	.24	--		
Issues	.55	−.41	.82*	−.01	.26	−.75	.79*	.37	.90**	--	
HLT	.60	−.63	.47	−.29	.54	−.50	.68	.00	.81*	.54	--

Note. Q5 = knowledge about introduced animal species. Q6 = knowledge about introduced plant species. Q7 = knowledge about human impacts on an ecosystem and associated timescales. SDK = system dynamics knowledge. Describe = *Describe* section of the final assessment task. Issues = *Issues* section of the final assessment task. HLT = *Higher Level Thinking* section of the final assessment task. $_{post}$ = post-test score. $_{change}$ = change in the score between the pre-test and the post-test.

$n = 7$.

$^{*}p < .05$; $^{**}p < .01$.

In the SDM & ABM group, the post-test score assessing knowledge of introduced animal species (Question 5) was negatively and significantly correlated with the change in the score assessing knowledge of human impacts on an ecosystem and associated timescales (Question 7). Students who had a greater change in their Question 5 score had a lower post-test score for Question 7. The post-test score assessing knowledge of introduced plant species (Question 6) was positively and significantly correlated with the score for the *Issues* section of the final assessment task. The significant correlation between the change in the Question 7 score and the *Describe* section of the final assessment task was negative.

Students who had a higher post-test score assessing system dynamics knowledge also had a higher score for the *Describe* and *Issues* sections of the final assessment task. The *Describe* section of the final assessment task was positively and significantly correlated with the scores for the *Issues* and *Higher Level Thinking* sections.

Table 4-17: Results of the correlations between pre-test scores and learning outcomes in the Text group

	Environmental and system dynamics pre-test knowledge scores			
	$Q5_{pre}$	$Q6_{pre}$	$Q7_{pre}$	SDK_{pre}
Environmental and system dynamics pre-test knowledge scores				
$Q5_{pre}$	--			
$Q6_{pre}$	.72	--		
$Q7_{pre}$	-.46	.24	--	
SDK_{pre}	-.15	.53	$.95^{*}$	--
Learning outcomes				
$Q5_{post}$	.87	.55	-.50	-.24
$Q5_{change}$	.10	-.05	-.46	-.46
$Q6_{post}$	.70	.67	.10	.36
$Q6_{change}$	.10	-.31	-.21	-.21
$Q7_{post}$	-.53	.16	$.97^{**}$	$.89^{*}$
$Q7_{change}$	.46	-.24	-1.00^{**}	$-.95^{*}$
SDK_{post}	.60	$.98^{*}$	.31	.56
SDK_{change}	.05	-.13	-.53	-.55
Describe	-.11	.57	.86	$.92^{*}$
Issues	-.05	.53	.50	.55
HLT	.72	$.92^{*}$	.26	.5

Note. Q5 = knowledge about introduced animal species. Q6 = knowledge about introduced plant species. Q7 = knowledge about human impacts on an ecosystem and associated timescales. SDK = system dynamics knowledge. Describe = *Describe* section of the final assessment task. Issues = *Issues* section of the final assessment task. HLT = *Higher Level Thinking* section of the final assessment task. $_{pre}$ = pre-test score. $_{post}$ = post-test score. $_{change}$ = change in the score between the pre-test and the post-test.

n = 5.

$^{*}p < .05$; $^{**}p < .01$.

As can be seen in Table 4-17, in the Text group, students who had a higher pre-test score for Question 6 also had a higher post-test score for the system dynamics knowledge test. In addition, the significant correlation between the pre-test score assessing knowledge about introduced plant species (Question 6) and the *Higher Level Thinking* section in the final assessment task was positive. Students who had a higher pre-test score assessing knowledge about human impacts on an ecosystem and associated timescales (Question 7) also had a higher system dynamics pre-test score, a higher post-test score for this question and a lower change in the Question 7 score.

The pre-test score assessing system dynamics knowledge was positively and significantly correlated with the post-test score for knowledge about human impacts on the environment and associated timescales (Question 7); the *Describe* section of the final assessment task, and negatively and significantly correlated with the change in the Question 7 score.

Table 4-18: Results of the correlations between learning outcomes in the Text group

	Learning outcomes										
	Q5$_{post}$	Q5$_{change}$	Q6$_{post}$	Q6$_{change}$	Q7$_{post}$	Q7$_{change}$	SDK$_{post}$	SDK$_{change}$	Describe	Issues	HLT
Learning outcomes											
Q5$_{post}$	--										
Q5$_{change}$	.41	--									
Q6$_{post}$	.56	–.50	--								
Q6$_{change}$	.15	–.50	.50	--							
Q7$_{post}$	–.65	–.53	.00	–.26	--						
Q7$_{change}$	.50	.46	–.10	.21	–.97**	--					
SDK$_{post}$	.41	.00	.50	–.50	.26	–.31	--				
SDK$_{change}$	.29	.98**	–.62	–.56	–.54	.53	–.05	--			
Describe	–.34	–.45	.22	–.45	.88*	–.86	.67	–.46	--		
Issues	.00	.41	–.21	–.87	.46	–.50	.67	.37	.63	--	
HLT	.63	–.21	.87	.05	.14	–.26	.82	–.34	.46	.29	--

Note. Q5 = knowledge about introduced animal species. Q6 = knowledge about introduced plant species. Q7 = knowledge about human impacts on an ecosystem and associated timescales. SDK = system dynamics knowledge. Describe = *Describe* section of the final assessment task. Issues = *Issues* section of the final assessment task. HLT = *Higher Level Thinking* section of the final assessment task. $_{\text{post}}$ = post-test score. $_{\text{change}}$ = change in the score between the pre-test and the post-test.

$n = 5$.

$^{*}p < .05$; $^{**}p < .01$.

In the Text group, students who had a greater change in the score assessing their knowledge of introduced animal species (Question 5) also had a greater change in their score for system dynamics knowledge. The post-test score for human impacts on an ecosystem and associated timescales (Question 7) was negatively and significantly correlated with the change in this score and significantly correlated with the *Describe* section of the final assessment task.

4.4.2 Discussion

The guiding hypothesis for this chapter remains: *a system dynamics model is too abstract for high school students, and an additional representation that constrained the interpretation of the model (one that was familiar to the students, such as the animated representation included in the agent-based model) will improve interpretation, and therefore understanding.*

The hypothesis was supported when the overall scores were analysed previously. If this hypothesis continues to be supported by the evidence, students in the SDM group will have few increases in knowledge scores, students in the ABM group will be able to increase scores related to the representational affordance of the animation provided, and the SDM & ABM group will provide students with the benefits of both representations, and allow them to identify the links between the micro and macro levels of understanding. This is because the stock and flow diagram should provide students with a better understanding of the macro level of the system than the graphs in the agent-based model, and the animation should provide students with a better understanding of the micro-level as the animation provides a high level of detail. The control group is important in this discussion, but only briefly. It should be noted that all students were given the text description, and would have been able to achieve similar results if the treatments had no effect on learning outcomes.

The remainder of the discussion focuses on the features of the models that allowed students to learn or not learn about environmental and system dynamics knowledge. Each of the following areas will now be addressed separately: the control group, the affordances of the agent-based model, the affordances of the system dynamics model, and the use of multiple representations.

4.4.2.1 The control group

Students in the Text group increased their knowledge score for all questions except Question 6, assessing knowledge of introduced plant species. The results of the correlations did not help to explain the lack of change in knowledge of introduced plant species. Significant correlations have indicated that prior knowledge played a role in students' interpretation of the text description.

Students in the Text group were able to add to existing knowledge to answer Question 7 (assessing knowledge of human impacts on an ecosystem and associated timescales), and students who had lower prior knowledge for this question had a greater change in their score. Positive significant correlations between the Question 6 pre-test score and the system dynamics knowledge post-test score suggest that prior knowledge about introduced plant species allowed students to learn about system dynamics knowledge. In addition, the correlation between the Question 6 and the system dynamics knowledge pre-test scores was non-significant, which suggests that the materials did have an effect on this relationship. The change in the system dynamics knowledge score was positively and significantly correlated with the change in the Question 5 score. It may be that students who concentrated on learning about introduced animal species were also able to learn about system dynamics concepts.

Understanding of the system in the Text group involved both prior knowledge and that which was learned from the materials. The *Describe* section of the final assessment task was positively correlated with prior knowledge about system dynamics concepts, and the post-test score assessing knowledge of human impacts on an ecosystem and associated timescales (Question 7). Investigation of the answers supported the correlation, and showed that students did use their prior knowledge of systems concepts and learned knowledge of impacts of humans on an ecosystem to describe what happened in the park. The *Higher Level Thinking* score was positively correlated with the pre-test score assessing knowledge of introduced plant species (Question 6). Despite the significant correlation, students did not include information about introduced plant species in their answers. Nevertheless, examination of the answers showed that students identified appropriate management decisions and predictions, including the effects of competition between introduced and native animals. Most decisions suggested by students focused on the provision of bins to reduce visible litter, rather than a reduction of the waste itself, which reflects the findings of other studies that have examined students' abilities to solve waste management issues (Palmberg & Kuru, 2000). However, other suggestions included killing feral animals and increasing the cost of entering the park to dissuade visitors from coming.

Students in the control group were able to increase knowledge scores for every question examined except that addressing knowledge about introduced plant species. Prior knowledge was used in addition to the materials in order to answer post-test questions and to understand the system. If access to a system dynamics model, agent-based model, or both has no effect on students' environmental knowledge, system dynamics knowledge, or understanding of the materials, then the results of the following sections would be expected to reflect those found in the control group.

4.4.2.2 The agent-based model

Given previous research conducted in the fields of learning from agent-based models and learning from animations, it has been predicted that students in the ABM group would learn about those areas that are distinctive in the animation used in the agent-based model. Subjects tend to be attracted to the information generated by the features in the animation that actually change in a contrasted way to the rest of the display (Lowe, 2003, 2004). In particular, this involved Question 5 (knowledge about introduced animal species), because *rats* are used to represent introduced animal species and are visible in the animated representation. While one of the advantages of learning from an agent-based model is to be able to link the behaviour of individuals to system-level effects, this is also a challenge for the learner. If this is the case in this study, then it would be expected that students would not have increased their scores for Question 7, which requires an application of knowledge specific to the system modelled, to another system.

4.4.2.2.1 Affordances of the agent-based model

Students in the ABM group were able to significantly increase their knowledge of introduced animal and plant species (large effect sizes were associated with each comparison), and a large effect size was associated with a non-significant increase in the system dynamics knowledge score. The hypothesis proposed suggested that the animation used in the agent-based model would particularly influence students to learn about introduced animal species because of the visual representation of the introduced animal species (rats) used in the animation (Lowe, 2003, 2004). The correlations between the post-test score for Question 5 (assessing knowledge of introduced animal species) and other learning outcomes were non-significant in the ABM group. It was expected that the pre-test score would be significantly correlated with the post-test score, as students were given the opportunity to add to their pre-test answers in the post-test. A correlation of 1.00 indicates that the ranks of the marks in the pre- and post-test (of the same question) were identical. In this case, because students were not required to re-answer the question if they were satisfied with their pre-test answer, it indicates no change in their ranking. A high, significant correlation indicates some deviation in rankings, and therefore from previous answers. When noted *in combination* with a significant increase in the scores (as was reported in the discussion sections throughout the thesis), it indicates that students added to their previous knowledge in order to answer the post-test questions and simply supports the findings of the Wilcoxon Signed-ranks tests. If, however, the value of the correlation was non-significant, then that indicates an area for further investigation, because the ranks in the pre- and post-test are markedly different. The non-significant correlations between the pre-test score and the post-test score suggest that an increase in the score for Question 5 was related to the learning materials.

Comparisons of the score assessing knowledge of introduced plant species (Question 6) between and within groups indicated that the agent-based model provided materials that allowed students to increase their score. Correlations showed that in the ABM group, the pre-test score for Question 6 and the post-test score were significantly positively correlated, as expected. In addition, students who had a higher post-test score also had a higher change in their score. Students in the control group did not increase their score for this question. It may be that the agent-based model helped students to add to existing knowledge in order to increase their score, while the other representations did not. Further investigation of the relationships between this learning outcome and how the models were used, in the following chapter, examines this further.

Students in the ABM group increased their system dynamics knowledge score between the pre- and post-test. Significant correlations suggest that prior knowledge about the domain as well as system dynamics knowledge were related to the post-test score. In particular, the role of knowledge about human impacts on an ecosystem and associated timescales (which involved application of knowledge learned from the materials to another ecosystem) is unclear. The results suggest that students who had a large change in their system dynamics concepts score also had a large change in their score for Question 7, however students who had a higher post-test system dynamics knowledge score had a lower change in their score for Question 7. It may be that they either had a higher post-test system dynamics knowledge score, or they increased their score for Question 7 (assessing knowledge of human impacts on an ecosystem and associated timescales), and as shown in the comparisons between the pre- and post-test scores, they increased their knowledge of system dynamics concepts. The way in which the model was used may explain why this relationship between the learning outcomes was present.

4.4.2.2.2 *Limitations of the agent-based model*

Students in the ABM group did not increase the score associated with applying the information presented in the materials to another situation (Question 7). This supports the finding of (Levy, Kim, & Wilensky, 2004) who showed that students were able to describe both macroscopic and microscopic behaviour of a system in chemistry, but unable to relate the two levels to each other. Question 7 assessed knowledge of the environmental impacts and respective timescales associated with building a road, littering and bushwalking. It may be that students who only used the agent-based model were unable to connect their specific domain knowledge (in which they did increase their scores as discussed above) to reality. Further investigation into any relationships between these learning outcomes and the ways in which the model was used will be presented in the following chapter.

4.4.2.2.3 *Understanding the system with the agent-based model*

Students who had higher pre-test system dynamics knowledge scores also had higher scores for the *Describe* section of the final assessment task. However, investigation of other learning outcomes has shown that students in this group were unable to apply knowledge learned from the materials to other systems. In order to understand the system modelled, and score highly on those sections assessing understanding, they needed to have a complete mental model. The *Describe* section of the final assessment task includes two questions: one asking students to describe what happens in the park; the other asking students to describe the park, in terms of visual features. Examination of students' answers showed that they concentrated on describing what happened in the model rather than describing the park itself. It is possible that students did not provide a description of the park because this was done by the animation.

The *Issues* section of the final assessment task assessed students' ability to identify the main issues addressed in the learning materials, both management and environmental. Students who had a higher pre-test system dynamics knowledge score also had a higher score for the *Issues* section of the final assessment task. Students who were able to identify management and environmental issues identified links between environmental and system dynamics knowledge, links between their knowledge of the system and the real world. Significant correlations showed that students who had higher scores for the *Issues* section also had higher scores for Questions 5 and 6 (knowledge of introduced animal and plant species) and the system dynamics knowledge test, and also had a higher score for the *Describe* section of the final assessment task. Students who had higher scores for the *Issues* section also had a lower change in their score assessing knowledge about human impacts on an ecosystem and associated timescales (Question 7), in which the group as a whole did not increase their score. Students in the ABM group had a statistically similar score to students in other groups. This suggests that students were able to link their knowledge the environment and system dynamics in the context of the system modelled, however students were not able to apply this knowledge to another ecosystem.

The *Higher Level Thinking* section of the final assessment task includes the answers to three questions asking students to outline decisions they would make as managers of the park, make a prediction about what would happen next if the model was more detailed, and identify any consequences of decisions made. In the ABM group the significant correlation between the pre-test score assessing applied system dynamics knowledge and the score for the *Higher Level Thinking* section of the final assessment task indicates that students in this group who had a higher score for this section may have already been able to identify whole system concepts. When students' answers were investigated further, it was seen that students who scored highly in making predictions included phrases such as "the natural cycle of the ecosystem will be interrupted", mention the effects on tourism and made the connection between increased nutrients and plants growing. Further investigation of the effects of the use of the model on learning outcomes may help to explain this finding.

4.4.2.3 The System dynamics model

Very little empirical work has been done examining what and how students learn from interrogating a system dynamics model. Many studies have identified issues concerned with students' ability to use system dynamics models to manage an environmental system (Booth Sweeney & Sterman, 2000; Diehl & Sterman, 1995; Kainz & Ossimitz, 2002; Moxnes, 2004). System dynamics models are useful for conceptual understanding (Wakeland et al., 2004), and they establish a link between the system structure and the system behaviour (Schieritz & Milling, 2003). Students have been shown to improve understanding of the scientific concepts underlying modelling, rather than their ability to interpret the models after a long-term intervention (Maryland Virtual High School, 2001). However, the high cognitive load involved in interpreting the abstract, scientific diagram may result in small learning gains (Lowe, 1993; Sweller & Chandler, 1994). Prior knowledge of the domain and system dynamics modelling was found to be important in *model-building* activities in high school students (Sins, Savelsbergh, & van Joolingen, 2005), and for interpreting representations (Lowe (1993)). As a result of this research, it could be predicted that students would increase their score for the system dynamics knowledge score due to their exposure to a system dynamics model. However, no change in environmental knowledge scores were expected, due to the high cognitive load associated with making sense of the stock and flow diagram.

4.4.2.3.1 Affordances of the system dynamics model

Students in the SDM group did not increase knowledge scores for environmental or system dynamics knowledge. Significant correlations showed that a large post-test score was indicative of a large change in the system dynamics knowledge score. The hypothesis that the representational affordance of the system dynamics model would result in an increase in system dynamics knowledge was not supported by these results. Further examination of relationships between this learning outcome and the way in which the model was used may explain this further.

4.4.2.3.2 Limitations of the system dynamics model

Students in the SDM group did not increase their score for any environmental knowledge question or system dynamics knowledge test. In a number of cases (knowledge about introduced animal species, about human impacts on an ecosystem and associated timescales, and system dynamics knowledge), students in the control group did increase their score. This indicates that the treatment had a negative effect on students' ability to increase their scores for these questions. Significant correlations indicated that students using the system dynamics model were not able to link their prior knowledge of the domain to interpret the representation. In the following chapter, the relationships between students' prior knowledge and the ways in which students used the model will be examined, and this may help to explain why the SDM group did not increase their environmental knowledge scores.

4.4.2.3.3 Understanding the system with a system dynamics model

Analysis of the knowledge tests showed that students in the SDM group did not increase their score for any knowledge test; however they had statistically similar final assessment task scores to students in the other groups. It was previously suggested that the system dynamics model provided students with a structure to describe what happened and the freedom to imagine what the national park looked like. Further investigation of students' answers showed that there was a mixture of both describing the park and identifying what happened in the model. Students in the SDM group could visualize a real situation and interpret the materials. However, they did not relate this to the environmental knowledge questions. Investigation of answers to the *Describe* section showed that one student mentioned “pests” another “animals” but most concentrated on the inorganic waste and the time delay associated with the accumulation of nutrients. It may be that students were examining the graphs rather than the stock and flow diagram. This is particularly important given the non-significant changes in environmental knowledge scores. This indicates that students were engaged and could interpret the system dynamics model. It may be that the cognitive load associated with interpreting the new representation was too high to allow students to relate this to the environmental knowledge questions.

4.4.2.4 Multiple representations

Providing or generating multiple external representations are well-researched strategies for understanding complex systems. Advantages include capturing the learners’ interest and providing an authentic learning environment for students (1999b; Kozma et al., 2000). 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). There are challenges involved with using multiple external representations. These include students changing their usual problem solving processes to accommodate the representation, resulting in further errors ((Tabachneck-)Schijf & Simon, 1998); and the high cognitive load associated with the coordination of information from different representations can be a major cost to learners of using multiple representations (Bodemer et al., 2004; de Jong et al., 1998). Regardless of cognitive load, some students still fail to coordinate between multiple representations (Ainsworth et al., 1998).

In particular, one strong advantage of using both an agent-based and system dynamics model may be to help students to be able to think of the two levels that are modelled at the same time (Schieritz & Milling, 2003). The addition of the alternate model may also overcome problems observed with learning with both types of model – such as making links between levels in the agent-based model and interpreting a new representation in the system dynamics model. The multiple representations of the models should *constrain* students’ understanding by providing a combination of a familiar representation and an authentic, scientific system view representation.

The research suggests that students in the SDM & ABM group will increase their knowledge scores for Question 5 and 6 (knowledge about introduced animal and plant species, as did students in the ABM group) and for the system dynamics knowledge test. It is also predicted that students given both models will be able to identify links between knowledge learned about the system studied and other systems. Therefore, students in the SDM & ABM group would increase their score for

Questions 7. Given these additional links identifiable by students in this group, and not in other groups, it is also predicted that students given both models would have a greater score assessing their understanding of the system, for all three measures (describing the system, identifying the issues, and engaging in higher level thinking).

4.4.2.4.1 Affordances of multiple representations

Students in the SDM & ABM group increased their score assessing knowledge of introduced animal and plant species, as students did in the ABM group. Significant correlations suggest that the increase in knowledge about introduced animal species was due to prior knowledge of this topic. Prior knowledge was also related to the post-test score assessing knowledge about introduced plant species in both the ABM group and the SDM & ABM group. It may be that the agent-based model helped students to add to existing knowledge in order to increase their score, while the other representations did not. It should be noted that students in the control group did not increase their Question 6 score, which suggests that the ABM and SDM & ABM groups allowed students to increase their knowledge about introduced plant species that the text description did not allow. Further investigation of the relationships between these learning outcome and how the models were used, in the following chapter, may confirm whether students used the agent-based model to increase their score for these two questions.

Students in the SDM & ABM group increased the score assessing knowledge of human impacts on an ecosystem and associated timescales. Question 7 gave students the opportunity to use knowledge about introduced animal and plant species and apply it to impacts other than those described in the learning materials. Students in the ABM group and in the SDM group did not increase their scores for this question. It may be that students in the SDM & ABM group, because they were required to make connections between the representations, were better able to make connections between the representation and the real world. There was a significant negative correlation between the change in the Question 5 score and the post-test Question 7 score, however students in the SDM & ABM group increased both scores. The negative relationship between the scores suggests that other factors may be involved. In addition, the change in the Question 7 score was negatively and significantly correlated with the pre-test score assessing knowledge about introduced plant species (Question 6), and with the pre-test score assessing knowledge about system dynamics concepts. These results support the findings of the overall scores, that students with lower prior knowledge about the environment had a larger increase in their environmental knowledge score. As in the ABM group, prior knowledge may have guided students in their interrogation of the model(s), and further investigation in the following chapter may explain this result further.

Students in this group increased the score for both the applied environmental knowledge and system dynamics knowledge questions between the pre- and post-tests. It may be that the use of the two models will explain any relationship between the two questions, and that a representational preference resulted in different knowledge learned.

4.4.2.4.2 Limitations of multiple representations

Students in the SDM & ABM group increased their knowledge scores for all measures, unlike either of the single model user groups. It may also be that the models were used differently when the groups are compared. Further investigation of the relationships between the ways in which the models were used and this learning outcome will be reported in the following chapter.

4.4.2.4.3 Understanding the system using multiple representations

Students in the SDM & ABM group increased their environmental knowledge scores and could identify links between different levels of knowledge; however the score measuring understanding of the system was statistically similar to other groups. Investigation of students' responses to the *Describe* section of the final assessment task showed that, similar to those found in the ABM group, students were able to describe what happened in the model rather than describe the park. The significant correlations suggest that students who had higher prior knowledge about topics that could be learned directly from the model, and who had learned about system dynamics concepts, were able to make sense of what happened in the model.

Despite the positive and significant correlation between the score for the *Issues* section and the pre- and post-test score assessing knowledge about introduced plant species (Question 6), students did not mention the link between nutrients in the environment and introduced plant species. Students mainly discussed introduced animal species, and focused on the issues that affected whole system. Answers included reference to visitors and their impact, animal proofing bins or just providing more bins. The significant correlation between the *Describe* section of the final assessment task and the *Issues* section, and between the post-test score assessing system dynamics knowledge and the *Issues* section suggests that students who were able to outline the process of what happened in the model identified visitors in the park as the main issue. Thus far, the main focus of the benefits of the animated representation has been on directing students' attention to the visual representation of the introduced animal species (rats), and the relationship between this and performance on the question assessing knowledge about introduced animal species (Lowe, 2003, 2004). The visitors in the park were the other main feature of the representation. Further analysis of the relationships between this learning outcome and students' use of the model may help to explain this further.

In order to make decisions, predictions and identify the consequences of these, students used prior knowledge of introduced animal species, and impacts of humans on the environment. Examination of students' answers supports this result. Students in the SDM & ABM group gave detailed information that was not drawn from the materials. Students identified consequences such as increased nutrients resulting in introduced plant species, and competition between feral and native animals. Students also identified the elements that were not an issue, such as the accumulation of inorganic waste. Students' answers focused on the reduction of littering (through the use of compost bins or animal-proof bins), rather than the reduction of waste products (such as visitors taking the waste with them when they leave). This supports findings from other studies that have examined students' abilities to solve waste management issues (Palmberg & Kuru, 2000). The score for the *Higher Level Thinking* section was also positively and significantly correlated with the *Describe* section of the final assessment task. It may be that the process of describing what happened in the model, allowed students to make appropriate decisions and predictions.

4.5 CONCLUSION

The results presented in this chapter served a number of purposes. The first was to support the hypothesis that multiple representations are an appropriate strategy to learn about a complex socio-environmental system. This was supported in terms of environmental knowledge, and to some extent, system dynamics knowledge, but not understanding of the socio-environmental system.

Further investigation has revealed that multiple representations allowed students to learn environmental knowledge that came directly from the learning materials (as was done by the ABM group), and to apply this knowledge to another ecosystem (which was not achieved by students given either of the single models). The correlations between learning outcomes and prior knowledge showed that both prior knowledge and the representation play a role in this. This supports other research that shows that learner characteristics as well as the representations themselves play a role in students' ability to learn from multiple representations (Ainsworth et al., 1998). In general, these results suggest that the group using multiple representations was successful because certain information was better presented using a particular style of representation (for example, the animation) (de Jong et al., 1998), because the links between the representations could be easily seen (for example, apply environmental knowledge to another ecosystem) (Wisnudel Spitulnik, Stratford, Krajcik, & Soloway, 1998), and because they provided learners with the choice of how they wished to learn (Ainsworth, 1999a; Savelsbergh et al., 1998). A number of negative correlations between learning outcomes suggested that students were not able to learn everything. Further investigation of the use of the models may explain whether this is a result of cognitive load (van der Meij & de Jong, 2006) or user preference (Ainsworth, 1999a).

Findings with regards to learning outcomes associated with the use of the agent-based model (such as specific environmental knowledge and understanding) supports the current literature related to learning from animations (Lowe, 2003, 2004) and relating information at different levels (Levy et al., 2004). There is little research about learning with system dynamics models, however these preliminary findings support research that suggests that the knowledge of system dynamics concepts may be important in interpreting stock and flow diagrams (Maryland Virtual High School, 2001), and that the cognitive load associated with learning from a new, abstract, scientific diagram is high, and students may be unable to also engage in relating this to specific knowledge arising from the model (Lowe, 1993). Conclusions made about the representational affordances of the agent-based model and the system dynamics model will be explored in the following chapter, which will report on analyses of data examining the use of the models.

5. USE OF THE MODELS

5.1 RATIONALE

The process that students use to interrogate a model may affect what they learn from the model; however there is little research that examines this process. Patterns of students' use of the models, as well as the preferences that students had with respect to the representations they used when given the choice, may aid in understanding differences in learning outcomes, and may be useful in general because there is little information about user preferences in interrogating multiple external representations (Van Labeke & Ainsworth, 2002).

Findings from the previous chapter indicated that some learning outcomes were not related to prior knowledge. In a number of these cases, previous research conducted in the fields of learning from animations and learning from agent-based models (for example, (Lowe, 2003, 2004)) and learning from abstract diagrams (for example, (Schieritz & Milling, 2003; Wakeland, Macovsky, Gallaher, & Aktipis, 2004)) resulted in the prediction that the representation itself encouraged learning about a particular area. For example, it has been predicted that students in the ABM group would learn about those areas that are distinctive in the animation used in the agent-based model. Subjects tend to be attracted to the information generated by the features in the animation that actually change in a contrasted way to the rest of the display (Lowe, 2003, 2004). In particular, this involved Question 5 (knowledge about introduced animal species), because *rats* are used to represent introduced animal species and are visible in the animated representation. This may allow students who have access to the agent-based model to increase the score associated with this learning outcome.

Levy and Wilensky (2005) classified styles of interrogating an agent-based model, and related these styles to learning outcomes. Further investigation into user preference and strategies used in this study will help to understand why the differences in learning outcomes between groups reported in Chapter 4 were the case, and will provide much needed research in this field.

5.2 EXPLORATORY QUESTIONS AND BRIEF INTRODUCTION TO THE CHAPTER

This chapter will address the following exploratory questions:

E1a: Despite the differences in the patterns of use due to the different run times of the agent-based and system dynamics models, will students be engaged and use the experiment screen more than other screens?

E1b: If students used the agent-based model to constrain interpretation of the system dynamics model then this will be reflected in their use of the models, and students will use the system dynamics model more than the agent-based model.

E1c: Will the use of the model be related to learning outcomes, particularly those with which prior knowledge had no relationship?

E1d: Are the strategies used to interrogate the models dependent on the models used?

The experiment compared measures of the use of the models (proportion of time spent on screens, activities, strategies used to change variables) from students randomly allocated to three groups: the SDM group, in which students were given a system dynamics model to examine, the ABM group, in which students were given an agent-based model of the system, or the SDM & ABM group, in which students were given both models. The sample size is smaller for each group included in this chapter because not all screen shots were successfully collected. In the ABM group $n = 5$, in the SDM group $n = 7$, and in the SDM & ABM group $n = 6$.

Three screens on the system dynamics model were included in the analysis: the *information* screen, the *explore the model* screen, and the *experiment* screen. The agent-based model had two screens that were analysed, the *information* screen and the *experiment* screen. The proportion of time spent *off task* was also calculated for each model. The activities that were analysed were the number of times each variable was changed, the number of times the model was run, and the total activity was recorded. The variables that could be changed were the *number of pieces of rubbish* each person left (Npr), the *proportion of rubbish collected* by the garbage collection person (Prc), and the *garbage collection time* (Gct), these variables will only be analysed with regards to the strategies, and not with regards to user preference. Others that were particular to the system dynamics model included: explore the model step by step (SbS), explore the model in full (IF), and selection of the "ideas" option (a more detailed explanation of each of these screens can be found in Chapter 3). The Total Activity included all of the above, as well as other activities not discussed in these results. Video screen shots were collected and coded with respect to times, activities and screens. Users' strategies were classified using the same parameters as Levy and Wilensky (2005) (refer to the Methods section for further discussion of the parameters used), and some additional parameters are also suggested. When the strategies were analysed, the amount of time as well as the proportion of time spent on screens was compared between strategies.

For a full discussion of the analyses performed, refer to Chapter 3. In brief, the results of analyses carried out on the general measures of use of the model will be compared between all three groups and within groups to determine whether there is a general pattern to the use of the models (*E1a*). The use of single models will then be compared to the use of the same type of model when an additional model is available (for example the use of the model by the ABM group will be compared to the use of the model in the SDM & ABM group). This will help to determine whether students used the agent-based model to constrain their interpretation of the system dynamics model (Ainsworth, 1999b). If this was the case, students would have used the system dynamics model to experiment with, and the agent-based model for context. Students in the SDM & ABM group would have a similar level of activity as those in the SDM group (*E1b*).

The second section will report on the significant correlations between measures of the use of the model and learning outcomes. It was suggested in Chapter 4 that the use of the model should be investigated specifically for those learning outcomes for which prior knowledge played no part. These scores were: knowledge of introduced animal species in the ABM group, knowledge about introduced animal species, introduced plant species, human impacts on an ecosystem and associated timescales, and system dynamics knowledge and the *Issues* and *Higher Level Thinking* sections of the final assessment task in the SDM group; and knowledge about system dynamics concepts in the SDM & ABM group (*E1c*).

The final section will identify the strategies used by students to interrogate the models overall and to change individual variables. Relationships between these strategies and the general measures of use of the models will help to define the classification system. An analysis of the relationships between learning outcomes and the strategies used will help to explain why students adopted particular strategies, and what effect these had on their learning outcomes (*E1d*).

5.3 PATTERNS OF USE AND USER PREFERENCE

5.3.1 Results

Results regarding general patterns of use and user preference will be discussed in this section. The proportion of time spent on each screen (*experiment, information* and *off task*) and the frequency of activities performed (including running the model, changing variables, and the total activity) common to the agent-based model and the system dynamics model will be compared between the groups using Kruskal-Wallis tests. The proportion of time, and the frequency of changes made to the three variables will then be compared within each group using Friedman's ANOVA and Mann Whitney tests post-hoc. User preference will then be explored by comparing the use of the single models with the use of both models using Mann Whitney tests. Due to the small sample size, large effect sizes were taken into account in addition to significance, and are noted where appropriate. Spearman's *rho* was used to determine the relationships between the measures of the use of the model in each group due to the non-parametric nature of the data.

5.3.1.1 Patterns of use

Patterns of use were compared to determine whether the representation had an effect on the way in which the models were used. The *experiment* screen is the screen on which the animation and the stock and flow diagrams are located, and the screen on which students interact with the models. The *information* screen contains the text description which is given to each group. The proportion of time spent *off task* is the time that was noticeably spent not on task (for example, moving the mouse off the main model screen to examine menu items in the list below, or opening files not pertaining to the materials). Other screens were accessible however they were not common to both models, are not relevant to this study, and are not reported here (more details on these can be found in Chapter 3).

The activities performed on the models that were common to both models were pressing 'go' (running the model), and the total activity (the sum of all activities including those not reported in this thesis).

Table 5-1: Medians and ranges of the proportion of time spent on each screen and activities

		Range	
Group	*Mdn*	Lower	Upper
ABM			
Exp	79	47	87
Inf	12	0	32
OT	6	0	30
Go	5	1	9
TA	25	11	28
SDM			
Exp	57	29	72
Inf	19	11	40
OT	3	0	30
Go	9	2	26
TA	36	17	65
SDM & ABM[a]			
Exp	67	46	79
Inf	28	9	33
OT	2	0	6
Go	9	1	16
TA	30	8	40

Note. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. OT = proportion of time spent *off task*. Go = number of times the model was run. TA = total activity.

[a] two models combined

Kruskal-Wallis tests showed that there were non-significant differences between the groups in terms of the proportion of time spent on the *experiment* screen (H (2) = 3.29, p = .19); the *information* screen (H (2) = 0.91, p = .64); and *off task* (H (2) = 2.13, p = .35). There were also non-significant differences between the groups in terms of the number of times the models were run (H (2) = 1.47, p = .48), and the total activity (H (2) = 3.69, p = .16).

Friedman's ANOVA was used to compare the use of the model within each group. There was a significant difference between the proportions of time spent on each screen in the ABM group ($\chi^2(2) = 7.60$, $p = .02$); and in the SDM group ($\chi^2(2) = 8.00$, $p = .02$). There was a significant difference between the proportions of time spent on the three screens in the SDM & ABM group with the models combined ($\chi^2(2) = 12.00$, $p = .002$); with the use of the agent-based model ($\chi^2(2) = 6.00$, $p = .05$); and with the use of the system dynamics model in this group ($\chi^2(2) = 5.44$, $p = .07$). Wilcoxon signed-rank tests were conducted as post-hoc tests to compare the proportion of time spent on each screen.

Table 5-2: Results of the Wilcoxon signed-rank tests to compare the proportions of time spent on each screen in each group

	Exp vs. Inf	Exp vs. OT	Inf vs. OT
	T	*T*	*T*
ABM group	**0.0***	**0.0***	5.0
SDM group	**0.0***	**1.0***	**3.0**^{a}
SDM & ABM group			
System dynamics model	3.0	**0.0**^{a}	**0.0**^{a}
Agent-based model	**3.0***	**0.0**^{a}	**1.0**
Models combined	**0.0***	**0.0***	**0.0***

Note. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. OT = proportion of time spent *off task*. Bold typeface indicates a large effect size ($r >= | .50 |$).

$^{a}p < .10$. $^{*}p < .05$.

Table 5-1 and Table 5-2 show that in the ABM group, the proportion of time spent on the *experiment* screen was higher than that spent on the *information* screen and higher than the proportion of time spent *off task*. The proportions of time spent on the *information* screen and *off task* were statistically similar.

In the SDM group, the proportion of time spent on the *experiment* screen was higher than that spent on the *information* screen and that spent *off task*. Students also spent a higher proportion of time on the *information* screen than they spent *off task*.

In the SDM & ABM group, the proportion of time spent on the *experiment* screen on the agent-based model was higher than the proportion of time spent on the *information* screen on this model, and higher than the proportion of time spent *off task* on the agent-based model. The proportion of time spent on the *experiment* screen on the system dynamics model was higher than the proportion of time spent *off task*, and statistically similar to the proportion of time spent on the *information* screen. Students also spent a higher proportion of time on the *information* screen on the system dynamics model than they spent *off task*.

When the use of the models was combined for the SDM & ABM group, the results show that students spent a higher proportion of time on *an* experiment screen than they spent on *an* information screen which was in turn higher than the proportion of time they spent *off task*.

Spearman's *rho* was used to determine the relationships between the measures of the use of the model in each group due to the non-parametric nature of the data. A correlation of 1.00 indicates that the ranks of the measures of use were identical. A high, significant correlation indicates some deviation in rankings. In all cases this was used only to indicate areas that may require further inquiry.

Table 5-3: Results the correlations comparing the use of the model in the ABM group

Use of the model	Proportion of time spent on each screen			Activity	
	Exp	Inf	OT	Go	TA
Proportion of time spent on each screen					
Exp	--				
Inf	-.70	--			
OT	-.50	-.20	--		
Activity					
Go	.50	-.90*	.50	--	
TA	.80	-.70	-.20	--	--

Note. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. OT = proportion of time spent *off task*. Go = number of times the model was run. TA = total activity.

$n = 5$.

$^{*}p < .05$.

Table 5-3 shows that students who spent a higher proportion of time on the *information* screen ran the model less often.

Table 5-4: Results of the correlations comparing the use of the model in the SDM group

Use of the model	Proportion of time spent on each screen				Activity				
	Exp	Inf	ETM	OT	Go	IF	SbS	Ideas	TA
Proportion of time spent on each screen									
Exp	--								
Inf	-.61	--							
ETM	-.32	-.46	--						
OT	.00	.16	-.38	--					
Activity									
Go	.78*	-.63	-.09	.06	--				
IF	.14	-.32	-.06	-.31	.06	--			
SbS	--	--	--	--	--	--	--		
Ideas	.42	-.80*	.26	-.36	.39	.74	--	--	
TA	.75	-.64	-.04	.13	--	--	--	--	--

Note. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. ETM = proportion of time spent on the *explore the model* screen. OT = proportion of time spent *off task*. Go = number of times the model was run. SbS = number of times explore the model step by step was selected. IF = number of times explore the model in full was selected. Ideas = number of times the ideas option was selected. TA = total activity.

$n = 7$.

$^{*}p < .05$.

Table 5-4 shows that in the SDM group, students who spent a higher proportion of time on the *experiment* screen ran the model more often. Students who spent a higher proportion of time on the *information* screen selected the ideas option less often.

Table 5-5: Results of the correlations comparing the use of the agent-based model in the SDM & ABM group

Use of the model	Proportion of time spent on each screen			Activity	
	Exp	Inf	OT	Go	TA
Proportion of time spent on each screen					
Exp	--				
Inf	.27	--			
OT	.68	-.11	--		
Activity					
Go	.68	-.10	.66	--	
TA	.52	.09	.55	--	--

Note. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. OT = proportion of time spent *off task*. Go = number of times the model was run. TA = total activity.

n = 6.

Table 5-5 shows that there were no significant correlations between measures of use of the agent-based model by the SDM & ABM group.

Table 5-6: Results of the correlations comparing the use of the model in the SDM & ABM group – system dynamics model only

Use of the model	Proportion of time spent on each screen				Activity				
	Exp	Inf	ETM	OT	Go	IF	SbS	Ideas	TA
Proportion of time spent on each screen									
Exp	--								
Inf	.63	--							
ETM	.19	.47	--						
OT	.38	.86*	.14	--					
Activity									
Go	.94**	.69	.25	.55	--				
IF	--	--	--	--	--	--	--		
SbS	.58	.81*	.81*	.58	.71	--	--		
Ideas	.81*	.58	.11	.58	.94**	--	.58	--	
TA	.93**	.73	.38	.54	--	--	--	--	--

Note. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. ETM = proportion of time spent on the *explore the model* screens. OT = proportion of time spent *off task*. Go = number of times the model was run. IF = number of times explore the model in full was selected. SbS = number of times explore the model step by step was selected. Ideas = number of times the ideas option was selected. TA = total activity.

$n = 6$.

$^{*}p < .05$; $^{**}p < .01$.

Table 5-6 shows that in the SDM & ABM group, students who spent a greater proportion of time on the system dynamics model *experiment* screen ran this model more often, selected the ideas option more often, and had greater total activity on the system dynamics model. Students who spent a greater proportion of their time on the *information* also spent a greater proportion of time *off task* and selected the explore the model step by step option more often. Students who spent a greater proportion of their time on the *explore the model* screen elected to explore the model step by step more often.

Students in the SDM & ABM group, who ran the system dynamics model more often selected the ideas option more often in this model.

Table 5-7: Results of comparing the combined use of the models in the SDM & ABM group

Use of the model	Proportion of time spent on each screen				Activity	
	SDM	Exp	Inf	OT	Go	TA
Proportion of time spent on each screen						
SDM	--					
Exp	.09	--				
Inf	-.31	-.60	--			
OT	.23	-.75	.03	--		
Activity						
Go	.89*	-.09	-.03	.38	--	
TA	.89*	-.09	-.03	.38	--	--

Note. SDM = proportion of time spent on the system dynamics model. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. OT = proportion of time spent *off task*. Go = number of times the model was run. TA = total activity.

$n = 6$.

$^{*}p < .05$.

Table 5-7 shows that students who spent a greater proportion of time with the system dynamics model ran *a* model more often overall, and had a greater total activity.

5.3.1.2 User preference

User preference was examined by comparing use of the model by the ABM group with the use of the agent-based model by the SDM & ABM group and similarly for the system dynamics model. Mann

Whitney tests were used to do this. Spearman’s *rho* was used to determine the relationships between the measures of the use of the model in each group due to the non-parametric nature of the data. Significant positive correlations between measures of use will indicate the rankings of the measures of use were identical. An example of such a relationship is a positive, significant correlation between the *experiment* screen and ‘go’ would indicate that students who spent a higher proportion of time on the *experiment* screen ran the model more often. Negative significant correlations will suggest screens and activities about which, a choice was made by users. An example of such a relationship is a negative, significant correlation between the proportion of time spent *off task* and the change in the Question 5 score would indicate that students who chose to spend a larger proportion of time *off task* did not increase their score for this question. Investigation of the correlations between screens and activities will provide information in addition to the direct comparisons, about user preference with regards to using the models. In addition to the measures discussed in the previous section, an additional screen (*explore the model*) and activities (explore the model in full, explore the model step by step, and the ideas option) are included in these analyses as they are available on the system dynamics model.

Table 5-8: Medians and ranges of the proportion of time spent on each screen and the activities performed by the SDM & ABM group

	Agent-based model			System dynamics model		
		Range			Range	
Use	*Mdn*	Lower	Upper	*Mdn*	Lower	Upper
Screen						
Exp	45	0	69	15	0	79
Inf	8	0	33	10	0	32
ETM	--	--	--	7	0	17
OT	0	0	3	0	0	6
Activity						
Go	2	0	3	6	0	16
IF	--	--	--	0	0	0
SbS	--	--	--	1	0	2
Ideas	--	--	--	1	0	2
TA	9	0	15	17	0	40

Note. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. ETM = proportion of time spent on the *explore the model* screens. OT = proportion of time spent *off task*. Go = number of times the model was run. IF = number of times explore the model in full was selected. SbS = number of times explore the model step by step was selected. Ideas = number of times the ideas option was selected. TA = total activity. -- indicates that the activity or screen is not available.

In order to further understand the preferences with regards to the representations used in the SDM & ABM group, use of the agent-based model in the ABM group was compared with that of the SDM & ABM group, and similarly the use of the system dynamics model in the SDM and SDM & ABM groups were compared.

Table 5-9: Results of the Mann-Whitney tests comparing the ABM group with the SDM & ABM group

	U	Direction
Proportion of time spent on each screen		
Exp	**6.0**	ABM > SDM & ABM
Inf	13.5	ABM = SDM & ABM
OT	**4.0**[a]	ABM > SDM & ABM
Activity		
Go	**3.5***	ABM > SDM & ABM
TA	**2.5***	ABM > SDM & ABM

Note. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. OT = proportion of time spent *off task*. Go = number of times the model was run. TA = total activity. Bold typeface indicates a large effect size ($r >= |.50|$).

[a] $p < .10$. * $p < .05$

Students in the ABM group and the SDM & ABM group spent a similar proportion of their time on the *information* screen. Students from the ABM group spent a greater proportion of time on the *experiment* screen (large effect size) and *off task* ($p < .10$) than those from the SDM & ABM group. More activities were performed on the agent-based model by students in the ABM group than students in the SDM & ABM group.

Table 5-10: Results of the Mann-Whitney tests comparing the SDM group with the SDM & ABM group

	U	Direction
Proportion of time spent on each screen		
Exp	10.0	SDM = SDM & ABM
Inf	**8.0**^{a}	SDM > SDM & ABM
ETM	17.0	SDM = SDM & ABM
OT	12.0	SDM = SDM & ABM
Activity		
Go	13.0	SDM = SDM & ABM
IF	**6.0***	SDM > SDM & ABM
SbS	17.5	SDM = SDM & ABM
Ideas	**4.5***	SDM > SDM & ABM
TA	10.0	SDM = SDM & ABM

Note. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. ETM = proportion of time spent on the *explore the model* screens. OT = proportion of time spent *off task*. Go = number of times the model was run. IF = number of times explore the model in full was selected. SbS = number of times explore the model step by step was selected. Ideas = number of times the ideas option was selected. TA = total activity. Bold typeface indicates a large effect size ($r >= | .50 |$).

$^{a}p < .01$, $^{*}p < .05$.

Students in the SDM group and the SDM & ABM group spent a similar proportion of their time on the *experiment* screen, the *explore the model* screen, and *off task*. Students from the SDM group spent a greater proportion of time on the *information* screen than those from the SDM & ABM group. Most activities were performed a similar number of times by students in the SDM and SDM & ABM groups. Students in the SDM group explored the model in full more often than those in the SDM & ABM group, and selected the ideas option more often.

The relationships between the activities performed and the screens that students spent time on for each model were compared using correlations for the SDM & ABM group. Spearman's *rho* was used to determine the relationships between the measures of the use of the model in each group due to the non-parametric nature of the data.

Table 5-11: Results of the correlations comparing the use of the system dynamics model and the agent-based model in the SDM & ABM group

Use of the model	Proportion of time spent on each screen in the agent-based model			Activity in the agent-based model	
	Exp	Inf	OT	Go	TA
Proportion of time spent on each screen in the system dynamics model					
SDM	–.83*	–.70	–.37	–.56	–.58
Exp	–.99**	–.40	–.57	–.63	–.50
Inf	–.58	–.68	–.46	–.19	–.27
ETM	–.06	–.68	.26	–.19	–.44
OT	–.37	–.29	–.48	.02	.02
Activity in the system dynamics model					
Go	–.93**	–.28	–.57	–.63	–.50
IF	--	--	--	--	--
SbS	–.49	–.59	–.24	–.43	–.56
Ideas	–.80	–.10	–.42	–.43	–.25
TA	–.89*	–.40	–.44	–.56	–.46

Note. SDM = proportion of time spent on the system dynamics model. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. ETM = proportion of time spent on the *explore the model* screens. OT = proportion of time spent *off task*. Go = number of times the model was run. IF = number of times the activity: explore the model in full was selected. SbS = number of times the activity: explore the model step by step was selected. Ideas = number of times the ideas option was selected. TA = total activity.

$n = 6$.

*$p < .05$; **$p < .01$.

Table 5-11 shows that students who spent a greater proportion of time on the agent-based model *experiment* screen spent a lower proportion of time on the system dynamics model, and spent a lower proportion of time on the system dynamics model *experiment* screen. The proportion of time spent on the agent-based model *experiment* screen was negatively and significantly correlated with running the system dynamics model fewer times, and the total activity on the system dynamics model.

5.3.2 Discussion

The exploratory questions addressed in this section are:

E1a: Despite the differences in patterns of use due to the different run times of the agent-based and system dynamics models, will students will be engaged and use the experiment screen ore than other screens?

E1b: If students used the agent-based model to constrain interpretation of the system dynamics model then this will be reflected in their use of the models, and students will use the system dynamics model more than the agent-based model.

If *E1a* is supported positively by the evidence, the largest proportion of time will be spent on the *experiment* screen for students in all groups as is was on this screen that student were able to interact with the simulation. If *E1b* is supported by the evidence, user preference will show that students in the SDM & ABM group used the system dynamics model more than the agent-based model. The agent-based model is familiar to students, while the system dynamics model is more abstract. If they concentrate on the abstract representation then the assumption is that they have used the familiar representation to aid them in their understanding of the system dynamics model, given the success in terms of increase in learning outcomes. The ways in which each of the types of model was used will now be discussed: the agent-based model, the system dynamics model, a comparison between the two types of model, and use of both the agent-based and system dynamics model.

5.3.2.1 Using the agent-based model

Students in the ABM group spent the largest proportion of their time on the *experiment* screen. This means that students spent most of their time on the screen where they could interact with the model. The difference between the frequencies of changes to the three variables in the ABM group was non-significant. The correlations between the *experiment* screen and other uses of the model were non-significant indicating that students may have spent more time observing the animation rather than interacting with the model.

5.3.2.2 Using the system dynamics model

Students in the SDM group spent the largest proportion of their time on the *experiment* screen. This means, as for the ABM group, students in the SDM group spent most of their time on a screen where they could interact with the model. Students in the SDM group had a higher total activity than students from the ABM group. This result was expected due to the differences in the running time of each model. The proportion of time spent on the *experiment* screen was correlated with running the model. This indicates that students used the time on the *experiment* screen to interact with the model.

5.3.2.3 Using the agent-based *and* the system dynamics model

5.3.2.3.1 E1a: General patterns of use

Students in the SDM & ABM group spent the largest proportion of their time on the *experiment* screen when measures of use of the models were combined for the two models and for each model separately. This means that students spent most of their time on a screen where they could interact with a model. The proportion of time spent on an experiment screen was correlated with most activities, and students who spent a greater proportion of time on an *experiment* screen spent a lower proportion of time *off task*. This implies that students were engaged with the models.

5.3.2.3.2 E1b: User preference and the coordination of multiple representations

In the SDM & ABM group, students could choose either model and interact with each in almost the same way. Students used the system dynamics model in a similar way those in the SDM group, and interacted with the agent-based model less than those in the ABM group. Students who used the system dynamics model concentrated on the *experiment* screen and changed the variables presented.

Students in the SDM and SDM & ABM groups spent similar proportions of time on the *experiment* screen and the *explore the model* screen and *off task*. They also interacted with the model in similar ways in terms of running the model and the total activity.

There were differences in the ways that students in the two groups used the system dynamics model. The system dynamics model itself involves multiple representations, and students could access the text description or explanation of the model structure in order to *constrain* their interpretation of the stock and flow diagram. Students in the SDM group spent a greater proportion of time on the *information* screen than those in the SDM & ABM group; and also elected to explore the model in full and select the ideas option more often. This indicates that students in the SDM group spent more time accessing the *constraining* options of the system dynamics model than students in the SDM & ABM group. In the SDM group, there was a negative and significant correlation between the selection of the ideas option and the proportion of time spent on the *information* screen. This suggests that students in this group acquired their *constraining* information from one of these options, and examined the model in full.

Students in the SDM & ABM group *constrained* their interpretation by exploring the model step by step, and observing the agent-based model. Significant correlations indicate that if students explored the model step-by-step, they also spent time on the *information* screen on the system dynamics model (although not as high a proportion of time as students in the SDM group). Students from the SDM & ABM group were, on the whole, more successful with respect to learning outcomes than those from the SDM group. While the way in which students interacted with the system dynamics model was similar, the source for the additional (constraining) information differed. For these students, their use of the agent-based model also has to be taken into account.

Students in the SDM & ABM group used the agent-based model less than students in the ABM group. Activities in the agent-based model were negatively and significantly correlated with activities in the system dynamics model. If students interacted with one model, they did not interact with the other. Students in the ABM group spent a greater proportion of time on the *experiment* screen, *off task*, and undertook all activities more often than those in the SDM & ABM group. Students in the SDM & ABM group who used the agent-based model were engaged with the task. This is illustrated by the fact that the proportion of time spent on this model was positively and significantly correlated with the proportion of time on the *experiment* screen and changing the number of pieces of rubbish. As was expected, more activity on the agent-based model was significantly correlated with fewer activities on the system dynamics model.

Students from the ABM and SDM & ABM groups spent similar proportions of time on the *information* screen in the agent-based model. While the proportion of time spent on the *information* screen on the agent-based model was not significantly correlated with any activities in the SDM & ABM group, the screen did provide students with an additional source of *constraining* information. Additionally, students from the SDM group used either the *information* screen or the ideas option, as well as exploring the model in full, however when given the choice, students in the SDM & ABM group used the *information* screen from the agent-based model and explored the model step-by-step (on the system dynamics model).

5.3.3 Conclusions

When given the choice, regardless of the model type, students choose to interact with the model, and not to spend a large proportion of their time off task. When given the choice between two models, students used the system dynamics model more than the agent-based model. This indicates that students used the agent-based model to *constrain* their understanding of the system dynamics model (Ainsworth, 1999b). The agent-based model includes a representation that is familiar to students, while the system dynamics model is more abstract. If students concentrate on the abstract representation then the assumption is that they used the familiar representation to aid them in their understanding of the system dynamics model. Students in the SDM & ABM group were able to add to the knowledge gained by using either of the models individually. Those who used only the system dynamics model did not improve knowledge scores, but did use the model similarly to students who had access to both. The difference identified in this study between the SDM group and the SDM & ABM group (given the similarity in user patterns) was the access to the agent-based model, and the ability of students to increase scores associated with direct knowledge, in a relatively short period of time, and their ability to transfer this knowledge to other systems.

The results of the correlations suggest that the source of the constraining information was an important difference between the groups. Students in the SDM group spent a greater proportion of time on the *information* screen than students in the SDM & ABM group, and explored the model in full and selected the ideas option more often. Students in the SDM & ABM group used the agent-based model. Students in the ABM group spent a similar proportion of time on the agent-based model *information* screen to that spent by students in the SDM & ABM group. These differences may help to explain the differences between the groups for specific learning outcomes. The relationships between the measures of use of the models and the learning outcomes in each group will be explored in the following section.

5.4 USE OF THE MODELS AND LEARNING OUTCOMES

5.4.1 Results

This second section will report on the significant correlations between measures of the use of the model and learning outcomes. Preliminary findings from Chapter 4 with regards to learning outcomes associated with the use of the agent-based model (such as specific environmental knowledge and understanding) supported the current literature related to learning from animations (Lowe, 2003, 2004) and relating information at different levels (Levy, Kim, & Wilensky, 2004). There is little research about learning with system dynamics models, however the findings supported research that suggested that the knowledge of general system dynamics concepts may be important in interpreting stock and flow diagrams (Maryland Virtual High School, 2001), and that the cognitive load associated with learning from a new, abstract, scientific diagram is high, and students may be unable to also engage in relating this to specific knowledge arising from the model (Lowe, 1993). In addition, the evidence suggested that the group using multiple representations were successful because certain information was better presented using a particular style of representation (for example the animation) (de Jong et al., 1998), because the links between the representations could be easily seen (for example apply environmental knowledge to another ecosystem) (Wisnudel Spitulnik, Stratford, Krajcik, & Soloway, 1998), and because they provided learners with the choice of how they wished to learn (Ainsworth, 1999a; Savelsbergh, de Jong, & Ferguson-Hessler, 1998). A number of negative correlations between learning outcomes suggested that students were not able to learn everything.

It was suggested in Chapter 4 that the use of the model should be investigated specifically for those learning outcomes for which prior knowledge played no part. The learning outcomes that this applies to are: knowledge of introduced animal species in the ABM group; knowledge about introduced animal species, introduced plant species, human impacts on an ecosystem and associated timescales, system dynamics knowledge and the *Issues* and *Higher Level Thinking* sections of the final assessment task in the SDM group; and knowledge about system dynamics concepts in the SDM & ABM group (*E1c*).

Correlations between the measures of the use of the models and both the pre-test scores and the learning outcomes will be presented. Positive or negative and significant correlations between pre-test scores and measures of the use of the models will indicate that a relationship exists between prior knowledge and the preference of the user. In turn, significant (positive or negative) correlations between those measures of the use of the models and learning outcomes will indicate relationships between user preference and learning outcomes.

Table 5-12: Results of correlations between pre-test scores and learning outcomes, and the use of the model in the ABM group

Use of the model	Proportion of time spent on each screen			Activity	
	Exp	Inf	OT	Go	TA
Prior knowledge					
Q5$_{pre}$	.46	-.56	.21	.67	.87
Q6$_{pre}$	.31	-.87	.56	.87	.56
Q7$_{pre}$	.58	-.63	.05	.63	$.95^{**}$
SDK$_{pre}$	.50	$-.90^{*}$	.50	1.00^{**}	.60
Learning outcome					
Q5$_{post}$	-.46	-.10	.82	.36	.10
Q5$_{change}$	-.78	.11	$.89^{*}$	.11	-.45
Q6$_{post}$	.36	-.87	.36	.72	.46
Q6$_{change}$	.29	-.58	.00	.29	.00
Q7$_{post}$	.50	-.60	.00	.50	$.90^{*}$
Q7$_{change}$	-.50	$.90^{*}$	-.50	-1.00^{**}	-.60
SDK$_{post}$	.50	$-.90^{*}$	.50	1.00^{**}	.60
SDK$_{change}$	.35	.00	-.35	.00	.71
Describe	.26	-.79	.53	.79	.63
Issues	.31	-.87	.56	.87	.56
HLT	.74	$-.95^{**}$	.21	$.95^{**}$	.79

Note. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. OT = proportion of time spent *off task*. Go = number of times the model was run. TA = total activity. Q5 = knowledge about introduced animal species. Q6 = knowledge about introduced plant species. Q7 = knowledge about human impacts on an ecosystem and associated timescales. SDK = system dynamics knowledge. Describe = *Describe* section of the final assessment task. Issues = *Issues* section of the final assessment task. HLT = *Higher Level Thinking* section of the final assessment task. $_{pre}$ = pre-test score. $_{post}$ = post-test score. $_{change}$ = change in the score between the pre- and post-test.

n = 5.

$^{*}p < .05$; $^{**}p < .01$.

Table 5-12 shows that students in the ABM group who had a lower pre-test score assessing system dynamics knowledge spent a higher proportion of their time on the *information* screen, and students who spent a higher proportion of their time on the *information* screen had a lower post-test score for system dynamics knowledge, a lower score for the *Higher Level Thinking* section of the final assessment task and a greater change in the score assessing knowledge of human impacts on an ecosystem and associated timescales (Question 7). Students who spent a greater proportion of their time *off task* had a greater change in the score assessing knowledge of introduced animal species (Question 5).

Students in the ABM group who had a higher pre-test score assessing system dynamics knowledge ran the model more often. Students who ran the model more often had a higher post-test score assessing system dynamics knowledge and for the *Higher Level Thinking* section of the final assessment task and a smaller change in their knowledge of human impacts on an ecosystem and associated timescales (Question 7).

Students who had a higher pre-test score assessing knowledge about human impacts on an ecosystem and associated timescales (Question 7) had a higher total activity. Students who had higher total activity had a higher post-test score for this question.

Table 5–13: Results of correlations between pre-test scores and the learning outcomes, and the use of the model in the SDM group

Use of the model	Proportion of time spent on each screen				Activity				
	Exp	Inf	ETM	OT	Go	IF	SbS	Ideas	TA
Prior knowledge									
Q5$_{\text{pre}}$	.36	.14	–.79*	–.02	.22	.50	--	.30	.11
Q6$_{\text{pre}}$	.36	.14	–.76*	.12	.19	.17	--	.19	.09
Q7$_{\text{pre}}$	–.27	.87**	–.63	.08	–.18	–.26	--	–.70	–.22
SDK$_{\text{pre}}$	.54	–.43	.13	–.38	.02	.06	--	.26	.02
Learning outcome									
Q5$_{\text{post}}$	.90**	–.85*	–.05	–.06	.84*	.35	--	.72	.81*
Q5$_{\text{change}}$	.32	–.79*	.76*	–.35	.54	–.10	--	.41	.58
Q6$_{\text{post}}$	.78*	–.41	–.32	.49	.66	–.36	--	.05	.69
Q6$_{\text{change}}$	.40	–.22	.14	.24	.46	–.74	--	–.39	.54
Q7$_{\text{post}}$	–.87**	.61	.12	.06	–.66	–.25	--	–.35	–.67
Q7$_{\text{change}}$	–.04	–.70	.70	.00	.00	.21	--	.62	.04

Use of the model	Proportion of time spent on each screen				Activity				
	Exp	Inf	ETM	OT	Go	IF	SbS	Ideas	TA
SDK_{post}	−.41	.34	.16	−.67	−.56	−.06	--	−.03	−.63
SDK_{change}	−.51	.25	.32	−.43	−.08	−.25	--	−.11	−.13
Describe	.06	−.11	.04	−.75	.25	.56	--	.49	.15
Issues	.47	−.32	.04	−.66	.38	.49	--	.36	.34
HLT	.02	.31	−.07	−.37	.28	−.47	--	−.43	.26

Note. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. ETM = proportion of time spent on the *explore the model* screens. OT = proportion of time spent *off task*. Go = number of times the model was run. IF = number of times explore the model in full was selected. SbS = number of times explore the model step by step was selected. Ideas = number of times the ideas option was selected. TA = total activity. Q5 = knowledge about introduced animal species. Q6 = knowledge about introduced plant species. Q7 = knowledge about human impacts on an ecosystem and associated timescales. SDK = system dynamics knowledge. Describe = *Describe* section of the final assessment task. Issues = *Issues* section of the final assessment task. HLT = *Higher Level Thinking* section of the final assessment task. $_{pre}$ = pre-test score. $_{post}$ = post-test score. $_{change}$ = change in the score between the pre- and post-test.

$n = 6$.

$^{*}p < .05$; $^{**}p < .01$.

Table 5-13 shows that in the SDM group, all pre-test scores were non-significantly correlated with the proportion of time spent on the *experiment* screen. Students who spent a larger proportion of their time on the *experiment* screen had higher post-test scores assessing knowledge about introduced animal and plant species (Questions 5 and 6), and a lower post-test score assessing knowledge of human impacts on an ecosystem and associated timescales (Question 7).

Students who had a higher pre-test score assessing knowledge about human impacts on an ecosystem and associated timescales (Question 7) spent a greater proportion of their time on the *information* screen. The proportion of time spent on this screen was negatively and significantly correlated with the post-test score assessing knowledge of introduced animal species (Question 5) and the change in this score.

Pre-test knowledge about introduced animal and plant species (Questions 5 and 6) scores were negatively and significantly correlated with the proportion of time spent on the *explore the model* screen. Students who spent a larger proportion of their time on the *explore the model* screen had a greater change in the Question 5 score.

The significant correlation between running the model and the post-test score assessing knowledge about introduced animal species (Question 5) was positive. Students who had a higher total activity had a higher post-test score assessing knowledge of introduced animal species (Question 5).

Table 5-14: Results of correlations between pre-test scores and learning outcomes, and the use of the agent-based model in the SDM & ABM group

Use of the model	Proportion of time spent on each screen			Activity	
	Exp	Inf	OT	Go	TA
Prior knowledge					
Q5$_{pre}$	−.70	.03	−.65	−.98**	−.92**
Q6$_{pre}$	−.60	−.09	−.03	−.68	−.58
Q7$_{pre}$	−.66	.15	−.27	−.80	−.64
SDK$_{pre}$	−.89*	.52	−.37	−.93**	−.93**
Learning outcome					
Q5$_{post}$	−.50	−.19	−.35	−.89*	−.96**
Q5$_{change}$	.66	−.42	.78	.42	.13
Q6$_{post}$	−.81*	−.34	−.15	−.56	−.44
Q6$_{change}$	−.27	−.87*	−.14	.20	.06
Q7$_{post}$	−.59	−.19	−.61	−.11	.05
Q7$_{change}$	.43	.15	−.03	.68	.70
SDK$_{post}$	−.75	.65	−.43	−.71	−.46
SDK$_{change}$	−.03	.49	−.17	.02	.31
Describe	−.80	−.03	−.29	−.73	−.56
Issues	−.87*	−.31	−.36	−.56	−.44
HLT	−.62	.30	−.42	−.77	−.56

Note. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. OT = proportion of time spent *off task*. Go = number of times the model was run. TA = total activity. Q5 = knowledge about introduced animal species. Q6 = knowledge about introduced plant species. Q7 = knowledge about human impacts on an ecosystem and associated timescales. SDK = system dynamics knowledge. Describe = describe section of the final assessment task. Issues = issues section of the final assessment task. HLT = higher level thinking section of the final assessment task. $_{pre}$ = pre-test score. $_{post}$ = post-test score. $_{change}$ = change in the score between the pre- and post-test.

n = 5.

$^{*}p < .05$. $^{**}p < .01$.

Table 5-14 shows that in the SDM & ABM group, students who had a lower pre-test score assessing system dynamics knowledge spent a greater proportion of their time on the experiment screen on the agent-based model. In addition, students who spent a higher proportion of their time on the *experiment* screen on the agent-based model had a lower post-test score assessing knowledge of introduced plant species (Question 6) and a lower score for the *Issues* section in the final assessment task. Students who spent a higher proportion of their time on the *information* screen had a smaller change in their knowledge of introduced plant species (Question 6).

Pre-test scores assessing knowledge about introduced animal species (Question 5) were significantly and negatively correlated with running the agent-based model, as were pre-test system dynamics knowledge scores. Students who ran the agent-based model more often had a lower post-test score assessing knowledge of introduced animal species (Question 5).

Students who had a higher pre-test scores assessing knowledge about introduced animal species (Question 5) and system dynamics concepts had lower total activity on the agent-based model. Students who had lower total activity in the agent-based model had a higher post-test score assessing knowledge of introduced animal species (Question 5).

Table 5-15: Results of correlations between pre-test scores, learning outcomes and the use of the system dynamics model, SDM & ABM group

Use of the model	Proportion of time spent on each screen				Activity				
	Exp	Inf	ETM	OT	Go	IF	SbS	Ideas	TA
Prior knowledge									
$Q5_{pre}$	.65	.15	.15	-.11	.59	--	.36	.36	.52
$Q6_{pre}$	.64	-.03	.32	-.34	.58	--	.34	.49	.60
$Q7_{pre}$	.64	-.12	.06	-.34	.58	--	.19	.49	.54
SDK_{pre}	.06	-.26	.38	-.17	.46	--	.46	.31	.43
Learning outcome									
$Q5_{post}$	.51	.15	.51	-.23	.45	--	.51	.19	.44
$Q5_{change}$	-.53	-.13	.66	-.31	-.53	--	.14	-.57	-.39
$Q6_{post}$	.87*	.32	.32	.02	.81	--	.50	.74	.84*
$Q6_{change}$	.34	.65	.28	.36	.15	--	.30	-.03	.21
$Q7_{post}$	.52	.30	-.51	.23	.31	--	-.19	.21	.24
$Q7_{change}$	-.49	-.12	-.64	.17	-.55	--	-.62	-.46	-.60

Use of the model	Proportion of time spent on each screen				Activity				
	Exp	Inf	ETM	OT	Go	IF	SbS	Ideas	TA
SDK_{post}	.71	−.46	−.13	.07	.74	--	.24	.78	.67
$\text{SDK}_{\text{change}}$	.72	−.25	−.46	.38	.49	--	−.05	.74	.44
Describe	.81*	.19	.19	−.02	.81*	--	.43	.77	.80
Issues	.91*	.60	.34	.43	.97**	--	.71	.94**	.99**
HLT	.55	−.25	−.25	−.42	.42	--	−.10	.32	.34

Note. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. ETM = proportion of time spent on the *explore the model* screens. OT = proportion of time spent *off task*. Go = number of times the model was run. IF = number of times explore the model in full was selected. SbS = number of times explore the model step by step was selected. Ideas = number of times the ideas option was selected. TA = total activity. Q5 = knowledge about introduced animal species. Q6 = knowledge about introduced plant species. Q7 = knowledge about human impacts on an ecosystem and associated timescales. SDK = system dynamics knowledge. Describe = *Describe* section of the final assessment task. Issues = *Issues* section of the final assessment task. HLT = *Higher Level Thinking* section of the final assessment task. $_{\text{pre}}$ = pre-test score. $_{\text{post}}$ = post-test score. $_{\text{change}}$ = change in the score between the pre- and post-test.

$n = 6$.

$^{*}p < .05$; $^{**}p < .01$.

Table 5-15 shows that students in the SDM & ABM group who spent a higher proportion of time on the *experiment* screen on the system dynamics model had a higher post-test score assessing knowledge of introduced plant species (Question 6), and higher scores for the *Describe* and *Issues* sections of the final assessment task. Students who selected ‘go’ more often on the system dynamics model had higher scores for the *Describe* and *Issues* sections of the final assessment task. The frequency of the selection of the ideas option was positively and significantly correlated with the *Issues* section of the final assessment task.

Students who had higher total activity had higher post-test scores assessing knowledge of introduced plant species (Question 6) and a higher score for the *Issues* section of the final assessment task.

Table 5-16: Results of the correlations between pre-test scores and learning outcomes, and the overall use of the models in the SDM & ABM group

Use of the model	Proportion of time spent on each screen				Activity	
	SDM	Exp	Inf	OT	Go	TA
Prior knowledge						
$Q5_{pre}$	.58	.27	.21	−.46	.52	.52
$Q6_{pre}$	.60	.66	−.31	−.38	.60	.60
$Q7_{pre}$	.49	.60	−.03	−.52	.54	.54
SDK_{pre}	.43	.20	.20	−.35	.43	.43
Learning outcome						
$Q5_{post}$	.62	.35	−.09	−.40	.44	.44
$Q5_{change}$	−.13	.13	−.66	.13	−.39	−.39
$Q6_{post}$	$.81^{*}$	.46	−.35	−.06	$.84^{*}$	$.84^{*}$
$Q6_{change}$	.52	−.09	−.46	.31	.21	.21
$Q7_{post}$	.29	.06	.12	−.15	.24	.24
$Q7_{change}$	−.60	−.37	.26	.12	−.60	−.60
SDK_{post}	.38	.17	.35	−.16	.67	.67
SDK_{change}	.00	−.17	.38	.29	.44	.44
Describe	.68	.40	−.06	−.17	.80	.80
Issues	$.84^{*}$	.03	−.06	.29	$.99^{**}$	$.99^{**}$
HLT	.31	.62	.12	−.72	.34	.34

Note. SDM = proportion of time spent on the system dynamics model. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. OT = proportion of time spent *off task*. TA = total activity. Q5 = knowledge about introduced animal species. Q6 = knowledge about introduced plant species. Q7 = knowledge about human impacts on an ecosystem and associated timescales. SDK = system dynamics knowledge. Describe = *Describe* section of the final assessment task. Issues = *Issues* section of the final assessment task. HLT = *Higher Level Thinking* section of the final assessment task. $_{pre}$ = pre-test score. $_{post}$ = post-test score. $_{change}$ = change in the score between the pre- and post-test.

$n = 6$.

$^{*}p < .05$. $^{**}p < .01$.

Table 5-16 shows that students who spent a greater proportion of their time on the system dynamics model had a higher post-test score assessing knowledge of introduced plant species (Question 6) and a higher score for the *Issues* section of the final assessment task. Students who selected 'go' more times overall had a higher post-test score assessing knowledge about introduced plant species (Question 6) and a higher score for the *Issues* section of the final assessment task.

The total activity was positively and significantly correlated with the post-test scores assessing knowledge of introduced plant species and the score for the *Issues* section of the final assessment task.

5.4.2 Discussion

The exploratory question addressed in this part of the chapter was:

E1c: Is the use of the model related to learning outcomes, particularly for those with which prior knowledge had no relationship?

Investigations of the relationships between prior knowledge and user preference, and between measures of use of the models and learning outcomes are presented in this section. In order for the hypothesis to be supported, significant correlations between the learning outcomes with which prior knowledge had non-significant relationships, and measures of use will be presented. It should be briefly acknowledged here that prior knowledge and these measures of use of the models are only two variables that could explain differences in learning outcomes between the groups. This discussion will elaborate on the informative relationships between measures of use of the models and both prior knowledge and learning outcomes for students using: the agent-based model, the system dynamics model, and both models.

5.4.2.1 Learning from the agent-based model

Findings from the previous chapter indicated that some learning outcomes were not related to prior knowledge. In a number of these cases, previous research conducted in the fields of learning from animations and learning from agent-based models (for example, (Lowe, 2003, 2004)) resulted in the prediction that the representation itself encouraged learning about a particular area. For example, it has been predicted that students in the ABM group would learn about those areas that are distinctive in the animation used in the agent-based model. Subjects tend to be attracted to the information generated by the features in the animation that actually change in a contrasted way to the rest of the display (Lowe, 2003, 2004). In particular, this involved Question 5 (knowledge about introduced animal species), because *rats* are used to represent introduced animal species and are visible in the animated representation. Research also suggests that the nature of the representations used in the agent-based model may make it difficult for students to relate their model-specific knowledge to other systems (Levy et al., 2004).

5.4.2.1.1 The role of prior knowledge

There is some research examining students' interaction with agent-based models; however the role of prior knowledge in patterns of use has not yet been explored. It is expected that prior knowledge will have some effect, and may explain some differences in the use of the models.

Significant correlations indicate that prior knowledge about the environment and about system dynamics were related to the use of the model. Students with lower system dynamics prior knowledge spent a greater proportion of time on the *information* screen, and students with higher prior knowledge ran the model more often. Prior knowledge about human impacts on an ecosystem was also related to the total activity. These results indicate that generally high domain knowledge and system dynamics knowledge was associated with greater interaction with the agent-based model. Students who had lower prior knowledge spent a greater proportion of the time on the *information* screen (which contained a text description of the system). It is possible that these students used the text description of the system to interpret the results of the model. These students did not run the model often, possibly because of the long running time of the agent-based model in addition to the greater proportion of time these students spent reading the text. The results of the previous section indicated that students may have spent more time observing the animation rather than interacting with the model. However, these new results suggest a more active learner, at least amongst students with higher prior knowledge.

5.4.2.1.2 Affordances of the agent-based model

Students in the ABM group increased knowledge scores assessing knowledge of introduced animal and plant species (Questions 5 and 6), and system dynamics knowledge. In the case of knowledge about introduced plant species and system dynamics concepts, results presented in Chapter 4 suggested that prior knowledge played a role in those answers. Correlations between post-test scores associated with introduced plant species and measures of use of the model were non-significant. The ways in which students in the ABM group used the model did not explain the increase in the Question 6 score. Knowledge about system dynamics concepts was related to the applied environmental knowledge score, and will be discussed in the following section.

Knowledge about introduced animal species was not related to prior knowledge. It was suggested in Chapter 4 that the increase in this score in the ABM group was due to the animation used in the agent-based model. The post-test score for Question 5 and the proportion of time spent *off task* were positively and significantly correlated. This implies that if students spent a greater proportion of time *off task*, they had a higher post-test score for Question 5, however students in this group did significantly increase this score. If the increase in the score *is* related to the animation used in the agent-based model, it may be that a very short exposure to the animation (given the relationship with the proportion of time spent *off task*) allowed students to increase their score for this learning outcome. It may also be that a greater proportion of time spent on-task resulted in increases in other learning outcomes.

5.4.2.1.3 Limitations of the agent-based model

Students in the ABM group did not increase their score for the question that required the application of system specific knowledge to other systems. The ability of students to make those links using an agent-based model has been identified as challenging for students, however many studies have shown that students were successful in this. There was a lack of significant correlations to explain the lack of increase in the applied system dynamics knowledge score. Significant correlations discussed in Chapter 4 showed that there was a negative relationship between the change in the applied environmental knowledge score and the post-test score assessing system dynamics knowledge. Investigation of the relationships between the ways in which the model was used and these learning outcomes provide further information about why students were unable to make these links using this model, and explain the reason for the negative relationship between learning outcomes.

It has already been discussed that students who had lower prior system dynamics knowledge spent a higher proportion of time on the *information* screen, and students who had higher environmental and system dynamics knowledge interacted more with the agent-based model. Significant correlations showed that students who spent a higher proportion of time on the *information* screen had a larger change in the score assessing knowledge of human impacts on an ecosystem and associated timescales (applied environmental knowledge). Students in the Text group did increase their score for this question, so the text description did allow students to apply their knowledge to another system. However, students in the ABM group did not increase their score for this question. Post-test system dynamics knowledge scores were positively and significantly correlated with running the model. These results suggest that higher prior knowledge about system dynamics concepts prompted students to run the agent-based model and change the variables. By doing this, they further increased their score assessing system dynamics knowledge, and had greater access to the animated representation (perhaps resulting in the increase in scores assessing knowledge of introduced animal and plant species as discussed above). Students who had lower prior knowledge about system dynamics concepts spent a greater proportion of time on the *information* screen, perhaps in order to constrain their interpretation of the agent-based model. However, this meant that they did not have as much time to spend interacting with the model, and so while they were able to apply their knowledge to other ecosystems, they did not increase their system dynamics knowledge. The challenge of identifying links between the representation and reality seems to be specifically related to the time restrictions and the constraining information used.

5.4.2.1.4 Understanding the system using the agent-based model

Three measures of students' understanding of the system have been examined (describing the system, identify the issues, and engaging in higher level thinking). Significant correlations between the use of the model and students' scores in describing the system did not explain students' answers beyond that already discussed in Chapter 4. Correlations between the use of the model and the *Issues* section of the final assessment task were non-significant. However, the discussion of the role of the *information* screen in relation to system dynamics knowledge has prompted a small correction of the explanation of the *Issues* score in the ABM group. It was suggested that in order to identify the issues in the materials, students in the ABM group elaborated on events outlined in the *Describe* section and used knowledge gained from the text. However, system dynamics knowledge was related to the *Describe* score; and system dynamics knowledge was not acquired from the text, instead from general use of the model. This indicates that students in the ABM group elaborated on events outlined in the *Describe* section and used *knowledge gained from general use of the model*. With respect to the *Higher Level Thinking* section, significant correlations showed that interacting with the model (and not the proportion of time spent on the *information* screen) as well as prior knowledge helped students to make predictions and identify consequences of their decisions.

5.4.2.2 Learning from the system dynamics model

There is little research about learning with system dynamics models, however the findings from Chapter 4 supported research that suggested that the knowledge of general system dynamics concepts may be important in interpreting stock and flow diagrams (Maryland Virtual High School, 2001), and that the cognitive load associated with learning from a new, abstract, scientific diagram is high, and students may be unable to also engage in relating this to specific knowledge arising from the model (Lowe, 1993). Findings from the previous chapter indicated that some learning outcomes were not related to prior knowledge. In a number of these cases, previous research conducted in the fields of learning from abstract diagrams (for example, (Schieritz & Milling, 2003; Wakeland et al., 2004)) resulted in the prediction that the representation itself encouraged or discouraged learning about a particular area. Knowledge about introduced animal species, introduced plant species, human impacts on an ecosystem and associated timescales, system dynamics knowledge and the *Issues* and *Higher Level Thinking* sections of the final assessment task in the SDM group were all suggested as being related to the use of the system dynamics model.

5.4.2.2.1 The role of prior knowledge

The first part of this discussion focuses on the role of prior knowledge in guiding use of the models. There is little research examining students' interaction with system dynamics models, and none of it explores this particular question. It is expected that prior knowledge will have some effect on the way in which the system dynamics model is used.

Prior knowledge about the environment was related to the type of constraining representation students used to help them interpret the results of their interaction with the system dynamics model. Students who had higher prior knowledge of human impacts on an ecosystem and associated timescales used the explanatory features of the system dynamics model (the information screen), and those who lacked knowledge about the areas that the materials presented (knowledge about introduced animal and plant species) chose to *explore the model*.

5.4.2.2.2 Affordances of the system dynamics model

Students given the system dynamics model did not increase any knowledge score. All relationships between use and learning outcomes for this group will be discussed in the following sections.

5.4.2.2.3 Limitations of the system dynamics model

Students in the SDM group had non-significant changes for all three environmental knowledge questions and the system dynamics knowledge question. Correlations between the post-test score assessing applied environmental knowledge and system dynamics knowledge and the measures of use of the model were not useful in explaining the lack of change in these items. However environmental knowledge scores were related to the use of the system dynamics model, and will each be discussed below.

The results of the correlations show that students who used the *explore the model* screen to constrain their interpretation of the system dynamics model, and who did not use the *information* screen, had a greater change in the score assessing knowledge of introduced animal species. Students who spent a greater proportion of time on the *information* screen also had a lower change in their score assessing knowledge of introduced plant species. In addition, interaction with the system dynamics model (knowledge of introduced animal species) and the proportion of time spent on the *experiment* screen (knowledge of introduced plant species) were positively related to system-specific environmental knowledge. These results suggest that for this item, the *explore the model* screen was a more successful additional representation than the text description. It may be that students, who explored the model, were then better able to interpret the stock and flow diagram than those who had read the text-based information. A number of studies have suggested that 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 (Ainsworth, Bibby, & Wood, 1998; Horwitz & Christie, 1999; Seufert, Janen, & Brunken, 2007). However these results suggest that, at least for learning from a system dynamics model, familiarity with the representation is more important than familiarity with the domain for interpreting the model. In order for students to increase their score for this question, they also needed to run the model and have generally high activity. Students in the SDM group did have high activity, but not significantly higher than the activity in the other groups, and these results suggest that the activity was without the necessary representational familiarity to make sense of the system dynamics model.

5.4.2.2.4 Understanding the system using the system dynamics model

Three measures of students' understanding of the system have been examined (describing the system, identifying the issues, engaging in higher level thinking). Significant correlations between the use of the model and students' scores in describing the system or assessing *Higher Level Thinking* did not explain students' answers beyond that already discussed in Chapter 4. In Chapter 4, evidence was outlined to suggest that students in the SDM group used the representation to answer the *Issues* section of the final assessment task. Examination of the potential impacts of management decisions (which changing the number of pieces of rubbish allows students to do) may have helped students to identify issues in the materials.

5.4.2.3 Learning from multiple representations

Findings from the previous chapter indicated that some learning outcomes were not related to prior knowledge. In a number of these cases, previous research conducted in the fields of learning from animations and learning from agent-based models (for example, (Lowe, 2003, 2004)) and learning from abstract diagrams (for example, (Schieritz & Milling, 2003; Wakeland et al., 2004)) resulted in the prediction that the representation itself encouraged learning about a particular area.

Preliminary findings from Chapter 4 with regards to learning outcomes associated with the use of the agent-based model (such as specific environmental knowledge and understanding) supported the current literature related to learning from animations (Lowe, 2003, 2004) and relating information at different levels (Levy et al., 2004). There is little research about learning with system dynamics models, however the preliminary findings suggested that the knowledge of system dynamics concepts may be important in interpreting stock and flow diagrams (Maryland Virtual High School, 2001), and that the cognitive load associated with learning from a new, abstract, scientific diagram is high, and students may be unable to also engage in relating this to specific knowledge arising from the model (Lowe, 1993). In addition, the evidence suggested that the group using multiple representations were successful because certain information was better presented using a particular style of representation (for example the animation) (de Jong et al., 1998), because the links between the representations could be easily seen (for example apply environmental knowledge to another ecosystem) (Wisnudel Spitulnik et al., 1998), and because they provided learners with the choice of how they wished to learn (Ainsworth, 1999a; Savelsbergh et al., 1998). A number of negative correlations between learning outcomes suggested that students were not able to learn everything.

Knowledge about system dynamics concepts in the SDM & ABM group was not related to prior knowledge, and this and Question 6 were the only knowledge scores for which there was a non-significant change in this group, although large effect sizes were associated with each. Investigation of the use of the models may explain whether this is a result of cognitive load (van der Meij & de Jong, 2006) or user preference (Ainsworth, 1999a).

5.4.2.3.1 The role of prior knowledge

There is little research examining students' interaction with either system dynamics or agent-based models, and none of it explores the role of prior knowledge. However there is research that has examined the role of prior knowledge in learning from multiple representations. From this, it is expected that prior knowledge will have some effect on the use of the individual models, and on the coordination between the two.

In the SDM & ABM group, correlations between the proportion of time spent on either model and learning outcomes were non-significant. Instead, interaction with the models was related to learning outcomes. Prior environmental knowledge was positively and significantly correlated with activities performed on the system dynamics model and prior environmental and system dynamics knowledge was negatively and significantly correlated with activities performed on the agent-based model and associated screens.

The significant correlations discussed previously indicate that in the ABM group and the SDM group, students with lower levels of prior environmental and system dynamics knowledge performed fewer activities, and spent a greater proportion of time on the *information* screen. In the SDM & ABM group, lower levels of prior environmental and system dynamics knowledge were associated with more activities performed on the agent-based model. Giving students access to both models allowed those students with lower prior environmental and system dynamics knowledge to interact with *a* model, an opportunity which was not taken by students with lower prior knowledge in the single-model groups.

5.4.2.3.2 Affordances of multiple representations

Students in the SDM & ABM group were able to increase knowledge scores for all environmental knowledge questions and applied system dynamics knowledge. Prior knowledge was shown to be a factor in all these learning outcomes. In addition, the evidence suggested that the group using multiple representations was successful because certain information was better presented using a particular style of representation (for example the animation) (de Jong et al., 1998), and because the links between the representations could be easily seen (for example apply environmental knowledge to another ecosystem) (Wisnudel Spitulnik et al., 1998). Significant correlations between use of the models and applied environmental knowledge and system dynamics knowledge questions were not able to explain alone whether students were able to increase these knowledge scores because the links between the representations could be easily seen. However, some evidence will be presented which suggests that certain information was better presented using particular styles of information.

The pre-test score for Question 5 (assessing knowledge of introduced animal species) and for system dynamics knowledge were negatively and significantly correlated with measures of interaction with the agent-based model. Interaction with the agent-based model was negatively and significantly correlated with the post-test Question 5 score. Students in this group increased their score for this question. It may be that, as was found in the ABM group, a very short exposure to the animation allowed students to increase their score for this learning outcome, and that a greater proportion of time spent with the model resulted in increases in other learning outcomes. These results do suggest that similar relationships between the use of the animated representation and this learning outcome were present in both the ABM and the SDM & ABM groups.

In the SDM & ABM group, the pre- and post-test scores assessing knowledge of introduced plant species were significantly correlated with each other. Prior knowledge of introduced plant species was related to the use of the system dynamics model, and the post-test score was related to not only the proportion of time spent on the *experiment* screen on the system dynamics model, but also to the total activity carried out on this model. The post-test score was negatively and significantly correlated with the proportion of time spent on the agent-based model *experiment* screen. The post-test score for this question was also correlated with the proportion of time spent on the *experiment* screen in the SDM group, and negatively correlated with the proportion of time spent on the *information* screen for this group. These results support the findings from the SDM group that the *constraining* representation in combination with interaction with the system dynamics model had an effect on post-test scores. Given the significant increase in the score for this question in the SDM & ABM group and the non-significant change in the SDM group, the results also suggest that using the agent-based model to constrain interpretation of the system dynamics model was more successful than using the text description.

5.4.2.3.3 Limitations of multiple representations

Students in the SDM & ABM group did increase the score assessing system dynamics knowledge. This was unexpected, given that students in the SDM group did not significantly increase their scores. In the SDM & ABM group the post-test score assessing system dynamics knowledge was non-significantly correlated with pre-test scores, and non-significantly correlated with the use of the system dynamics model. It may be that the cognitive load attached to interpreting the materials, translating between them, and increasing their environmental knowledge and applied system dynamics knowledge scores was too great.

5.4.2.3.4 Understanding the system using multiple representations

Three measures of students' understanding of the system have been examined. Significant correlations between the use of the model and students' scores assessing *Higher Level Thinking* did not explain students' answers beyond that already discussed in Chapter 4.

Significant correlations between learning outcomes and examination of the answers outlined in Chapter 4 indicated that students in the SDM & ABM group incorporated environmental knowledge to interpret the models, but not to describe the national park itself. This is supported by significant correlations that show that the use of the system dynamics model, and not the agent-based model, was significantly correlated with the score for the *Describe* section. Students who spent a larger proportion of time on the *experiment* screen and interacted with the system dynamics model had a higher score for the *Describe* section. Despite interaction with the system dynamics model, students only answered one part of the *Describe* section of the final assessment task. It may be that having access to the agent-based model gave these students little reason to visualize the park themselves.

In the SDM & ABM group, prior and acquired knowledge scores assessing environmental (introduced plant species) and system dynamics knowledge were significantly correlated with the *Issues* section of the final assessment task, however students' answers concentrated on animals and visitors, possibly due to the animation used in the agent-based model. The score for the *Issues* section was negatively and significantly correlated with the proportion of time spent on the *experiment* screen and interaction with the agent-based model. However, this learning outcome was positively and significantly correlated with the proportion of time spent on the *experiment* screen and interaction with the system dynamics model. Perhaps students used the agent-based model to interpret the system dynamics model, and were able to identify issues in relation to their experience with the agent-based model.

5.4.3 Conclusion

In conclusion, prior knowledge had an impact on the use of the agent-based model by the ABM group. Prior knowledge of both the domain and general system dynamics concepts had an impact on how students used the explanatory features of the model and how they interacted on the *experiment* screen. Higher domain knowledge was related to interaction, and higher general system dynamics knowledge to running the model and the time spent on the *information* screen. Prior domain knowledge was also related to the explanatory features students used in the SDM group. Those who had higher prior knowledge of human impacts on an ecosystem and associated timescales spent a greater proportion of time on the *information* screen. Students who had higher knowledge that came directly from the materials used the *explore the model* screens. In the SDM & ABM group, prior knowledge was related to the model that students chose to use. Students with higher prior environmental and system dynamics knowledge chose not to experiment with the agent-based model. Giving students access to both models allowed those students with lower prior environmental and system dynamics knowledge to interact with *a* model, an opportunity which was not taken by students in the ABM group or the SDM group.

General interaction with the model had an effect on knowledge about introduced animals and plants, and students' ability to describe what happened in the park and what the park looked like in the SDM and SDM & ABM groups. Changing specific variables was related to applied environmental knowledge in the SDM & ABM group, system dynamics knowledge in the ABM group and SDM group, and the ability of students to identify the environmental and management issues presented in the materials in the SDM group.

The use of a representation to constrain interpretation of the model for students in each group was related to learning outcomes as well as prior knowledge. Use of the *information* screen (containing a text description of the system) enabled students in the ABM group to apply environmental knowledge to other systems, while interaction with the model did not. In Chapter 4 it was suggested that students were not able to identify links between system specific knowledge and other systems because this is challenging with an agent-based model. The results of the use of the model indicate that students were able to do this using the text description to constrain their interpretation of the materials. Interaction with the model without this constraining information resulted in increases in system dynamics knowledge, and higher scores associated with understanding of the system. Use of the *explore the model* screen in the SDM group was associated with a higher post-test scores, whereas the *information* screen was associated with lower post-test scores. Perhaps because the *explore the model* screen improved students' knowledge of the representation, allowing them to recognise the connection between the representation and the domain (Ainsworth et al., 1998; Horwitz & Christie, 1999; Seufert et al., 2007). However these results suggest that, at least for system dynamics models, familiarity with the representation is more important than familiarity with the domain for interpreting the model. In the SDM & ABM group, students used the agent-based model to constrain interpretation of the system dynamics model. This allowed them to identify issues in relation to their experience with the agent-based model.

To make sense of the patterns of use, they were classified according to Levy and Wilensky's (2005) *strategies*. The purpose of the following section is to investigate whether these strategies differed depending on the model, whether more information can be added to identify and describe strategies, and finally whether these strategies were influenced by or influenced learning outcomes.

5.5STRATEGIES

To make sense of the patterns of use, the strategies used by the students to interact with the model were classified according to Levy and Wilensky's (2005) *strategies*. After examination of the individual cases, it was decided that the strategies for changing the three variables would also be determined. The use of the model was then compared between the strategies that students used to determine whether any more factors could be used to make each classification. Finally, learning outcomes were compared between the classifications to investigate the effect of the strategy used to interrogate the model, regardless of the model used.

Table 5-17: Patterns found in Levy and Wilensky's (2005) study

	Strategy		
Name	Straight to the point	Homing in	Oscillating
Description	The most informative state is accessed directly	The most informative state is gradually approached through decreasing increments	The model oscillates between two regimes, back and forth between high and low values
Overall observation time	Lower	Lower	Higher
Observation time per run	Higher	Lower	Lower
Time between actions	Higher	Lower	Lower
Runs	Lower	Higher	Medium

The time observing the model was taken as the time spent on the *experiment* screen. The time spent observing the model in each setting was calculated by dividing the total time spent observing the model by number of times 'go' was selected. The time spent off-task and spent reading the text/instructions were included as a result of the pilot study. The number of runs was equal to the number of times 'go' was selected. Time per action was calculated by dividing the time observing the model by the number of changes made. And the number of changes made was equal to the total activity. After examination of the individual cases, it was decided that the strategies for changing the three variables would also be determined. The use of the model was then compared between the strategies that students used in order to determine whether any more factors could be used to make each classification. Finally, learning outcomes were compared between the classifications to investigate the effect of the strategy used to the interrogate the model, regardless of the model used.

5.5.1 Results

In this section, the overall strategies used to interrogate the models are classified for students in each group. Classification criteria are applied to variables, and an additional classification is suggested. Kruskal-Wallis tests are used to compare the measures of use of the models between strategies, with Mann Whitney tests used post-hoc. Kruskal-Wallis tests are also used to compare learning outcomes between strategies; with Mann Whitney tests used post-hoc. Due to the small sample size, large effect sizes were taken into account in addition to significance, and are noted where appropriate.

5.5.1.1 Classifications of patterns of use for each group

Table 5-18: Patterns of use in the ABM group

Strategy	ABM I1	ABM I2	ABM I3	ABM I4	ABM I5
Observation					
Time observing the model	16:52 (H)	17:21 (H)	13:20 (M)	15:43 (H)	9:29 (L)
Time observing the model in each setting	3:22 (H)	1:56 (M)	1:54 (M)	15:43 (H)	2:22 (M)
Time spent off task	0:38	1:17	6:56	0	4:05
Time spent reading text / instructions	2:20	0	2:41	4:17	6:26
Explorativeness					
Number of runs	5 (L)	9 (M)	7 (M)	1 (L)	4 (L)
Action					
Time per action	0:36 (M)	0:40 (M)	0:32 (M)	1:19 (H)	0:52 (M)
Number of changes made	28 (M)	26 (M)	25 (M)	12 (L)	11 (L)
Pattern	Osc.	Osc.	Osc.	STP	STP

Note. ABM I*n* = student *n* in the ABM group in the individual learning environment. H = high. M = medium. L = low. Osc. = oscillating strategy. HI = homing in strategy. STP = straight to the point strategy.

Table 5-18 shows that in the ABM group, only two patterns were identified. Two students used the straight to the point strategy; the remaining students used the oscillating strategy.

Table 5-19: Patterns of use – SDM group

Strategy	SDM I1	SDM I2	SDM I3	SDM I4	SDM I5	SDM I6	SDM I7
Observation							
Time observing the model	9:21 (L)	14:53 (M)	16:11 (H)	12:15 (M)	5:53 (L)	11:23 (M)	9:46 (L)
Time observing the model in each setting	2:20 (M)	0:41 (L)	0:37 (L)	0:37 (L)	1:28 (M)	5:41 (H)	1:05 (M)
Time spent off task	0:34	3:15	1:07	0	5:58	0:40	0
Time spent reading text / instructions	10:05	5:06	5:11	8:38	8:09	7:57	10:14
Explorativeness							
Number of runs	4 (L)	22 (H)	26 (H)	20 (H)	4 (L)	2 (L)	9 (M)
Action							
Time per action	0:26 (M)	0:17 (L)	0:15 (L)	0:15 (L)	0:12 (L)	0:40 (M)	0:16 (L)
Number of changes made	22 (M)	53 (H)	65 (H)	49 (H)	30 (M)	17 (M)	36 (M)
Pattern	STP	HI	Osc.	HI	STP	STP	Osc.

Note. SDM I*n* = student *n* in the SDM group in the individual learning environment. H = high. M = medium. L = low. Osc. = oscillating strategy. HI = homing in strategy. STP = straight to the point strategy.

Students' patterns of use of the model in the SDM group were recorded and classified using Levy and Wilensky's method. Table 5-19 shows that in the SDM group, all three patterns were identified. Three students used the straight to the point strategy; two students used the oscillating strategy; and two students used the homing in from one side strategy.

Table 5-20: Patterns of use - SDM & ABM group (models treated separately)

Strategy	SDM & ABM I1	SDM & ABM I2	SDM & ABM I3	SDM & ABM I4	SDM & ABM I5	SDM & ABM I6
Observation						
System dynamics model						
Time observing the model	11:02 (M)	15:49 (H)	2:04 (L)	0 (L)	0 (L)	5:05 (L)
Time observing the model in each setting	0:41 (L)	1:19 (M)	0:31 (L)	0 (L)	0 (L)	0:38 (L)
Time spent off task	0:43	0	0	0	0	1:26
Time spent reading text / instructions	6:10	4:11	0:17	0:06	6:51	11:28
Agent-based model						
Time observing the model	0:32 (L)	0 (L)	15:29 (H)	13:14 (M)	16:26 (H)	5:45 (L)
Time observing the model in each setting	0 (L)	0 (L)	5:10 (H)	13:14 (H)	5:29 (H)	1:55 (M)
Time spent off task	0	0	0:11	0	0:42	0
Time spent reading text / instructions	3:24	0	5:47	8:40	0	0
Explorativeness						
Number of runs - system dynamics model	16 (H)	12 (M)	4 (L)	0 (L)	0 (L)	8 (M)
Number of runs - agent-based model	0 (L)	0 (L)	3 (L)	1 (L)	3 (L)	3 (L)
Action						
System dynamics model						

Strategy	SDM & ABM I1	SDM & ABM I2	SDM & ABM I3	SDM & ABM I4	SDM & ABM I5	SDM & ABM I6
Time per action	0:17 (L)	0:26 (M)	0:11 (L)	0 (L)	0 (L)	0:13 (L)
Number of changes made	40 (H)	37 (M)	11 (L)	0 (L)	1 (L)	23 (M)
Agent-based model						
Time per action	0 (L)	0 (L)	1:02 (H)	1:39 (H)	1:39 (H)	0:31 (M)
Number of changes made	0 (L)	0 (L)	15 (L)	8 (L)	10 (L)	11 (L)
Pattern						
System dynamics model	HI	HI	HI	None	None	HI
Agent-based model	None	None	STP	STP	STP	STP

Note. SDM & ABM I*n* = student *n* in the SDM & ABM group in the individual learning environment. H = high. M = medium. L = low. Osc. = oscillating strategy. HI = homing in strategy. STP = straight to the point strategy.

Students' patterns of use of the model in the SDM & ABM group were recorded and classified separately for the two models using Levy and Wilensky's method. Table 5-20 shows that in the SDM & ABM group, only two patterns were identified. All students using the system dynamics model used the homing in strategy, and all students using the agent-based model used the straight to the point strategy. Two students only used the system dynamics model, and two only used the agent-based model.

Most students used only one model rather than changing between the two. The results for the overall use of models can be seen in Table 5-21 below.

Table 5-21: Patterns of use - SDM & ABM group (models combined)

Strategy	SDM & ABM I1	SDM & ABM I2	SDM & ABM I3	SDM & ABM I4	SDM & ABM I5	SDM & ABM I6
Observation						
Time observing the model	11:34 (M)	15:49 (H)	17:33 (H)	13:14 (M)	16:26 (H)	10:50 (M)
Time observing the model in each setting	0:43 (L)	1:19 (M)	2:30 (M)	13:14 (H)	5:29 (H)	0:59 (L)
Time spent off task	0:43	0	0:11	0	0:42	1:26
Time spent reading text / instructions	9:34	4:11	6:04	8:46	6:51	11:28
Explorativeness						
Number of runs	16 (H)	12 (M)	7 (M)	1 (L)	3 (L)	11 (M)
Action						
Time per action	0:17 (L)	0:26 (M)	0:41 (M)	1:39 (H)	1:30 (H)	0:19 (L)
Number of changes made	40 (H)	37 (M)	26 (M)	8 (L)	11 (L)	34 (M)
Pattern	HI	HI	Osc.	STP	STP	Osc.

Note. SDM & ABM I*n* = student *n* in the SDM & ABM in the individual learning environment. H = high. M = medium. L = low. Osc. = oscillating strategy. HI = homing in strategy. STP = straight to the point strategy.

Students' patterns of use of the model in the SDM & ABM group were recorded and classified for the two models combined using Levy and Wilensky's method. Table 5-21 shows that in the SDM & ABM group, all three patterns were identified. Two students used the oscillating strategy; two students used the homing in strategy; and two students used the straight to the point strategy.

5.5.1.2 The classification criteria

The strategies used by students to change the three variables were also determined using graphs of the changes in addition to the parameters outlined above. Table 5-22 shows the classification of the strategy for each student.

Table 5-22: Patterns of use for each variable - ABM group

Variable	ABM I1	ABM I2	ABM I3	ABM I4	ABM I5
Change the garbage collection time	Osc.	Osc.	OOT	STP	STP
Change the percentage of rubbish collected	Osc.	HI	OOT	STP	STP
Change the number of pieces of rubbish	Osc.	Osc.	Osc.	STP	STP

Note. ABM I*n* = student *n* in the ABM group in the individual learning environment. Osc. = oscillating strategy. HI = homing in strategy. STP = straight to the point strategy. OOT = oscillating over time strategy.

The patterns used to change each of the variables, in the main, was the same as the overall pattern as determined by Levy and Wilensky's classification scheme for the overall pattern. Examination of the graphs of use over time determined that an additional category should be used - that of oscillating over time. The graph for one such student can be seen below (Figure 5-1).

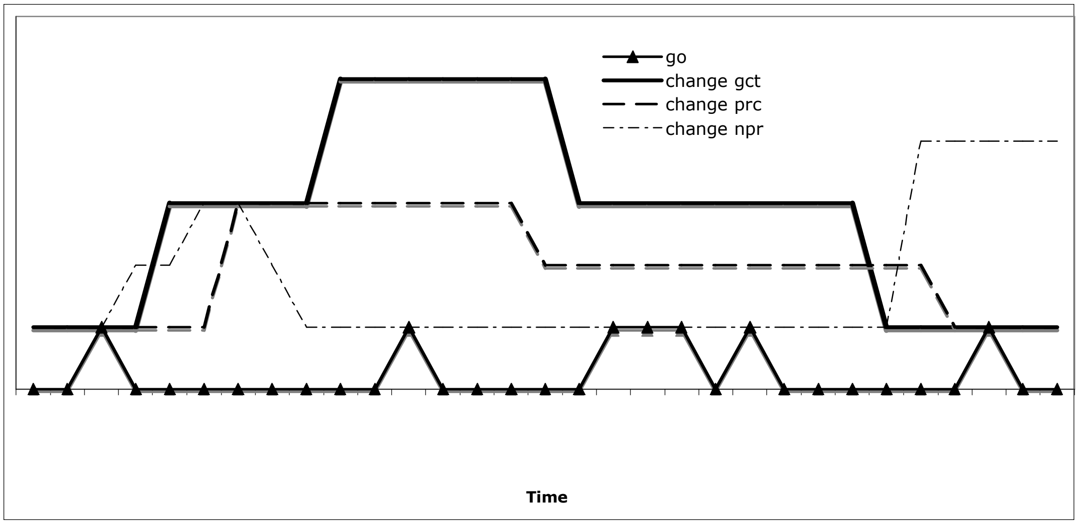


Figure 5-1: Use of the model by one student in the ABM group

The strategy used for changing the garbage collection time and changing the percentage of rubbish collected was classified as oscillating over time. Changing the number of pieces of rubbish was classified as oscillating. The differences in the strategies are clear in Figure 5-1. The number of pieces of rubbish was increased, decreased, and increased again in the 20 minutes that students were given to interact with the model. Both the garbage collection time and the percentage of rubbish were increased and decreased during the course of the 20 minutes, however the changes were so gradual, and the time limited, that it is expected that they would have increased the variable again had the time allowed.

Table 5-23: Patterns of use for each variable - SDM group

Variables	SDM I1	SDM I2	SDM I3	SDM I4	SDM I5	SDM I6	SDM I7
Change the garbage collection time	HI	HI	OOT	HI	STP	STP	STP
Change the percentage of rubbish collected	STP	STP	STP	HI	STP	STP	STP
Change the number of pieces of rubbish	HI	HI	Osc.	HI	STP	STP	Osc.

Note. SDM I*n* = student *n* in the SDM group in the individual learning environment. Osc. = oscillating strategy. HI = homing in strategy. STP = straight to the point strategy. OOT = oscillating over time strategy.

The patterns used to change each of the variables, in the main, was the same as the overall pattern as determined by Levy and Wilensky's classification scheme. Table 5-23 shows that most students used the straight to the point strategy for changing the percentage of rubbish collected. Only two students used this approach to interrogate the model as a whole. Other students made many changes, and either homed in on an outcome from one direction, while making specific changes to other variables, or chose to vary the other variables in an oscillating pattern. One example of this is the SDM I2 student as seen in Figure 5-2 below.

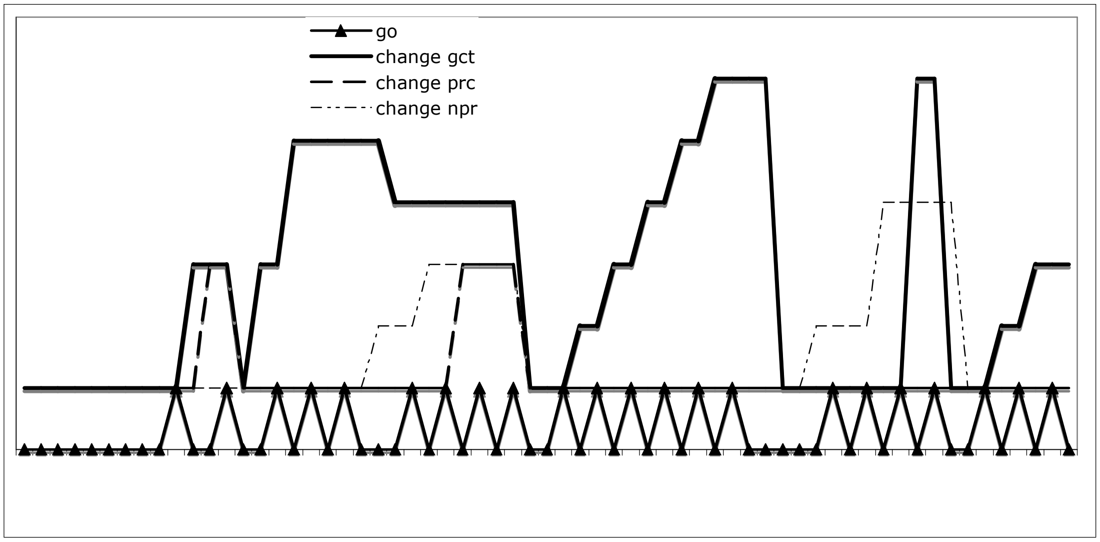


Figure 5-2: Use of the model by one student in the SDM group

The strategy used to change the garbage collection time and, to a lesser extent to change the number of pieces of rubbish, was homing in. This is typified by the steady increase in the value used, and the model was run after each change. This student used a straight to the point strategy to change the percentage of rubbish collected. The student made a change to the percentage of rubbish collected, ran the model, and continued changing other variables to investigate the effects of changing both.

Table 5-24: Patterns of use – SDM & ABM group

Strategy	SDM & ABM I1	SDM & ABM I2	SDM & ABM I3	SDM & ABM I4	SDM & ABM I5	SDM & ABM I6
Change the garbage collection time	Osc.	HI	Osc.	STP	HI	OOT
Change the percentage of rubbish collected	OOT	HI	Osc.	STP	STP	STP
Change the number of pieces of rubbish	STP	HI	Osc.	STP	HI	Osc.

Note. SDM & ABM I*n* = student *n* in the SDM & ABM group in the individual learning environment. Osc. = oscillating strategy. HI = homing in strategy. STP = straight to the point strategy. OOT = oscillating over time strategy.

The patterns used to change each of the variables, in the main, was the same as the overall pattern as determined by Levy and Wilensky's classification scheme. Table 5-24 shows that there was no clear pattern that students used to interrogate the models in this group.

Table 5-25: Summary of patterns of use by group

	Overall strategy	Strategy gct	Strategy prc	Strategy npr
ABM				
Osc.	3	2	1	3
HI	0	0	1	0
STP	2	2	2	2
OOT	--	1	1	0
SDM				
Osc.	2	0	0	2
HI	2	3	1	3
STP	3	3	6	2
OOT	--	1	0	0
SDM & ABM				
Osc.	3	2	1	2
HI	1	2	1	2
STP	2	1	3	2
OOT	--	1	1	0

Note. Strategy gct = strategy used to change the garbage collection time. Strategy prc = strategy used to change the percentage of rubbish collected. Strategy npr = strategy used to change the number of pieces of rubbish. Osc. = oscillating strategy. HI = homing in strategy. STP = straight to the point strategy. OOT = oscillating over time strategy.

Table 5-25 shows that there was no clear relationship between the group and the strategy used. Students in the ABM group tended not to use the homing in strategy, and did use the oscillating strategy. Students in the other groups used all strategies.

The relationship between the strategies and the measures of use was investigated. For this part of the analysis, the representation was ignored, and data was divided according to the strategy that the student used to interrogate the model. However, use of specific models was taken into account as well as general use. Kruskal-Wallis tests compared measures of the use of the models between the strategies used. Only those measures for which a significant result was found are reported below.

Table 5-26: Results of the Kruskal-Wallis tests comparing the use of the model between the strategy overall, and the strategy for each of the three variables

	Strategy – overall	Strategy – gct	Strategy – prc	Strategy – npr
$\mathrm{Inf}_{\mathrm{ABM}}$ (time)	2.56	9.33^{*}	2.97	8.65^{*}
$\mathrm{Go}_{\mathrm{SDM}}$	8.38^{*}	3.24	2.43	1.79
$\mathrm{Npr}_{\mathrm{SDM}}$	7.04^{*}	2.13	3.42	4.13
$\mathrm{Gct}_{\mathrm{SDM}}$	6.62^{*}	4.97	2.48	1.59
$\mathrm{SbS}_{\mathrm{SDM}}$	0.49	0.71	8.12^{*}	0.71
TA	11.12^{**}	3.90	1.83	3.01
Go	13.28^{**}	7.11	3.49	5.09
Npr	9.32^{**}	3.48	2.88	7.79^{*}
Gct	10.49^{**}	10.48^{*}	2.50	5.83

Note. Strategy gct = strategy used to change the garbage collection time. Strategy prc = strategy used to change the percentage of rubbish collected. Strategy npr = strategy used to change the number of pieces of rubbish. Inf = proportion of time spent on the *information* screen. Go = number of times the model was run. Npr = frequency of changes to the number of pieces of rubbish. Gct = frequency of changes to the garbage collection time. TA = total activity. SbS = number of times the activity: explore the model step by step was selected. $_{\mathrm{ABM}}$ = specifically the agent-based model. $_{\mathrm{SDM}}$ = specifically the system dynamics model.

$^{*}p < .05$. $^{**}p < .01$.

The findings in Table 5-26 indicate that the overall strategy was important with respect to the overall use and more particularly the use of the system dynamics model. The strategy for changing the garbage collection time was related to the amount of time spent on the agent-based model *information* screen, and changing the garbage collection time in any model. The strategy for changing the percentage of rubbish collected was related to the explore the model step by step activity. The strategy for changing the number of pieces of rubbish was related to the overall measure of this activity, as well as the time spent on the *information* screen on the agent-based model.

Table 5-27: Results of the Mann Whitney tests comparing measures of the use of the models between overall strategies used

	System dynamics model use			Combined model use			
	Go	Npr	Gct	TA	Go	Npr	Gct
Osc. Vs.							
HI	4.0	4.0	4.5	4.0	4.0	4.5	5.0
STP	**1.0**	**3.0**	**3.5**	**4.0***	**0.0***	**8.0**	**5.0***
HI vs.							
STP	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Note. Go = number of times the model was run. Npr = frequency of changes to the number of pieces of rubbish. Gct = frequency of changes to the garbage collection time. TA = total activity. Osc. = oscillating strategy. HI = homing in strategy. STP = straight to the point strategy. OOT = oscillating over time strategy. Bold typeface indicates a large effect size ($r > | .50 |$).

*$p < .05$.

The medians and ranges are reported below.

Table 5-28: Medians and ranges of learning outcomes with respect to the strategy overall

	Oscillating			Homing in			Straight to the point		
		Range			Range			Range	
	Mdn	Lower	Upper	*Mdn*	Lower	Upper	*Mdn*	Lower	Upper
Go$_{SDM}$	9	4	26	20	12	22	2	0	4
Npr$_{SDM}$	4	2	10	8	6	10	1	0	4
Gct$_{SDM}$	6	3	16	8	7	14	1	0	6
TA	31	25	65	49	37	53	12	8	30
Go	9	5	26	20	12	22	3	1	4
Npr	4.5	3	10	8	6	10	3	1	5
Gct	5.5	3	16	8	7	14	1	1	6

Note. Go = number of times the model was run. Npr = frequency of changes to the number of pieces of rubbish. Gct = frequency of changes to the garbage collection time. TA = total activity. $_{SDM}$ = specifically the system dynamics model.

Table 5-27 and Table 5-28 show the significance and direction of the relationships between activities for students using the different strategies overall. Students who used an oscillating strategy overall had higher activity in either model than students using the straight to the point strategy (large effect size only applied to changing the npr). Similarly, large effect sizes were associated with the higher activity that students using the homing in strategy had on the system dynamics model and in either model than students who used the straight to the point strategy.

The results for comparisons between the strategies used to change the individual variables are seen below.

Table 5-29: Results of the Mann Whitney tests comparing measures of the use of the models between the gct strategy and the npr strategy

	Agent-based model use	Combined model use	
	Inf (time)	Gct	Npr
Strategy – gct			
Osc. vs.			
HI	**2.0**	7.0	--
STP	**1.0**	**0.0***	--
OOT	3.0	5.0	--
HI vs.			
STP	**0.0**[a]	**2.0***	--
OOT	4.0	6.5	--
STP vs.			
OOT	**0.0**	**0.0***	--
Strategy – npr			
Osc. vs.			
HI	6.0	--	17.0
STP	**2.0***	--	**3.5***
HI vs.			
STP	**0.0***	--	**3.0***

Note. Strategy gct = strategy used to change the garbage collection time. Strategy npr = strategy used to change the number of pieces of rubbish. Inf (time) = time spent on the *information* screen. Npr = frequency of changes to the number of pieces of rubbish. Gct = frequency of changes to the garbage collection time. Osc. = oscillating strategy. HI = homing in strategy. STP = straight to the point strategy. OOT = oscillating over time strategy. Bold typeface indicates a large effect size ($r > | .50 |$).

$^{a}p < .10$; $^{*}p < .05$.

The medians and range are reported below.

Table 5-30: Medians and ranges of measures of use of the models in the strategy – gct and the strategy – npr

	Strategy – gct			Strategy – npr		
		Range			Range	
	Mdn	Lower	Upper	*Mdn*	Lower	Upper
Osc.						
Inf_{ABM}(time)	2:52	0:00	5:47	1:10	0:00	5:47
Gct	5.5	5	8	5	3	16
Npr	4	3	6	5	4	10
HI						
Inf_{ABM}(time)	0:00	0:00	0:00	0:00	0:00	0:00
Gct	7	2	14	7	2	14
Npr	6	3	10	6	3	10
STP						
Inf_{ABM}(time)	6:26	4:17	6:40	5:21	3:24	6:40
Gct	1	1	3	1	1	8
Npr	2.5	1	10	2.5	1	5
OOT						
Inf_{ABM}(time)	0:00	0:00	2:41	--	--	--
Gct	7	4	16	--	--	--
Npr	5	4	8	--	--	--

Note. Strategy gct = strategy used to change the garbage collection time. Strategy npr = strategy used to change the number of pieces of rubbish. Inf (time) = time spent on the *information* screen. Npr = frequency of changes to the number of pieces of rubbish. Gct = frequency of changes to the garbage collection time. Osc. = oscillating strategy. HI = homing in strategy. STP = straight to the point strategy. OOT = oscillating over time strategy.

Table 5-29 and Table 5-30 show the significance and direction of the relationships between learning outcomes for students using the different strategies. Students who used the straight to the point strategy spent longer on the *information* screen on the agent-based model than students who used the homing in strategy. Students who used the straight to the point strategy to change the garbage collection time changed the garbage collection time less often than students using any other strategy.

Students who used the straight to the point strategy to change the number of pieces of rubbish spent longer on the *information* screen on the agent-based model than students using the oscillating or homing in strategies. Students who used the straight to the point strategy to change the number of pieces of rubbish changed the number of pieces of rubbish less often overall ($p <$ .05) than students using the oscillating or homing in strategies.

5.5.1.3 Strategies and learning outcomes

The relationship between the strategies and the learning outcomes was investigated. For this part of the analysis, the representation was ignored, and data was divided according to the strategy that the student used to interrogate the model. Kruskal-Wallis tests compared learning outcomes between the strategies used. Only those learning outcomes for which a significant result was found are reported below.

Table 5-31: Results of the Kruskal-Wallis tests comparing learning outcomes between the strategy overall, and the strategy for each of the three variables

	Strategy – overall	Strategy – gct	Strategy – prc	Strategy – npr
Prior knowledge				
$Q6_{pre}$	2.55	8.19*	2.68	4.77
SDK_{pre}	1.80	2.67	8.71*	0.14
Learning outcomes				
$Q5_{post}$	8.08*	3.05	3.35	2.78
$Q6_{post}$	8.42*	7.74	5.10	3.30
SDK_{post}	2.29	6.71	9.61*	1.02
Issues	7.37*	4.73	9.18*	3.14
HLT	3.23	5.17	10.58*	2.87

Note. Strategy gct = strategy used to change the garbage collection time. Strategy prc = strategy used to change the percentage of rubbish collected. Strategy npr = strategy used to change the number of pieces of rubbish. Q5 = knowledge about introduced animal species (Maximum score is 9). Q6 = knowledge about introduced plant species (Maximum score is 8). SDK = system dynamics knowledge (Maximum score is 12). Issues = *Issues* section of the final assessment task (Maximum score is 16). HLT = *Higher Level Thinking* section of the final assessment task (Maximum score is 24). $_{pre}$ = pre-test score. $_{post}$ = post-test score.

$^{*}p < .05$.

The initial findings seen in Table 5-31 indicate that the overall strategy was important with respect to the environmental knowledge that was apparent from the model, and identifying the issues present in the materials. Prior knowledge was important in terms of the strategy adopted for changing the garbage collection time. The strategy used to change the percentage of rubbish collected was important in terms of both understanding and system dynamics knowledge, and prior system dynamics knowledge was also important for this. The strategy adopted for changing the number of pieces of rubbish was not related to learning outcomes. Mann Whitney tests compared individual strategies,

Table 5-32: Results of the Mann Whitney tests comparing learning outcomes between the strategy overall, the strategy – gct and the strategy – prc

	Prior knowledge		Learning outcomes				
	$Q6_{pre}$	SDK_{pre}	$Q5_{post}$	$Q6_{post}$	SDK_{post}	Issues	HLT
Strategy – overall							
Osc. vs.							
HI	--	--	25.5	**27.5***	--	19.0	--
STP	--	--	**39.0**^{a}	40.5^{a}	--	**39.0***	--
HI vs.							
STP	--	--	**27.0***	**27.0***	--	**24.0**^{a}	--
Strategy – gct							
Osc. vs.							
HI	16.5	--	--	--	--	--	--
STP	**22.5***	**--**	--	--	--	--	--
OOT	13.0	--	--	--	--	--	--
HI vs.							
STP	**23.0***	**--**	--	--	--	--	--
OOT	10.0	--	--	--	--	--	--
STP vs.							
OOT	20.0	--	--	--	--	--	--
Strategy – prc							
HI vs.							
STP	--	**2.0***	--	--	**2.5***	**36.0***	**39.0****

Note. Strategy gct = strategy used to change the garbage collection time. Strategy prc = strategy used to change the percentage of rubbish collected. Q5 = knowledge about introduced animal species (Maximum score is 9). Q6 = knowledge about introduced plant species (Maximum score is 8). SDK = system dynamics knowledge (Maximum score is 12). Issues = *Issues* section of the final assessment task (Maximum score is 16). HLT = *Higher Level Thinking* section of the final assessment task (Maximum score is 24). $_{pre}$ = pre-test score. $_{post}$ = post-test score. Osc. = oscillating strategy. HI = homing in strategy. STP = straight to the point strategy. OOT = oscillating over time strategy. Bold typeface indicates a large effect size ($r > | .50 |$).

$^{a}p < .10$; $^{*}p < .05$; $^{**}p < .001$.

The medians and range are reported below.

Table 5-33: Medians and ranges of learning outcomes with respect to the strategy overall, the strategy – gct and the strategy – prc

	Strategy – overall			Strategy – gct			Strategy – prc		
		Range			Range			Range	
	Mdn	Lower	Upper	*Mdn*	Lower	Upper	*Mdn*	Lower	Upper
Osc.									
$Q6_{pre}$	3.25	0	4	3.25	1	4	2	1	3
SDK_{pre}	2.5	0	10	5	1	10	2.5	1	4
$Q5_{post}$	4	2	7	3.5	2	4	3	2	4
$Q6_{post}$	3.5	0	6	3.5	1	4.5	2	1	3
SDK_{post}	5.5	0	10	7.25	5	10	5.5	5	6
Issues	7	2	9	5.5	2	9	2.5	2	3
HLT	4.5	2	8	5.5	4	8	5.5	4	7
HI									
$Q6_{pre}$	4.5	1	6	4.5	1	8	3.5	1	4
SDK_{pre}	4	1	5	2.5	0	5	5	4	10
$Q5_{post}$	6	5	7	5	1	7	5	3	6
$Q6_{post}$	5.5	5	7	5	1	7	5	4.5	5.5
SDK_{post}	5	1	6	5	1	7	6	5	10
Issues	6	3	7	4	2	7	7	6	8
HLT	7	1	10	5	1	10	8	7	10
STP									
$Q6_{pre}$	1	0	8	0	0	1.5	1	0	8
SDK_{pre}	1	0	7	1	0	7	1	0	7
$Q5_{post}$	2.5	0.5	4	2.75	0.5	5.0	3	0.5	7
$Q6_{post}$	1	0	2	1	0	2	2	0	7
SDK_{post}	1.5	0	7	1.5	0	5	1.5	0	7
Issues	2	1	5	1.5	1	7	3	1	7

	Strategy – overall			Strategy – gct			Strategy – prc		
		Range			Range			Range	
	Mdn	Lower	Upper	*Mdn*	Lower	Upper	*Mdn*	Lower	Upper
HLT	2	1	5	2	1	4	2	1	5
OOT									
$Q6_{pre}$	--	--	--	4	0	4	4	4	4
SDK_{pre}	--	--	--	1	0	7	6.5	6	7
$Q5_{post}$	--	--	--	6	2	7	5.5	4	7
$Q6_{post}$	--	--	--	5	2	6	4.5	4	5
SDK_{post}	--	--	--	2	0	7	7.75	7	8.5
Issues	--	--	--	7	3	9	9	9	9
HLT	--	--	--	5	2	7	5.5	4	7

Note. Strategy gct = strategy used to change the garbage collection time. Strategy prc = strategy used to change the percentage of rubbish collected. Q5 = knowledge about introduced animal species (Maximum score is 9). Q6 = knowledge about introduced plant species (Maximum score is 8). SDK = system dynamics knowledge (Maximum score is 12). Issues = *Issues* section of the final assessment task (Maximum score is 16). HLT = *Higher Level Thinking* section of the final assessment task (Maximum score is 24). $_{pre}$ = pre-test score. $_{post}$ = post-test score. Osc. = oscillating strategy. HI = homing in strategy. STP = straight to the point strategy. OOT = oscillating over time strategy.

Table 5-32 and Table 5-33 show the significance and direction of the relationships between learning outcomes for students using the different strategies. Students who used the oscillating strategy overall had a higher post-test score assessing knowledge of introduced animal species (Question 5) than those students who used the straight to the point strategy. The post-test score for this item was higher amongst students using the homing in strategy than those using the straight to the point strategy. Students who used the oscillating strategy overall had a lower post-test score assessing knowledge of introduced plant species (Question 6) than students using the homing in strategy, as did students using the straight to the point strategy. The score for the *Issues* section of the final assessment task was higher for students who used the oscillating strategy than students who used the straight to the point strategy, and students; and higher for students who used the homing in strategy than who used the straight to the point strategy.

Students who used the oscillating strategy to change the garbage collection time had higher prior knowledge of introduced plant species (Question 6) than students who used a straight to the point approach. The Question 6 pre-test score was higher for students using a homing in strategy than a straight to the point strategy.

Students who used the homing in strategy to change the percentage of rubbish collected had a higher pre-test system dynamics knowledge score than those who used a straight to the point strategy. Students who used the straight to the point strategy to change the percentage of rubbish collected had a lower system dynamics post-test score than those who used a homing in strategy. The score for the *Issues* section of the final assessment task was higher for students who used a homing in strategy than a straight to the point strategy. Students who used the homing in strategy had a higher score for the *Higher Level Thinking* section of the final assessment task than students who used the straight to the point strategy.

5.5.2 Discussion

The exploratory question addressed in this section was:

E1d: Are the strategies used to interrogate the models dependent on the models used?

If *E1d* is supported positively by the evidence, a typical pattern of use will be identified for each group. The discussion that follows outlines the strategies used by students to interrogate the models overall and to change individual variables, and uses relationships between these strategies and the general measures of use of the models to further define the classification system. The results of the relationships between learning outcomes and the strategies used will also be discussed.

5.5.2.1 Classification of strategies used

All strategies were used by students in the SDM group and the SDM & ABM group, and both the oscillating and straight to the point strategies were used by students in the ABM group.

The classification scheme was examined because it was developed for the interrogation of agent-based models in an activity where students could move on to the next step once a conclusion was reached (Levy & Wilensky, 2005). More detailed investigation of the data revealed that the overall strategy did not always reflect the strategies used to change the three variables. In some cases, students used a combination of strategies, changing one variable using a straight to the point strategy while others were changed using one of the other strategies. Analysis of the strategies with respect to other measures of use confirmed that the measurement of activities was a valuable classification. In particular, the amount of time spent on the *information* screen was important with respect to the straight to the point approach in this study, and indicates that students who used this approach were doing so in an informed way. In terms of changing the garbage collection time and the number of pieces of rubbish, students who spent a large amount of time on the *information* screen also used a straight to the point approach. This implies that students were making informed decisions about their strategy for changing these variables. It was thought that the proportion of time spent *off task* would add information to this classification scheme, however no relationship was detected.

5.5.2.2 Strategies and learning outcomes

The overall strategy and the strategies used to change the garbage collection time and percentage of rubbish collected were related to learning outcomes. Levy and Wilensky's original study suggested that the straight to the point strategy is a planned approach which may result in a deeper understanding of each regime, but that critical settings or transitions may be missed which are evident through a broader investigation of the model (Levy & Wilensky, 2005). The oscillating approach involved students moving between extremes, constantly comparing results between now and previous, however the previous settings tend to disappear, unlike the homing in strategy (Levy & Wilensky, 2005).

5.5.2.2.1 Overall strategy

Students who used a straight to the point approach overall had a lower post-test score for knowledge about introduced animal species (Question 5) than students who used an oscillating or homing in strategy; a lower post-test score assessing knowledge about introduced plant species (Question 6) than students who used the homing in strategy; and a lower score for the *Issues* section of the final assessment task than students who used the other two strategies. Students who used an oscillating strategy had a lower post-test score for Question 6 than those who used the homing in strategy. These three learning outcomes address system specific knowledge. The results suggest that students who used a broad strategy such as oscillating or homing in, rather than a deliberate, straight to the point approach, were better able to answer system-specific questions; and that students who used a homing in strategy, that allows students to keep previous system states in mind after small changes, were better able to answer system-specific questions than students who used an oscillating strategy. These are supported by findings from the original study (Levy & Wilensky, 2005).

5.5.2.2.2 Strategy used to change the variables

In terms of the strategies used to change the garbage collection time and the percentage of rubbish collected, there were two main findings. Students who had less prior knowledge about introduced plant species had a straight to the point strategy for changing the garbage collection time. Perhaps students with lower prior knowledge in this area spent more time reading the text description, or perhaps they had a goal to learn about introduced plant species. Students who had higher prior knowledge about introduced plants species used the oscillating or homing in strategy.

The strategy used to change the percentage of rubbish collected was related to system dynamics knowledge and the *Issues* and *Higher Level Thinking* sections of the final assessment task. Students who used the straight to the point strategy to change the percentage of rubbish collected had a lower score for both general and applied system dynamics knowledge than students who used the homing in strategy and the oscillating over time strategy. In addition, students who used the oscillating over time strategy had a higher general system dynamics knowledge post-test score than students who used the oscillating strategy. Again, the straight to the point approach was not successful in terms of gaining general knowledge that should have been apparent by use of the model. In this case, the oscillating over time approach was successful which is a strategy that was identified in this study. This strategy is a combination of the homing in and the oscillating strategy. There is an overall oscillating pattern, but with changes made between the extremes. This strategy appears to have similar advantages to the homing in strategy. Both the oscillating over time strategy and the homing in strategy were more successful than the other strategies in terms of identifying the issues in the learning materials. Finally, students who used the homing in strategy to change the percentage of rubbish collected had higher scores for the *Higher Level Thinking* section of the final assessment task than students who used the other three strategies. Once again, the planned, but broad strategy of changing this variable allowed to students to make management decisions, predictions, and identify the consequences of decisions made.

5.5.3 Conclusion

In conclusion, the classification scheme was able to be applied to the use of a system dynamics model; an extra classification and an additional criterion were suggested. Prior knowledge had an effect on the choice of strategy to change specific variables. The proportion of time spent on the *information* screen was important for students who used the STP strategy. Despite this more informed approach to the STP strategy, students who used it overall, and to change specific variables (such as the percentage of rubbish collected) had lower post-test environmental knowledge scores. The homing in strategy was the most successful of the three in terms of post-test scores associated with information that came from the materials and the score for the *Higher Level Thinking* section of the final assessment task.

5.6 CONCLUSIONS

Four hypotheses related to the differences in how the models were used between the groups, with respect to learning outcomes, and in terms of strategies used to interrogate the models were discussed in this chapter.

General patterns of use of the models were identified. When given the choice, regardless of the model type, students choose to interact with the model, and not to spend a large proportion of their time off task. When given the choice between two models, students used the system dynamics model more than the agent-based model. This indicates that students used the agent-based model to *constrain* their understanding of the system dynamics model (Ainsworth, 1999b).

General interaction with the model had an effect on knowledge about introduced animals and plants, system dynamics knowledge, students' ability to describe what happened in the park and what the park looked like, and students' ability to make predictions and identify consequences of their decisions. The strategies used to change the variables also had an effect on learning outcomes. Despite the more informed approach to the STP strategy, students who used it overall, and to change specific variables (such as the percentage of rubbish collected) had lower post-test environmental knowledge scores. The homing in strategy was the most successful of the four in terms of post-test scores associated with information that came from the materials and the score for the *Higher Level Thinking* section of the final assessment task.

Students who were given both models not only used the system dynamics model, but they used this model in a similar way to those who were in the SDM group. Students from the SDM & ABM group were, on the whole, more successful with respect to learning outcomes than those from the SDM group. While the way in which students interacted with the system dynamics model was similar, the source for the additional (constraining) information differed in that it came from the agent-based model rather than the text (as it did for the single model groups).

Prior knowledge of the domain and the representations had an effect on the use of the explanatory features such as the *information* screen in the ABM group and the *information* and *explore the model* screens in the SDM group. In the SDM & ABM group, prior knowledge had an effect on which model students chose to use. Students with higher prior environmental and system dynamics knowledge chose not to experiment with the agent-based model. Giving students access to both models allowed those students with lower prior environmental and system dynamics knowledge to interact with *a* model, an opportunity which was not taken by students with lower prior knowledge in the ABM group or the SDM group.

The use of the constraining information available for students in each group was also important in terms of learning outcomes. Use of the *information* screen (containing a text description of the system) was important in the ABM group for applying their environmental knowledge to other systems. The results of the use of the model indicate that students were able to do this using the text description to constrain their interpretation of the materials. Interaction with the model without this constraining information resulted in increases in system dynamics knowledge, and higher scores associated with understanding of the system. Use of the *explore the model* screen in the SDM group was associated with a higher post-test scores, whereas the proportion of time spent on the *information* screen was associated with lower post-test scores. Perhaps because the *explore the model* screen improved students' knowledge of the representation, allowing them to recognise the connection between the representation and the domain (Ainsworth et al., 1998; Horwitz & Christie, 1999; Seufert et al., 2007). However these results suggest that, at least for system dynamics models, it may be that familiarity with the representation is more important than familiarity with the domain for interpreting the model. In the SDM & ABM group, students used the agent-based model as the explanatory feature for the system dynamics model. This allowed them to identify issues in relation to their experience with the agent-based model.

In the following chapter, the examination of learning outcomes and measures of use of the models presented in Chapter 4 and Chapter 5 will be explored for students in a collaborative learning environment.

6. COLLABORATIVE LEARNING

6.1 RATIONALE

Collaborative learning is a well-researched strategy for understanding complex systems. The aim of this part of the study was to determine how learning from models differed between an individual learning environment and a collaborative learning environment. Research shows that students learn more in a collaborative learning environment because they interact more with the model (Singhanayok & Hooper, 1998) and because it encourages students to explain concepts to each other (Kramarski, 2004). Studies have found that students in cooperative learning groups out performed individual learners in a biology subject (Singhanayok & Hooper, 1998). Cooperative learning also supports a range of learning styles (Wang, Hinn, & Kanfer, 2001). Suthers and Hundhausen (2001) showed that a shared graphical representation made central characteristics of the learning object salient, which provided representational guidance to the learning discourse. In particular, it has been suggested that providing multiple representations of the solution combined with a strong understanding of the topic will support interaction about science in computer-supported collaborative learning (Baker, de Vries, Lund, & Quignard, 2001). Research also suggests that the learner's perception of the technology is also an important component of the collaborative learning process, as learners must be scaffolded within their learning environments (Beatty & Nunan, 2004). In this study, the students were not scaffolded in the collaborative learning environment and data related to interaction between partners was not collected (further discussion of this limitation can be found in Chapter 3).

A number of authors have investigated collaboration in science education (see for example (Jeong & Chi, 2007; Oliveira & Sadler, 2007; Roschelle, 1992; Suthers & Hundhausen, 2003)). These authors identify *convergence* as the main advantage of a collaborative learning environment. Convergence occurs when students engage in collaborative inquiry learning and mutually construct understanding of the phenomenon (Roschelle, 1992). Jeong and Chi (Jeong & Chi, 2007) analysed conversations and determined that the convergence in their study could be attributed to collaborative interaction. They also found that a modest amount of convergence is typical in an unstructured, naturalistic collaborative learning situation. That suggests that in this study, which is similarly unstructured, and in which students were randomly allocated to dyads, some convergence is expected. These authors say that convergence is due to interaction and shared input, in other words the materials. Interaction data was not collected as part of this thesis. The purpose of this section of the thesis is to make a preliminary comparison of differences in learning outcomes and measures of use between students working alone and in dyads. This will provide directions for future research in the field of collaborative learning with system dynamics and agent-based models.

6.2 HYPOTHESES, AN EXPLORATORY QUESTION AND BRIEF INTRODUCTION TO THE CHAPTER

This chapter addresses three hypotheses and one exploratory question:

H2a: Students working in a collaborative learning environment will have higher scores for all learning outcomes than students in an individual learning environment.

H2b: Students working in a collaborative learning environment will interact more with the model than students in an individual learning environment.

H2c: A system dynamics model is too abstract for high school students, and an additional representation that constrained the interpretation of the model (one that was familiar to the students, such as the animated representation included in the agent-based model) will improve interpretation, and therefore understanding for students in the collaborative learning environment.

E2a: Are the strategies used to interrogate the models independent of the learning environment?

The way in which the agent-based model was used, however, suggests that time factors played a role in students' ability to identify links between system-specific knowledge and other systems. A partner is not expected to change this, and the additional time spent in negotiation of the use of the model may result in lower learning outcomes.

Research already presented in this thesis suggested that students presented with a representation that constrained their interpretation of the system dynamics model had higher post-test scores. Comparisons between groups suggested that the second representation should increase students' familiarity with the main representation, or provide information at a different level, rather than a text description. A partner may also help students to interpret the system dynamics model.

Students using multiple representations were able to interpret the system dynamics model using the agent-based model, and increase all environmental knowledge scores and the applied system dynamics knowledge score. Students in this group did not increase their system dynamics knowledge score, and it seemed to have been related to the high cognitive load associated with increasing knowledge of all other learning outcomes. The addition of a partner may help to decrease this cognitive load. However, given the successful use of the multiple representations by individuals, it is not expected that a partner will result in much improvement to learning outcomes further beyond this.

In the Text group, students were able to increase knowledge for all learning outcomes except that addressing knowledge of introduced plant species. Given the successful use of the materials by individuals, it is not expected that a partner will result in much improvement to learning outcomes.

In brief, the first half of this chapter focuses on learning outcomes, and the second half on measures of use of the models. The results of analyses carried out on the overall environmental knowledge and system dynamics knowledge test scores and the final assessment task score will be reported on first. A number of key items and sections within the overall scores will then be analysed. Each of these parts has the following structure:

- Comparison of pre-test and post-test scores between learning environments, between groups, and comparison of pre-test and post-test scores within each group,
- Comparison of the change in knowledge scores between learning environments and between the groups, and
- Comparison of the final assessment task scores between learning environments and between the groups.

The second half will compare measures of use of the models. In brief, the results of analyses carried out on the general measures of use of the model will be compared between all three groups and within groups to determine whether there is a general pattern of use of the models in both learning environments. The use of single models will then be compared to the use of the same type of model when an additional model is available (for example the use of the model by the ABM group will be compared to the use of the model in the SDM & ABM group) in both learning environments. This will help to determine whether students used the agent-based model to constrain their interpretation of the system dynamics model (Ainsworth, 1999). If this was the case, students would have used the system dynamics model to experiment with, and the agent-based model for context. Students in the SDM & ABM group would have a similar level of activity as those in the SDM group (*H2b*). The final part of this chapter will identify the strategies used by students to interrogate the models overall and to change individual variables in both learning environments. Relationships between these strategies and the general measures of use of the models will help to define the classification system. When the strategies were analysed, the amount of time as well as the proportion of time spent on screens was compared between strategies. An analysis of the relationships between learning outcomes and the strategies used in the collaborative learning environment will help to explain why students adopted particular strategies, and what effect these had on their learning outcomes. For a full discussion of the analyses performed, refer to Chapter 3.

6.3 MULTIPLE EXTERNAL REPRESENTATIONS

The experimental design in the collaborative learning environment was the same as that in the individual learning environment. The experiment compared the learning outcomes from students in four groups: a control group (Text group) in which students were exposed to a text-based description of visitor impacts on a national park (see Appendix 1), and three treatment groups, in which students were either given a system dynamics model to examine (SDM group), an agent-based model of the system (ABM group), or both of these combined (SDM & ABM group). The two learning environments were an individual learning environment (ILE) in which each student had their own computer and were not allowed to interact with other members of their class; and the collaborative learning environment (CLE) in which one computer was shared between two students, who were allowed to interact with each other during their interrogation of the learning materials, but completed all assessment individually.

Learning outcomes were the environmental knowledge and system dynamics knowledge tests (pre-tests and post-tests allowed the change in knowledge to be determined); and the final assessment task (which assessed understanding of this particular system). Total scores will be discussed first, followed by key items and sections. The environmental knowledge test has three questions that will be discussed individually, and the final assessment task has three.

6.3.1 Learning outcomes: Environmental knowledge, system dynamics knowledge and understanding

Students from both School 1 and School 2 participated in the individual learning environment; students from School 1 participated in the collaborative learning environment. The comparison between learning environments will only include students from School 1 to make sure that the comparisons between the learning environments are appropriate. The sample for this section is therefore as follows, ILE: Text group, *n* = 2; ABM group, *n* = 4; SDM group, *n* = 4; and SDM & ABM group, *n* = 3. CLE: Text group, *n* = 3; ABM group, *n* = 4; SDM group, *n* = 6; and SDM & ABM group, *n* = 5. The small sample size of the Text group in the individual learning environment meant that it was unable to be included in the statistical comparisons, and so differences between this group and the findings presented in Chapter 4 are discussed in broad terms.

6.3.1.1 Results

As outlined above, this section reports on the results of the analyses performed on overall test scores. All pre-test scores and learning outcomes are compared between learning environments using Mann Whitney tests. In addition, the following analyses will be reported for both learning environments. Pre-test and post-test knowledge test scores will be compared between the groups using Kruskal-Wallis tests. Pre- and post-test scores will be compared for each group using Wilcoxon signed ranks tests. The results of Kruskal-Wallis tests comparing the change in knowledge test scores between groups will then be reported. Final assessment task scores will also be compared between groups using Kruskal-Wallis tests. Due to the small sample size, large effect sizes were taken into account in addition to significance, and are noted where appropriate. The meaning of these results in terms of the hypothesis will then be discussed.

6.3.1.1.1 Pre- and post-test environmental and system dynamics knowledge scores

Students in each group completed two knowledge tests in a pre- and post-test design. Pre-tests were administered before interaction with the materials. Post-tests were completed by students after the treatment, and students were given the opportunity to change their original answer, or to keep it (see Chapter 3 for further discussion of this). The environmental knowledge test was worth 32 marks, and contained items that related specifically to the materials and items that required application of this knowledge to other systems. The system dynamics knowledge test was worth 12 marks, and also contained general system dynamics knowledge questions and an applied question.

Table 6-1: Median and range of scores for the total environmental knowledge and system dynamics knowledge pre-test and post-test for the ILE and the CLE

	ILE				CLE				ILE vs. CLE
		Range		Score >		Range		Score >	
Group	*Mdn*	Lower	Upper	50% (%)	*Mdn*	Lower	Upper	50% (%)	*U*
ABM									
EK$_{pre}$	17	16	25	75	12.75	11.5	18	25	**3.0**
EK$_{post}$	20.75	13.5	28	75	13.25	12.5	19	25	**3.0**
SDK$_{pre}$	5.5	3	10	50	4	3	7	25	6.0
SDK$_{post}$	7.5	6	10	75	4	3	7	25	**1.5**^{a}
SDM									
EK$_{pre}$	21	10	31	75	18.75	18	23.5	100	10.5
EK$_{post}$	17.5	15	24	75	23.5	19	25	100	**4.0**
SDK$_{pre}$	1	0	4	0	4.5	1	8	33	**3.5**^{a}
SDK$_{post}$	3.5	0	7	25	7.5	1	10	67	**4.5**
SDM & ABM									
EK$_{pre}$	18.5	17	20.5	100	20	12	21	80	7.0
EK$_{post}$	19.5	17	22.5	100	21	17.5	24	100	5.0
SDK$_{pre}$	6	5	7	33	5	3	9	20	5.0
SDK$_{post}$	7	5	8.5	67	6	3	6	0	3.0
Text									
EK$_{pre}$	22.75	18.5	27	100	22	21	24	100	--
EK$_{post}$	23	19	27	100	22	21	24	100	--
SDK$_{pre}$	4.75	2	7.5	50	3	2	3.5	0	--
SDK$_{post}$	6.25	5	7.5	50	3.5	1	4	0	--

Note. ILE = individual learning environment; CLE = collaborative learning environment; EK = environmental knowledge score (Maximum score is 32). SDK = system dynamics knowledge score (Maximum score is 12). $_{pre}$ = pre-test score. $_{post}$ = post-test score. Bold typeface indicates large effect size ($r > | .50 |$).

$^{a}p < .10$.

In the ABM group, students in the individual learning environment had higher scores for the environmental knowledge pre- and post-test scores (large effect size) and the system dynamics post-test scores ($p < .10$) than students in the collaborative learning environment. However in the SDM group, environmental knowledge post-test scores were higher in the collaborative learning environment than the individual learning environment (large effect size). Both pre- ($p < .10$) and post-test (large effect size) system dynamics knowledge scores were higher in the collaborative learning environment than the individual learning environment for this group. There were non-significant differences between the learning environments for these scores in the SDM & ABM group.

Kruskal-Wallis tests were used to compare the learning outcomes between the groups. In the individual learning environment, there was a non-significant difference between the groups in terms of pre-test environmental knowledge scores ($H(3) = 1.88$, $p = .60$) and between the groups in terms of post-test environmental knowledge scores ($H(3) = 1.47$, $p = .69$). However, in the collaborative learning environment, pre-test environmental knowledge scores were significantly different when the groups were compared ($H (3) = 9.81$, $p = .02$) as were the post-test environmental knowledge scores ($H (3) = 9.00$, $p = .03$). The environmental knowledge scores can be seen in Figure 6-1.

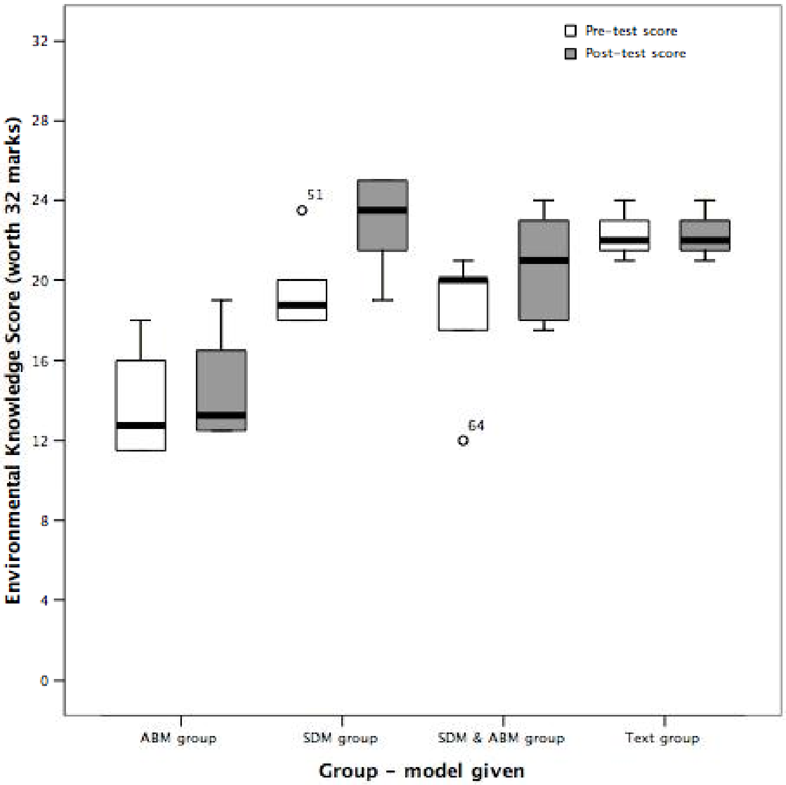


Figure 6-1: Total environmental knowledge pre-test and post-test scores in each group in the collaborative learning environment

In the individual learning environment, there was a non-significant difference between the groups when the system dynamics knowledge pre-test was compared ($H(3) = 5.88$, $p = .12$) and the post-test ($H(3) = 3.88$, $p = .28$). There was a non-significant difference between the groups in the collaborative learning environment when pre-test system dynamics knowledge scores were compared ($H(3) = 3.95$, $p = .27$), and similarly for the post-test scores ($H(3) = 5.55$, $p = .14$).

Mann Whitney tests the groups with respect to the environmental knowledge score in the collaborative learning environment (Table 6-2).

Table 6-2: Results of the Mann Whitney test comparing total pre- and post-test environmental knowledge scores between the groups in the collaborative learning environment

Group	EK_{pre}	EK_{post}
ABM vs.		
SDM	**1.5***	**0.5***
SDM & ABM	**3.0**	**2.0**^{a}
Text	**0.0**^{a}	**0.0**^{a}
SDM vs.		
SDM & ABM	14.0	7.0
Text	**2.0**	7.0
SDM & ABM vs.		
Text	**0.5**^{a}	5.0

Note. EK = environmental knowledge score (Maximum score is 32). SDK = system dynamics knowledge score (Maximum score is 12). $_{\text{pre}}$ = pre-test score. $_{\text{post}}$ = post-test score. Bold typeface indicates large effect size ($r > |.50|$).

$^{a}p < .10$; $^{*}p < .05$.

Table 6-2 shows that in the pre-test environmental knowledge scores, students in the ABM group in the collaborative learning environment had lower scores than students in the SDM and Text groups. In addition, students in the Text group had higher median scores than students in the SDM & ABM groups. When post-test environmental knowledge scores were compared, the Text, SDM and SDM & ABM groups were statistically similar, however the differences in the environmental knowledge score between the ABM group and the other three groups increased.

Table 6-3: Results of the Wilcoxon signed-rank tests comparing total environmental knowledge and system dynamics knowledge pre- and post-test scores, for each group in the individual and collaborative learning experiments

	ILE		CLE	
	T	Direction	*T*	Direction
ABM				
EK	2.5	No change	**0.0**[a]	**Increase**
SDK	**0.0**	**Increase**	0.0	No change
SDM				
EK	4.0	No change	**0.0**[*]	**Increase**
SDK	**1.0**	**Increase**	**0.0**[a]	**Increase**
SDM & ABM				
EK	**0.0**	**Increase**	**0.0**	**Increase**
SDK	**0.0**	**Increase**	3.5	No change
Text				
EK	--	--	0.0	No change
SDK	--	--	1.5	No change

Note. ILE = individual learning environment. CLE = collaborative learning environment. EK = environmental knowledge test (Maximum score is 32). SDK = system dynamics knowledge test (Maximum score is 12). Bold typeface indicates large effect size ($r > | .50 |$).

[a] $p < .10$. [*] $p < .05$.

There were differences in the results for the Wilcoxon signed ranks test when the individual and collaborative learning environments were examined (Table 6-3). The change between the environmental knowledge pre- and post-test score in the ABM group in the individual learning environment was non-significant. However there was a large effect size associated with an increase in the system dynamics knowledge test. There was a significant ($p < .10$) increase between the environmental pre- and post-test in the collaborative learning environment. However, in the system dynamics knowledge test, the change was non-significant.

In the SDM group, in the individual learning environment the change in the environmental knowledge score was non-significant, whereas students in the collaborative learning environment significantly increased their environmental knowledge score. There was a large effect size associated with the increase in the system dynamics knowledge score in the individual learning environment, and a significant ($p < .10$) increase in the collaborative learning environment.

Large effect sizes were associated with increases in environmental knowledge scores in the SDM & ABM groups in both learning environments. Only those students in the individual learning environment had a large effect size associated with an increase in the system dynamics knowledge score.

In the Text group, the change in both scores in the collaborative learning environment was non-significant.

6.3.1.1.2 The change in the environmental and system dynamics knowledge scores

The change in the knowledge scores was calculated by subtracting the pre-test score from the post-test score. The purpose of comparing these changes is to determine whether the treatments had an effect on the size of the difference between the scores.

Table 6-4: Median and range of the change in scores for the environmental knowledge and system dynamics knowledge scores for the individual and collaborative learning environments

	ILE				CLE				ILE vs. CLE:
		Range		Increase in		Range		Increase in	
Group	*Mdn*	Lower	Upper	score (%)	*Mdn*	Lower	Upper	score (%)	*U*
ABM									
EK_{change}	2.5	-3	6	75	1	0	1	75	4.0
SDK_{change}	1	0	5	50	0	0	0	0	**4.0**
SDM									
EK_{change}	-0.5	-16	8	50	3.5	0	7	83	11.0
SDK_{change}	1	-1	7	50	2.25	0	4	67	9.5
SDM & ABM									
EK_{change}	1	0	2	67	3	0	6	60	5.0
SDK_{change}	0	0	2.5	33	0	-3	2	40	5.0
Text									
EK_{change}	0.25	0	0.5	50	0	0	0	0	--
SDK_{change}	1.5	0	3	50	0	-1	1	33	--

Note. EK = environmental knowledge score (Maximum score is 32). SDK = system dynamics knowledge score (Maximum score is 12). $_{pre}$ = pre-test score. $_{post}$ = post-test score. Bold typeface indicates large effect size ($r > |.50|$)

In the ABM group, there was a non-significant difference between the change in the environmental knowledge score when the two learning environments were compared (Table 6-4). There was a large effect size associated with the larger change in the system dynamics knowledge score in the individual learning environment than that in the collaborative learning environment.

There were non-significant differences in the change in both the environmental knowledge and system dynamics knowledge scores when the individual and collaborative learning environments were compared in the SDM group and in the SDM & ABM group.

Kruskal-Wallis tests showed that there was a non-significant difference between the groups in terms of the change in the environmental knowledge score in the individual learning environment

(*H* (3) = 0.85, *p* = .84). There was also a non-significant difference between the groups with respect to the change in the system dynamics knowledge score (*H* (3) = 0.59, *p* = .90). Similarly in the collaborative learning environment, there were non-significant differences between the groups with regards to the change in the environmental knowledge score (*H* (3) = 5.78, *p* = .12) and the change in the system dynamics knowledge score (*H* (3) = 5.33, *p* = .15).

6.3.1.1.3 Understanding of the system: Final assessment task scores

The final assessment contained five questions that allowed students to assume the role of a national park manager. Questions addressed areas such as self-reported interrogation of the materials, description of the system, environmental and management issues raised by the materials, and decisions, predictions and consequences of the decisions suggested. The purpose of these questions was to assess understanding of the system itself, rather than more general environmental knowledge.

Table 6-5: Median and range of scores for the final assessment task in the individual and collaborative learning environments

	ILE				CLE				ILE vs. CLE
		Range		Score >		Range		Score >	
Group	*Mdn*	Lower	Upper	50% (%)	*Mdn*	Lower	Upper	50% (%)	*U*
ABM	23	16	36	0	19	16	34	0	7.0
SDM	21.75	19	24	0	19.5	16	29	0	9.5
SDM & ABM	32	21	34	0	20	8	32	0	**2.5**
Text	33	29	37	0	30	21	37	0	--

Note. ILE = individual learning environment. CLE = collaborative learning environment. Bold typeface indicates large effect size (*r* > | .50 |). Maximum score is 91.

There was a large effect size associated with the higher final assessment task score that students in the individual learning environment in the SDM & ABM group had when compared to those in the collaborative learning environment. There were non-significant differences between the learning environments when the final assessment task score was compared in the other groups.

In the individual learning environment, there was a non-significant difference between the groups when the final assessment task scores were compared (*H* (3) = 4.13, *p* = .25). There was similarly a non- significant difference between the groups in the collaborative learning environment (H (3) = 3.39, p = .36).

6.3.1.2 Discussion

Two hypotheses were associated with this part of the analysis:

H2a: Students working in a collaborative learning environment will have higher scores for all learning outcomes than students in an individual learning environment.

H2c: A system dynamics model is too abstract for high school students, and an additional representation that constrained the interpretation of the model (one that was familiar to the students, such as the animated representation used in the agent-based model) will improve interpretation, and therefore understanding in a collaborative learning environment.

As this was an experimental design, the control group will be described first, followed by a discussion of the effect of the collaborative learning environment on learning from agent-based models, learning from system dynamics models, and learning from multiple representations.

6.3.1.2.1 The control group

Chapter 4 showed that students in the Text group in the individual learning environment were able to increase knowledge for the total environmental and system dynamics knowledge scores. Given the successful use of the materials by individuals, it is not expected that a partner will result in a large improvement to learning outcomes.

In the collaborative learning environment, the only significant increase between pre- and post-test scores was found in the environmental knowledge test, and not the system dynamics knowledge scores. This is in contrast to the results discussed above.

6.3.1.2.2 Learning from the agent-based model

Previous research has shown that students in a collaborative learning environment have had a greater understanding of the system than those in the individual learning environment when using an agent-based model (Abrahamson & Wilensky, 2005). However, the results discussed in this thesis have suggested that time factors played a role in students' ability to identify links between system-specific knowledge and other systems when using the agent-based model. A partner is not expected to change this, and the additional time spent in negotiation of the use of the model may result in lower learning outcomes.

Students in the collaborative learning environment in the ABM group increased their environmental knowledge score, while students in the individual learning environment increased their system dynamics score. Students in the collaborative learning environment had lower environmental knowledge (pre- and post-test) and system dynamics knowledge (post-test) scores than those in the individual learning environment. In fact, students in the collaborative learning environment had significantly lower pre- and post-test environmental knowledge scores than students in all other groups. Students in the two learning environments had similar final assessment task scores. These findings do not provide clear support for the hypothesis, and further investigation of key items is needed.

6.3.1.2.3 Learning from the system dynamics model

It was expected that students in the collaborative learning environment learning from a system dynamics model would have greater understanding and higher knowledge scores than those in the individual learning environment due to studies that have focussed on general collaborative learning (Abrahamson & Wilensky, 2005; Johnson & Johnson, 1985; Kozma, 2003). However there have been no specific studies comparing learning from system dynamics models in the two learning environments. Research already presented in this thesis suggested that students presented with a representation that constrained their interpretation of the system dynamics model had higher post-test scores. Comparisons between groups suggested that the representation should increase students' familiarity with the representation, or provide information at a different level, rather than a text description. A partner may also help students to interpret the system dynamics model.

The hypothesis was supported with respect to environmental knowledge in the SDM group. Students in the two learning environments had similar pre-test environmental knowledge scores, and those in the collaborative learning environment had higher post-test environmental knowledge scores than students in the individual learning environment. Only those students in the collaborative learning environment increased their environmental knowledge score. Students in the SDM group increased their system dynamics knowledge scores in both learning environments; although students in the collaborative learning environment had higher pre- and post-test scores than those in the individual learning environment. Students in the two learning environments in most groups had similar final assessment task scores.

6.3.1.2.4 Learning from multiple representations

Research has shown that the collaborative learning environment may result in greater understanding of the system for students given multiple representations (Kozma, 2003). As has already been discussed in this thesis, students using multiple representations were able to interpret the system dynamics model using the agent-based model, and increase all environmental knowledge scores and the applied system dynamics knowledge score. Students in this group did not increase their system dynamics knowledge score, and it may have been related to the high cognitive load associated with increasing knowledge of all other learning outcomes. The addition of a partner may help to decrease this cognitive load. However, given the successful use of the multiple representations by individuals, it is not expected that a partner will result in a large improvement to learning outcomes.

The hypothesis was not supported by the results found in the SDM & ABM group. Students in the individual and collaborative learning environments had similar environmental and system dynamics knowledge scores in both the pre-test and post-test. Students from both learning environments increased their environmental knowledge score, and only students from the individual learning environment increased their system dynamics score. Students from the individual learning environment had a higher score for the final assessment task than those from the collaborative learning environment (a large effect size was associated with this difference).

It was also expected that students given multiple representations would be the most successful of any of the groups. This was due to the findings outlined in Chapter 4 and Chapter 5, and a number of studies reporting on the advantages of multiple representations (for example (Ainsworth, 1999; Ainsworth, Bibby, & Wood, 1998; Tsui & Treagust, 2003)). However, this hypothesis was not supported. In the collaborative learning environment, there was a large effect size associated with an increase between the pre- and post-test environmental knowledge score in the ABM, SDM and SDM & ABM groups. This increase was significant only in the SDM group; therefore the SDM group was the most successful in terms of an increase in knowledge about the environment.

6.3.1.3 Conclusion

The main hypothesis, that a collaborative learning environment would produce higher learning outcomes than an individual learning environment was only supported by results from the SDM group. Students had similar results in the individual and collaborative learning environments in the

SDM & ABM group for environmental knowledge. The individual learning environment resulted in higher system dynamics knowledge scores for the ABM group, and a higher final assessment task score in the SDM & ABM group. In terms of the hypothesis that multiple external representations and a collaborative learning environment would be the most successful, this was not the case; the SDM group was the most successful. Further examination of the learning outcomes and use of the models will explain this further.

6.3.2 Individual Questions

The following hypotheses also apply to this section of the chapter:

H2a: Students working in a collaborative learning environment will have higher scores for all learning outcomes than students in an individual learning environment.

H2c: A system dynamics model is too abstract for high school students, and an additional representation that constrained the interpretation of the model (one that was familiar to the students, such as the animated representation included in the agent-based model) will improve interpretation, and therefore understanding in the collaborative learning environment.

As for the individual learning environment, presented in Chapter 4, key items and sections of the environmental knowledge test will be compared between pre- and post-tests for each group. Each pre-test, post-test, change in knowledge test and final assessment task score for these sections will be compared between the groups and between the learning environments.

6.3.2.1 Results of the analysis of key items

As outlined above, this section reports on the results of the analyses performed on key test scores. All pre-test scores and learning outcomes are compared between learning environments using Mann Whitney tests. In addition, the following analyses will be reported for both learning environment. Pre-test and post-test knowledge test scores will be compared between the groups using Kruskal-Wallis tests. Pre- and post-test scores will be compared for each group using Wilcoxon signed ranks tests. The results of Kruskal-Wallis tests comparing the change in knowledge test scores between groups will then be reported. Final assessment task scores will also be compared between groups using Kruskal-Wallis tests. Due to the small sample size, large effect sizes were taken into account in addition to significance, and are noted where appropriate. The meaning of these results in terms of the hypothesis will then be discussed.

6.3.2.1.1 Pre- and post-test environmental knowledge scores

Three questions were analysed as part of the environmental knowledge tests. Question 5 (9 marks) questioned students about the types of activities that could cause an increase in the number of introduced animal species, and asked them to name one effect of such an increase. Question 6 (8 marks) asked students to identify the types of activities that could cause an increase in the number of introduced plant species, and what the effects of such an increase might be. Question 7 (12 marks) asked students to describe the impact of building a road, littering and bushwalking in terms of the initial impact, the time scale involved in that impact, any further impacts, and their associated time scales.

Table 6-6: Median and range of scores for key questions in the environmental knowledge pre-test and post-test, and the results of the Mann Whitney tests comparing learning environments

	ILE				CLE				ILE vs. CLE
		Range				Range			
Question	*Mdn*	Lower	Upper	Score > 50% (%)	*Mdn*	Lower	Upper	Score > 50% (%)	*U*
ABM									
$Q5_{pre}$	2.5	2	6	25	2.75	2	3	0	8.0
$Q5_{post}$	5.5	3	7	50	3.25	3	4	0	3.5
$Q6_{pre}$	3.75	1	4	0	1.75	0.5	3	0	**3.0**
$Q6_{post}$	4.75	1	6	75	1.75	1.5	3	0	4.0
$Q7_{pre}$	9.5	9	12	100	6.5	4	11	50	**3.0**
$Q7_{post}$	10	4	12	75	6	4	11	50	5.0
SDM									
$Q5_{pre}$	5.5	1	8	75	3	2	5	17	6.5
$Q5_{post}$	5.5	1	7	75	5	4	5	67	8.0
$Q6_{pre}$	5	1	8	50	2.75	2	5.5	17	7.5
$Q6_{post}$	5.5	1	7	75	5	3.5	6	67	9.5
$Q7_{pre}$	9.5	5	12	75	10	9	12	100	10.0
$Q7_{post}$	8	2	10	75	11.25	8	12	100	**2.5***
SDM & ABM									
$Q5_{pre}$	3	3	5	33	3	2	4	0	5.0
$Q5_{post}$	4	3	6	33	5	3	7	60	6.0
$Q6_{pre}$	4	2	4.5	33	4	1	5	40	7.0
$Q6_{post}$	4	2	5.5	33	4.5	0.5	6	60	7.0
$Q7_{pre}$	10	8	11	100	10	5	11	80	7.5
$Q7_{post}$	10	7	12	100	10.5	8	12	100	6.0
Text									
$Q5_{pre}$	2.75	0.5	5	50	5	3	6	67	--
$Q5_{post}$	3.5	3	4	0	4	4	5	33	--
$Q6_{pre}$	5	3	7	50	4	3	5	33	--

	ILE				CLE				ILE vs. CLE
		Range		Score >		Range		Score >	
Question	*Mdn*	Lower	Upper	50% (%)	*Mdn*	Lower	Upper	50% (%)	*U*
Q6$_{post}$	4.5	1	8	50	5	4	5	67	--
Q7$_{pre}$	12	12	12	100	11	10	11	100	--
Q7$_{post}$	12	12	12	100	10	10	11	100	--

Note. Q5 = knowledge about introduced animal species (Maximum score is 9). Q6 = knowledge about introduced plant species (Maximum score is 8). Q7 = knowledge about human impacts on an ecosystem and associated timescales (Maximum score is 12). $_{pre}$ = pre-test score. $_{post}$ = post-test score. Bold typeface indicates large effect size ($r > | .50 |$).

$^{*}p < .05$.

In the ABM group large effect sizes were associated with higher pre-test scores assessing knowledge about introduced plant species (Question 6) and human impacts on an ecosystem and associated timescales (Question 7) in the individual learning environment that the collaborative learning environment.

In the SDM group, students in the collaborative learning environment had a significantly ($p < .05$) higher post-test score assessing knowledge of human impacts on an ecosystem and associated timescales (Question 7) than students in the individual learning environment.

Table 6-7: Results of the Kruskal-Wallis tests for each question in each learning environment

	Pre-test		Post-test	
Question	*ILE*	*CLE*	*ILE*	*CLE*
Q5	1.70	5.19	1.53	6.70^{a}
Q6	1.29	5.45	0.57	6.08
Q7	3.42	3.61	4.67	4.76

Note. Q5 = knowledge about introduced animal species (Maximum score is 9). Q6 = knowledge about introduced plant species (Maximum score is 8). Q7 = knowledge about human impacts on an ecosystem and associated timescales (Maximum score is 12).

$^{a}p < .10$.

In the collaborative learning environment, there was a significant difference when the groups were compared in terms of the post-test score assessing knowledge of introduced animal species (Question 5). Mann Whitney tests were carried out (Table 6-8).

Table 6-8: Results of the Mann Whitney tests comparing the groups in the individual and collaborative learning environment

	CLE
	$Q5_{post}$
ABM vs.	
SDM	**1.0***
SDM & ABM	**3.5**
Text	**1.0**
SDM vs.	
SDM & ABM	15.0
Text	6.0
SDM & ABM vs.	
Text	6.0

Note. ILE = individual learning environment. CLE = collaborative learning environment. $Q5_{post}$ = post-test score assessing knowledge of introduced animal species (Maximum score is 9). Bold typeface indicates large effect size ($r > | .50 |$).

$^{*}p < .05$.

In the collaborative learning environment, students in the ABM group had a lower post-test score assessing knowledge of introduced animal species (Question 5) than students in the SDM group.

Table 6-9: Results of the Wilcoxon Signed Ranks tests for each question in each learning environment

	ILE		CLE	
	T	Direction	*T*	Direction
ABM group				
Q5	**0.0**^{a}	Increase	**0.0**^{a}	Increase
Q6	**0.0**	Increase	**0.0**	Decreased range
Q7	1.0	No change	**0.0**	Decrease
SDM group				
Q5	3.0	No change	**0.0**^{a}	Increase
Q6	4.0	No change	**0.0***	Increase
Q7	2.0	No change	2.5	No change
SDM & ABM group				
Q5	**0.0**	Increase	**0.0**^{a}	Increase
Q6	**0.0**	Increase	3.0	No change
Q7	1.5	No change	**0.0**	Increase
Text group				
Q5	--	--	1.0	No change
Q6	--	--	**0.0**	Increase
Q7	--	--	**0.0**	Decrease

Note. ILE = individual learning environment. CLE = collaborative learning environment. Q5 = knowledge about introduced animal species (Maximum score is 9). Q6 = knowledge about introduced plant species (Maximum score is 8). Q7 = knowledge about human impacts on an ecosystem and associated timescales (Maximum score is 12). Bold typeface indicates large effect size ($r > | .50 |$).

$^{a}p < .10$. $^{*}p < .05$.

In the ABM group, students in both learning environments significantly ($p < .10$) increased their score assessing knowledge about introduced animal species (Question 5). There was a large effect size associated with the increase in scores assessing knowledge of introduced plant species (Question 6). A non-significant change in the score assessing knowledge of human impacts on the environments and the associated time scales (Question 7) was found in the individual learning environment. In the collaborative learning environment the median Question 7 score was lower in the post-test than in the pre-test.

In the SDM group, there was a non-significant change between the Question 7 pre- and post-test in both learning environments. In the collaborative learning environment there were significant increases in the scores for the questions involving introduced animal and plant species (Question 5 and Question 6). In the individual learning environment, the changes in these questions were non-significant.

In the SDM & ABM group, students in both learning environments increased their Question 5 score between the pre- and post-test (large effect size in the individual learning environment, significant ($p < .10$) in the collaborative learning environment). In the individual learning environment there was an increase in the score assessing knowledge of introduced plant species (Question 6), and not in the collaborative learning environment. Students in the collaborative learning environment increased the score assessing their knowledge of human impacts on environments and the associated time scales (Question 7), while students in the individual learning environment did not.

In the Text group, students in the collaborative learning environments did not change their score assessing knowledge of introduced animal species (Question 5). In the collaborative learning environment the score assessing knowledge of introduced plant species (Question 6) increased between the pre- and post-test. In the collaborative learning environment the score assessing knowledge of human impacts on an ecosystem and associated timescales (Question 7) decreased between the pre- and post-test.

6.3.2.1.2 The change in the environmental knowledge scores

The change in the knowledge scores was calculated by subtracting the pre-test score from the post-test score. The purpose of comparing these changes is to determine whether the treatments had an effect on the size of the difference between the scores.

Table 6-10: Median and range of the change in key questions in the environmental knowledge scores, and the results of the Mann Whitney tests comparing learning environments

	ILE				CLE				ILE vs. CLE
		Range		Increased		Range		Increased	
Question	*Mdn*	Lower	Upper	score (%)	*Mdn*	Lower	Upper	score (%)	*U*
ABM									
Q5$_{\text{change}}$	1	1	5	100	1	0	1	75	4.5
Q6$_{\text{change}}$	1	0	2	75	0	0	1	25	**3.5**
Q7$_{\text{change}}$	0	-5	1	25	0	-1	0	0	7.0
SDM									
Q5$_{\text{change}}$	1	-7	4	50	1.5	0	3	67	11.0
Q6$_{\text{change}}$	1.5	-7	4	75	1.5	0	4	83	11.5
Q7$_{\text{change}}$	-1	-9	3	25	0.25	-1	2	50	8.0
SDM & ABM									
Q5$_{\text{change}}$	1	0	1	67	2	0	3	80	**2.5**
Q6$_{\text{change}}$	0	0	1	33	0	-3	1	40	7.0
Q7$_{\text{change}}$	0	-1	1	33	0	0	3	40	4.5
Text									
Q5$_{\text{change}}$	0.75	-1	2.5	50	0	-2	1	33	--
Q6$_{\text{change}}$	-0.5	-2	1	50	0	0	2	33	--
Q7$_{\text{change}}$	0	0	0	0	0	-1	0	0	--

Note. ILE = individual learning environment. CLE = collaborative learning environment. Q5 = knowledge about introduced animal species (Maximum score is 9). Q6 = knowledge about introduced plant species (Maximum score is 8). Q7 = knowledge about human impacts on an ecosystem and associated timescales (Maximum score is 12). $_{\text{change}}$ = change in the score between the pre- and post-test. Bold typeface indicates large effect size ($r > |.50|$).

In the ABM group, students in the individual learning environment had a larger change in the score assessing knowledge of introduced plant species (Question 6) than students in the collaborative learning environment (large effect size). In the SDM & ABM group, a large effect size indicated that students in the collaborative learning environment had a larger change in the score assessing knowledge of introduced animal species (Question 5) than students in the individual learning environment.

In the individual learning environment, the difference between the groups was non-significant when the change in Question 5 was compared (H (3) = 0.99, p = .80), and similarly the difference was non-significant when the change in knowledge about introduced plant species (Question 6) was compared (H (3) = 1.91, p = .59). There was also a non-significant difference observed when comparing the change in the score assessing knowledge of human impacts on an ecosystem and associated timescales (Question 7) (H (3) = 0.36, p = .95).

In the collaborative learning environment, the difference between the groups was non-significant when the change in Question 5 was compared (H (3) = 5.19, p = .16), and similarly the difference was non significant when the change in knowledge about introduced plant species (Question 6) was compared (H (3) = 5.30, p = .15). There was also a non-significant difference observed when comparing the change in the score assessing knowledge of human impacts on an ecosystem and associated timescales (Question 7) (H (3) = 4.18, p = .24).

6.3.2.1.3 Understanding of the system – key outcomes

Individual questions in the final assessment task were grouped into three sections. The first section assessed students' abilities to describe what they saw in the model (*Describe*, 8 marks). The second section addressed students' abilities to identify the issues that were raised by the materials (*Issues*, 16 marks), and the third assessed students' abilities to make decisions, predictions, and identify the consequences of their decisions (*Higher Level Thinking*, 24 marks).

Table 6-11: Median and range of scores for key sections of the final assessment task, and the results of the Mann Whitney tests comparing learning environments

	ILE				CLE				ILE vs. CLE
		Range		Score >		Range		Score >	
Question	*Mdn*	Lower	Upper	50% (%)	*Mdn*	Lower	Upper	50% (%)	*U*
ABM									
Describe	3	2	5	25	2	0	4	0	6.0
Issues	6.5	2	9	50	4	1	8	25	5.0
HLT	7	2	8	0	4	1	8	0	5.0
SDM									
Describe	4	3	5	25	3	1	4	0	5.5
Issues	5	3	7	25	5	2	9	17	11.5
HLT	5	1	7	0	4.5	3	8	0	12.0
SDM & ABM									
Describe	4	4	4	0	4	0	5	20	6.0
Issues	7	5	9	25	6	0	9	40	5.0
HLT	5	4	10	0	4	0	11	0	4.0
Text									
Describe	5	4	6	50	3	2	5	33	--
Issues	8.5	8	9	100	6	4	9	33	--
HLT	8	5	11	0	6	5	7	0	--

Note. ILE = individual learning environment. CLE = collaborative learning environment. Describe = *Describe* section of the final assessment task (Maximum score is 8). Issues = *Issues* section of the final assessment task (Maximum score is 16). HLT = *Higher Level Thinking* section of the final assessment task (Maximum score is 24). Bold typeface indicates large effect size (*r* > | .50 |).

No significant differences in understanding were found when the learning environments were compared.

In the individual learning environment, the differences between the groups were non-significant when the *Describe* section ($H(3) = 3.33$, $p = .34$), the *Issues* section ($H(3) = 3.63$, $p = .31$) and the *Higher Level Thinking* section ($H(3) = 1.69$, $p = .64$) of the final assessment task were compared. In the collaborative learning environment, the differences between the groups were also non-significant when the *Describe* section ($H(3) = 0.90$, $p = .83$), the *Issues* section ($H(3) = 0.92$, $p = .82$) and the *Higher Level Thinking* section ($H(3) = 2.21$, $p = .53$) of the final assessment task were compared.

6.3.2.2 Discussion

Two hypotheses were associated with this part of the analysis:

H2a: Students working in a collaborative learning environment will have higher scores for all learning outcomes than students in an individual learning environment.

H2c: A system dynamics model is too abstract for high school students, and an additional representation that constrained the interpretation of the model (one that was familiar to the students, such as the animated representation included in the agent-based model) will improve interpretation, and therefore understanding in the collaborative learning environment.

As this was an experimental design, the control group will be described first, followed by a discussion of the effect of the collaborative learning environment on learning from agent-based models, learning from system dynamics models, and learning from multiple representations.

6.3.2.2.1 The control group

In the Text group, students in the individual learning environment were able to increase knowledge for all learning outcomes except those addressing knowledge of introduced plant species and system dynamics concepts, although changes in both were associated with large effect sizes. Given the successful use of the materials by individuals, it is not expected that a partner will result in a great improvement in learning outcomes.

Students in the collaborative learning environment increased their score assessing knowledge of introduced plant species, which students in the individual learning environment did not. Students in the two learning environments learned about different areas of the materials. A collaborative learning environment did allow students to increase their score assessing knowledge of introduced plant species, which was not achieved in the individual learning environment.

6.3.2.2.2 Learning from the agent-based model

Previous research has shown that students in a collaborative learning environment have had a greater understanding of the system than those in the individual learning environment when using an agent-based model (Abrahamson & Wilensky, 2005). However, the results discussed in this thesis have suggested that time factors played a role in students' ability to identify links between system-specific knowledge and other systems when using the agent-based model. A partner is not expected to change this, and the additional time spent in negotiation of the use of the model may result in lower learning outcomes.

Students in the ABM group in the collaborative learning environment did not have higher learning outcomes than those in the individual learning environment. Students in both learning environments increased their scores assessing knowledge of introduced plant species; however students in the individual learning environment had a greater change in this score. Students in the individual learning environment had a higher post-test score assessing system dynamics knowledge than students in the collaborative learning environment.

6.3.2.2.3 Learning from the system dynamics model

It was expected that students in the collaborative learning environment learning from a system dynamics model would have greater understanding and higher knowledge scores than those in the individual learning environment due to studies that have focussed on general collaborative learning (Abrahamson & Wilensky, 2005; Johnson & Johnson, 1985; Kozma, 2003). However there have been no specific studies comparing learning from system dynamics models in the two learning environments. Research already presented in this thesis suggested that students presented with a representation that constrained their interpretation of the system dynamics model had higher post-test scores. Comparisons between groups suggested that the representation should increase students' familiarity with the representation, or provide information at a different level, rather than a text description. A partner may also help students to interpret the system dynamics model.

The hypothesis was supported with respect to environmental knowledge in the SDM group. Students in the collaborative learning environment significantly increased the score assessing knowledge of introduced animal and plant species, which was not the case for students in the individual learning environment. Students in the collaborative learning environment also had higher post-test scores assessing knowledge of human impacts on an ecosystem and associated timescales. The answers for this question were more closely examined for students in both learning environments. Students in the collaborative learning environment did apply the knowledge learned, indicated by their inclusion of impacts of different activities on a different system such as an increase in soil nutrients, increased rodent populations and increased waste left at the site. Students in the individual learning environment, however, only changed their answers to address the effects of the impacts of littering rather than being able to apply this knowledge to other types of impacts.

The hypothesis was not supported with respect to system dynamics knowledge. Both groups experienced an increase in the system dynamics score.

6.3.2.2.4 Learning from multiple representations

Research has shown that the collaborative learning environment may result in greater understanding of the system for students given multiple representations (Kozma, 2003). As has already been discussed in this thesis, students using multiple representations were able to interpret the system dynamics model using the agent-based model, and increase all environmental knowledge scores and the applied system dynamics knowledge score. Students in this group did not increase their system dynamics knowledge score, and it may have been related to the high cognitive load associated with increasing knowledge of all other learning outcomes. The addition of a partner may help to decrease this cognitive load. However, given the successful use of the multiple representations by individuals, it is not expected that a partner will result in a large improvement to learning outcomes.

The results suggested that students in the SDM & ABM group learned about different areas of environmental knowledge in the two learning environments. In the collaborative learning environment, students had a larger change in the score assessing knowledge of introduced animal species, and increased their score assessing knowledge of human impacts on an ecosystem and associated timescales. On further examination of the answers to Question 5, assessing knowledge of introduced animal species, it can be seen that the increase in the score came from the ability of students to identify a greater number of activities that could result in an increased number of introduced animal species. Such activities included littering, which was not identified in any pre-test answer for this group. In the individual learning environment, students increased their score assessing introduced plant species. The collaborative learning environment enhanced the advantage of multiple representations in allowing students to identify the links between knowledge gained from the materials and reality. The way in which students used both models was found to be key in explaining the success of this group, and further investigation is required into differences between the learning environments.

It was also expected that students given multiple representations would be the most successful of any of the groups. This was due to the findings outlined in Chapter 4 and Chapter 5, and a number of studies reporting on the advantages of multiple representations (for example (Ainsworth, 1999; Ainsworth et al., 1998; Tsui & Treagust, 2003)). While students in the SDM & ABM group were successful in different areas in the learning environments, those in the SDM group were more successful in the collaborative learning environment than in the individual environment, and also the most successful of all the groups in the collaborative learning experiment. Students in the ABM group increased their score for both environmental knowledge and system dynamics knowledge, while those in the SDM & ABM group only increased their environmental knowledge scores. These results indicate that individual models may be more effective in a collaborative learning environment than multiple models. These results also indicate that in terms of using a system dynamics model, a partner provides a similar advantage to an additional representation to make sense of the representation.

6.3.2.3 Conclusion

The collaborative learning environment provided an advantage for students in the control group, and for the group given only the system dynamics model. There was not a clear advantage for students in either the ABM group or the SDM & ABM group. The findings from the previous chapter outlining the role of the way in which the models are used, particularly the way in which explanatory features are used, may help to explain these differences. These findings will be extended in the following section.

6.4 USE OF THE MODELS

The process that students use to interrogate a model may affect what they learn from the model; however there is little research that examines this process. Findings from the previous chapters indicate that some learning outcomes were related to the ways in which the models were used. Patterns of students' use of the models, as well as the preferences that students had with respect to the representations they used when given the choice may aid in understanding differences in learning outcomes, and may be useful in general because there is little information about user preferences in interrogating multiple external representations (Van Labeke & Ainsworth, 2002).

In a number of these cases, previous research conducted in the fields of learning from animations and learning from agent-based models (for example, (Lowe, 2003, 2004)) and learning from abstract diagrams (for example, (Schieritz & Milling, 2003; Wakeland, Macovsky, Gallaher, & Aktipis, 2004)) resulted in the prediction that the representation itself encouraged learning about a particular area. For example, it has been predicted that students in the ABM group would learn about those areas that are distinctive in the animation used in the agent-based model. Subjects tend to be attracted to the information generated by the features in the animation that actually change in a contrasted way to the rest of the display (Lowe, 2003, 2004). In particular, this involved Question 5 (knowledge about introduced animal species), because *rats* are used to represent introduced animal species and are visible in the animated representation.

Levy and Wilensky (2005) classified styles of interrogating an agent-based model, and related these styles to learning outcomes. Further investigation into user preference and strategies used will help to understand why the differences in learning outcomes between groups reported above were the case, and will provide much needed research in this field.

This section addresses the following hypotheses:

H2b: Students working in a collaborative learning environment will interact more with the model than students in an individual learning environment.

H2c: A system dynamics model is too abstract for high school students, and an additional representation that constrained the interpretation of the model (one that was familiar to the *students, such as the animated representation included in the agent-based model) will improve interpretation, and therefore understanding.*

Video screen shots were collected and coded with respect to times, activities and screens. The system dynamics model had three screens: the *background information* screen, the *explore the model* screen, and the *experiment* screen. The agent-based model had two screens, the *information* screen and the *experiment* screen. For both models the proportion of time spent *off task* was also calculated. The variables that could be changed were the *number of pieces of rubbish* each person left (npr), the *proportion of rubbish collected* by the garbage collection person (prc), and the *garbage collection time* (gct). Others that are reported on from the system dynamics model relate to the explore the model screen – step by step (SbS) and in full (IF). Also, the system dynamics model had an "ideas" option which gave students suggestions of how to interact with the model. The total activity included all of the above, as well as other activities not discussed in these results. The sample size for this section of the chapter is smaller than the first section because not all video screen shots were successful, and there was only one video screen shot for each pair of students. In the collaborative learning environment, for the ABM group $n = 2$, for the SDM group $n = 4$, and for the SDM & ABM group $n = 2$.

This half of the chapter will compare measures of use of the models. In brief, the results of analyses carried out on the general measures of use of the model will be compared between all three groups and within groups to determine whether there is a general pattern of use of the models in both learning environments. The use of single models will then be compared to the use of the same type of model when an additional model is available (for example the use of the model by the ABM group will be compared to the use of the model in the SDM & ABM group) in both learning environments, however only descriptively given the small sample sizes. This will help to determine whether students used the agent-based model to constrain their interpretation of the system dynamics model (Ainsworth, 1999). If this was the case, students would have used the system dynamics model to experiment with, and the agent-based model for context. Students in the SDM & ABM group would have a similar level of activity as those in the SDM group (*H2b*). The final part of this chapter will identify the strategies used by students to interrogate the models overall and to change individual variables in both learning environments. Relationships between these strategies and the general measures of use of the models will help to define the classification system. An analysis of the relationships between learning outcomes and the strategies used will help to explain why students adopted particular strategies, and what effect these had on their learning outcomes.

6.4.1 Patterns of Use and User Preference

6.4.1.1 Results

Results regarding general patterns of use and user preference will be discussed in this section. All measures of use are compared between learning environments using Mann Whitney tests. In addition, the following analyses will be reported for both learning environment. The proportion of time spent on each screen (*experiment, information* and *off task*) and the frequency of activities performed (running the model, and the total activity) common to the agent-based model and the system dynamics model will be compared between the groups using Kruskal-Wallis tests. The proportion of time will then be compared within each group using Friedman's ANOVA and Mann Whitney tests post-hoc. User preference will then be explored by comparing the use of the single models with the use of both models using Mann Whitney tests. Due to the small sample size, large effect sizes were taken into account in addition to significance, and are noted where appropriate.

6.4.1.1.1 Patterns of use

Patterns of use were compared to determine whether the representation had an effect on the ways in which the models were used. The *experiment* screen is the screen on which the animation and the stock and flow diagrams are located, and the screen on which students interact with the models. The *information* screen contains the text description which is given to each group. The proportion of time spent *off task* is the time that was noticeably spent not on task (for example, moving the mouse off the main model screen to examine menu items in the list below, or open files not pertaining to the materials. Other screens were accessible however they were not common to both models, are not relevant to this study, and are not reported here.

The activities performed on the models that were common to both models were 'go' (running the model), and the total activity (the sum of all activities including those not reported in this thesis.

Table 6-12: Medians and ranges of the proportion of time spent on each screen and activities, and the results of the Mann Whitney tests comparing the two learning environments

	ILE			CLE			ILE vs. CLE
		Range (%)			Range (%)		
	Mdn (%)	Lower	Upper	*Mdn (%)*	Lower	Upper	*U*
ABM							
Exp	84	58	87	76	70	81	--
Inf	12	0	12	18	17	18	--
OT	6	3	30	6	0	13	--
Go	7	5	9	6	6	6	--
TA	26	25	28	24.5	23	26	--
SDM							
Exp	61	47	72	57	44	68	7.0
Inf	18	11	40	7	2	18	**2.0**
ETM	9	4	12	7	1	13	8.0
OT	4	0	14	26	9	35	**1.0**[a]
Go	21	4	26	14	4	19	3.5
IF	1	0	1	1	0	1	8.0
SbS	1	1	1	0.5	0	1	**4.0**
Ideas	2	2	3	3.5	1	5	4.5
TA	51	22	65	40.5	12	52	4.0
SDM & ABM							
Exp	66	53	79	80	77	84	--
Inf	22	11	32	7	4	10	--
OT	2	0	4	6	0	13	--
Go	14	12	16	11	3	19	--
TA	38.5	37	40	32	14	50	--

Note. ILE = individual learning environment. CLE = collaborative learning environment. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. ETM = proportion of time spent on the *explore the model* screen. OT = proportion of time spent *off task*. Go = number of times the model was run. IF = number of times explore the model in full was selected. SbS = number of times explore the model step by step was selected. Ideas = number of times the ideas option was selected. TA = total activity. Bold typeface indicates a large effect size (*r* > | .50 |).

$^{a}p < .10$.

Table 6-12 shows that large effect sizes were associated with a larger proportion of time spent on the *information* screen by students in the individual learning environment than the collaborative learning environment in the SDM group. Students in the SDM group in the collaborative learning environment spent a significantly higher proportion of time *off task* than students in the individual learning environment.

In the SDM group, students in the individual learning environment explored the model step by step more often than students in the collaborative learning environment (large effect size).

In the individual learning environment, Kruskal-Wallis tests showed that the difference between the groups was non-significant when the proportion of time spent on *an* experiment screen (H (2) = 1.71, p = .43), spent on an *information* screen (H (3) = 1.94, p = .38), and spent *off task* (H (2) = 2.02, p = .36) were compared. In the collaborative learning environment there was a significant difference between the groups in terms when the proportion of time spent on *an* experiment screen (H (3) = 5.50, p = .06) were compared; however the differences between the groups when the proportion of time spent on an *information* screen (H (3) = 2.79, p = .25), and *off task* (H (3) = 3.08, p = .22) were compared were non-significant. Mann Whitney tests were unable to be performed post-hoc due to the sample size for the ABM and SDM & ABM groups. Examination of the median proportions shows that students in the ABM group spent 84% of their time on the *experiment* screen, while students in the SDM group spent 61% and in the SDM & ABM group spent 66% of their time on *an* experiment screen.

In the individual learning environment, Kruskal-Wallis tests also showed that the difference between the groups was non-significant when the number of times: ‘go’ was selected (H(2) = 2.50, p = .29), and the total activity (H(2) = 2.50, p = .29) were compared. In the collaborative learning environment, the difference between the groups was non-significant when the number of times: ‘go’ was selected (H(2) = 0.63, p = .73), and the total activity (H(2) = 0.50, p = .78) were compared.

Friedman's ANOVA was used to compare the use of the model for each group in the individual learning environment. The difference between the proportions of time spent on each screen in the ABM group ($\chi^2(2) = 4.67$, $p = .10$) was non-significant. There was a significant difference between the proportions of time spent on the three screens in the SDM group ($\chi^2(2) = 6.50$, $p = .04$). The differences between the proportions of time spent on the three screens in the SDM & ABM group with the models combined ($\chi^2(2) = 4.00$, $p = .14$), the use of the agent-based model ($\chi^2(2) = 2.00$, $p = .37$), and the use of the system dynamics model ($\chi^2(2) = 4.00$, $p = .14$) were non-significant.

Wilcoxon Signed Rank tests were carried out post-hoc for the SDM group. Students in the SDM group in the individual learning environment spent a significantly greater proportion of their time on the *experiment* screen than they did on the *information* screen ($T = 0.00$, $p = .07$, $r = -.91$), and greater than they spent *off task* ($T = 0.00$, $p = .07$, $r = -.91$). However, the difference between the proportion of time spent *off task* and on the *information* screen was not significant ($T = 1.00$, $p = .14$, $r = -.73$).

In the collaborative learning environment Friedman's ANOVA showed that the difference between the proportions of time spent on each screen in the ABM group ($\chi^2(2) = 4.00$, $p = .14$) was non-significant. There was a significant difference between the proportions of time spent on the three screens in the SDM group ($\chi^2(2) = 6.50$, $p = .04$). The differences between the proportions of time spent on the three screens in the SDM & ABM group with the models combined ($\chi^2(2) = 3.00$, $p = .22$), the use of the agent-based model ($\chi^2(2) = 3.71$, $p = .16$), and the use of the system dynamics model ($\chi^2(2) = 2.00$, $p = .37$) were non-significant.

Wilcoxon Signed Rank tests were carried out post-hoc for the SDM group. Students in the SDM group spent a greater proportion of their time on the *experiment* screen than they did on the *information* screen ($T = 0.00$, $p = .07$, $r = -.91$), and greater than they spent *off task* ($T = 0.00$, $p = .07$, $r = -.91$). However, the difference between the proportion of time spent *off task* and on the *information* screen was not significant ($T = 1.00$, $p = .14$, $r = -.73$).

6.4.1.1.2 User preference

User preference was examined by comparing the use of the model by the ABM group with the use of the agent-based model by the SDM & ABM group and similarly with the use of the system dynamics model in a descriptive way only due to the small sample sizes in this part of the analysis.

Table 6-13: Medians and ranges of the proportion of time spent on the individual model screens and the activities performed on each in the SDM & ABM group

	ILE			CLE		
		Range			Range	
	Mdn	Lower	Upper	*Mdn*	Lower	Upper
Agent-based model						
Exp	1	0	2	53	23	84
Inf	8	0	16	2	0	4
OT	0	0	0	6	0	13
Go	0	0	0	2	1	3
TA	0	0	0	8	2	14
ABM	9	0	18	62	23	100
System dynamics model						
Exp	65	51	79	27	0	53
Inf	12	11	14	5	0	10
ETM	11	9	13	6	0	12
OT	2	0	3	0	0	0
Go	14	12	16	9	0	18
IF	0	0	0	0	0	0
SbS	1.5	1	2	0.5	0	1
Ideas	1.5	1	2	0.5	0	1
TA	38.5	37	40	24	0	48
SDM	91	82	100	38	0	77

Note. ILE = individual learning environment. CLE = collaborative learning environment. Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. ETM = proportion of time spent on the *explore the model* screen. OT = proportion of time spent *off task*. Go = number of times the model was run. IF = number of times explore the model in full was selected. SbS = number of times explore the model step by step was selected. Ideas = number of times the ideas option was selected. TA = total activity. ABM = proportion of time spent on the agent-based model. SDM = proportion of time spent on the system dynamics model.

In the SDM & ABM group, students in the collaborative learning environment (*Mdn* = 53%) spent a higher proportion of time on the *experiment* screen on the agent-based model than students in the individual learning environment (*Mdn* = 1%). Students in the individual learning environment (*Mdn* = 12%) also spent a greater proportion of time on the *information* screen on the system dynamics model than students in the collaborative learning environment (*Mdn* = 5%).

In the SDM & ABM group, students in the collaborative learning environment (Mdn_{Go} = 2, Mdn_{TA} = 8) ran the agent-based model more often, and had greater total activity on the agent-based model than those in the individual learning environment (Mdn_{Go} = 0, Mdn_{TA} = 0). Students in the individual learning environment (*Mdn* = 1.5) selected explore the model step by step and ideas more often than those in the collaborative learning environment (*Mdn* = 0.5).

Students spent a greater proportion of time on the system dynamics model in the individual learning environment (*Mdn* = 91%) than the collaborative learning environment (*Mdn* = 38%); and a greater proportion of time on the agent-based model in the collaborative learning environment (*Mdn* = 62%) than in the individual learning environment (*Mdn* =9%).

In order to further understand the preferences with regards to the representations used in the SDM & ABM group, use of the agent-based model in the ABM group was compared with that of the SDM & ABM group, and similarly the use of the system dynamics model in the SDM and SDM & ABM groups were compared in the two learning environments in a descriptive manner.

Students in the individual learning environment spent a greater proportion of time on the *experiment* screen in the ABM group (*Mdn* = 84%) than on the *experiment* screen on the agent-based model in the SDM & ABM group (*Mdn* = 1%), and similarly for the proportion of time spent *off task* (Mdn_{ABM} = 6%, $Mdn_{SDM\ \&\ ABM}$ = 0%). Students in the collaborative learning environment spent comparatively similar proportions of time on the *experiment* screen in the ABM (*Mdn* = 53%) and SDM & ABM (*Mdn* = 76%) groups. However, students in the ABM group (*Mdn* = 18%) spent a greater proportion of time on the *information* screen than those in the SDM & ABM group (*Mdn* = 2%).

In terms of the activities, students in the ABM group (*Mdn* = 26) did all activities more often than students in the SDM & ABM (*Mdn* = 0) group in the individual learning environment. In the collaborative learning environment, students in the ABM group (*Mdn* = 24.5) also did all activities more often than students in the SDM & ABM group (*Mdn* = 8).

In the individual learning environment, students spent a greater proportion of time on the *information* screen in the SDM group (*Mdn* = 18%) than the SDM & ABM group (*Mdn* = 12%), and students in the SDM & ABM group (*Mdn* = 11%) spent a greater proportion of their time on the *explore the model* screen than students in the SDM group (*Mdn* = 9%). In the collaborative learning environment, students in the SDM group (*Mdn* = 26%) spent a greater proportion of their time *off task* than students in the SDM & ABM group (*Mdn* = 0%).

Students performed most activities a similar number of times (ILE: Mdn_{SDM} = 51, $Mdn_{SDM\ \&\ ABM}$ = 38.5; CLE: Mdn_{SDM} = 40.5, $Mdn_{SDM\ \&\ ABM}$ = 24), except explore the model in full and the selection of the ideas option. In both learning environments, students from the SDM group (ILE: Mdn_{IF} = 1, Mdn_{Ideas} = 2; CLE: Mdn_{IF} = 1, Mdn_{Ideas} = 3.5) performed these activities more often than those in the SDM & ABM group (ILE: Mdn_{IF} = 0, Mdn_{Ideas} = 1.5; CLE: Mdn_{IF} = 0, Mdn_{Ideas} = 0.5). In the individual learning environment students in the SDM & ABM group (*Mdn* = 1.5) selected the explore the model step by step option more often than students in the SDM group (*Mdn* = 1).

6.4.1.2 Discussion

This section addresses the following hypotheses:

H2b: Students working in a collaborative learning environment will interact more with the model than students in an individual learning environment.

H2c: A system dynamics model is too abstract for high school students, and an additional representation that constrained the interpretation of the model (one that was familiar to the students, such as the animated representation included in the agent-based model) will improve interpretation, and therefore understanding.

If *H3b* is supported by the evidence, students in the collaborative learning environment will spend a greater proportion of time on the *experiment* screen than students in the individual learning environment, and perform all activities more often. If *H3c* is supported by the evidence, user preference will show that students in the SDM & ABM group used the system dynamics model more than the agent-based model, similarly to students in the individual learning environment. The ways in which each of the types of model was used will now be discussed: the agent-based model, the system dynamics model, a comparison between the two types of model, and use of both the agent-based and system dynamics model in relation to the comparison between the learning environments.

6.4.1.2.1 Using the agent-based model

Previous research has shown that students in a collaborative learning environment have had a greater understanding of the system being modelled than those in the individual learning environment when using an agent-based model (Abrahamson & Wilensky, 2005). However, the results discussed in this thesis have suggested that time factors played a role in students' ability to identify links between system-specific knowledge and other systems when using the agent-based model. A partner is not expected to change this, and the additional time spent in negotiation of the use of the model may result in lower learning outcomes. As already discussed in this chapter, students in the ABM group in the two learning environments had similar learning outcomes, and in some cases, such as knowledge about introduced plant species, students in the individual learning environment had higher changes in the post-test scores (Question 6) than students in the collaborative learning environment. This suggests that when examined, students in the two learning environments will have similar patterns of use.

Students in both learning environments, in the ABM group, when given the choice, chose to interact with the model, and not to spend a large proportion of their time off task. Students in this group in both learning environments spent statistically similar proportions of time on the *experiment* screen, the *information* screen and *off task*. Students in both learning environments had similar levels of total activity when the learning environments were compared. Students in the collaborative learning environment spent a higher proportion of their time on the *information* screen than students in the individual learning environment.

6.4.1.2.2 Using the system dynamics model

It was expected that students in the collaborative learning environment learning from a system dynamics model would have greater understanding and higher knowledge scores than those in the individual learning environment due to studies that have focussed on general collaborative learning (Abrahamson & Wilensky, 2005; Johnson & Johnson, 1985; Kozma, 2003). However there have been no specific studies comparing learning from system dynamics models in the two learning environments. Research already presented in this thesis suggested that students presented with a representation that constrained their interpretation of the system dynamics model had higher post-test scores. Comparisons between groups suggested that the representation should increase students' familiarity with the representation, or provide information at a different level, rather than a text description. A partner may also help students to interpret the system dynamics model.

As has already been discussed in this chapter, students in the SDM group in the collaborative learning environment had a higher environmental knowledge post-test score and increased two environmental knowledge scores, which students in the individual learning environment did not do. However, learning outcomes associated with system dynamics knowledge were similar when the groups were compared. If the higher learning outcomes in the collaborative learning environment are due to the use of the materials, a difference in the patterns of use will be observed. If the patterns are not observed, this indicates that it may have been interaction with a partner that helped students to interpret the system dynamics model.

When given the choice, students in the SDM group chose to interact with the model, and not to spend a large proportion of their time off task. There were differences between the learning environments for some measures. These included the higher proportion of time spent *off task* by students in the collaborative learning environment. Students in the individual learning environment had greater interaction with the model than those in the collaborative learning environment. Differences were mainly concerned with the explanatory features of the models, such as the proportion of time spent on the *information* screen (higher in the individual learning environment) and the explore the model step by step option (used more often by students in the individual learning environment). These similar results in terms of the use of the model itself suggest that it was interaction with a partner, rather than interaction with the materials, that resulted in the higher learning outcomes.

6.4.1.2.3 Using the agent-based and *the system dynamics models*

Research has shown that the collaborative learning environment may result in greater understanding of the system for students given multiple representations (Kozma, 2003). As has already been discussed in this thesis, students using multiple representations were able to interpret the system dynamics model using the agent-based model, and increase all environmental knowledge scores and the applied system dynamics knowledge score. Students in this group did not increase their system dynamics knowledge score, and it may have been related to the high cognitive load associated with increasing knowledge of all other learning outcomes. The addition of a partner may help to decrease this cognitive load. However, given the successful use of the multiple representations by individuals, it is not expected that a partner will result in a large improvement to learning outcomes. As discussed already in this chapter, in the collaborative learning environment, students had a larger change in the score assessing knowledge of introduced animal species, and increased their score assessing knowledge of human impacts on an ecosystem and associated timescales. In the individual learning environment, students increased their score assessing introduced plant species. The collaborative learning environment enhanced the advantage of multiple representations in allowing students to identify the links between knowledge gained from the materials and reality.

There were also differences in system dynamics knowledge. Students in the individual learning environment had a higher system dynamics knowledge post-test score than those in the collaborative learning environment, although students in neither group increased their scores. There was a very small sample size for the SDM & ABM group in the collaborative learning environment with data regarding the use of the models, and further investigation shows that one student used both models and the other only the agent-based model. However, the majority of the comparisons between single and multiple model use were similar in the two learning environments.

When given the choice, students chose to interact with the model, and not to spend a large proportion of their time off task. There were differences between the learning environments for some measures. These involved the model choice in the SDM & ABM group. In the individual learning environment, students chose to use the system dynamics model more than the agent-based model. This indicates that students used the agent-based model to *constrain* their understanding of the system dynamics model (Ainsworth, 1999). However, in the collaborative learning environment, students chose to use the agent-based model more than the system dynamics model. This indicates that students used the system dynamics model to *construct* a deeper understanding of the agent-based model (Ainsworth, 1999).

Specifically, students in the collaborative learning environment spent a greater proportion of time on the agent-based model *experiment* screen and a lower proportion of time on the *information* screen on the system dynamics model than those in the individual learning environment. Overall, students in the individual learning environment spent a greater proportion of time on *an* information screen (either model) than those in the collaborative learning environment. Students in the SDM & ABM group had higher activity on the agent-based model. With respect to the overall activity, students in the two learning environments had similar levels of activity.

In addition to spending more time using the agent-based model, students used the agent-based model in a similar way to students in the ABM group. Students in the ABM and SDM & ABM groups in the collaborative learning environment spent similar proportions of time on the *experiment* and *information* screens and *off task*, while students in the individual learning environment spent a statistically larger proportion of time on the *experiment* screen than other screens in both these groups. However, when the use of the model was compared between the learning environments, students spent similar proportions of time on the *experiment* screen and *off task*. Students in the ABM group spent a greater proportion of time on the *information* screen. Students in both learning environments interacted more with the agent-based model in the ABM group than the SDM & ABM group.

In the collaborative learning environment, students in the SDM and SDM & ABM groups spent statistically similar proportions of time on the *experiment* screen, as they did in the individual learning environment. Students in the SDM group spent more time *off task* than those in the SDM & ABM group in the collaborative learning environment, which was not the case in the individual learning environment. Students in the individual learning environment in the SDM & ABM group spent a greater proportion of their time on the *explore the model* screen than students in the SDM group. However, neither of these differences explains the differences in learning outcomes. Students in the two groups in the collaborative learning environment spent similar proportions of time on the *information* screen, whereas in the individual learning environment, students in the SDM group spent longer on this screen than those in the SDM & ABM group. The patterns of the activities that students engaged in were similar in the two learning environments. Students manipulated the system dynamics model in the same way in both groups in both learning environments for all activities except exploring the model in full and selecting ideas, both of which were done more often in the SDM group than the SDM & ABM group in both learning environments. In addition, in the individual learning environment, students in the SDM & ABM group selected the explore the model step by step option more often than students in the SDM group. These are explanatory activities and perhaps students with access to the agent-based model tended to use that for explanation instead.

In the collaborative learning environment, students spent the same proportion of time on the *experiment* screen in the ABM group and the SDM & ABM group. Students also spent the same proportion of time on the *experiment* screen in the SDM and SDM & ABM groups, but had similar activity in the two groups. While students in the collaborative learning environment did use the system dynamics model for experimenting, they spent longer on the agent-based model *experiment* screen than those in the individual learning environment. Students spent less time on the *information* screens in the collaborative learning environment on either model. Perhaps as part of the negotiation of the use of the models, students used the agent-based model for longer before experimenting with the system dynamics model as before. Students in the SDM & ABM group in the collaborative learning environment did have a greater change in knowledge of introduced animal species (Question 5) than those in the individual learning environment, which was thought to be related to the animated representation.

6.4.1.3 Conclusions

The hypothesis that a collaborative learning environment encourages interaction with the model was not supported by these findings. Instead, there were differences in how the explanatory features of the models were used (*information* screen in the ABM group, explore the model step-by-step in the SDM group and the alternate model in the SDM & ABM group). It may be that the patterns of use of the models were different (rather than generally higher in one learning environment than the other) and that this allowed difference connections to be made between prior knowledge and learning outcomes. The relationships between these measures will be analysed below.

In the collaborative learning environment, students used the two models in a more balanced way, but had a similar pattern in terms of what the models were used for as those who used them in the individual learning environment. This suggests that user preference was, in the main, independent of the learning environment. However, students in the SDM & ABM group used the agent-based model and not the system dynamics model. Further research into interaction between the partners, decision making, and with a larger sample size are needed to explain this.

6.4.2 Strategies

To make sense of the patterns of use, they were classified according to Levy and Wilensky's (2005) *strategies*. The purpose of this section is to investigate whether these strategies differed depending on the model, whether more information can be added to identify and describe strategies, and finally whether these strategies were influenced by or influenced learning outcomes in the collaborative learning environment, and whether the strategies differed depending on the learning environment.

Table 6-14: Patterns found in Levy and Wilensky's (2005) study

	Strategy		
Name	Straight to the point	Homing in	Oscillating
Description	The most informative state is accessed directly	The most informative state is gradually approached through decreasing increments	The model oscillates between two regimes, back and forth between high and low values
Overall observation time	Lower	Lower	Higher
Observation time per run	Higher	Lower	Lower
Time between actions	Higher	Lower	Lower
Runs	Lower	Higher	Medium

The time observing the model was taken as the time spent on the *experiment* screen. The time spent observing the model in each setting was calculated by dividing the total time spent observing the model by number of times 'go' was selected. The time spent off-task and spent reading the text/instructions were added as a result of the pilot study. The number of runs was equal to the number of times 'go' was selected. Time per action was calculated by dividing the time observing the model by the number of changes made. And the number of changes made was equal to the total activity. After examination of the individual cases, it was decided that the strategies for changing the three variables would also be determined. The use of the model was then compared between the strategies that students used to determine whether any more factors could be used to make each classification. Finally, learning outcomes were compared between the classifications to investigate the effect of the strategy used to the interrogate the model, regardless of the model used.

Chapter 5 outlined the following boundaries for classifying the overall strategy used in interrogating the model (Table 6-15).

Table 6-15: Boundaries for classifying the overall strategy used to interrogate the model, based on Chapter 5

	Low	Medium	High
Time observing the model	0-10:00	10:01-15:00	15:01-20:00
Time in each setting	0:00-1:00	1:01-2:30	2:31-20:00
Runs	1-5	6-15	16-50
Time per action	0-0:20	0:21-1:00	1:01-2:00
Total number of actions	0-15	16-39	40-65

After the investigation of the strategies used by students in the individual learning environment, a number of conclusions were made. Examination of the strategies used to change individual variables was also valuable. Students preferred to use the straight to the point strategy to alter the percentage of rubbish collected, in particular students in the SDM group preferred to use this strategy. However, the remaining strategies were not affected by the representation. The amount of time spent on explanatory features of the model was also found to be informative, particularly with respect to the use of the straight to the point approach.

6.4.2.1 Results

In this section, the overall strategies used to interrogate the models are classified for students in each group. Classification criteria are applied to variables, and an additional classification is suggested. Kruskal-Wallis tests are used to compare the measures of use of the models between strategies, with Mann Whitney tests used post-hoc. Kruskal-Wallis tests are also used to compare learning outcomes between strategies; with Mann Whitney tests used post-hoc. Due to the small sample size, large effect sizes were taken into account in addition to significance, and are noted where appropriate.

6.4.2.1.1 Classifications of patterns of use for each group

Table 6-16: Patterns of use in the ABM group in the collaborative learning environment

Strategy	ABM C1	ABM C2
Observation		
Time observing the model	16:20 (H)	14:01 (M)
Time observing the model in each setting	2:43 (H)	2:20 (M)
Time spent off task	0:00	2:32
Time spent reading text / instructions	3:40	3:23
Explorativeness		
Number of runs	6 (M)	6 (M)
Action		
Time per action	0:43 (M)	0:32 (M)
Number of changes made	23 (M)	26 (M)
Pattern	Osc.	Osc.

Note. ABM C*n* = student *n* in the ABM group in the collaborative learning environment. H = high. M = medium. L = low. . Osc. = oscillating strategy.

Students’ patterns of use of the model in the ABM group were recorded and classified using Levy and Wilensky’s method. In the collaborative learning environment (Table 6-16), only the oscillating strategy was identified.

Table 6-17: Patterns of use in the SDM group in the collaborative learning environment

Strategy	SDM C1	SDM C2	SDM C3	SDM C4
Observation				
Time observing the model	9:10 (L)	9:28 (L)	15:57 (M)	15:05 (M)
Time observing the model in each setting	0:42 (L)	2:22 (M)	0:50 (L)	1:00 (L)
Time spent off task	7:12	6:04	2:07	4:59
Time spent reading text / instructions	4:30	4:28	5:20	2:43
Explorativeness				
Number of runs	13 (M)	4 (L)	19 (H)	15 (M)
Action				
Time per action	0:13 (L)	0:47 (M)	0:18 (L)	0:23 (M)
Number of changes made	42 (H)	12 (L)	52 (H)	39 (M)
Pattern	HI	STP	HI	Osc.

Note. SDM C*n* = student *n* in the SDM group in the collaborative learning environment. H = high. M = medium. L = low. Osc. = oscillating strategy. HI = homing in strategy. STP = straight to the point strategy.

Students' patterns of use of the model in the SDM group were recorded and classified using Levy and Wilensky's method. Table 6-17 shows that in the SDM group in the collaborative learning environment, all three patterns were identified. One student used the straight to the point strategy, one student used the oscillating strategy, and two students used the homing in strategy.

Table 6-18: Patterns of use in the SDM & ABM group (models treated separately) in the collaborative learning environment

Strategy	SDM & ABM C1	SDM & ABM C2
Observation		
System dynamics model		
Time observing the model	10:41 (M)	0:00 (L)
Time observing the model in each setting	0:36 (L)	0:00 (L)
Time spent off task	0:00	0:00
Time spent reading text / instructions	4:40	0:00
Agent-based model		
Time observing the model	4:39 (L)	16:43 (H)
Time observing the model in each setting	4:39 (H)	5:34 (H)
Time spent off task	0:00	2:30
Time spent reading text / instructions	0:00	0:47
Explorativeness		
Number of runs – system dynamics model	18 (H)	0 (L)
Number of runs – agent-based model	1 (L)	3 (L)
Action		
System dynamics model		
Time per action	0:13 (L)	0:00 (L)
Number of changes made	48 (H)	0 (L)
Agent-based model		
Time per action	2:20 (H)	1:12 (H)
Number of changes made	2 (L)	14 (L)
Pattern		
System dynamics model	HI	None
Agent-based model	STP	STP

Note. SDM & ABM C*n* = student *n* in the SDM & ABM group in the collaborative learning environment. H = high. M = medium. L = low. HI = homing in strategy. STP = straight to the point strategy.

Students' patterns of use of the model in the SDM & ABM group were recorded and classified separately for the two models using Levy and Wilensky's method. In the collaborative learning environment, one student only used the agent-based model, and used a straight to the point strategy. The other student used the homing in strategy on the system dynamics model, and the straight to the point strategy on the agent-based model.

The results for the overall use of models can be seen in Table 6-19 below.

Table 6-19: Patterns of use in the SDM & ABM group (models treated combined) in the collaborative learning environment

Strategy	SDM & ABM C1	SDM & ABM C2
Observation		
Time observing the model	15:20 (H)	16:43 (H)
Time observing the model in each setting	0:48 (L)	5:34 (H)
Time spent off task	0:00	2:30
Time spent reading text / instructions	4:40	0:47
Explorativeness		
Number of runs	19 (H)	3 (L)
Action		
Time per action	0:18 (L)	1:12 (H)
Number of changes made	50 (H)	14 (L)
Pattern	HI	STP

Note. SDM & ABM C*n* = student *n* in the SDM & ABM group in the collaborative learning environment. H = high. M = medium. L = low. HI = homing in strategy. STP = straight to the point strategy.

Students' patterns of use of the model in the SDM & ABM group were recorded and classified for the two models combined using Levy and Wilensky's method. In the collaborative learning environment, in terms of overall use of the models, one student used the homing in strategy and the other the straight to the point strategy.

6.4.2.1.2 Strategies used to change variables

The strategies used by students to change the three variables were also determined using graphs of the changes in addition to the parameters outlined above. Table 6-20 shows the classification of the strategy for each student.

Table 6-20: Patterns of use for each variable – ABM group in the collaborative learning environment

Strategy	ABM C1	ABM C2
Change the garbage collection time	Osc.	Osc.
Change the percentage of rubbish collected	Osc.	Osc.
Change the number of pieces of rubbish	Osc.	Osc.

Note. ABM C*n* = student *n* in the ABM group in the collaborative learning environment. H = high. M = medium. L = low. Osc. = oscillating strategy.

The patterns used to change each of the variables were the same as the overall pattern as determined by Levy and Wilensky's classification scheme.

Table 6-21: Patterns of use for each variable – SDM group in the collaborative learning environment

Strategy	SDM C1	SDM C2	SDM C3	SDM C4
Change the garbage collection time	HI	Osc.	HI	HI
Change the percentage of rubbish collected	STP	STP	HI	Osc.
Change the number of pieces of rubbish	HI	STP	STP	Osc.

Note. SDM C*n* = student *n* in the SDM group in the collaborative learning environment. H = high. M = medium. L = low. Osc. = oscillating strategy. HI = homing in strategy. STP = straight to the point strategy.

The patterns used to change each of the variables, in the main, were the same as the overall pattern as determined by Levy and Wilensky's classification scheme. Three of the four students held one variable constant, and changed the others. The remaining student changed the three variables in different ways.

Table 6-22: Patterns of use for each variable - SDM & ABM group in the collaborative learning environment

Strategy	SDM & ABM C1	SDM & ABM C2
Change the garbage collection time	HI	Osc.
Change the percentage of rubbish collected	Osc.	OOT
Change the number of pieces of rubbish	Osc.	HI

Note. SDM & ABM C*n* = student *n* in the ABM group in the collaborative learning environment. H = high. M = medium. L = low. Osc. = oscillating strategy. HI = homing in strategy. OOT = oscillating over time.

The patterns used to change each of the variables, in the main, were the same as the overall pattern as determined by Levy and Wilensky's classification scheme. None of the students in the collaborative learning environment used a straight to the point strategy. Students changed all variables many times, and used a homing in strategy to change at least one of the variables while oscillating the others.

Table 6-23: Summary of patterns of use by learning environment

	Overall strategy		Strategy gct		Strategy prc		Strategy npr	
	ILE	CLE	ILE	CLE	ILE	CLE	ILE	CLE
Osc.	8	3	4	4	2	4	7	4
HI	3	3	5	4	3	1	5	2
STP	7	2	6	0	11	2	6	2
OOT	--	--	3	0	2	1	0	0

Note. Strategy gct = the strategy used to change the garbage collection time. Strategy prc = the strategy used to change the percentage of rubbish collected. Strategy npr = the strategy used to change the number of pieces of rubbish. ILE = individual learning environment. CLE = collaborative learning environment. Osc. = the oscillating strategy. HI = the homing in strategy. STP = the straight to the point strategy. OOT = the oscillating over time strategy.

Table 6-23 shows that there was no clear preference for the overall strategy in the collaborative learning environment for any of the patterns.

Table 6-24: Summary of patterns of use by group

	Overall strategy		Strategy gct		Strategy prc		Strategy npr	
	ILE	CLE	ILE	CLE	ILE	CLE	ILE	CLE
ABM								
Osc.	3	2	2	2	1	2	3	2
HI	0	0	0	0	1	0	0	0
STP	2	0	2	0	2	0	2	0
OOT	--	0	1	0	1	0	0	0
SDM								
Osc.	2	1	0	1	0	1	2	1
HI	2	2	3	3	1	1	3	1
STP	3	1	3	0	6	2	2	2
OOT	--	0	1	0	0	0	0	0
SDM & ABM								
Osc.	3	0	2	1	1	1	2	1
HI	1	1	2	1	1	0	2	1
STP	2	1	1	0	3	0	2	0
OOT	--	0	1	0	1	1	0	0

Note. Strategy gct = the strategy used to change the garbage collection time. Strategy prc = the strategy used to change the percentage of rubbish collected. Strategy npr = the strategy used to change the number of pieces of rubbish. ILE = individual learning environment. CLE = collaborative learning environment. Osc. = the oscillating strategy. HI = the homing in strategy. STP = the straight to the point strategy. OOT = the oscillating over time strategy.

Table 6-24 shows that there was no clear relationship between the group and the strategy used. Students in the ABM group tended to use an oscillating strategy, however there were only two students in this group, so generalizations should not be made. In the collaborative learning environment students in the SDM and SDM & ABM groups used all strategies to change the three variables.

The relationship between the strategies and the measures of use was investigated. For this part of the analysis, the representation was ignored, and data was divided according to the strategy that the student used to interrogate the model. Mann Whitney tests were used to compare measures of use of the models in each strategy between learning environments. Kruskal-Wallis tests compared measures of the use of the models between the strategies used. Only those measures for which a significant result was found are reported below.

Table 6-25: Results of the Mann Whitney tests used to compare the use of the model for each strategy for overall model use, between the learning environments

	Oscillating		Homing in	
	U	Direction	*U*	Direction
System dynamics model				
OT	**0.0**	ILE < CLE	3.0	ILE = CLE
Total time	**0.0**	ILE > CLE	4.0	ILE = CLE
SbS	**0.5**	ILE > CLE	3.0	ILE = CLE
Ideas	**0.5**	ILE < CLE	2.5	ILE = CLE
Npr	2.0	ILE = CLE	**0.0**	ILE > CLE
Prc	2.0	ILE = CLE	**0.0**	ILE < CLE
Overall				
Npr	11.0	ILE = CLE	**0.0**	ILE > CLE
Prc	10.5	ILE = CLE	**0.0**	ILE < CLE

Note. OT = proportion of time spent *off task*. Go = number of times the model was run. SbS = number of times the activity: explore the model step by step was selected. Ideas = number of times the ideas option was selected. Npr = frequency of changes to the number of pieces of rubbish. Prc = frequency of changes to the percentage of rubbish collected. Total time = total time spent on the model. Bold typeface indicates a large effect size ($r > | .50 |$).

Students who used the oscillating strategy overall in the individual learning environment spent a lower proportion of time *off task* on the system dynamics model, and selected ideas less often; spent a greater amount of time on the system dynamics model and explored the model step by step more often than those in the collaborative learning environment. Large effect sizes were associated with all these comparisons.

Large effect sizes were associated with a higher frequency of changes made to the number of pieces of rubbish overall and on the system dynamics model for students who used the homing in strategy overall, in the individual learning environment. Students in the individual learning environment changed the percentage of rubbish collected less often overall and on the system dynamics model (large effect size).

Table 6-26: Results of the Mann Whitney tests comparing the use of the model for each strategy used to change the garbage collection time between the learning environments

	Strategy – gct	
	U	Direction
Oscillating		
Go$_{SDM}$	**0.50**	ILE > CLE
Ideas	**0.50**	ILE > CLE
Npr$_{SDM}$	**0.00**	ILE > CLE
Prc$_{SDM}$	**0.50**	ILE > CLE
Go	**2.00**	ILE > CLE
TA	**1.00**[a]	ILE > CLE
Homing in		
SbS	**5.00**	ILE > CLE
Prc$_{SDM}$	**0.50***	ILE < CLE
Prc	**0.50***	ILE < CLE

Note SbS = number of times the activity: explore the model step by step was selected. Ideas = number of times the ideas option was selected. Npr = frequency of changes to the number of pieces of rubbish. Prc = frequency of changes to the percentage of rubbish collected. TA = total activity. $_{SDM}$ = specifically on the system dynamics model. Bold typeface indicates a large effect size ($r > | .50 |$).

[a] $p < .10$. *$p < .05$.

Students who used the oscillating strategy to change the garbage collection time had significantly higher activity in the individual learning environment than in the collaborative learning environment ($p < .10$). Large effect sizes were associated with higher frequency of running the system dynamics model, selecting ideas and changing the number of pieces of rubbish and the percentage of rubbish collected on the system dynamics model. Students who used this strategy in the individual learning environment also ran *a* model more often than students in the collaborative learning environment (large effect size). Students who used the homing in strategy in the individual learning environment had generally similar activity to students in the collaborative learning environment. Students in the individual learning changed the percentage of rubbish collected in the system dynamics model (*p*and overall less often than those in the collaborative learning environment ($p < .05$ for both).

Kruskal-Wallis tests compared measures of the use of the models between the strategies used. Only those measures for which a significant result was found are reported below.

Table 6-27: Results of the Kruskal-Wallis tests comparing the use of the model between the strategy overall, and the strategy for each of the three variables in the collaborative learning environment

	Strategy – overall[a]	Strategy – gct[b]	Strategy – prc[a]	Strategy – npr[a]
TA	6.25*	5.33*	3.46	0.13
Go	5.49	5.46*	4.24	1.06
Prc	5.56	4.08*	2.54	0.13

Note. Strategy gct = the strategy used to change the garbage collection time. Strategy prc = the strategy used to change the percentage of rubbish collected. Strategy npr = the strategy used to change the number of pieces of rubbish left for each person. Go = number of times the model was run. Prc = frequency of changes to the percentage of rubbish collected. TA = total activity.

[a]df= 2. [b]df = 1.

*$p < .05$.

In the collaborative learning environment, the overall strategy influenced the total activity. Mann Whitney tests were carried out to determine differences between individual strategies. Students using the homing in strategy had higher total activity than those using the oscillating strategy ($U = 0.00$, $p = .10$, $r = -.80$).

In the collaborative learning environment, the strategy for changing the garbage collection time was relevant for running any model, changing the percentage of rubbish collected and the total activity overall. Mann Whitney tests compared the strategies used to change the garbage collection time. Students who used the homing in strategy to change the garbage collection time had a higher total activity than students using the oscillating strategy ($U = 0.00$, $p = .03$, $r = -.82$). Students who used the homing in strategy also ran the model more often than students who used the oscillating strategy ($U = 0.00$, $p = .03$, $r = -.83$). Finally, students who used the homing in strategy to change the garbage collection time changed the percentage of rubbish collected more often than those who used the oscillating strategy ($U = 1.00$, $p = .06$, $r = -.71$).

6.4.2.1.3 *Strategies and learning outcomes*

The relationship between the strategies and the learning outcomes was investigated. For this part of the analysis, the representation was ignored, and data was divided according to the strategy that the student used to interrogate the model. Kruskal-Wallis tests were used to determine whether there were differences in the learning outcomes between the overall strategy used, and between the strategies for the individual variables. Only significant results are reported. All reported differences are associated with large effect sizes.

Table 6-28: Results of the Mann Whitney tests comparing learning outcomes between learning environments in terms of the overall strategy

	Oscillating		Homing in	
	U	Direction	*U*	Direction
Environmental knowledge test				
$Q5_{post}$	12.0	ILE = CLE	**1.0**	ILE > CLE

Note. Q5 = knowledge about introduced animal species (Maximum score is 9). $_{post}$ = post-test score. Bold typeface indicates large effect size ($r > | .50 |$).

$^{a}p < .10$.

Students who used the homing in strategy overall in the individual learning environment had a higher post-test score assessing knowledge of introduced animal species (Question 5) than those in the collaborative learning environment.

Table 6-29: Results of the Kruskal-Wallis tests comparing learning outcomes between strategies used overall, to change the garbage collection time, the percentage of rubbish collected, and the number of pieces of rubbish

	Strategy – overall[b]	Strategy – gct[c]	Strategy – prc[b]	Strategy – npr[b]
Environmental and system dynamics knowledge tests				
$Q6_{post}$	2.42	4.18*	0.60	1.88
$Q6_{change}$	3.74	3.45[a]	4.53	1.06

Note. Strategy gct = the strategy used to change the garbage collection time. Strategy prc = the strategy used to change the percentage of rubbish collected. Strategy npr = the strategy used to change the number of pieces of rubbish. Q6 = knowledge about introduced plant species (Maximum score is 8). $_{post}$ = post-test score. $_{change}$ = the change between the pre- and post-test score.

[b]df = 2. [c]df = 1.

[a]$p < .10$. *$p < .05$.

The findings presented in Table 6-29 indicate that post-test knowledge of introduced plant species (Question 6), and the change in this score were affected by the strategy used to change the garbage collection time. The medians and ranges for these learning outcomes are reported below.

Table 6-30: Medians and ranges of learning outcomes with respect to the strategy – gct in the collaborative learning environment

		Range	
	Mdn	Lower	Upper
Osc.			
$Q6_{post}$	2.5	1.5	4.5
$Q6_{change}$	0.5	0	1
HI			
$Q6_{post}$	5	4	6
$Q6_{change}$	1.5	1	4

Note. Osc. = the oscillating strategy. HI = the homing in strategy. Q6 = knowledge about introduced plant species (Maximum score is 8). $_{post}$ = post-test score. $_{change}$ = the change between the pre- and post-test score.

Mann Whitney tests compared learning outcomes between the strategies used to change the garbage collection time. Students who used the homing in strategy to change the garbage collection time had a higher post-test score for knowledge of introduced plant species' than those who used the oscillating strategy (*U* = 1.00, *p* = .06, *r* = -.72) and a large effect size associated with a greater change in this question (*U* = 2.00, *p* = .11, *r* = -.66).

6.4.2.2 Discussion

The exploratory question addressed in this section was:

E2a: The strategies used to interrogate the models will be independent of the learning environment

If *E2a* is positively supported by the evidence, similar patterns of use will be identified when learning environments are compared. The discussion that follows outlines the strategies used by students to interrogate the models overall and to change individual variables. For a more detailed discussion of the classification system, please see Chapter 5. The results of the relationships between learning outcomes and the strategies used in the collaborative learning environment will also be discussed.

6.4.2.2.1 Classification of strategies used

Given the small sample size in the collaborative learning environment, it is difficult to make conclusions but there was no evidence to discount the findings from the individual learning environment that there was not a relationship between the strategy used and the representation. There was also not a relationship between the strategy used and the learning environment.

The classifications identified in the individual learning environment for individual variables were applied in the collaborative learning environment. Differences that were identified between strategies in terms of the use of the model were related to explanatory features, such as *information* screens, and options available on the system dynamics model such as explore the model step by step or ideas. Other differences in use involved the proportion of time spent *off task*. And differences were also noted that were concerned with interaction with the models. These are discussed separately below.

It was suggested in Chapter 5, that students who used the straight to the point strategy to change two of the variables spent a higher proportion of time on the *information* screen than students using other strategies in order to determine which changes to make to the model. Students in the individual learning environment who used a straight to the point strategy overall, to change the percentage of rubbish collected, and the number of pieces of rubbish spent a greater proportion of time on the *information* screen than students in the collaborative learning environment. It may be that decisions were made after interaction within the dyad rather than after gathering information from the text description (*information* screen).

Differences were observed in proportion of time spent *off task*; however they were not related to a specific strategy or variable. Students in the collaborative learning environment spent a greater proportion of time *off task* than students in the individual learning environment when using the oscillating strategy overall. It may be that during this time spent *off task*, students were interacting with each other. Differences in levels of interaction with the models may help to explain this result.

Students in the individual learning environment who used the oscillating strategy to change the garbage collection time had greater total activity and ran the model more often than students in the collaborative learning environment. This higher level of interaction suggests that students in the individual learning environment had a more chaotic approach to interacting with the model than students in the collaborative learning environment.

Students who used the homing in strategy overall in the individual learning environment had higher levels of interaction, involving changing the number of pieces of rubbish on the system dynamics model and overall. Students in the collaborative learning environment who used the homing in strategy overall, and to change the garbage collection time changed the percentage of rubbish collected more often on the system dynamics model and overall. These results indicate that students in the individual learning environment were homing in on the number of pieces of rubbish, and in the collaborative learning environment, students were homing in on the percentage of rubbish collected. In both cases this strategy was associated with higher use of the system dynamics model.

6.4.2.2.2 Strategies and learning outcomes

The overall strategy and the strategy used to change the garbage collection time were related to learning outcomes. The original study suggested that the straight to the point strategy is a planned approach which may result in a deeper understanding of each regime, but that critical settings or transitions may be missed which are evident through a broader investigation of the model (Levy & Wilensky, 2005). The oscillating approach involved students moving between extremes, constantly comparing results between now and previous, however the previous settings tend to disappear, unlike the homing in strategy (Levy & Wilensky, 2005). Due to these challenges, the oscillating strategy is considered to be the riskiest, followed by the straight to the point strategy, and the homing in strategy is a safe option for students to interrogate the models.

6.4.2.2.2.1 Overall strategy

The differences between learning environments with respect to prior knowledge are related to one of the two strategies described as risky, the oscillating strategy. Students in the individual learning environment who used this strategy had lower prior knowledge about system dynamics than students in the collaborative learning environment. In a collaborative learning environment, students have to agree on a strategy to use, it may be that students needed a higher level of prior knowledge in order to be confident enough to convince their partner to adopt a risky strategy. It may also be that there was additional prior knowledge available given that additional time was spent on explanatory features such as an *information* screen or exploring the model step-by-step in the individual learning environment than in the collaborative learning environment for both strategies discussed above. Perhaps students did not need as much prior knowledge in the individual learning environment because they used knowledge gained from the materials to inform the choice of the strategy.

The homing in strategy is a safe option, and one that allows students to undertake a planned, broad approach to interrogating the model. Students who used the homing in strategy in the individual learning environment had a higher post-test score for knowledge about introduced animal species (Question 5) than those in the collaborative learning environment. Previous discussion has suggested that the representational affordance of the agent-based model, and the (informed) use of the system dynamics model allowed students to improve their score for Question 5. The homing in strategy was associated with the use of the system dynamics model in the collaborative learning environment. These findings support the suggestion that the agent-based model was valuable in increasing knowledge associated with this learning outcome.

6.4.2.2.2.2 Strategy used to change the variables

The Homing In strategy was a successful strategy to use with respect to environmental knowledge scores in the collaborative learning environment. Students who used a homing in strategy to change the garbage collection time had a higher post-test score assessing knowledge of introduced plant species (Question 6), and a higher change in this score than those who used an oscillating strategy. Question 6 assesses knowledge that can be learned directly from interrogating the learning materials, a structured interrogation strategy should result in knowledge gain. Students who used the homing in strategy to change the number of pieces of rubbish in the individual learning environment had a higher score assessing knowledge of human impacts on an ecosystem and associated timescales than students in the collaborative learning environment.

6.4.2.3 Conclusion

The use of the models in each strategy did differ between the learning environments, with respect to the proportion of time spent on the *information* screen, *off task*, and general interaction with the models. Students in the individual learning environment were homing in on the number of pieces of rubbish, and in the collaborative learning environment, on the percentage of rubbish collected. In both cases this strategy was associated with higher use of the system dynamics model.

Prior knowledge had an effect on the choice of strategy to change specific variables. The proportion of time spent on the *information* screen was important for students who used the oscillating strategy in the individual learning environment. A higher level of prior knowledge was associated with this strategies in the collaborative learning environment compared to the individual learning environment. While it is not clear whether the effects of the differences in levels of prior knowledge was because students needed to convince their partner to undertake the risky behaviour; or because students in the individual learning environment spent a greater proportion of time on the information screen, therefore decreasing the time available to interact with the model, it is clear that students in the individual learning environment who used these strategies were not successful. The homing in strategy was the most successful of the three in terms of post-test scores associated with information that came from the materials and that benefited from a broad, planned approach.

6.5 CONCLUSIONS

The purpose of this chapter was to make a preliminary comparison of differences in learning outcomes and measures of use between students working alone and in dyads in order to provide directions for future research in the field of collaborative learning with system dynamics and agent-based models.

A collaborative learning environment provided advantages for those instances where students needed to interpret a representation or make a decision. The instances identified in this chapter were the case of learning from a system dynamics model and undertaking risky strategies to interrogate any model. In those instances where students had access to a partner, they had higher environmental knowledge scores and greater understanding of the system. Further research into students' interaction in these situations would provide further insight into how students interpret a system dynamics model, and how they make decisions about interrogating a model.

A collaborative learning environment was not an advantage for students in the ABM group, probably because of the time constraints and similarities in the use of the model, or for students learning from multiple representations. In both these cases, this is contrary to findings reported in the literature. Due to specific circumstances, the collaborative learning environment was not required to improve knowledge or understanding. Further research that addressed the limitations of this study, such as a longer treatment time and the collection of interaction data, will provide greater understanding of the processes involved in collaborative learning from agent-based models and multiple representations.

7. CONCLUSIONS

The aim of this thesis was to compare different ways for school-aged children to understand a complex socio-environmental system, namely the environmental impacts of recreational use of a national park. The study addressed Rickinson's 2001 recommendation that more research needed to occur that addressed "The processes, experiences and contexts of young people's environmental learning, including what kinds of conditions are helpful for which kinds of students undertaking which kinds of learning." p. 307.

This study had three main limitations:

- Small sample size
    - This is common in educational research, and in all relevant instances in this study, effect sizes were reported which take sample size into account
    - The sample size limits the generalisability of the study, and conclusions are limited to these experiments
- Short treatment time
    - 20 minutes is a short amount of time during which to expect learning to occur. For practical reasons, it was necessary for this study. However, the results do show that increases in knowledge scores and understanding can be achieved in a short amount of time. This is relevant for environmental educators who often have time restrictions in their programs.
- No interaction data for the collaborative learning environment
    - The literature agrees that the benefits that a collaborative learning environment brings to learners are related to the interaction between learners. For practical reasons, this data was not collected in this study. However, the investigation of differences in use of learning

outcomes have suggested specific areas for further research and provided information about general patterns of use and learning.

This study is innovative because

- Experimental design
    - Studies in education rarely use an experimental design with a random allocation of students into control and treatment groups. This is often because an experimental design has the potential to disadvantage some students. By choosing a subject area not covered specifically in the curriculum, and allowing all students access to the materials after the experiment was finished, experiments were able to be carried out without disadvantaging participants.
- Systematic comparison of learning outcomes and measures of use of the models between treatment and control groups
    - The range of information that was collected allowed knowledge and understanding and the application of this, as well as measures of the ways in which the models were used, and user preferences to be systematically compared between the treatment and control groups. This has not been done in any of the fields of learning from agent-based models, learning from system dynamics models or learning from multiple representations.
- Application of a classification system
    - The application of the patterns of use classification framework to the use of system dynamics models has not been done before. The investigation of the impact on learning outcomes and the role of prior knowledge in the choice of strategies is also new research.

Specific findings in the areas of learning from agent-based models, learning from system dynamics models, and learning from representations will be discussed below. The pedagogical implications of the findings will be presented, and further areas of research will be identified.

7.1 LEARNING FROM THE AGENT-BASED MODEL

Students who used the agent-based model:

- Increased scores assessing system-specific knowledge due to the representational affordance of the animation used to represent the system.

- Did not increase scores requiring the application of system-specific knowledge to other systems due to the poor use of the text description to constrain understanding of the agent-based model, and due to time limitations.

- Were able to identify links between levels of the system that was modelled.

- Did not have higher learning outcomes in a collaborative learning environment because students had the same patterns of use of the agent-based model.

7.2 LEARNING FROM THE SYSTEM DYNAMICS MODEL

Students who used the system dynamics model:

- Did not increase any environmental knowledge scores or the system dynamics knowledge score in the individual learning environment due to poor use of the step by step explanation of the stock and flow diagram to constrain understanding of the system dynamics model.

- Were able to describe what happened in the model and visualise the system.

- Were able to increase environmental knowledge scores in the collaborative learning environment despite similar patterns of use of the system dynamics model, suggesting that interaction with a partner was responsible.

7.3 LEARNING FROM MULTIPLE EXTERNAL REPRESENTATIONS

Students who used both the agent-based model and the system dynamics model:

- Increased system-specific environmental knowledge scores due to the representational affordance of the agent-based model in the individual and collaborative learning environment.

- Increased scores requiring the application of system-specific environmental and system dynamics knowledge to other systems due to the coordinated use of the agent-based model and the system dynamics model in the individual and collaborative learning environment.

- Were successful in the individual learning environment because students could choose which representation to use, because some information is better presented using different representations, and because the representations could be used to identify links between levels of information.

- Used the agent-based model to constrain their interpretation of the system dynamics model in the individual learning environment; and used the system dynamics model to deepen their understanding of the agent-based model in the collaborative learning environment.

7.4 PATTERNS OF USE

Investigation of the pattern of use of the model overall and the strategies used to change the variables showed:

- That the classification system developed for use of an agent-based model could be applied to the use of a system dynamics model.

- That the strategies used to change variables were independent of the model used and independent of the learning environment.

- The role of prior knowledge and the use of the text description, in combination with the learning environment are important predictors of the successful use of risky strategies.

- A broad, planned strategy used to change the variables allowed students to increase system-specific and applied environmental knowledge scores, and improved understanding of the system.

7.5 PEDAGOGICAL IMPLICATIONS

This thesis has added to the theory about multiple external representations, learning from system dynamics models, learning from agent-based models and collaborative learning. In all cases, it has extended the current theory into areas not studied elsewhere. There are clear observations and recommendations that can be made as a result of these studies.

Students who learn from agent-based models:

- Need instruction with regards to the use of a constraining representation, such as a text description, in order to apply system-specific knowledge to other systems.

- Given the choice, will spend time with the animation rather than the text description.

- May need more than 20 minutes interrogation time in order to apply system-specific knowledge to other systems.

- Will not benefit from a collaborative learning environment if the way in which the model is used does not change.

Students who learn from system dynamics models:

- Need support to interpret the stock and flow diagram. Successful support (identified in this study) includes a step-by-step explanation of the stock and flow diagram, an agent-based model, or a partner. The text description may not be as useful for students.

- Given free choice, will use the support provided by an agent-based model or a partner, and will not use the step-by-step explanation of the stock and flow diagram.

Students who learn from multiple representations:

- Are able to coordinate representations without additional instruction.

7.6FURTHER RESEARCH

This study has raised areas for further research. These include research examining:

- The effect of the representation on retention of knowledge and understanding
- The effect of treatment time on learning outcomes when using an agent-based model
- An experimental comparison of constraining representations in the use of a system dynamics model
- Interaction between students when learning from models in a collaborative learning environment
- An experimental comparison of strategies used to interrogate models and their effect on learning outcomes.

7.7CONCLUSIONS

These experiments have provided evidence that strategies for understanding complex systems provide viable methods of communicating complex ideas to school-aged students with varying levels of prior knowledge. In particular, multiple external representations provided students with flexibility in how they learned; models allowed students to experiment with a system otherwise not allowed; and a collaborative learning environment facilitated students' interpretation of a system dynamics model.

8. REFERENCES

(Tabachneck-)Schijf, H. J. M., & Simon, H. A. (1998). One Person, Multiple Representations: An Analysis of a Simple, Realistic Multiple Representation Learning Task. In M. W. van Someren, P. Reimann, H. P. A. Boshuizen & T. de Jong (Eds.), *Learning with Multiple Representations* (pp. 197-236). Oxford: Elsevier Science Ltd.

Abdel-Hamid, T. K. (2003). Exercise and diet in obesity treatment: An integrative System Dynamics perspective. *Medicine & Science in Sports & Exercise, 35*, 400-414.

Abrahamse, W., Steg, L., Vlek, C., & Rothengatter. (2005). A review of intervention studies aimed at household energy conservation. *Journal of Environmental Psychology, 25*, 273-291.

Abrahamson, D., & Wilensky, U. (2005). *Prolab goes to school: Design, teaching, and learning of probability with multi-agent interactive computer models.* Paper presented at the Fourth Conference of the European Society for Research in Mathematics Education.

Adam, P., Stricker, P., & Anderson, D. J. (1989). Species-richness and soil phosphorus in plant communities in coastal New South Wales. *Australian Journal of Ecology, 14*, 189-198.

Adamson, D. A., & Fox, M. D. (1982). Change in Australiasian Vegetation since European Settlement. In J. M. B. Smith (Ed.), *A History of Australasian Vegetation* (pp. 109-146). Sydney: McGraw-Hill Book Company.

Ainsworth, S. (1999a). *Designing effective multi-representational learning environments*: University of Nottingham, ESRC Tech report No. 58.

Ainsworth, S. (1999b). The functions of multiple representations. *Computers & Education, 33*, 131-152.

Ainsworth, S., & Loizou, A. T. (2003). The effects of self-explaining when learning with text or diagrams. *Cognitive Science, 27*, 669-681.

Ainsworth, S., & Van Labeke, N. (2002). *Using a multi-representational design framework to develop and evaluate a dynamic simulation environment.* Paper presented at the *International Workshop on Dynamic Visualizations and Learning*, Tübingen.

Ainsworth, S. E., Bibby, P. A., & Wood, D. J. (1998). Analysing the Costs and Benefits of Multi-Representational Learning Environments. In M. W. van Someren, P. Reimann, H. P. A. Boshuizen & T. de Jong (Eds.), *Learning with Multiple Representations* (pp. 120-134). Oxford: Elsevier Science Ltd.

Alberti, M., Marzluff, J. M., Shulenberger, E., Bradley, G., Ryan, C., & Zumbrunnen, C. (2003). Integrating humans into ecology: opportunities and challenges for studying urban ecosystems. *BioScience, 53*(12), 1169-1179.

Aleixandre, M. P. J., & Rodriguez, R. L. (2001). Designing a field code: environmental values in primary school. *Environmental Education Research, 7*(1), 5-22.

Alerby, E. (2000). A way of visualising children's and young people's thoughts about the environment: a study of drawings. *Environmental Education Research, 6*(3), 205-222.

Alessi, S. (2000). The application of system dynamics in elementary and secondary school curricular. Retrieved 29 October 2003, from http://www.c5.cl/ieinvestiga/actas/ribie2000/charlas/alessi.htm

Anglin, G. J., Vaez, H., & Cunningham, K. L. (2003). Visual representations and learning: The role of static and animated graphics. In D. Jonassen (Ed.), *Handbook of Research for Educational Communications and Technology* (2 ed., pp. 865-916). Mahwahm NJ: Erlbaum.

Arocena, J. M., Nepal, S. K., & Rutherford, M. (2006). Visitor-induced changes in the chemical composition of soils in backcountry areas of Mt Robson Provincial Park, British Columbia, Canada. *Journal of Environmental Management, 79*, 10-19.

Asch, J., & Shore, B. M. (1975). Conservation behavior as the outcome of environmental education. *Journal of Environmental Education, 6*(4), 25-33.

Avni, T. (1999). Simulation modeling primer. *IIE Solutions, September*, 38-41.

Baker, M., de Vries, E., Lund, K., & Quignard, M. (2001). *Computer mediated epistemic interactions for co-constructing scientific notions: lessons learned from a five year research programme.* Paper presented at the Proceedings of EuroCSCL 2001 - European Perspectives on Computer-Supported Collaborative Learning, Maastricht.

Ballantyne, R., Fien, J., & Packer, J. (2001). School environmental education programme impacts upon student and family learning: a case study analysis. *Environmental Education Research, 7*(1), 23-37.

Bamberg, S., & Moser, G. (2007). Twenty years after Hines, Hungerford, and Tomera: A new meta-analysis of psycho-social determinants of pro-environmental behaviour. *Journal of Environmental Psychology, 27*, 14-25.

Barr, S., & Gilg, A. W. (2005). Conceptualising and analysing household attitudes and actions to a growing environmental problem. Development and application of a framework to guide local waste policy. *Applied Geography, 25*, 226-247.

Bayraktar, S. (2001/2002). A meta-analysis of the effectiveness of computer-assisted instruction in science education. *Journal of Research on Computing in Education, 34*(2), 173-188.

Beadle, N. C. W. (1954). Soil phosphate and the delimitation of plant communities in Eastern Australia. *Ecology, 35*(3), 370-375.

Beatty, K., & Nunan, D. (2004). Computer-mediated collaborative learning. *System, 32*, 165-183.

Bellinger, G. (2003). Modeling and Simulation, an introduction. Retrieved 12/10/2003, from http://www.systems-thinking.org/modsim/modsim.htm

Benda, L. E., Poff, L., Tague, C., Palmer, M. A., Pizzuto, J., Cooper, S., et al. (2002). How to avoid train wrecks when using science in environmental problem solving. *BioScience, 52*(12), 1127-1136.

BenDor, T. K., & Metcalf, S. S. (2006). The spatial dynamics of invasive species spread. *System Dynamics Review, 22*(1), 27-50.

Benson, D., & Howell, J. (1990). *Taken for Granted. The Bushland of Sydney and its Suburbs*. Sydney: Kangaroo Press in Association with the Royal Botanic Gardens.

Bieri, J. A., & Roberts, C. A. (2000). Using the Grand Canyon River Trip Simulator to Test New Launch Schedules on the Colorado River. *AWIS Magazine, 29,* 6-10.

Bilkstein, P., & Wilensky, U. (2005). *Less is More: Agent-Based Simulation as a Powerful Learning Tool in Materials Science, Paper* presented at the IV International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS 2005) Utrecht, Holland.

Bjerknes, A.-L., Totland, O., Hegland, S. J., & Nielsen, A. (2007). Do alien plant invasions really affect pollination success in native plant species? *Biological Conservation, 138*, 1-12.

Bodemer, D., & Faust, U. (2006). External and mental referencing of multiple representations. *Computers in Human Behavior, 22*, 27-42.

Bodemer, D., Ploetzner, R., Feuerlein, I., & Spada, H. (2004). The active integration of information during learning with dynamic and interactive visualisations. *Learning and Instruction, 14*, 325-341.

Bonabeau, E. (2002). Agent-based modeling: Methods and techniques for simulating human systems. *Proceedings of the National Academy of Sciences, 99* (suppl. 3), 7280-7287.

Booth Sweeney, L., & Sterman, J. D. (2000). Bathtub dynamics: initial results of a systems thinking inventory. *System Dynamics Review, 16*(4), 249-286.

Borden, R. J., & Schettino, A. P. (1979). Determinants of environmentally responsible behavior. *Journal of Environmental Education, 10*(4), 35-39.

Borshchev, A., & Filippov, A. (2004). From system dynamics and discrete event to practical agent based modeling: reasons, techniques, tools. Retrieved 12/8/2004, 2004, from www.xjtek.com/files/papers/fromsystemdynamics2004.pdf

Boshuizen, H. P. A., & (Tabachneck-)Schijf, H. J. M. (1998). Problem Solving with Multiple Representations by Multiple and Single Agents: An Analysis of the Issues Involved. In M. W. van Someren, P. Reimann, H. P. A. Boshuizen & T. de Jong (Eds.), *Learning with Multiple Representations* (pp. 137-151). Oxford: Elsevier Science Ltd.

Boulain, N., Simioni, G., & Gignoux, J. (2007). Changing scale in ecological modelling: A bottom up approach with an individual-based vegetation model. *Ecological Modelling, 203*, 257-269.

Bousquet, F., & Le Page, C. (2004). Multi-agent simulations and ecosystem management: a review. *Ecological Modelling, 176*, 313-332.

Brackney, M., & McAndrew, F. T. (2001). Ecological worldviews and receptivity to different types of arguments for preserving endangered species. *The Journal of Environmental Education, 33*(1), 17-20.

Brown, D. G., Page, S. E., Riolo, R., & Rand, W. (2004). Agent-based and analytical modeling to evaluate the effectiveness of greenbelts. *Environmental Modelling & Software, 19*, 1097-1109.

Buckley, B. C., & Boulter, C. J. (1999). Analysis of representations in model-based teaching and learning in science. In R. Paton & I. Neilson (Eds.), *Visual Representations and Interpretations* (pp. 289-294). London: Springer-Verlag London Limited.

Buckley, B. C., Gobert, J. D., Kindfield, A. C. H., Horwitz, P., Tinker, R. F., Gerlits, B., et al. (2004). Model-based teaching and learning with BioLogica: What do they learn? How do they learn? How do we know? *Journal of Science Education and Technology, 13*(1), 23-41.

Byrne, M. D., Catrambone, R., & Stasko, J. T. (1999). Evaluating animations as student aids in learning computer algorithms. *Computers & Education, 33*, 253-278.

Calvert, F. (2004). *The Role of Research in Cool Communities.* Paper presented at the Effective Sustainability Education: What Works? Why? Where Next? Linking Research and Practice, Sydney, Australia.

Campbell Bradley, J., Waliczek, T. M., & Zajicek, J. M. (1999). Relationship between environmental knowledge and environmental attitude of high school students. *The Journal of Environmental Education, 30*(3), 17-.

Carbonell, G., Ramos, C., Pablos, M. V., Ortiz, J. A., & Tarazona, J. V. (2000). A system dynamic model for the assessment of different exposure routes in aquatic ecosystems. *Science of the Total Environment, 247*(2-3), 107-118.

Caro, T., Borgerhoff Mulder, M., & Moore, M. (2003). Effects of conservation education on reasons to conserve biological diversity. *Biological Conservation, 114*, 143-152.

Castillo, A., Garcia-Ruvalcaba, S., & Martinez R., L. M. (2002). Environmental education as facilitator of the use of ecological information: a case study in Mexico. *Environmental Education Research, 8*(4), 395-411.

Chandler, P., & Sweller, J. (1992). The split-attention effect as a factor in the design of instruction. *British Journal of Educational Psychology, 62*(2), 233-246.

Chang, C.-Y. (1997). Using computer simulation to manage the crowding problem in parks: a study. *Landscape and urban planning, 37*, 147-161.

Cheng, P. C.-H. (1999). Unlocking conceptual learning in mathematics and science with effective representational systems. *Computers & Education, 33*, 109-130.

Cheng, P. C.-H., Lowe, R. K., & Scaife, M. (2001). Cognitive Science approaches to understanding diagrammatic representations. *Artificial Intelligence Review, 15*, 79-94.

Cole, D. N. (1993). Minimising conflict between recreation and nature conservation. In D. S. Smith & P. C. Hellmund (Eds.), *Ecology of Greenways: Design and Function of Linear Conservation Areas* (pp. 105-122). Minneapolis, MN.: University of Minnesota Press.

Cole, D. N., & Hammitt, W. E. (2000). *Wilderness management dilemmas: Fertile ground for wilderness management research.* Paper presented at the Wilderness science in a time of change conference, Missoula, MT.

Cole, D. N., & Landres, P. B. (1996). Threats to wilderness ecosystems: impacts and research needs. *Ecological Applications, 6*(1), 168-184.

Commission on Sustainable Development. (2001). *Education and public awareness for sustainable development*: United Nations, Economic and Social Council.

Cooke, D. L. (2003). A system dynamics analysis of the Westray mine disaster. *System Dynamics Review, 19*(2), 139-166.

Corraliza, J. A., & Berenguer, J. (2000). Environmental values, beliefs, and actions. A situational approach. *Environment and Behavior, 32*(6), 832-848.

Costanza, R., Duplisea, D., & Kautsky, U. (1998). Introduction to special issue: Ecological Modelling on modelling ecological and economic systems with STELLA. *Ecological Modelling, 110*, 1-4.

Costarelli, S., & Colloca, P. (2004). The effects of attitudinal ambivalence on pro-environmental behavioural intentions. *Journal of Environmental Psychology, 24*, 279-288.

Cox, R. (1999). Representation construction, externalised cognition and individual differences. *Learning and Instruction, 9*, 343-363.

Coyle, G. (2000). Qualitative and quantitative modelling in system dynamics: some research questions. *System Dynamics Review, 16*(33), 225-244.

Culen, G. R., & Volk, T. L. (2000). Effects of an extended case study on environmental behavior and associated variables in seventh- and eighth-grade students. *The Journal of Environmental Education, 31*(2), 9-15.

Cumming, J. (1998). Why are misconceptions in science so hard to change? *Paper presented at the British Educational Research Association Annual Conference, Queen's University of Belfast, Northern Ireland, 27th - 30th August 1998*.

Daniel, B., Stanisstreet, M., & Boyes, E. (2004). How can we best reduce global warming? School students' ideas and misconceptions. *International Journal of Environmental Studies, 61*(2), 211-222.

Daniels, S. E., & Walker, G. B. (2001). *Working through environmental conflict: the collaborative learning approach*. Westport: Praeger Publishers.

Darlington, P., & Black, R. (1996). Helping to protect the Earth - the Kosciusko National Park Education Program. *Australian Journal of Environmental Education, 12*, 3-8.

Davies, C. H. J. (2002). Student engagement with simulations: a case study. *Computers & Education, 39*, 271-282.

Davies, R., & Webber, L. (2004). *Enjoying our backyard buddies - social research informing the practice of mainstream community education for the conservation of urban wildlife.* Paper presented at the Effective Sustainability Education: What Works? Why? Where Next? Linking Research and Practice, Sydney, Australia.

Davison, K. (2000). *A Discrete Event Simulation Model of Visitor Usage at Botany Bay National Park, Kurnell.*, The University of New South Wales, Sydney.

de Hoog, R., de Jong, T., & de Vries, F. (1991). Interfaces for instructional use of simulations. *Education & Computing, 6*, 359-385.

de Jong, T., Ainsworth, S., Dobson, M., van der Hulst, A., Levonen, J., Reimann, P., et al. (1998). Acquiring knowledge in science and mathematics: The use of multiple representations in technology-based learning environments. In M. W. van Someren, P. Reimann, H. P. A.

Boshuizen & T. de Jong (Eds.), *Learning with Multiple Representations* (pp. 9-40). Oxford: Elsevier Science Ltd.

de Jong, T., & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research, 68*(2), 179-201.

Department of Environment and Climate Change NSW. (2007). Education Resources. Retrieved 12/11/07, 2007, from http://www.environment.nsw.gov.au/education/index.htm

Department of Environment and Conservation (NSW). (2004). *Who Cares about the Environment in 2003?* Sydney: Department of Environment and Conservation (NSW).

Department of Environment and Conservation (NSW). (2006). *Living Parks. A sustainable visitation strategy*. Sydney: Department of Environment and Conservation (NSW).

Dettmann-Easler, D., & Pease, J. L. (1999). Evaluating the effectiveness of residential environmental education programs in fostering positive attitudes toward wildlife. *The Journal of Environmental Education, 31*(1), 33-39.

Diehl, E., & Sterman, J. D. (1995). Effects of feedback complexity on dynamic decision making. *Organizational Behavior and Human Decision Processes, 62*(2), 198-215.

Doyle, J. K. (1997). The cognitive psychology of systems thinking. *System Dynamics Review, 13*, 253-265.

Doyle, J. K., & Ford, D. N. (1998). Mental models concepts for system dynamics research. *System Dynamics Review, 14*, 3-29.

Doyle, J. K., Radzicki, M. J., & Trees, W. S. (1998). Measuring change in mental models of dynamic systems: An exploratory study.

Draper, F. (1993). A proposed sequence for developing systems thinking in a grades 4-12 curriculum. *System Dynamics Review, 9*(2), 207-214.

Dudley, R. G. (2004). Modeling the effects of a log export ban in Indonesia. *System Dynamics Review, 20*(2), 99-116.

Duffus, D. A., & Dearden, P. (1990). Non-consumptive Wildlife-Oriented Recreation: A conceptual framework. *Biological Conservation, 53*, 213-231.

Duit, R. (1995). The Constructivist View: A Fashionable and Fruitful Paradigm for Science Education Research and Practice. In L. P. Steffe & J. Gale (Eds.), *Constructivism in Education* (pp. 271-285). New Jersey: Lawrence Erlbaum Associates.

Edwards, L. D., Coddington, A., & Caterina, D. (1997). Girls teach themselves, and boys too: Peer learning in a computer-based design and construction activity. *Computers & Education, 29*(1), 33-48.

Environment Australia. (2000). *Environmental Education for a Sustainable Future, National Action Plan.* Canberra: The Department of Environment and Heritage.

Environment Protection Authority. (2003). *Patches of Green. Early childhood environmental education in Australia: Scope, status and direction*. Sydney: Environment Protection Authority.

Faust, L. J., Jackson, R., Ford, A., Earnhardt, J. M., & Thompson, S. D. (2004). Models for management of wildlife populations: lessons from spectacled bears in zoos and grizzly bears in Yellowstone. *System Dynamics Review, 20*(2), 163-178.

Faust, L. J., Thompson, S. D., Earnhardt, J. M., Brown, E., Ryan, S., Sherman, M., et al. (2003). Using stage-based system dynamics modeling for demographic management of captive populations. *Zoo Biology, 22*, 45-64.

Feinstein, A. H., & Cannon, H. M. (2002). Constructs of simulation evaluation. *Simulation and Gaming, 33*(4), 425-440.

Field, A. (2005). *Discovering Statistics Using SPSS* (2nd ed.). London: SAGE Publications Ltd.

Fien, J. (1993). *Education for the Environment. Critical Curriculum Theorising and Environmental Education*. Geelong: Deakin University.

Fien, J. (2000). 'Education for the Environment: a critique' - An analysis. *Environmental Education Research, 6*(2), 179-182.

Fleer, M. (2002). Curriculum compartmentalisation?: a futures perspective on environmental education. *Environmental Education Research, 8*(2), 137-154.

Forrester, J. W. (1961). *Industrial Dynamics*. Cambridge, Massachusetts: The M.I.T. Press.

Forrester, J. W. (1968). Industrial Dynamics - A response to Ansoff and Slevin. *Management Science, 14*(9), 601-618.

Forrester, J. W. (1971). *World Dynamics*. Massachusetts: Wright-Allen Press, Inc.

Forrester, J. W. (1992). System dynamics and learner-centred-learning in kindergarten through 12th grade education. Retrieved 1/8/2005, 2005, from http://sysdyn.clexchange.org/sdep/Roadmaps/RM1/D-4337.pdf

Friedman, W., & McMillian Culp, K. (2001). *Evaluation of the CoreModels Project*. Maryland: Education Development Center/Center for Children & Technology.

Gigliotti, L. M. (1990). Environmental education: What went wrong? What can be done? *Journal of Environmental Education, 22*(1), 9-12.

Gilbert, J. K., & Boulter, C. J. (1998). Learning Science through models and modelling. In B. J. Fraser & K. G. Tobin (Eds.), *International Handbook of Science Education* (Vol. 2, pp. 53-66). Dordrecht: Kluwer Academic Publishers.

Gilioli, G., & Pasquali, S. (2007). Use of individual-based models for population parameters estimation. *Ecological Modelling, 200*, 109-118.

Gilllies, R. M. (2003). Structuring cooperative group work in classrooms. *International Journal of Educational Research, 39*, 35-49.

Gimblett, R., Roberts, C. A., Daniel, T. C., Ratliff, M., Meitner, M. J., Cherry, S., et al. (2000a). An Intelligent Agent Based Model for Simulating and Evaluating River Trip Scenarios Along the Colorado River in Grand Canyon National Park. In R. Gimblett (Ed.), *Integrating GIS and Agent based modeling techniques for Understanding Social and Ecological Processes* (pp. 245-275). New York: Oxford Press.

Gimblett, R., Roberts, C. A., Daniel, T. C., Ratliff, M., Meitner, M. J., Cherry, S., et al. (2000b). An intelligent agent based model for simulating and evaluating river trip scenarios along the Colorado River in Grand Canyon National Park. In H. R. Gimblett (Ed.), *Integrating GIS and agent based modeling techniques for understanding social and ecological processes* (pp. 245-275): Oxford Press.

Ginot, V., Le Page, C., & Souissi, S. (2002). A multi-agents architecture to enhance end-user individual-based modelling. *Ecological Modelling, 157*(1), 23-41.

Glenberg, A. M., & Langston, W. E. (1992). Comprehension of illustrated text: Pictures help to build mental models. *Journal of Memory and Language, 31*, 129-151.

Gobert, J., Snyder, J., & Houghton, C. (2002). *The influence of students' understanding of models on model-based reasoning.* Paper presented at the American Educational Research Association Meeting.

Gobert, J. D., & Pallant, A. (2004). Fostering Students' epistemologies of models via authentic Model-based tasks. *Journal of Science Education and Technology, 13*(1), 7-22.

Goldstone, R. L., & Son, J. Y. (2005). The transfer of scientific principles using concrete and idealized simulations. *The Journal of the Learning Sciences, 14*(1), 69-110.

Gough, A. (2002). Mutualism: A different agenda for environmental and science education. *International Journal of Science Education, 24*(11), 1201-1215.

Gough, A. (2004). *Achieving "sustainability education" in primary schools as a result of the Victorian Science in Schools Research Project.* Paper presented at the Effective Sustainability

Education: What Works? Why? Where Next? Linking Research and Practice 18-20 February 2004, Sydney, Australia.

Grimm, V. (1999). Ten years of individual-based modelling in ecology: what have we learned and what could we learn in the future? *Ecological Modelling, 115*, 129-148.

Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., et al. (2006). A standard protocol for describing individual-based and agent-based models. *Ecological Modelling, 198*, 115-126.

Größler, A. (2004). Don't let history repeat itself - methodological issues concerning the use of simulators in teaching and experimentation. *System Dynamics Review, 20*(3), 263-274.

Guo, H. C., Liu, L., Huang, G. H., Fuller, G. A., Zou, R., & Yin, Y. Y. (2001). A system dynamics approach for regional environmental planning and management: A study for the Lake Erhai Basin. *Journal of Environmental Management, 61*(1 Special Issue), 93-111.

Guthrie, S., & Fisher, D. (1999). Systems thinking and system dynamics in the CC-STADUS high school project (How high school students become system thinkers). Retrieved 07/05/06, 2006, from http://www.clexchange.org/ftp/documents/Implementation/IM1997-07SDLeveragePoints.pdf

Halford, G. S. (1993). *Children's understanding. The development of mental models.*: Lawrence Erlbaum Associates, Publishers.

Halford, G. S., & Andrews, G. (2004). The development of deductive reasoning: how important is complexity? *Thinking and Reasoning, 10*(2), 123-145.

Ham, S. H., & Sewing, D. R. (1988). Barriers to environmental education. *Journal of Environmental Education, 19*(2), 17-24.

Hare, M., & Deadman, P. (2003). Further towards a taxonomy of agent-based simulation models in environmental management. *Mathematics and Computers in Simulation, in press*.

Harre, R. (1999). Models and Type-hierarchies: Cognitive Foundations of Iconic Thinking. In R. Paton & I. Neilson (Eds.), *Visual Representations and Interpretations* (pp. 97-111). London: Springer-Verlag London Limited.

Harvey, J. T. (2002). Keynes' Chapter 22: A System Dynamics Model. *Journal of Economic Issues, XXXVI*(2), 373-381.

Haslett, T. (2001). Experiences and reflections on the transition from classroom to practice. *System Dynamics Review, 17*(2), 161-169.

Hausbeck, K. W., Milbrath, L. W., & Enright, S. M. (1992). Environmental knowledge, awareness and concern among 11th-grade students: New York State. *Journal of Environmental Education, 24*, 27-34.

Hill, W., & Pickering, C. M. (2006). Vegetation associated with different walking track types in the Kosciuszko alpine area, Australia. *Journal of Environmental Management, 78*, 24-34.

Hillery, M., Nancarrow, B., Griffin, G., & Syme, G. (2001). Tourist perception of environmental impact. *Annals of Tourism Research, 28*(4), 853-867.

Hilty, L. M., Arnfalk, P., Erdmann, L., Goodman, J., Lehmann, M., & Wager, P. A. (2006). The relevance of information and communication technologies for environmental sustainability - A prospective simulation study. *Environmental Modelling & Software, 21*, 1618-1629.

Hoody, L. (1995). *The educational efficacy of environmental education*. San Diego, California: State Education and Environment Roundtable.

Hopson, M. H., Simms, R. L., & Knezek, G. A. (2001/2002). Using a technology-enriched environment to improve higher-order thinking skills. *Journal of Research on Computing in Education, 34*(2), 109-119.

Horwitz, P., & Christie, M. A. (1999). Hypermodels: Embedding curriculum and assessment in computer-based manipulatives. Retrieved 12/8/2004, 2004, from www.virtual.gmu.edu/EDIT611/BioLogic.pd

Hsu, S.-J. (2004). The effects of an environmental education program on responsible environmental behavior and associated environmental literacy variables in Taiwanese college students. *The Journal of Environmental Education, 35*(2), 37-49.

Hungerford, H. (2002). Environmental Educators: A conversation with Bora Simmons. *The Journal of Environmental Education, 33*(3), 5-9.

Hungerford, H. (2004). Responsible citizenship and the affective domain in environmental education. Retrieved 10/6/04, from http://plaza1.snu.ac.kr/~enviedu/plus/board/include/DOWNLOAD.php3?table=colloquium&l=7&inc=local&f=upfile.

Hungerford, H., & Volk, T. L. (1990). Changing learner behavior through environmental education. *Journal of Environmental Education, 21*(3), 8-21.

Hunter, L. M., & Rinner, L. (2004). The association between environmental perspective and knowledge and concern with species diversity. *Society and Natural Resources, 17*, 517-532.

Hwang, Y.-H., Kim, S.-I., & Jeng, J.-M. (2000). Examining the causal relationships among selected antecedents of responsible environmental behavior. *The Journal of Environmental Education, 31*(4), 19-25.

isee Systems. (2005). Build understanding in environmental sciences. Retrieved 11/4/05, 2005, from http://www.iseesystems.com/community/downloads/EducationDownloads.aspx

isee Systems. (2007). Chapter 1: Systems Thinking and the *STELLA* software: Thinking, communicating, learning and acting more effectively in the new millennium. Retrieved 08/11/07, from http://www.iseesystems.com/Resources/Whitepapers.aspx

Jacobson, M. J., & Wilensky, U. (2006). Complex systems in education: Scientific and educational importance and implications for the learning sciences. *The Journal of the Learning Sciences, 15*(1), 11-34.

Jenkins, E. W., & Pell, R. G. (2006). "Me and the Environmental Challenges": A survey of English secondary students' attitudes towards the environment. *International Journal of Science Education, 28*(7), 765-780.

Jeong, H., & Chi, M. T. H. (2007). Knowledge convergence and collaborative learning. *Instructional Science, 35*, 287-315.

Jickling, B., & Spork, H. (1998). Education for the environment: A critique. *Environmental Education Research, 4*(3), 309-328.

Jimoyiannis, A., & Komis, V. (2001). Computer simulations in physics teaching and learning: a case study on students' understanding of trajectory motion. *Computers & Education, 36*, 183-204.

Johnson, D. W., & Johnson, R. T. (1985). The internal dynamics of cooperative learning groups. In R. Slavin, S. Shlomo, K. Spencer, R. Hertz-Lazarowitz, C. Webb & R. Schmuck (Eds.), *Learning to cooperate, cooperating to learn* (pp. 103-124). New York: Plenum.

Jonassen, D. (2000). *Computers as mindtools for schools. Engaging critical thinking.* (2nd ed.): Merrill.

Jonassen, D. (2003). Using cognitive tools to represent problems. *Journal of Research on Technology in Education, 35*(3), 362-381.

Jonassen, D. H., Carr, C., & Yueh, H.-P. (1998). Computers as mindtools for engaging learners in critical thinking. *TechTrends, 43*(2), 24-32.

Jones, A., Seville, D., & Meadows, D. (2002). Resource sustainability in commodity systems: the sawmill industry in the Northern Forest. *System Dynamics Review, 18*(2), 171-204.

Jurin, R. R., & Fortner, R. W. (2002). Symbolic beliefs as barriers to responsible environmental behavior. *Environmental Education Research, 8*(4), 373-394.

Kainz, D., & Ossimitz, G. (2002). *Can students learn stock-flow-thinking? An empirical investigation.* Paper presented at the 2002 System Dynamics Conference, Palermo, Italy.

Kelleher, R. (2000). A review of recent developments in the use of information communication technologies (ICT) in science classrooms. *Australian Science Teachers Journal, 46*(1), 33-38.

Kennedy, G. E., & Judd, T. S. (1007). Expectations and reality: Evaluating patterns of learning behaviour using audit trails. *Computers & Education, 49*, 840-855.

Kennedy, G. E., & Judd, T. S. (2007). Expectations and reality: Evaluating patterns of learning behaviour using audit trails. *Computers & Education, 49*, 840-855.

Kiboss, J. K., Ndirangu, M., & Wekesa, E. W. (2004). Effectiveness of a Computer-Mediated simulations program in school biology on pupils' learning outcomes in cell theory. *Journal of Science Education and Technology, 13*(2), 207-213.

Knussen, C., Yule, F., MacKenzie, J., & Wells, M. (2004). An analysis of intentions to recycle household waste: The roles of past behaviour, perceived habit, and perceived lack of facilities. *Journal of Environmental Psychology, 24*, 237-246.

Kolsto, S. D. (2006). Patterns in students' argumentation confronted with a risk-focused socio-scientific issue. *International Journal of Science Education, 28*(14), 1689-1716.

Kozma, R. (2003). The material features of multiple representations and their cognitive and social affordances for science understanding. *Learning and Instruction, 13*, 205-226.

Kozma, R., Chin, E., Russell, J., & Marx, N. (2000). The roles of representations and tools in the chemistry laboratory and their implications for chemistry learning. *The Journal of the Learning Sciences, 9*(2), 105-143.

Kramarski, B. (2004). Making sense of graphs: does metacognitive instruction make a difference on students' mathematical conceptions and alternative conceptions? *Learning and Instruction, 14*, 593-619.

Kurtz dos Santos, A. C., Thielo, M. R., & Kleer, A. A. (1997). Students modelling environmental issues. *Journal of Computer Assisted Learning, 13*, 35-47.

Lacitignola, D., Petrosillo, I., Cataldi, M., & Zurlini, G. (2007). Modelling socio-ecological tourism-based systems for sustainability. *Ecological Modelling, 206*, 191-204.

Land, S. M., & Hannafin, M. J. (2000). Student-Centered Learning Environments. In D. H. Jonassen & S. M. Land (Eds.), *Theoretical foundations of learning environments* (pp. 1-24). New Jersey, USA: Lawrence Erlbaum Associates Inc.

Larkin, J. H., & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science, 11*, 65-99.

Lee, H., Plass, J. L., & Homer, B. D. (2006). Optimizing cognitive load for learning from computer-based science simulations. *Journal of Educational Psychology, 98*(4), 902-913.

Leeming, F. C., Dwyer, W. O., Porter, B. E., & Cobern, M. K. (1993). Outcome research in environmental education: A critical review. *Journal of Environmental Education, 24*(4), 8-21.

Levy, S. T., Kim, H., & Wilensky, U. (2004). *Connected Chemistry - A study of secondary students using agent-based models to learn Chemistry.* Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, CA.

Levy, S. T., & Wilensky, U. (2005). An analysis of student' patterns of exploration with NetLogo models embedded in the Connected Chemistry environment: Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

Lewalter, D. (2003). Cognitive strategies for learning from static and dynamic visuals. *Learning and Instruction, 13*, 177-189.

Limburg, K. E., O'Neill, R. V., Costanza, R., & Farber, S. (2002). Complex systems and valuation. *Ecological Economics, 41*, 409-420.

Linke, R. D. (1980). *Environmental Education in Australia*. North Sydney: George Allen & Unwin.

Littledyke, M. (1997). Science education for environmental education? Primary teacher perspectives and practices. *British Educational Research Journal, 23*(5), 641-659.

Littledyke, M. (2000). Science education and the environment. *Paper presented at the British Educational Research Association Conference, Cardiff University, September 7-10 2000*.

Lohner, S., & van Joolingen, W. R. (2002). *The effect of representations on communication and product during collaborative modeling.* Paper presented at the Proceedings of CSCL, 2002, Boulder, Colorado.

Loiselle, S., Carpaneto, G. M., Hull, V., Waller, T., & Rossi, C. (2000). Feedback analysis in reserve management: studying local myths using qualitative models. *Ecological Modelling, 129*, 25-37.

Loughland, T., Reid, A., Walker, K., & Petocz, P. (2003). Factors influencing young people's conceptions of environment. *Environmental Education Research, 9*(1), 3-20.

Lowe, R. (1993). Constructing a mental representation from an abstract technical diagram. *Learning and Instruction, 3*, 157-179.

Lowe, R. K. (2003). Animation and learning: selective processing of information in dynamic graphics. *Learning and Instruction, 13*, 157-176.

Lowe, R. K. (2004a). *Animation and learning: Value for money?* Paper presented at the ASCILITE, Perth.

Lowe, R. K. (2004b). Interrogation of a dynamic visualisation during learning. *Learning and Instruction, 14*, 257-274.

Lucas, A. M. (1979). *Environment and Environmental Education: Conceptual Issues and Curriculum Implications*: Australia International Press and Publications Pty. Ltd.

Lundegard, I., & Wickman, P.-O. (2007). Conflicts of interest: An indispensable element of education for sustainable development. *Environmental Education Research, 13*(1), 1-15.

Ma, X., & Bateson, D. J. (1999). A multivariate analysis of the relationship between attitude toward science and attitude toward the environment. *The Journal of Environmental Education, 31*(1), 27-32.

Maloney, J., & Simon, S. (2006). Mapping children's discussions of evidence in science to assess collaboration and argumentation. *International Journal of Science Education, 28*(15), 1817-1841.

Manlove, S., Lazonder, A. W., & de Jong, T. (2005). Regulative support for collaborative scientific inquiry learning. *Journal of Computer Assisted Learning, 22*, 87-98.

Martinez Fernandez, J., & Esteve Selma, M. A. (2004). The dynamics of water scarcity on irrigated landscapes: Mazarron and Aguilas in south-eastern Spain. *System Dynamics Review, 20*(2), 117-137.

Martinez-Fernandez, J., Esteve-Selma, M. A., & Calvo-Sendin, J. F. (2000). Environmental and socioeconomic interactions in the evolution of traditional irrigated lands: a dynamic system model. *Human Ecology, 28*(2), 279-299.

Martinez-Moyano, I. J., Sallah, D. L., Bragen, M. J., & Thimmapuram, P. R. (2007). *Design for a multilayer model of financial stability: Exploring the integration of system dynamics and agent-based models.* Paper presented at the 2007 International Conference of the System Dynamics Society and 50th Anniversary Celebration, Boston, Massachusetts, USA.

Maryland Virtual High School. (2001). CoreModels Final Report (9707702) Findings. Retrieved 08/11/07, from http://mvhs.shodor.org/coremodels/cmindex.html

May, T. S. (2000). Elements of success in environmental education through practitioner eyes. *The Journal of Environmental Education, 31*(3), 4-11.

Mayer, R. E., Dow, G. T., & Mayer, S. (2003). Multimedia learning in an interactive self-explaining environment: What works in the design of agent-based microworlds? *Journal of Educational Psychology, 95*(4), 806-813.

McCleave, J., Espiner, S., & Booth, K. (2006). The New Zealand people-park relationship: An exploratory model. *Society and Natural Resources, 19*, 547-561.

Medeiros, R., Ramos, J. A., Paiva, V. H., Almeida, A., Pedro, P., & Antunes, S. (2007). Signage reduces the impact of human disturbance on little tern nesting success in Portugal. *Biological Conservation, 135*, 99-106.

Metz, K. (1998). Scientific Inquiry within reach of young children. In B. J. Fraser & K. G. Tobin (Eds.), *International Handbook of Science Education* (Vol. 2, pp. 81-96). Dordrecht: Kluwer Academic Publishers.

Milfont, T. L., & Duckitt, J. (2004). The structure of environmental attitudes: A first- and second-order confirmatory factor analysis. *Journal of Environmental Psychology, 24*, 289-303.

Milrad, M. (2002). Using construction kits, modeling tools and system dynamics simulations to support collaborative discovery learning. *Educational Technology and Society, 5*(4), 76-87.

Milrad, M., Spector, M., & Davidsen, P. I. (2003). Model facilitated learning. In S. Naidu (Ed.), *Learning & teaching with technology: principles and practices* (pp. 13-27). London: Kogan Page Ltd.

Monticino, M., Acevedo, M., Callicott, B., Cogdill, T., & Lindquist, C. (2007). Coupled human and natural systems: A multi-agent-based approach. *Environmental Modelling & Software, 22*, 656-663.

Moore, P. J. (1993). Metacognitive processing of diagrams, maps and graphs. *Learning and Instruction, 3*, 215-226.

Morgan, J. W. (1998). Patterns of invasion of an urban remnant of a species-rich grassland in southeastern Australia by non-native plant species. *Journal of Vegetation Science, 9*, 181-190.

Morgan, M., & Soucy, J. (2006). Usage and evaluation of nonformal environmental education services at a state park: Are anglers catching more than fish? *Environmental Education Research, 12*(5), 595-608.

Moxnes, E. (1998). Overexploitation of renewable resources: The role of misperceptions. *Journal of Economic Behavior & Organization, 37*, 107-127.

Moxnes, E. (2000). Not only the tragedy of the commons: misperceptions of feedback and policies for sustainable development. *System Dynamics Review, 16*(4), 325-348.

Moxnes, E. (2004). Misperceptions of basic dynamics: the case of renewable resource management. *System Dynamics Review, 20*(2), 139-162.

Munson, B. H. (1994). Ecological misconceptions. *Journal of Environmental Education, 25*(4), 30-34.

Murdock, E. (2004). Understanding recreation flow to protect wilderness resources at Joshua Tree National Park, California. *Working Papers of the Finnish Forest Research Institute 2* Retrieved 22/11/2007, 2007, from http://www.metla.fi/julkaisut/workingpapers/2004/mwp002.htm

Murray, T., Winship, L., Bellin, R., & Cornell, M. (2001). *Toward glass box educational simulations: Reifying models for inspection and design.* Paper presented at the External Representations in AIED: Multiple Forms and Multiple Roles, San Antonio, Texas.

Nagel, M. (2005). Constructing apathy: How environmentalism and environmental education may be fostering "learned hopelessness" in children. *Australian Journal of Environmental Education, 21*, 71-80.

Norman, D. A. (1983). Some observations on mental models. In D. Gentner & A. L. Stevens (Eds.), *Mental Models* (pp. 7-14). New Jersey: Lawrence Erlbaum Associates, Inc., Publishers.

NSW Council on Environmental Education. (2001). *Environmental Education in NSW: Towards a three-year plan*. Sydney South: NSW Council on Environmental Education.

NSW Department of Education and Training. (2001). *Environmental Education Policy for Schools.* Sydney: The Department of Education and Training, Curriculum Support Directorate.

Oliveira, A. W., & Sadler, T. D. (2007). Interactive patterns and conceptual convergence during student collaborations in science [Electronic Version]. *Journal of Research in Science Teaching*, Early View: DOI 05/11/2007. Retrieved 03/12/2007.

Orams, M. B. (1997). The effectiveness of environmental education: Can we turn tourists into 'greenies'? *Progress in Tourism and Hospitality Research, 3*, 295-306.

Osgood, N. (2007). *Using traditional and agent based toolsets for system dynamics: Present tradeoffs and future evolution.* Paper presented at the 2007 International Conference of the System Dynamics Society and 50th Anniversary Celebration, Boston, Massachusetts, USA.

Ossimitz, G. (1997). The Development of Systems Thinking Skills Using System Dynamics Modelling Tools. Retrieved 6 April 2004, from http://www.uni-klu.ac.at/users/gossimit/sdyn/gdm_eng.htm

Ozkan, O., Tekkaya, C., & Geban, O. (2004). Facilitating conceptual change in students' understanding of ecological concepts. *Journal of Science Education and Technology, 13*(1), 95-105.

Pahl-Wostl, C. (2007). The implications of complexity for integrated resources management. *Environmental Modelling & Software, 22*, 561-569.

Pallant, A., & Tinker, R. F. (2004). Reasoning with atomic-scale molecular dynamic models. *Journal of Science Education and Technology, 13*(1), 51-66.

Palmberg, I. E., & Kuru, J. (2000). Outdoor activities as a basis for environmental responsibility. *The Journal of Environmental Education, 31*(4), 32-36.

Palmer, J. A. (1999). Research matters: A call for the application of empirical evidence to the task of improving the quality and impact of environmental education. *Cambridge Journal of Education, 29*(3), 379-395.

Parrott, L., & Kok, R. (2001). A generic primary producer model for use in ecosystem simulation. *Ecological Modelling, 139*, 75-99.

Patterson, T., Gulden, T., Cousins, K., & Kraev, E. (2004). Integrating environmental, social and economic systems: a dynamic model of tourism in Dominica. *Ecological Modelling, 175*, 121-136.

Pooley, J. A., & O'Connor, M. (2000). Environmental education and attitudes. Emotions and beliefs are what is needed. *Environment and Behavior, 32*(5), 711-723.

Potential, T. (1992). Systems thinking encourages interdisciplinary approach. *T H E Journal (Technological Horizons In Education), 20*(4), 43-44.

Powers, A. L. (2004). Evaluation of one- and two-day forestry field programs for elementary school children. *Applied Environmental Education and Communication, 3*, 39-46.

Ragan, S. (1999). Student-built computer models enhance learning in science and mathematics. Retrieved 18/4/05, 2005, from http://mvhs1.mbhs.edu/mvhsproj/coremodels/mast.html

Railsback, S. F. (2001). Concepts from complex adaptive systems as a framework for individual-based modelling. *Ecological Modelling, 139*, 47-62.

Ramsey, D. C., & Ramsey, P. L. (2002). Reframing the perfectionist's Catch 22 dilemma: a systems thinking approach. *Journal for the education of the gifted, 26*(2), 99-111.

Ramsey, J., Hungerford, H., & Tomera, A. N. (1981). The effects of environmental action and environmental case study instruction on the overt environmental behavior of eighth-grade students. *Journal of Environmental Education, 13*(1), 24-30.

Reimann, P., Thompson, K., & Weinel, M. (2007). *Decision making patterns in virtual teams. .* Paper presented at the Supporting learning flow through integrative technologies, Amsterdam.

Rickinson, M. (2001). Learners and Learning in Environmental Education: a critical review of the evidence. *Environmental Education Research, 7*(3), 207-320.

Rieber, L. P. (1990). Using computer animated graphics in science instruction with children. *Journal of Educational Psychology, 82*(1), 135-140.

Rieber, L. P. (1996). Seriously considering play: Designing interactive learning environments based on the blending of microworlds, simulations and games. *Educational Technology Research and Development, 44*(2), 43-58.

Rieber, L. P., Tzeng, S.-C., & Tribble, K. (2004). Discovery learning, representation, and explanation within a computer-based simulation: finding the right mix. *Learning and Instruction, 14*, 307-323.

Roberts, C. A., & Gimblett, H. R. (2000). *Computer simulation for rafting traffic on the Colorado River.* Paper presented at the 4th Biennial Conference of Research on Colorado Plateau.

Roberts, C. A., Stallman, D., & Bieri, J. A. (2002). Modeling complex human-environment interactions: The Grand Canyon river trip simulator. *Ecological Modelling, 153*, 181-196.

Robottom, I. (2004). Environmental Education and local initiatives: a rationale, international examples and an issue for research. *Applied Environmental Education and Communication, 3*, 21-28.

Rohr, M., & Reimann, P. (1998). Reasoning with Multiple Representations when Acquiring the Particulate Model of Matter. In M. W. van Someren, P. Reimann, H. P. A. Boshuizen & T. de Jong (Eds.), *Learning with Multiple Representations* (pp. 41-66). Oxford: Elsevier Science Ltd.

Romesburg, H. C. (1974). Scheduling models for wilderness recreation. *Journal of Environmental Management, 2*, 159-177.

Roschelle, J. (1992). Learning by collaborating: Convergent conceptual change. *The Journal of the Learning Sciences, 2*(3), 235-276.

Roth, W.-M., & Bowen, G. M. (1999). Complexities of graphical representations during ecology lectures: an analysis rooted in semiotics and hermeneutic phenomenology. *Learning and Instruction, 9*, 235-255.

Rouwette, E. A. J. A., Vennix, J. A. M., & Thijssen, C. M. (2000). Group model building: a decision room approach. *Simulation & Gaming, 31*(3), 359-379.

Satsangi, P. S., Mishra, D. S., Gaur, S. K., Singh, B. K., & Jain, D. K. (2003). Systems dynamics modelling, simulation and optimization of integrated urban systems: a soft computing approach. *Kybernetes, 32*(5/6), 808-817.

Savelsbergh, E. R., de Jong, T., & Ferguson-Hessler, M. G. M. (1998). Competence-Related Differences in Problem Representations: A Study in Physics Problem Solving. In M. W. van Someren, P. Reimann, H. P. A. Boshuizen & T. de Jong (Eds.), *Learning with Multiple Representations* (pp. 263-282). Oxford: Elsevier Science Ltd.

Saysel, A. K., Barlas, Y., & Yenigun, O. (2002). Environmental sustainability in an agricultural development project: A system dynamics approach. *Journal of Environmental Management., 64*(3), 247-260.

Scaife, M., & Rogers, Y. (1996). External cognition: How do graphical representations work? *International Journal of Human-Computer Studies, 45*, 185-213.

Schaffernicht, M. (2006). *LaTina - An online system for teaching and learning stock-and-flow thinking skills.* Paper presented at the 24th International Conference of the System Dynamics Society, Nijmegen, The Netherlands.

Schieritz, N. (2002). Integrating system dynamics and agent-based modelling. Retrieved 12/8/2004, 2004, from iswww.bwl.uni-mannheim.de/lehrstuhl/ mitarbeiter/schieritz/Palermo%202002.pdf

Schieritz, N., & Grossler, A. (2003). *Emergent structures in supply chains - a study integrating agent-based and system dynamics modelling.* Paper presented at the Proceedings of the 36th Hawaii International Conference on System Sciences.

Schieritz, N., & Milling, P. M. (2003). *Modeling the forest or modeling the trees. A comparison of system dynamics and agent-based simulation.* Paper presented at the 21st International System Dynamics Society Conference, New York City, USA.

Schmidt, J. C., Webb, R. H., Valdez, R. A., Marzolf, G. R., & Stevens, L. E. (1998). Science and values in river restoration in the Grand Canyon. *BioScience, 48*(9), 735-760.

Schnotz, W. (2002). Towards an integrated view of learning from text and visual displays. *Educational Psychology Review, 14*(1), 101-120.

Schnotz, W., & Bannert, M. (2003). Construction and interference in learning from multiple representations. *Learning and Instruction, 13*, 141-156.

Scholl, H. J. (2001). *Agent-based and System Dynamics Modeling : A Call for Cross Study and Joint Research.* Paper presented at the 34th Annual Hawaii International Conference on System Sciences, Maui, Hawaii.

Sengupta, P., & Wilensky, U. (1999). N.I.E.L.S 1: An Emergent Multi-Agent Based Modeling Environment for learning Physics Retrieved 31/5/06, 2006, from https://ccl.northwestern.edu/papers/AAMAS-Pratim.pdf

Seufert, T. (2003). Supporting coherence formation in learning from multiple representations. *Learning and Instruction, 13*, 227-237.

Seufert, T., Janen, I., & Brunken, R. (2007). The impact of intrinsic cognitive load on the effectiveness of graphical help for coherence formation. *Computers in Human Behavior, 23*, 1055-1071.

Shechter, M., & Lucas, R. C. (1980). Validating a large scale simulation model of wilderness recreational travel. *INTERFACES, 10*(5), 11-18.

Sheehy, N. P., Wylie, J. W., McGuinness, C., & Orchard, G. (2000). How children solve environmental problems: using computer simulations to investigate systems thinking. *Environmental Education Research, 6*(2), 109-126.

Sherwood, D. (2002). *Seeing the forest for the trees. A manager's guide to applying systems thinking*. London: Nicholas Brealey Publishing.

Short, J., Turner, B., & Risbey, D. (2002). Control of feral cats for nature conservation. III. Trapping. *Wildlife Research, 29*, 475-487.

Siemer, W. F., & Knuth, B. (2001). Effects of fishing education programs on antecedents of responsible environmental behavior. *The Journal of Environmental Education, 32*(4), 23-29.

Simmons, B., & Volk, T. L. (2002). Environmental Educators: A conversation with Harold Hungerford. *The Journal of Environmental Education, 34*(1), 5-8.

Simmons, D., & Widmar, R. (1990). Motivations and barriers to recycling: Toward a strategy for public education. *Journal of Environmental Education, 22*(1), 13-18.

Singhanayok, C., & Hooper, S. (1998). The effects of cooperative learning and learner control on students' achievement, option selections, and attitudes. *Educational Technology, Research and Development, 46*(2), 17-32.

Sins, P. H. M., Savelsbergh, E. R., & van Joolingen, W. R. (2005). The difficult process of scientific modelling: An analysis of novices' reasoning during computer-based modelling. *International Journal of Science Education, 27*(14), 1695-1721.

Slavin, R. E. (1983). When does cooperative learning increase student achievement? *Psychological Bulletin, 94*(3), 429-445.

Slavin, R. E. (1996). Research for the future. Research on Cooperative learning and achievement: What we know, what we need to know. *Contemporary Educational Psychology, 21*, 43-69.

Spector, J. M. (2000). System dynamics and interactive learning environments: Lessons learned and implications for the future. *Simulation & Gaming, 31*(4), 528-535.

Spector, J. M., & Davidsen, P. I. (1997). Creating Engaging Courseware Using System Dynamics. *Computers in Human Behavior, 13*(2), 127-155.

Stave, K. A. (2002). Using system dynamics to improve public participation in environmental decisions. *System Dynamics Review, 18*(2), 139-167.

Stave, K. A. (2003). A system dynamics model to facilitate public understanding of water management options in Las Vegas, Nevada. *Journal of Environmental Management, 67*(4), 303-313.

Stavredes, T. (2001). A system dynamics evaluation model and methodology for instructional technology support. *Computers in Human Behavior, 17*, 409-419.

Stenning, K. (1998). Representation and Conceptualisation in Educational Communication. In M. W. van Someren, P. Reimann, H. P. A. Boshuizen & T. de Jong (Eds.), *Learning with Multiple Representations* (pp. 320-333). Oxford: Elsevier Science Ltd.

Sterman, J. D. (2000). *Business Dynamics. Systems Thinking and Modeling for a Complex World.*: McGraw-Hill Higher Education.

Sterman, J. D. (2001). System Dynamics Modeling: Tools for learning in a complex world. *California Management Review, 43*(4), 8-27.

Sterman, J. D., & Booth Sweeny, L. (2002). Cloudy skies: assessing public understanding of global warming. *System Dynamics Review, 18*(2), 207-240.

Stieff, M., & Wilensky, U. (2002). *ChemLogo: An emergent modeling environment for teaching and learning chemistry.* Paper presented at the fifth biannual International Conference of the Learning Sciences, Seattle, WA, USA.

Stieff, M., & Wilensky, U. (2003). Connected chemistry - Incorporating interactive simulations into the chemistry classroom. *Journal of Science Education and Technology, 12*(5), 285-302.

Stratford, S. J., Krajcik, J., & Soloway, E. (1998). Secondary students' dynamic modeling processes: Analyzing, reasoning about, synthesizing, and testing models of stream ecosystems. *Journal of Science Education and Technology, 7*(3), 215-234.

Stuntz, L. (2000). *Building system dynamics skills in K-3 (Ages 5-8) students.* Paper presented at the 18th International Conference of The System Dynamics Society: Sustainability in the Third Millennium, Bergen, Norway.

Stylianidou, F., Boohan, R., & Ogborn, J. (2004). Science Teachers' transformations of the use of computer modeling in the classroom: using research to inform training. *Science Education, 89*(1), 56-70.

Sun, D., & Walsh, D. (1998). Review of studies on environmental impacts of recreation and tourism in Australia. *Journal of Environmental Management, 53*, 323-338.

Sureda, J., Oliver, M. F., & Castells, M. (2004). Indicators for the evaluation of environmental education, interpretation and information in protected areas. *Applied Environmental Education and Communication, 3*, 171-181.

Suthers, D. D., & Hundhausen, C., D. (2003). An experimental study of the effects of representational guidance on collaborative learning processes. *Journal of the Learning Sciences, 12*(2), 183-218.

Sweller, J., & Chandler, P. (1994). Why some material is difficult to learn. *Cognition and Instruction, 12*(3), 185-233.

Sycara, K. P. (1998). Multiagent systems. *AI Magazine, Summer*, 79-92.

Tabachneck-Schijf, H. J. M., Leonardo, A. M., & Simon, H. A. (1997). CaMeRa: A computational model of multiple representations. *Cognitive Science, 21*(3), 305-350.

Talsma, V. (2001). The rouge education project: challenges of implementation. *The Journal of Environmental Education, 32*(3), 26-30.

Thomas, G. (2005). Facilitation in Education *for* the environment. *Australian Journal of Environmental Education, 21*, 107-116.

Tilman, D. (1987). Secondary succession and the pattern of plant dominance along experimental nitrogen gradients. *Ecological Monographs, 57*(3), 189-214.

Tisue, S., & Wilensky, U. (2004a). *NetLogo: A Simple Environment for Modeling Complexity* Paper presented at the International Conference on Complex Systems, Boston.

Tisue, S., & Wilensky, U. (2004b). *NetLogo: Design and Implementation of a Multi-Agent Modeling Environment* Paper presented at the SwarmFest, Ann Arbor.

Tsui, C.-Y., & Treagust, D. F. (2003). Genetics reasoning with multiple external representations. *Research in Science Education, 33*, 111-135.

Tversky, B., Bauer Morrison, J., & Betrancourt, M. (2002). Animation: can it facilitate? *International Journal of Human-Computer Studies, 57*, 247-262.

Uchmanski, J. (2000). Resource partitioning among competing individuals and population persistence: an individual-based model. *Ecological Modelling, 131*, 21-32.

Underwood, J. D. M., & Underwood, G. (1990). *Helping children acquire thinking skills*: Basil Blackwell.

United Nations. (1992). Agenda 21 - Chapter 36. Retrieved 16/7/2004, 2004, from http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21chapter36.htm

Usher, M. B., Kruger, F. J., Macdonald, I. A. W., Loope, L. L., & Brockie, R. E. (1988). The ecology of biological invasions into nature reserves: An introduction. *Biological Conservation, 44*, 1-8.

van der Meij, J., & de Jong, T. (2006). Supporting students' learning with multiple representations in a dynamic simulation-based learning environment. *Learning and Instruction, 16*, 199-212.

van Joolingen, W. R., & Lohner, S. (2001). *Representations in collaborative modeling tasks.* Paper presented at the AI-ED Workshop. External Representations in AIED: Multiple forms and multiple roles, San Antonio, Texas.

Van Labeke, N., & Ainsworth, S. (2002). *Representational decisions when learning population dynamics with an instructional simulation.* Paper presented at the 6th International Conference ITS 2002, Berlin.

van Wagtendonk, J. W. (2004). *Simulation modeling of visitor flows: Where have we been and where are we going?* Paper presented at the Proceedings of the Second International Conference on Monitoring and Management of Visitor Flows in Recreational and Protected Areas.

Vaske, J. J., & Kobrin, K. C. (2001). Place attachment and environmentally responsible behavior. *The Journal of Environmental Education, 32*(4), 16-21.

Verona, M. E., Ragan, S., Shaffer, D., & Trout, C. (2001). Working paper: A case study of materials development fostered by the MVHS CoreModels Project. Retrieved 18/4/05, from mvhs1.mbhs.edu/mvhsproj/workmatdev.pdf

Volk, T. L., & Cheak, M. J. (2003). The effects of an environmental education program on students, parents, and community. *The Journal of Environmental Education, 34*(4), 12-25.

Wakeland, W. W., Macovsky, L. M., Gallaher, E. J., & Aktipis, C. A. (2004). *A comparison of system dynamics and agent-based simulation applied to the study of cellular receptor dynamics.* Paper presented at the 37th Hawaii International Conference on System Sciences, Hawaii.

Walker, P. A., Greiner, R., McDonald, D., & Lyne, V. (1999). The tourism futures simulator: a systems thinking approach. *Environmental Modelling & Software, 14*, 59-67.

Wang, B., & Manning, R. E. (1999). Computer simulation modeling for recreation management: A study on carriage road use in Acadia National Park, Maine, USA. *Environmental Management, 23*(2), 193-203.

Wang, M., & Grimm, V. (2007). Home range dynamics and population regulation: An individual-based model of the common shrew *Sorex araneus*. *Ecological Modelling, 205*, 397-409.

Wang, X. C., Hinn, D. M., & Kanfer, A. G. (2001). Potential of computer-supported collaborative learning for learners with different learning styles. *Journal of Research on Technology in Education, 34*(1), 75-85.

Weclaw, P., & Hudson, R. J. (2004). Simulation of conservation and management of woodland caribou. *Ecological Modelling, 177*, 75-94.

Whelan, J., Flowers, R., & Roberto Guevara, J. (2004). *An imbalance between what is researched and practiced: a case for researchers to direct more attention to popular and informal environmental education.* Paper presented at the Effective Sustainability Education: What Works? Why? Where Next? Linking Research and Practice 18-20 February 2004, Sydney, Australia.

Wild, M., & Quinn, C. (1998). Implications of educational theory for the design of instructional multimedia. *British Journal of Educational Technology, 29*(1), 73-82.

Wilensky, U. (2003). Statistical mechanics for secondary school: The gaslab multi-agent modeling toolkit. *International Journal of Computers for Mathematical Learning, 8*, 1-41.

Wilensky, U. (2007). *NetLogo User Manual. Version 4.0*. Evanston, IL: Center for Connected Learning and Computer-Based Modeling, Northwestern University.

Wilensky, U., & Reisman, K. (2006). Thinking like a Wolf, a Sheep, or a Firefly: Learning biology through constructing and testing computational theories - an embodied modeling approach. *Cognition and Instruction, 24*(2), 171-209.

Wisnudel Spitulnik, M., Stratford, S., Krajcik, J., & Soloway, E. (1998). Using Technology to Support Students' Artefact Construction in Science. In B. J. Fraser & K. G. Tobin (Eds.), *International Handbook of Science Education* (Vol. 2, pp. 363-381). Dordrecht: Kluwer Academic Publishers.

Woodwell, J. C. (1998). A simulation model to illustrate feedbacks among resource consumption, production, and factors of production in ecological-economic systems. *Ecological Modelling, 112*(2-3), 227-247.

Woolsey, K., & Bellamy, R. (1997). Science education and technology: opportunities to enhance student learning. *The Elementary School Journal, 97*(4), 385-399.

Xu, H.-g. (2001). Exploring effective policies for underground water management in artificial oasis: a systems dynamics analysis of a case study of Yaoba Oasis. *Journal of Environmental Sciences, 13*(4), 476-480.

Young, G. (1996). New South Wales Environment Protection Authority environmental Education: The place of theory, models and concepts in developing policy, strategy and programs: NSW Environment Protection Authority.

Young, R. M. (1983). Surrogates and mappings: two kinds of conceptual models for interactive devices. In D. Gentner & A. L. Stevens (Eds.), *Mental Models* (pp. 35-52). New Jersey: Lawrence Erlbaum Associates, Inc., Publishers.

Zelezny, L. C. (1999). Educational interventions that improve environmental behaviors: a meta-analysis. *The Journal of Environmental Education, 31*(1), 5-14.

Zhang, J. (1997). The nature of external representations in problem solving. *Cognitive Science, 21*(2), 179-217.

Zhang, J., & Norman, D. A. (1994). Representations in distributed cognitive tasks *Cognitive Science, 18*, 87-122.

APPENDIX 1: TEXT DESCRIPTION OF THE SYSTEM

The University of Sydney

Centre for Research on Computer-Supported Learning and Cognition - CoCo
Faculty of Education and Social Work
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NSW 2006 Australia

VISITOR USAGE OF A NATIONAL PARK

The public visits a national park for a number of reasons. One is to have a picnic. Visitors who visit this national park for the purpose of a picnic have a unique arrival cycle. The arrival cycle is the distribution of times that visitors arrive at the park. Most visitors tend to arrive around lunch time and fewer arrive before 11:00am and after 2pm, although some still do. The departure cycle of the visitors is also unique. There are a steady number of people leaving between 1pm and 5pm, and then this increases between 5pm and 7pm. In the case in question, the park closes at 7:30pm. Some days there are more visitors than others, for example, a weekend will have more people visiting than a weekday. However, school holidays may not mean that more visitors are in the park. So what impact could visitors having a picnic have on a national park? Some people will leave their rubbish on the ground, or collect firewood for bbq's, and some will bring their pets. All of these activities will have an impact on the natural ecosystem. Even if the visitors do the right thing and put their rubbish in the rubbish bins provided, they can still have an impact on the ecosystem. We'll assume for a moment that each person in a group leaves one piece of rubbish in the bin. And we'll also assume that half of this is inorganic rubbish (bottles, plastic, anything that will not decompose) and the other half is organic rubbish (food scraps, anything that CAN decompose). So, how does the rubbish get removed from the park? A garbage collector comes around and empties the bins once a day. We'll assume that the garbage collector arrives at 5pm every day. We're going to assume that each time he collects about 95% of the rubbish in the bins. The rubbish that is left in the bins is either inorganic, which means that it will not decompose, and so it stays in the bin until visitors arrive the next day and put their rubbish in, or organic. If the rubbish is organic then it will either begin to decompose, or it may be eaten by animals. We will assume that half is eaten by animals and the other half decomposes. Organic rubbish like this tends to attract introduced species like rats or mice, which in turn attract feral cats. These animals are often nocturnal, or at least do not come out while there are a lot of people around. Decomposing organic rubbish adds nutrients to the environment, which has further impacts on the ecosystem. In our case, we will assume that it takes 3 days from the organic waste being left in the bin and it being broken down and resulting in the addition of nutrients to the environment. And then the cycle continues the next day. As the cycle continues the amount of waste increases, as does the amount of nutrients in the environment.

So, what's important about all this? Well for a start, the time that the garbage collector comes is important. What do you think this could influence? Also, the percentage of rubbish that is collected could be different, let's assume either 90% (0.9), 95% (0.95) or 100% (1). What do you think will be the implications of that?

You'll be asked to describe how the visitors influence the running of the park. Think about what will happen if the amount of rubbish that each person leaves changes (1, 2 or 3 pieces of rubbish). Combine this with different percentages of rubbish removal and different collection times.

You'll be given paper to draw graphs and make notes as you go.

APPENDIX 2: SYSTEM DYNAMICS MODEL EQUATIONS

Additional_Nutrients_in_the_soil(t) = Additional_Nutrients_in_the_soil(t - dt) + (nutrients__to_the_soil) * dt

INIT Additional_Nutrients_in_the_soil = nutrients__to_the_soil

nutrients__to_the_soil = CONVEYOR OUTFLOW

decomposing_waste(t) = decomposing_waste(t - dt) + (decomposition - nutrients__to_the_soil) * dt

INIT decomposing_waste = 0

TRANSIT TIME = 84

INFLOW LIMIT = °

CAPACITY = °

decomposition = 0.25*waste_accumulating__at_the_site

nutrients__to_the_soil = CONVEYOR OUTFLOW

Visitors_at_picnic_ground_1(t) = Visitors_at_picnic_ground_1(t - dt) + (arrival_cycle_1 - departure_cycle_1) * dt

INIT Visitors_at_picnic_ground_1 = 0

arrival_cycle_1 = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 19.0), (6.00, 9.00), (7.00, 12.0), (8.00, 17.0), (9.00, 22.0), (10.0, 18.0), (11.0, 35.0), (12.0, 4.00), (13.0, 10.0), (14.0, 10.0), (15.0, 0.00), (16.0, 0.00), (17.0, 4.00), (18.0, 4.00), (19.0, 0.00), (20.0, 0.00), (21.0, 7.00), (22.0, 0.00), (23.0, 0.00), (24.0, 0.00), (25.0, 0.00), (26.0, 0.00), (27.0, 0.00), (28.0, 0.00), (29.0, 0.00), (30.0, 0.00), (31.0, 0.00), (32.0, 0.00), (33.0, 0.00), (34.0, 6.00), (35.0, 5.00), (36.0, 2.00), (37.0, 7.00), (38.0, 3.00), (39.0, 0.00), (40.0, 0.00), (41.0, 2.00), (42.0, 0.00), (43.0, 0.00), (44.0, 0.00), (45.0, 0.00), (46.0, 0.00), (47.0, 0.00), (48.0, 0.00), (49.0, 0.00), (50.0, 0.00), (51.0, 0.00), (52.0, 0.00), (53.0, 0.00), (54.0, 0.00), (55.0, 0.00), (56.0, 0.00), (57.0, 0.00), (58.0, 0.00), (59.0, 0.00), (60.0, 19.0), (61.0, 0.00), (62.0, 0.00), (63.0, 2.00), (64.0, 3.00), (65.0, 0.00), (66.0, 5.00), (67.0, 2.00), (68.0, 2.00), (69.0, 9.00), (70.0, 8.00), (71.0, 7.00), (72.0, 7.00), (73.0, 0.00), (74.0, 0.00), (75.0, 0.00), (76.0, 3.00), (77.0, 0.00), (78.0, 0.00), (79.0, 0.00), (80.0, 0.00), (81.0, 0.00), (82.0, 0.00), (83.0, 0.00), (84.0, 0.00), (85.0, 0.00), (86.0, 0.00), (87.0, 0.00), (88.0, 1.00), (89.0, 0.00), (90.0, 0.00), (91.0, 0.00), (92.0, 0.00), (93.0, 8.00), (94.0, 4.00), (95.0, 0.00), (96.0, 4.00), (97.0, 0.00), (98.0, 5.00), (99.0, 0.00), (100, 0.00), (101, 0.00), (102, 0.00), (103, 0.00), (104, 0.00), (105, 6.00), (106, 0.00), (107, 0.00), (108, 0.00), (109, 0.00), (110, 0.00), (111, 0.00), (112, 0.00), (113, 0.00), (114, 0.00), (115, 0.00), (116, 0.00), (117, 0.00), (118, 5.00), (119, 0.00), (120, 0.00), (121, 5.00), (122, 0.00), (123, 3.00), (124, 0.00), (125, 0.00), (126, 2.00), (127, 0.00), (128, 0.00), (129, 4.00), (130, 0.00), (131, 0.00), (132, 0.00), (133, 5.00), (134, 0.00), (135, 0.00), (136, 0.00), (137, 0.00), (138, 0.00), (139, 0.00), (140, 0.00), (141, 0.00), (142, 0.00), (143, 1.00), (144, 0.00), (145, 0.00), (146, 4.00), (147, 0.00), (148, 6.00), (149, 7.00), (150, 6.00), (151, 9.00), (152, 1.00), (153, 0.00), (154, 8.00), (155, 0.00), (156, 0.00), (157, 0.00), (158, 0.00), (159, 0.00), (160, 0.00), (161, 0.00), (162, 0.00), (163, 0.00), (164, 0.00), (165, 0.00), (166, 0.00), (167, 0.00), (168, 0.00), (169, 0.00), (170, 0.00), (171, 0.00), (172, 0.00), (173, 0.00), (174, 0.00), (175, 1.00), (176, 6.00), (177, 0.00), (178, 8.00), (179, 2.00), (180, 4.00), (181, 0.00), (182, 0.00), (183, 0.00), (184, 0.00), (185, 0.00), (186, 0.00), (187, 0.00), (188, 0.00), (189, 0.00), (190, 0.00), (191, 0.00), (192, 0.00), (193, 0.00), (194, 0.00), (195, 0.00), (196, 0.00)

departure_cycle_1 = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 4.00), (10.0, 9.00), (11.0, 0.00), (12.0, 2.00), (13.0, 6.00), (14.0, 0.00), (15.0, 0.00), (16.0, 14.0), (17.0, 21.0), (18.0, 0.00), (19.0, 13.0), (20.0, 15.0), (21.0, 22.0), (22.0, 38.0), (23.0, 27.0), (24.0, 0.00), (25.0, 0.00), (26.0, 0.00), (27.0, 0.00), (28.0, 0.00), (29.0, 0.00), (30.0, 0.00), (31.0, 0.00), (32.0, 0.00), (33.0, 0.00), (34.0, 0.00), (35.0, 0.00), (36.0, 0.00), (37.0, 0.00), (38.0, 0.00), (39.0, 5.00), (40.0, 6.00), (41.0, 2.00), (42.0, 2.00), (43.0, 0.00), (44.0, 7.00), (45.0, 3.00), (46.0, 0.00), (47.0, 0.00), (48.0, 0.00), (49.0, 0.00), (50.0, 0.00), (51.0, 0.00), (52.0, 0.00), (53.0, 0.00), (54.0, 0.00), (55.0, 0.00), (56.0, 0.00), (57.0, 0.00), (58.0, 0.00), (59.0, 0.00), (60.0, 0.00), (61.0, 0.00), (62.0, 0.00), (63.0, 0.00), (64.0, 0.00), (65.0, 5.00), (66.0, 0.00), (67.0, 0.00), (68.0, 5.00), (69.0, 0.00), (70.0, 2.00), (71.0, 0.00), (72.0, 12.0), (73.0, 7.00), (74.0, 4.00), (75.0, 21.0), (76.0, 8.00), (77.0, 0.00), (78.0, 0.00), (79.0, 0.00), (80.0, 3.00), (81.0, 0.00), (82.0, 0.00), (83.0, 0.00), (84.0, 0.00), (85.0, 0.00), (86.0, 0.00), (87.0, 0.00), (88.0, 0.00), (89.0, 1.00), (90.0, 0.00), (91.0, 0.00), (92.0, 0.00), (93.0, 0.00), (94.0, 0.00), (95.0, 0.00), (96.0, 0.00), (97.0, 0.00), (98.0, 4.00), (99.0, 5.00), (100, 0.00), (101, 3.00), (102, 0.00), (103, 5.00), (104, 0.00), (105, 4.00), (106, 0.00), (107, 0.00), (108, 6.00), (109, 0.00), (110, 0.00), (111, 0.00), (112, 0.00), (113, 0.00), (114, 0.00), (115, 0.00), (116, 0.00), (117, 0.00), (118, 0.00), (119, 0.00), (120, 0.00), (121, 0.00), (122, 0.00), (123, 0.00), (124, 3.00), (125, 0.00), (126, 0.00), (127, 0.00), (128, 0.00), (129, 0.00), (130, 0.00), (131, 5.00), (132, 9.00), (133, 0.00), (134, 2.00), (135, 5.00), (136, 0.00), (137, 0.00), (138, 0.00), (139, 0.00), (140, 0.00), (141, 0.00), (142, 0.00), (143, 0.00), (144, 0.00), (145, 0.00), (146, 0.00), (147, 0.00), (148, 0.00), (149, 0.00), (150, 4.00), (151, 6.00), (152, 2.00), (153, 0.00), (154, 4.00), (155, 3.00), (156, 5.00), (157, 14.0), (158, 4.00), (159, 0.00), (160, 0.00), (161, 0.00), (162, 0.00), (163, 0.00), (164, 0.00), (165, 0.00), (166, 0.00), (167, 0.00), (168, 0.00), (169, 0.00), (170, 0.00), (171, 0.00), (172, 0.00), (173, 0.00), (174, 0.00), (175, 0.00), (176, 0.00), (177, 0.00), (178, 0.00), (179, 0.00), (180, 3.00), (181, 0.00), (182, 6.00), (183, 0.00), (184, 0.00), (185, 0.00), (186, 0.00), (187, 0.00), (188, 0.00), (189, 0.00), (190, 6.00), (191, 6.00), (192, 0.00), (193, 0.00), (194, 0.00), (195, 0.00), (196, 0.00)

waste_accumulating__at_the_site(t) = waste_accumulating__at_the_site(t - dt) + (remaining_waste - inorganic_waste - eaten_by_animals - decomposition) * dt

INIT waste_accumulating__at_the_site = 0

remaining_waste = Pulse(Waste_left_at_the_site-garbage_services,26,28)

inorganic_waste = 0.5*waste_accumulating__at_the_site

eaten_by_animals = 0.25*waste_accumulating__at_the_site

decomposition = 0.25*waste_accumulating__at_the_site

Waste_left_at_the_site(t) = Waste_left_at_the_site(t - dt) + (accumulation + inorganic_waste - garbage_services - remaining_waste) * dt

INIT Waste_left_at_the_site = 0

accumulation = departure_cycle_1*number_of_pieces_of_rubbish_per_person

inorganic_waste = 0.5*waste_accumulating__at_the_site

garbage_services = pulse(Waste_left_at_the_site*amount_of_garbage_collected,garbage_collection_time,28)

remaining_waste = Pulse(Waste_left_at_the_site-garbage_services,26,28)

amount_of_garbage_collected = 0.9

garbage_collection_time = 18

number_of_pieces_of_rubbish_per_person = 1

APPENDIX 3: AGENT-BASED MODEL EQUATIONS

```
breed [ person-32-1 ]
breed [ person-32-2 ]
breed [ person-32-4 ]
breed [ person-32-6 ]
breed [ orgrubbish-1 ]
breed [ inorgrubbish-1 ]
breed [ orgrubbish-2 ]
breed [ inorgrubbish-2 ]
breed [ garbage-person ]
breed [ garbage-truck ]
breed [ rat-1 ]
breed [ rat-2 ]
breed [ decomp-1-1 ]
breed [ decomp-1-2 ]

globals [time
    wait-time-1
    wait-time-2
    wait-time-26
    minutes
    bin-1
    bin-1-1
    time-rat-2
    orgrubbish-to-be-eaten-1
    orgrubbish-to-be-eaten-2
    number-people-1
    number-people-9
    decomp-time-4-2
    decomp-time-8-1
    day
    time-clock-hour
    time-clock-minutes
    time-clock-ampm
```

```
    minutes-15-list
    minutes-30-list
    minutes-45-list
    hour-5-list
    hour-11-list
    hour-12am-list
    hour-12pm-list
    hour-1-list
    hour-4-list
]

to setup
  ca
  import-pcolors "picnic 220905 1.png"
  set time 0
  set minutes 0
  wait-time-set
  create-rat-1 30
  create-rat-2 30
  set bin-1 0
  set bin-1-1 0
  set bin-2 0
  set bin-2-1 0
  set number-of-people-list (list 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15)
  set garbage-1 0
  set garbage-2 0
  set garbage-wait-time 0
  set-number-people
  set decomp-time-4-1 10000
  set decomp-time-4-2 10000
  set decomp-time-8-1 10000
  set decomp-time-8-2 10000
  set decomp-time-18-1 10000
  set decomp-time-18-2 10000
  set decomp-time-20-1 10000
  set decomp-time-20-2 10000
  set decomp-time-21-1 10000
```

```
set decomp-time-21-2 10000
set decomp-time-22-1 10000
set decomp-time-22-2 10000
set decomp-time-32-1 10000
set decomp-time-32-2 10000
set hour-5-list (list 540   840    1380   1680   2220   2520   3060   3360   3900   4200
        4740    5040    5580    5880)
set hour-6-list (list 15    600    855    1440   1695   2280   2535   3120   3375   3960
        4215    4800    5055    5640)
set hour-7-list (list 30    660    870    1500   1710   2340   2550   3180   3390   4020
        4230    4860    5070    5700)
set hour-8-list (list 45    720    885    1560   1725   2400   2565   3240   3405   4080
        4245    4920    5085    5760)
set hour-9-list (list 60    735    900    1575   1740   2415   2580   3255   3420   4095
        4260    4935    5100    5775)
set hour-10-list (list 120  750    960    1590   1800   2430   2640   3270   3480   4110
        4320    4950    5160    5790)
set hour-11-list (list 180  765    1020   1605   1860   2445   2700   3285   3540   4125
        4380    4965    5220    5805)
set hour-12am-list (list 780       1620   2460   3300   4140   4980   5820)
set hour-12pm-list (list 240       1080   1920   2760   3600   4440   5280)
set hour-1-list (list 300   792    1140   1632   1980   2472   2820   3312   3660   4152
        4500    4992    5340    5832)
set hour-2-list (list 360   804    1200   1644   2040   2484   2880   3324   3720   4164
        4560    5004    5400    5844)
set hour-3-list (list 420   816    1260   1656   2100   2496   2940   3336   3780   4176
        4620    5016    5460    5856)
set hour-4-list (list 480   828    1320   1668   2160   2508   3000   3348   3840   4188
        4680    5028    5520    5868)
set minutes-15-list (list 419      34     49     75     135    195    255    315    385
        435     495     555     615    675    724    739    754    769    783    795
        807     819     831     844    859    874    889    915    975    1035   1095
        1155    1225    1275    1335   1395   1455   1515   1564   1579   1594   1609
        1623    1635    1647    1659   1671   1684   1699   1714   1729   1755   1815
        1875    1935    1995    2065   2115   2175   2235   2295   2355   2404   2419
        2434    2449    2463    2475   2487   2499   2511   2524   2539   2554   2569
        2595    2655    2715    2775   2835   2905   2955   3015   3075   3135   3195
```

```
         3244   3259   3274   3289   3303   3315   3327   3339   3351   3364   3379
         3394   3409   3435   3495   3555   3615   3675   3745   3795   3855   3915
         3975   4035   4084   4099   4114   4129   4143   4155   4167   4179   4191
         4204   4219   4234   4249   4275   4335   4395   4455   4515   4585   4635
         4695   4755   4815   4875   4924   4939   4954   4969   4983   4995   5007
         5019   5031   5044   5059   5074   5089   5115   5175   5235   5295   5355
         5425   5475   5535   5595   5655   5715   5764   5779   5794   5809   5823
         5835   5847   5859   5871)
set minutes-30-list (list 823   38     53     90     150    210    270    330    390
         450    510    570    630    690    728    743    758    773    786    798
         810    822    834    848    863    878    893    930    990    1050   1110
         1170   1230   1290   1350   1410   1470   1530   1568   1583   1598   1613
         1626   1638   1650   1662   1674   1688   1703   1718   1733   1770   1830
         1890   1950   2010   2070   2130   2190   2250   2310   2370   2408   2423
         2438   2453   2466   2478   2490   2502   2514   2528   2543   2558   2573
         2610   2670   2730   2790   2850   2910   2970   3030   3090   3150   3210
         3248   3263   3278   3293   3306   3318   3330   3342   3354   3368   3383
         3398   3413   3450   3510   3570   3630   3690   3750   3810   3870   3930
         3990   4050   4088   4103   4118   4133   4146   4158   4170   4182   4194
         4208   4223   4238   4253   4290   4350   4410   4470   4530   4590   4650
         4710   4770   4830   4890   4928   4943   4958   4973   4986   4998   5010
         5022   5034   5048   5063   5078   5093   5130   5190   5250   5310   5370
         5430   5490   5550   5610   5670   5730   5768   5783   5798   5813   5826
         5838   5850   5862   5874)
set minutes-45-list (list 12    27     42     57     105    165    225    285    345
         405    465    525    585    645    705    732    747    762    777    789
         801    813    825    837    852    867    882    897    945    1005   1065
         1125   1185   1245   1305   1365   1425   1485   1545   1572   1587   1602
         1617   1629   1641   1653   1665   1677   1692   1707   1722   1737   1785
         1845   1905   1965   2025   2085   2145   2205   2265   2325   2385   2412
         2427   2442   2457   2469   2481   2493   2505   2517   2532   2547   2562
         2577   2625   2685   2745   2805   2865   2925   2985   3045   3105   3165
         3225   3252   3267   3282   3297   3309   3321   3333   3345   3357   3372
         3387   3402   3417   3465   3525   3585   3645   3705   3765   3825   3885
         3945   4005   4065   4092   4107   4122   4137   4149   4161   4173   4185
         4197   4212   4227   4242   4257   4305   4365   4425   4485   4545   4605
         4665   4725   4785   4845   4905   4932   4947   4962   4977   4989   5001
```

```
       5013    5025    5037    5052    5067    5082    5097    5145    5205    5265    5325
       5385    5445    5505    5565    5625    5685    5745    5772    5787    5802    5817
       5829    5841    5853    5865    5877)
end

to go
 set time time + 1
 ifelse time >= 0 and time < 840
  [move-day-1]
  [ifelse time >= 840 and time < 1680
   [move-day-2]
   [ifelse time >= 1680 and time < 2520
    [move-day-3]
    [ifelse time >= 2520 and time < 3360
     [move-day-4]
     [ifelse time >= 3360 and time < 4200
      [move-day-5]
      [ifelse time >= 4200 and time < 5040
       [move-day-6]
       [ifelse time >= 5040 and time < 5880
        [move-day-7]
           [stop]]]]]]]
 if time = 720
  [night-1]
 if time = 840
  [day-2]
 if time = 1560 or time = 2400 or time = 3240 or time = 4080 or time = 4920 or time = 5760
  [night-time]
 if time = 1680 or time = 2520 or time = 3360 or time = 4200 or time = 5040 or time = 5820
  [day-time]
 waste-accumulation-1
 waste-accumulation-2
 garbage-service
 garbage-pick-up-1
 garbage-pick-up-2
 rat-loose-organic-1-1
 rat-loose-organic-1-2
```

```
  rat-loose-organic-1-3
  rat-loose-organic-2-1
  rat-loose-organic-2-2
  rat-loose-organic-2-3
  rat-time-set-1
  rat-time-set-2
  decomposition-stage-1-1
  decomposition-stage-1-2
  decomposition-stage-1-1-a
  decomposition-stage-1-2-a
  decomposition-stage-2-1
  decomposition-stage-2-2
  decomposition-stage-2-1-a
  decomposition-stage-2-2-a
  decomposition-stage-3-1
  decomposition-stage-3-2
  time-display
  decomp-time-set-1
  decomp-time-set-2
  do-plotting
end

to night-1
  ask patches [
    if pcolor = 85.9 or pcolor = 85.8 or pcolor = 86.0 or pcolor = 97.1 or pcolor = 76.9 or pcolor = 97.0 or
pcolor = 86.1
         [set pcolor 91]
    if pcolor = 87.6 or pcolor = 87.8 or pcolor = 87.7 or pcolor = 86.6 or pcolor = 86.8 or pcolor = 87.0 or
pcolor = 87.3 or pcolor = 86.4
         [set pcolor 95]
     ]
end

to day-2
  ask patches  [
    if pcolor = 91
      [set pcolor 85.9]
```

```
    if pcolor = 95
      [set pcolor 87.6]]
end

to night-time
  ask patches [
    if pcolor = 85.9
     [set pcolor 91]
    if pcolor = 87.6
      [set pcolor 95]
     ]
end

to day-time
  ask patches  [
    if pcolor = 95
     [set pcolor 87.6]
    if pcolor = 91
     [set pcolor 85.9]
    ]
end

to move-day-1
  move-person-4-6
  move-person-4-1
  move-person-4-3
  move-person-4-5
  move-person-4-4
  move-person-4-2
  move-person-4-9
  move-person-4-7
  move-person-4-10
  move-person-4-8
end

to move-person-4-6
```

```
  if time = 163 or time = 165 or time = 175 or time = 210 or time = 218 or time = 252 or time = 276 or time =
311 or time = 405
    [create-custom-person-4-6 1 [
        setxy -125 -77
        set shape "person picnic 6"
        set size 25
        set heading 0
        ]
      ]
  if time = 163
    [spot-1-arrive]
  if time >= 163 and time <= 655
    [set wait-time-1 time - 163]
  if time >= 163 and time <= 655 and wait-time-1 = 492
    [set person-number-1 number-people-6
     spot-1-depart]
  if time = 165
    [spot-3-arrive]
  if time >= 165 and time <= 368
    [set wait-time-3 time - 165]
  if time >= 165 and time <= 368 and wait-time-3 = 203
    [set person-number-2 number-people-6
     spot-3-depart]
  if time = 175
    [spot-4-arrive]
  if time >= 175 and time <= 560
    [set wait-time-4 time - 175]
  if time >= 175 and time <= 560 and wait-time-4 = 385
    [set person-number-1 number-people-6
     spot-4-depart]
  if time = 210
    [spot-6-arrive]
  if time >= 210 and time <= 635
    [set wait-time-6 time - 210]
  if time >= 210 and time <= 635 and wait-time-6 = 425
    [set person-number-2 number-people-6
     spot-6-depart]
```

```
  if time = 218
    [spot-8-arrive]
  if time >= 218 and time <= 552
    [set wait-time-8 time - 218]
  if time >= 218 and time <= 552 and wait-time-8 = 334
    [set person-number-1 number-people-6
     spot-8-depart]
  if time = 252
    [spot-12-arrive]
  if time >= 252 and time <= 682
    [set wait-time-12 time - 252]
  if time >= 252 and time <= 682 and wait-time-12 = 430
    [set person-number-2 number-people-6
     spot-12-depart]
  if time = 276
    [spot-10-arrive]
  if time >= 276 and time <= 641
    [set wait-time-10 time - 276]
  if time >= 276 and time <= 641 and wait-time-10 = 365
    [set person-number-2 number-people-6
     spot-10-depart]
  if time = 311
    [spot-16-arrive]
  if time >= 311 and time <= 497
    [set wait-time-16 time - 311]
  if time >= 311 and time <= 497 and wait-time-16 = 186
    [set person-number-2 number-people-6
     spot-16-depart]
  if time = 405
    [spot-23-arrive]
  if time >= 405 and time <= 659
    [set wait-time-23 time - 405]
  if time >= 405 and time <= 659 and wait-time-23 = 254
    [set person-number-1 number-people-6
     spot-23-depart]
end
```

```
to spot-1-arrive
  ask turtles at-points [[-125 -77]] [
    rt 45
    fd 90
    rt 40
    fd 120]
end

to spot-1-depart
  ask turtles at-points [[58 -3]] [
    rt 150
    fd 40
    set bin-1-1 who + 1
    set bin-1 who + 1
    rt 30
    fd 110
    lt 40
    fd 75
    die]
end

to waste-accumulation-1
  if bin-1 = bin-1-1
    [ifelse random 2 > 0
      [create-custom-orgrubbish-1  item  person-number-1  number-of-people-list  *  pieces-of-rubbish-per-
person
       [setxy 34 -46
       set shape "apple"
       set size 5
       set color red
       set heading (random 360)
       fd random 7]
        ]
       [create-custom-inorgrubbish-1  item  person-number-1  number-of-people-list  *  pieces-of-rubbish-per-
person
```

```
        [setxy 34 -46
         set shape "bottle"
         set size 5
         set color blue
         set heading (random 360)
         fd random 7]
         ]
     set bin-1-1 0]
end

to garbage-service
  if garbage-collection-time = "5:00pm"
    [set garbage-time-collect 540]
  if garbage-collection-time = "5:30pm"
    [set garbage-time-collect 570]
  if garbage-collection-time = "6:00pm"
    [set garbage-time-collect 600]
  if garbage-collection-time = "6:30pm"
    [set garbage-time-collect 630]
  if garbage-collection-time = "7:00pm"
    [set garbage-time-collect 660]
  if time = garbage-time-collect or time = garbage-time-collect + 840 or time = garbage-time-collect + 1680
or time = garbage-time-collect + 2520 or time = garbage-time-collect + 3360 or time = garbage-time-collect
+ 4200 or time = garbage-time-collect + 5040
      [create-custom-garbage-truck 1 [
        setxy -100 -77
        set shape "truck"
        set size 75
        set heading 0
        ]
      ]
   if time >= garbage-time-collect and time <= garbage-time-collect + 30
     [set garbage-wait-time time - garbage-time-collect
     collect-garbage]
   if time >= garbage-time-collect + 840 and time <= garbage-time-collect + 870
     [set garbage-wait-time time - (garbage-time-collect + 840)
     collect-garbage]
```

```
  if time >= garbage-time-collect + 1680 and time <= garbage-time-collect + 1710
   [set garbage-wait-time time - (garbage-time-collect + 1680)
   collect-garbage]
  if time >= garbage-time-collect + 2520 and time <= garbage-time-collect + 2550
   [set garbage-wait-time time - (garbage-time-collect + 2520)
   collect-garbage]
  if time >= garbage-time-collect + 3360 and time <= garbage-time-collect + 3390
   [set garbage-wait-time time - (garbage-time-collect + 3360)
   collect-garbage]
  if time >= garbage-time-collect + 4200 and time <= garbage-time-collect + 4230
   [set garbage-wait-time time - (garbage-time-collect + 4200)
   collect-garbage]
  if time >= garbage-time-collect + 5040 and time <= garbage-time-collect + 5070
   [set garbage-wait-time time - (garbage-time-collect + 5040)
   collect-garbage]
  if time >= garbage-time-collect and garbage-wait-time = 10
   [ask garbage-truck at-points [[-100 -77]]
     [die]
   ]
end

to collect-garbage
   if time = garbage-time-collect or time = garbage-time-collect + 840 or time = garbage-time-collect + 1680
or time = garbage-time-collect + 2520 or time = garbage-time-collect + 3360 or time = garbage-time-collect
+ 4200 or time = garbage-time-collect + 5040
     [create-custom-garbage-person 1 [
       setxy -99 -54
       set shape "person truck"
       set size 25
       set heading 0]
   ]
  if time = garbage-time-collect + 1 or time = garbage-time-collect + 841 or time = garbage-time-collect +
1681 or time = garbage-time-collect + 2521 or time = garbage-time-collect + 3361 or time = garbage-time-
collect + 4201 or time = garbage-time-collect + 5041
   [move-bin-1]
```

```
  if time = garbage-time-collect + 4 or time = garbage-time-collect + 844 or time = garbage-time-collect + 1684 or time = garbage-time-collect + 2524 or time = garbage-time-collect + 3364 or time = garbage-time-collect + 4204 or time = garbage-time-collect + 5044
    [move-bin-1-bin-2]
  if time = garbage-time-collect + 7 or time = garbage-time-collect + 847 or time = garbage-time-collect + 1687 or time = garbage-time-collect + 2527 or time = garbage-time-collect + 3367 or time = garbage-time-collect + 4207 or time = garbage-time-collect + 5047
    [move-bin-2]
end

to move-bin-1
  ask garbage-person at-points [[-99 -54]]
    [rt 45
    fd 30
    rt 45
    fd 95
    set garbage-1 1]
end

to move-bin-1-bin-2
  ask garbage-person at-points [[17 -33]]
    [lt 135
     fd 100
     set garbage-2 1]
end

to move-bin-2
  ask garbage-person at-points [[-53 38]]
    [lt 115
    fd 85
    rt 45
    fd 20
    die]
end

to garbage-pick-up-1
  if garbage-1 = 1
```

```
    [let rubbish-1 turtles with [breed = orgrubbish-1 or breed = inorgrubbish-1]
    set sub-total-rubbish-1 (percentage-of-rubbish-collected * (count rubbish-1))
    ask n-of sub-total-rubbish-1 rubbish-1 [die]
    ]
  set garbage-1 0
end

to rat-loose-organic-1-1
  if count orgrubbish-1 > 1
    [if time = time-rat-1
       [create-custom-rat-1 1 [
         setxy 122 -90
         set shape "rat-1"
         set size 19
         set heading 0
       ]
     ]
    ]
    if time = time-rat-1 and count orgrubbish-1 > 1
     [rat-bin-1-1]
    if time = time-rat-1 + 5 and count orgrubbish-1 > 1
     [rat-eat-bin-1]
    if time = time-rat-1 + 10
     [rat-1-leave-1]
end

to decomp-time-set-1
  if time = 720
    [set decomp-time-4-1 800 + random 30]
  if time = 1560
    [set decomp-time-8-1 1640 + random 30]
  if time = 2400
    [set decomp-time-18-1 2480 + random 30]
  if time = 3240
    [set decomp-time-20-1 3320 + random 30]
  if time = 4080
    [set decomp-time-21-1 4160 + random 30]
```

```
  if time = 4920
    [set decomp-time-22-1 5000 + random 30]
  if time = 5760
    [set decomp-time-32-1 5840 + random 30]
end

to decomposition-stage-1-1
  if time = decomp-time-4-1 or time = decomp-time-8-1 or time = decomp-time-18-1 or time = decomp-time-20-1 or time = decomp-time-21-1 or time = decomp-time-22-1 or time = decomp-time-32-1
    [ask orgrubbish-1
      [ifelse random 2 = 0
        [setxy 43 + random 10 -49 - random 13]
        [setxy 8 + random 16 -53 - random 9]]
     ask orgrubbish-1
       [set breed decomp-1-1
        set shape "apple"
        set size 5
        set color red]]
end


to decomp-time-set-2
  if time = 720
    [set decomp-time-4-2 800 + random 55]
  if time = 1560
    [set decomp-time-8-2 1640 + random 55]
  if time = 2400
    [set decomp-time-18-2 2480 + random 55]
  if time = 3240
    [set decomp-time-20-2 3320 + random 55]
  if time = 4080
    [set decomp-time-21-2 4160 + random 55]
  if time = 4920
    [set decomp-time-22-2 5000 + random 55]
  if time = 5760
    [set decomp-time-32-2 5840 + random 55]
end
```

```
to decomposition-stage-1-2
  if time = decomp-time-4-2 or time = decomp-time-8-2 or time = decomp-time-18-2 or time = decomp-
time-20-2 or time = decomp-time-21-2 or time = decomp-time-22-2 or time = decomp-time-32-2
    [ask orgrubbish-2
      [ifelse random 2 = 0
        [setxy -56 + random 8 40 + random 8]
        [setxy -72 + random -17 28 - random 4]]
      ask orgrubbish-2
       [set breed decomp-1-2
        set shape "apple"
        set size 5
        set color red]]
end

to do-plotting
  set-current-plot "Additional Nutrients in the Environment"
  set-current-plot-pen "Nutrients"
  plot count decomp-3-1 + count decomp-3-2
  set-current-plot "Waste accumulating"
  set-current-plot-pen "Waste"
  plot count orgrubbish-1 + count inorgrubbish-1 + count orgrubbish-2 + count inorgrubbish-2
end
```

APPENDIX 4: BACKGROUND QUESTIONNAIRE

The University of Sydney

Centre for Research on Computer-Supported Learning and Cognition – CoCo
Faculty of Education and Social Work
College of Humanities & Social Sciences
NSW 2006 Australia

BACKGROUND QUESTIONS

Personal Information

1. What is your date of birth? ____________________
2. What school do you attend? ____
3. What is your science teacher's name? ______________________________
4. What suburb do you live in? _________________________________
5. What is your gender? (Please circle) Male Female
6. Is English the primary language spoken at home? (Please circle)Yes No

If no, what is the primary language spoken at home? ____________________

Your computer skills

7. Have you been taught to use computers during (Please circle one)

Primary school?	Yes	No
High school?	Yes	No

8. In what subjects have you used a computer this year? ___________________________

____

____

____

9. How would you rate your experience in using the following (please tick the circle):
   a. An Apple Macintosh computer

No experience	Beginner	Competent	Experienced
○	○	○	○

   b. Microsoft Windows

No experience	Beginner	Competent	Experienced
○	○	○	○

c. Word

No experience	Beginner	Competent	Experienced
○	○	○	○

d. Excel

No experience	Beginner	Competent	Experienced
○	○	○	○

e. Powerpoint

No experience	Beginner	Competent	Experienced
○	○	○	○

f. Dreamweaver

No experience	Beginner	Competent	Experienced
○	○	○	○

g. Flash

No experience	Beginner	Competent	Experienced
○	○	○	○

h. Photoshop

No experience	Beginner	Competent	Experienced
○	○	○	○

i. Stella

No experience	Beginner	Competent	Experienced
○	○	○	○

j. NetLogo

No experience	Beginner	Competent	Experienced
○	○	○	○

Science skills

10. What was your science grade in the last half yearly exam? ________________

11. What was your science grade in the most recent yearly exam? ________________

12. What was your mathematics grade in the most recent yearly or half yearly exam? ________ ________Please indicate the extent to which you agree or disagree with the following statements by ticking the appropriate circle

a. I enjoy science

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

b. I enjoy my science class

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

c. It is important to know science to get a good job

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

d. I will use science knowledge in may ways as an adult

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

e. Science is useful in every day life

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

f. Science helps me to think in a logical way

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

g. Whether the science content is difficult or easy, I am sure that I will be

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

h. able to understand it

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

i. I am not confident that I will be able to understand difficult science concepts

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

j. I am sure that I can do well in science tests

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

k. No matter how much effort I put in, I cannot understand science

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

l. When I am learning new science concepts, I try to understand them

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

m. When I am learning new science concepts, I try to memorise them

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

n. When I am learning new science concepts, I try to connect them to the knowledge

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

o. that I already have about science

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

p. When I do not understand a science concept, I try to find other relevant information that will help me to understand

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

q. When I do not understand a science concept, I discuss it with the teacher to clarify my understanding

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

r. When I do not understand a science concept, I discuss it with other students to clarify my understanding

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

s. During the learning process I try to make connections between the concepts that I learn

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

t. When I make a mistake, I try to find out what was wrong

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

u. When new science concepts that I have learned conflict with my previous knowledge, I try to find out why

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

v. In science, I think it is important to learn to solve problems

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

w. When learning science, it is important to have the opportunity to satisfy my own curiosity

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

Attitudes about the environment

13. Define the term: ecosystem

____

____

____

____

14. Please indicate the extent to which you agree or disagree with the following statements by ticking the appropriate circle

a. Humans have the right to alter nature to satisfy wants and desires

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

b. Science knowledge forms the basis for solving environmental problems

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

c. Nature consists of resources for humans to use

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

d. A change in attitudes and values is necessary in order to solve environmental problems

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

e. Humans should live in harmony with the rest of nature

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

f. There is a limit to the number of people that the Earth can support

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

g. Present generations of humans have moral duties and obligations to future generations

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

h. Litter in streets and parks does not bother me

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

i. I want to inform people of the importance of pollution and environmental problems

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

j. I want to participate in protest activities against environmental problems

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

k. I do participate in protest activities against environmental problems

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

l. I am interested in attending lectures on pollution and other environmental problems

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

m. I attend lectures on pollution and other environmental problems

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

n. Pollution does not affect my life

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

o. I want to take an active part in solving environmental problems

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

p. I take an active part in solving environmental problems

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

q. I separate waste materials for recycling

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

r. Humans will survive, even if the natural environment loses equilibrium

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

s. Even rich countries will not survive if pollution becomes serious

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

t. I do <u>not</u> think that pollution could cause the extinction of many species

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

15. Consider the following situation:

‘You read in the newspaper that greenhouse gas emissions have increased more than expected. The authorities plan to do nothing. You believe – for one reason or another – that people should do anything they can to stop the steady increase in greenhouse gas emissions.’

Indicate how much <u>you</u> think you can influence the outcome of this situation, where *1* represents the statement: “***I have absolutely no ability to influence the outcome***” and *10* represents the statement: “***I can influence the situation’s outcome completely***”

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

Indicate how much <u>you</u> feel you would have control over a similar situation in the future, where *1* represents the statement: “***I have absolutely no ability to influence the outcome***” and *10* represents the statement: “***I can influence the situation’s outcome completely***”

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

16. Consider the following situation:

‘You take a walk in the forest and see dying trees. You believe people should do anything they can to stop the demise of the forests.’

Indicate how much <u>you</u> think you can influence the outcome of this situation, where *1* represents the statement: “***I have absolutely no ability to influence the outcome***” and *10* represents the statement: “***I can influence the situation’s outcome completely***”

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

Indicate how much <u>you</u> feel you would have control over a similar situation in the future, where *1* represents the statement: “***I have absolutely no ability to influence the outcome***” and *10* represents the statement: “***I can influence the situation’s outcome completely***”

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

APPENDIX 5: KNOWLEDGE TESTS

The University of Sydney

Centre for Research on Computer-Supported
Learning and Cognition - CoCo
Faculty of Education and Social Work
College of Humanities & Social Sciences
NSW 2006 Australia

PRE-TEST AND POST-TEST

You will be asked to complete the answers to these questions at the beginning of the task. After you have finished the activities you have been given, you will be asked to revise your answers in the space provided. Please provide the most complete answer that you can. If you do not want to revise your answer please write “as above”.

General Environmental Knowledge Questions

1. What do you think is the most important environmental issue?

Pre-test
Post-test

2. What activities could a person engage in if they were visiting a National Park?

Pre-test
Post-test

3. What environmental features could you find in a National Park (e.g. trees)?

Pre-test
Post-test

Environmental Impacts

4. Choose one effect of the loss of vegetation on:

	Soil	*Water run-off*	*The whole ecosystem*
Pre-test			
Post-test			

5. Have a think about introduced species of animals (such as cats, rats or mice)

   a. Please circle any of the following activities that you think would cause an increase in the number of introduced species of animals

   Pre-test:

Bushwalking	Fishing	Having a picnic	Going for a drive	Horseriding	Walking a dog	Littering	Collecting fire wood	Collecting shells

   Post-test

Bushwalking	Fishing	Having a picnic	Going for a drive	Horseriding	Walking a dog	Littering	Collecting fire wood	Collecting shells

   b. Name one effect of introduced animals on the environment?

Pre-test
Post-test

6. Now think about introduced species of vegetation

   a. Please circle any of the following activities that you think would cause an increase in the number of introduced species of vegetation

Pre-test:

Bushwalking	Fishing	Having a picnic	Going for a drive	Horseriding	Walking a dog	Littering	Collecting fire wood	Collecting shells

Post-test

Bushwalking	Fishing	Having a picnic	Going for a drive	Horseriding	Walking a dog	Littering	Collecting fire wood	Collecting shells

   b. Name one effect of the introduction of *non-native* vegetation on *native* vegetation?

Pre-test
Post-test

7. Now imagine you are in an ecosystem that is not a national park, for example a beach, a mangrove swamp, or a local creek. Please complete the following table. For each activity listed identify one effect on the ecosystem, choose one possible further effect and indicate how long these effects would take to occur.

Pre-test

Activity	Initial impact on ecosystem	Time Scale (tick one)				What further effects?	Time Scale (tick one)			
		Same day	1 week	1 year	More than 1 year		Same day	1 week	1 year	More than 1 year
Building a road										
Littering										
Bushwalking										

Post-test

Activity	Initial impact on ecosystem	Time Scale (tick one)				What further effects?	Time Scale (tick one)			
		Same day	1 week	1 year	More than 1 year		Same day	1 week	1 year	More than 1 year
Building a road										
Littering										
Bushwalking										

System dynamics questions

Some of the following questions are multiple choice questions. If you do not know the answer to a question PLEASE *do not* guess, and instead choose option e) I do not know.

8. Please choose the definition of *time delay* that best fits your understanding of the term with respect to system dynamics

	Pre-test	*Post-test*
a) when the cause and effect are separated by time		
b) when you are running late for an appointment		
c) when something scheduled is late		
d) when something is postponed		
e) I do not know		

9. Identify one environmental impact that involves a *time delay* from any that you have discussed so far and indicate the approximate length of time involved (short term or long term).

Pre-test
Post-test

10. Which of the following describes the term *reinforcing feedback* as it relates to system dynamics?

	Pre-test	*Post-test*
a) the two variables change in the same direction		
b) the two variables change in opposite directions		
c) positive information that a teacher gives you about your work		
d) a loop that exists between an audio input and an audio output		
e) I do not know		

11. Which of the following is an example of *reinforcing feedback* as it relates to system dynamics?

	Pre-test	*Post-test*
a) interest added to a bank account		
b) lake shrinking due to evaporation		
c) "your assignment was good, though your spelling needs some work"		
d) when a microphone is placed in the general direction of the output speakers resulting in a high-pitched squealing		
e) I do not know		

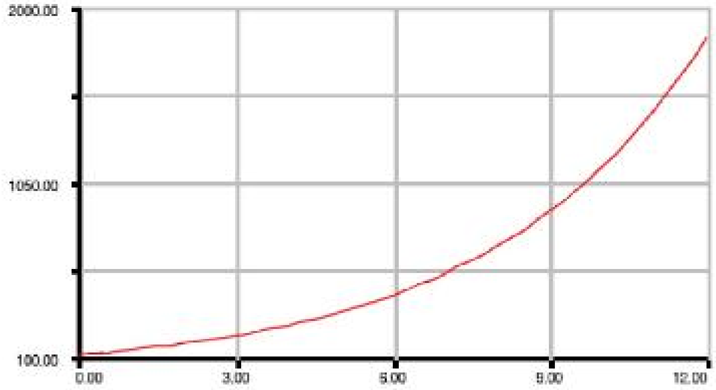
12. Which of the following describes the term *balancing feedback* as it relates to system dynamics?

	Pre-test	*Post-test*
a) the two variables change in opposite directions		
b) the two variables change in the same direction		
c) negative information that a teacher gives you about your work		
d) a loop that exists between an audio input and an audio output		
e) I do not know		

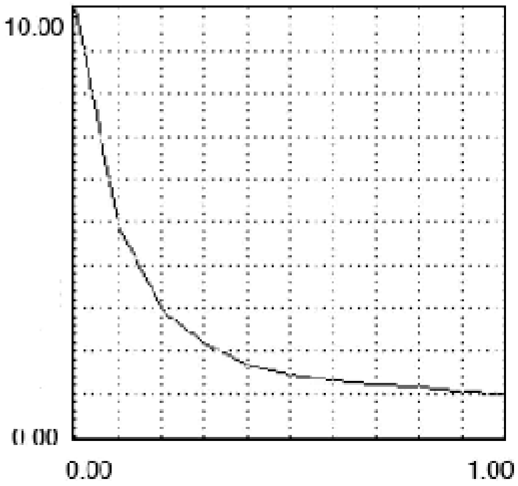
13. Which of the following is an example of *balancing feedback* as it relates to system dynamics?

	Pre-test	*Post-test*
a) lake shrinking due to evaporation		
b) interest in a bank account		
c) "your assignment was terrible, you didn't try at all"		
d) when a microphone is placed in the general direction of the output speakers resulting in a high-pitched squealing		
e) I do not know		

14. How would you describe the behaviour of the variables of the two graphs below:



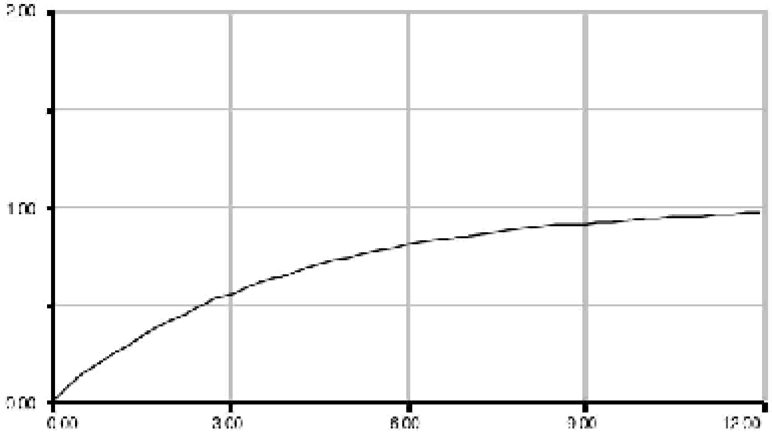
(i)



(ii)

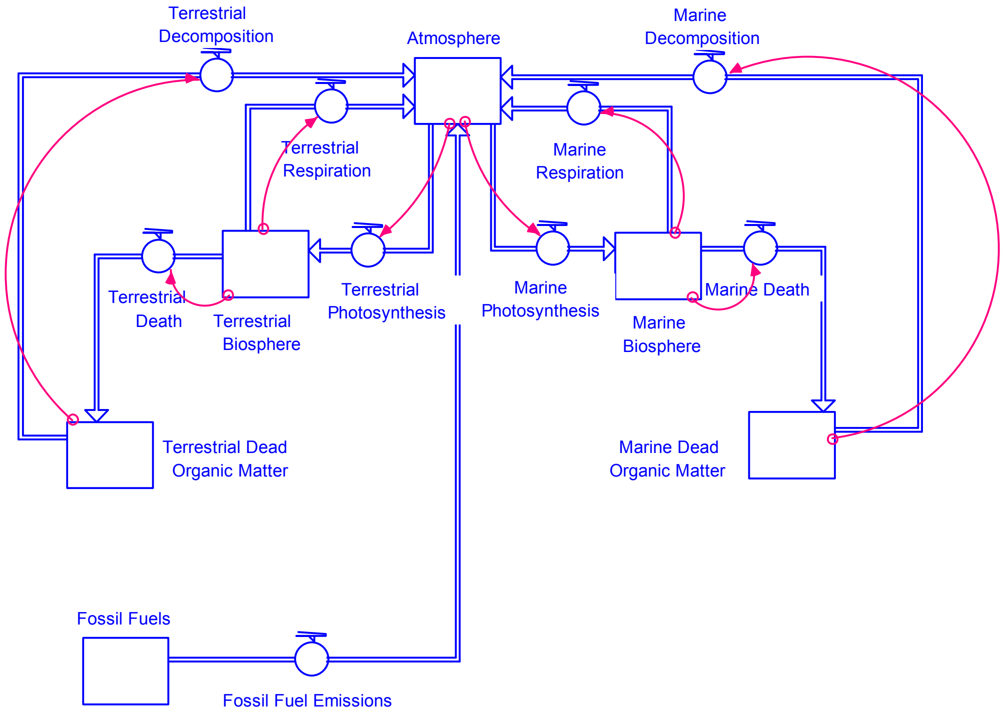
	Pre-test	***Post-test***
a) (i) exponential growth and (ii) exponential decay		
b) (i) exponential decay and (ii) exponential growth		
c) (i) equilibrium and (ii) exponential decay		
d) (i) oscillation and (ii) equilibrium		
e) I do not know		

15. How would you describe the *system* represented by the graph below?



	Pre-test	*Post-test*
a) equilibrium		
b) exponential growth		
c) exponential decay		
d) oscillation		
e) I do not know		

16. Case study



What environmental issue is this model describing?

Pre-test
Post-test

What element of the system is not in balance?

Pre-test
Post-test

What are the potential issues if the system is not balanced?

Pre-test
Post-test

APPENDIX 6: FINAL ASSESSMENT TASK

The University of Sydney

Centre for Research on Computer-Supported Learning and Cognition - CoCo
Faculty of Education and Social Work
College of Humanities & Social Sciences
NSW 2006 Australia

FINAL ASSESSMENT

1. What variables did you alter? What happened to the system when you altered the variables?

(You can include graphs or diagrams)

2. What are the management issues that are involved in looking after this area of the National Park?

3. What decisions would you make if you were the manager of this park?

4. If this description (the model/s and the text) of the National Park was more detailed, what do you think would happen next? What are the possible problems that could occur for the environment?

5. Imagine **you are** the manager of this National Park, and you have to write a report for your boss who has never been to the park before. Describe the park, what happens in the park, what the main issues are, and the consequences of the different management options.

APPENDIX 7: EVALUATION

The University of Sydney

Centre for Research on Computer-Supported Learning and Cognition – CoCo
Faculty of Education and Social Work
College of Humanities & Social Sciences
NSW 2006 Australia

EVALUATION

1. Please indicate the extent to which you agree with the following statements:

a. I would have preferred more guidance in doing this activity

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

b. The content was interesting

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

c. The pre-test was challenging

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

d. The post-test was challenging

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

e. Understanding how to use the representations (text, system dynamics model or animated model) was easy

Strongly disagree	Disagree	Neutral	Agree	Strongly agree	This question doesn't apply to my activity
○	○	○	○	○	○

f. I found the text difficult to understand

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

g. I needed more time to examine the materials

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

h. I found it easy to relate one representation to another (text, system dynamics model or animated model)

Strongly disagree	Disagree	Neutral	Agree	Strongly agree	This question doesn’t apply to my activity
○	○	○	○	○	○

i. I was able to visualise what the real situation was like

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

j. There was too much information

Strongly disagree	Disagree	Neutral	Agree	Strongly agree	This question doesn’t apply to my activity
○	○	○	○	○	○

k. I didn’t like working with a partner

Strongly disagree	Disagree	Neutral	Agree	Strongly agree	This question doesn’t apply to my activity
○	○	○	○	○	○

l. I would have preferred a partner to help me understand

Strongly disagree	Disagree	Neutral	Agree	Strongly agree	This question doesn’t apply to my activity
○	○	○	○	○	○

m. Being in the national park helped me to understand what the representations meant

Strongly disagree	Disagree	Neutral	Agree	Strongly agree	This question doesn’t apply to my activity
○	○	○	○	○	○

n. Being in the national park made the task too confusing

Strongly disagree	Disagree	Neutral	Agree	Strongly agree	This question doesn’t apply to my activity
○	○	○	○	○	○

o. I would like to learn like this more often

Strongly disagree	Disagree	Neutral	Agree	Strongly agree	This question doesn’t apply to my activity
○	○	○	○	○	○

p. This activity improved my opinion about science

Strongly disagree	Disagree	Neutral	Agree	Strongly agree	This question doesn’t apply to my activity
○	○	○	○	○	○

2. What did you like the most?

3. What did you like the least?

4. What would you change in this activity?

5. ______________________________

____

6. Other comments? ______________________________

____

____

____

____

APPENDIX 8: EXAMPLE OF VIDEO CODING

Time	Screen	Time	Activity	Total time screen	Total time activity
06:17	Home			02:49	
09:06	Explore the model	09:08	In full	00:07	00:05
09:13	Home			00:08	
09:21	Experiment			00:22	
09:43	Home			00:03	
09:46	Information			00:03	
09:49	Explore the model	09:50	Step-by-step	03:07	03:06
12:56	Home			00:03	
12:59	Information			02:17	
15:16	Explore the model	15:19	In full	00:09	00:06
15:25	Home			00:04	
15:29	Experiment	15:32	Ideas	02:35	00:19
		15:51	Change NPR=2		00:14
		16:05	Ideas		00:25

Screen	Total time	Time (%)
Home	04:06	20.50%
Explore the model	03:37	18.08%
Experiment	09:46	48.83%
Information	02:31	12.58%
Off task	00:00	0.00%
TOTAL	20:00	100.00%

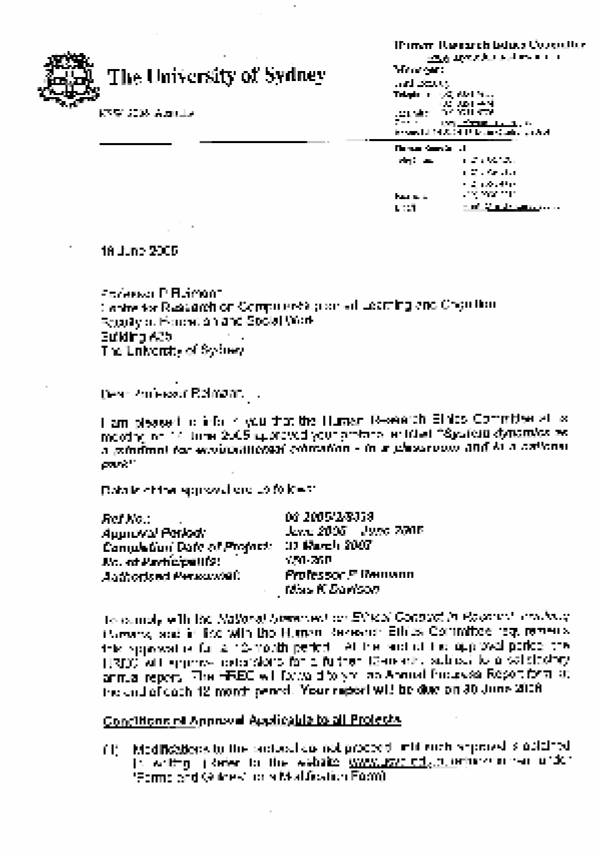
Activity	Instances (frequency)	Instances (%)
Go	9	25.00%
Step-by-step	1	2.78%
Reset	4	11.11%
In full	3	8.33%
Explore model	0	0.00%
Ideas	3	8.33%
Change NPR	10	27.78%
Change PRC	3	8.33%
Change GCT	3	8.33%
Misc	0	0.00%
TOTAL	36	100.00%

Time	Screen	Time	Activity	Total time screen	Total time activity	Screen	Total time	Time (%)	Activity	Instances (frequency)	Instances (%)
		16:30	Change NPR=3		00:01						
		16:31	Go		00:14						
		16:45	Change NPR=1		00:01						
		16:46	Go		00:14						
		17:00	Change NPR=4		00:03						
		17:03	Go		00:17						
		17:20	Reset		00:16						
		17:36	Change NPR=2		00:01						
		17:37	Go		00:04						
		17:41	Change NPR=1		00:02						
		17:43	Go		00:07						
		17:50	Reset		00:14						
18:04	Home			00:05							
18:09	Experiment			00:01							
18:10	Home			00:01							
18:11	Explore the model	18:14	In full	00:06	00:03						
18:17	Explore the model			00:06							

Time	Screen	Time	Activity	Total time screen	Total time activity	Screen	Total time	Time (%)	Activity	Instances (frequency)	Instances (%)
18:23	Home			00:03							
18:26	Explore the model			00:02							
18:28	Experiment			00:03							
18:31	Home			00:02							
18:33	Information			00:11							
18:44	Home			00:48							
19:32	Experiment	21:31	Change GCT=6:00	06:45	00:05						
		21:36	Ideas		00:11						
		21:47	Change PRC=1.0		00:03						
		21:50	Go		00:27						
		22:17	Change NPR=4		00:01						
		22:18	Go		01:00						
		23:18	Reset		00:05						
		23:23	Change NPR=2		00:04						
		23:27	Change GCT=6:00		00:04						
		23:31	Change PRC=1.0		00:08						
		23:39	Change NPR=1		00:01						

Time	Screen	Time	Activity	Total time screen	Total time activity	Screen	Total time	Time (%)	Activity	Instances (frequency)	Instances (%)
		23:40	Reset		00:01						
		23:41	Go		00:05						
		23:46	Change NPR=2		00:03						
		23:49	Change GCT=6:00		00:02						
		23:51	Change PRC=1.0		00:02						
		23:53	Go		02:24						
26:17	End										

APPENDIX 9: ETHICS APPROVAL: UNIVERSITY OF SYDNEY



The University of Sydney
NSW 2006 Australia

Human Research Ethics Committee
[illegible]

18 June 2005

Professor P Reimann
Centre for Research on Computer Supported Learning and Cognition
Faculty of Education and Social Work
Building A35
The University of Sydney

Dear Professor Reimann

I am pleased to inform you that the Human Research Ethics Committee at its meeting on [illegible] June 2005 approved your protocol entitled "*System dynamics as a [illegible] for environmental education – in a classroom and in a national park*".

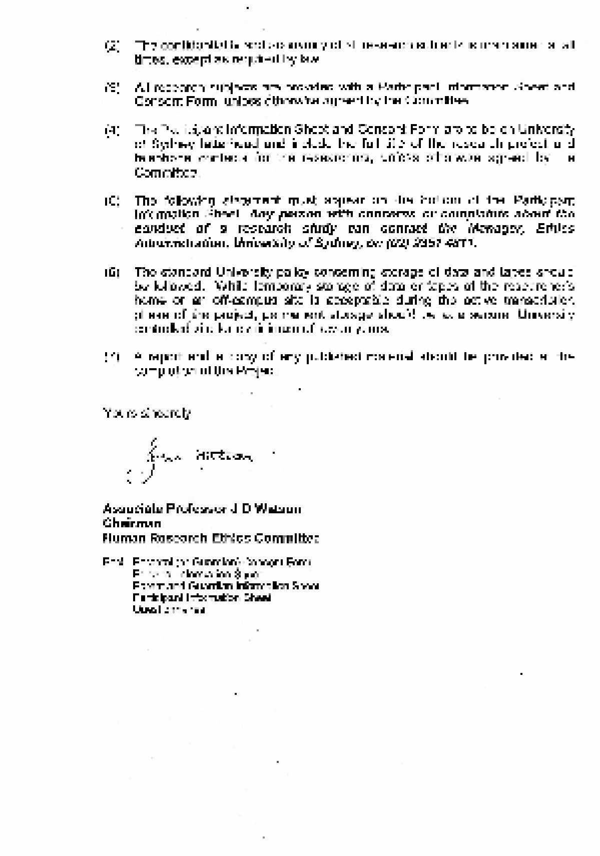
Details of the approval are as follows:

Ref No.: 06-2005/2/8038
Approval Period: June 2005 – June 2006
Completion Date of Project: 30 March 2007
No. of Participant(s): 150-200
Authorised Personnel: Professor P Reimann
Miss K Davidson

To comply with the *National Statement on Ethical Conduct in Research Involving Humans*, and in line with the Human Research Ethics Committee requirements this approval is for a 12-month period. At the end of the approval period the HREC will approve extensions for a further 12-months subject to a satisfactory annual report. The HREC will forward to you an Annual Progress Report form at the end of each 12 month period. **Your report will be due on 30 June 2006.**

Conditions of Approval Applicable to all Projects

(1) Modifications to the protocol cannot proceed until such approval is obtained in writing. (Refer to the website www.usyd.edu.au/ethics/human under "Forms and Guides" for a Modification Form)



(2) The confidentiality and anonymity of all research subjects is to be maintained at all times, except as required by law.

(3) All research subjects are provided with a Participant Information Sheet and Consent Form, unless otherwise agreed by the Committee.

(4) The Participant Information Sheet and Consent Form are to be on University of Sydney letterhead and include the full title of the research project and telephone contacts for the researchers, unless otherwise agreed by the Committee.

(5) The following statement must appear on the bottom of the Participant Information Sheet. *Any person with concerns or complaints about the conduct of a research study can contact the Manager, Ethics Administration, University of Sydney, on (02) 9351 4811.*

(6) The standard University policy concerning storage of data and tapes should be followed. While temporary storage of data or tapes at the researcher's home or an off-campus site is acceptable during the active transcription phase of the project, permanent storage should be at a secure, University controlled site for a minimum of seven years.

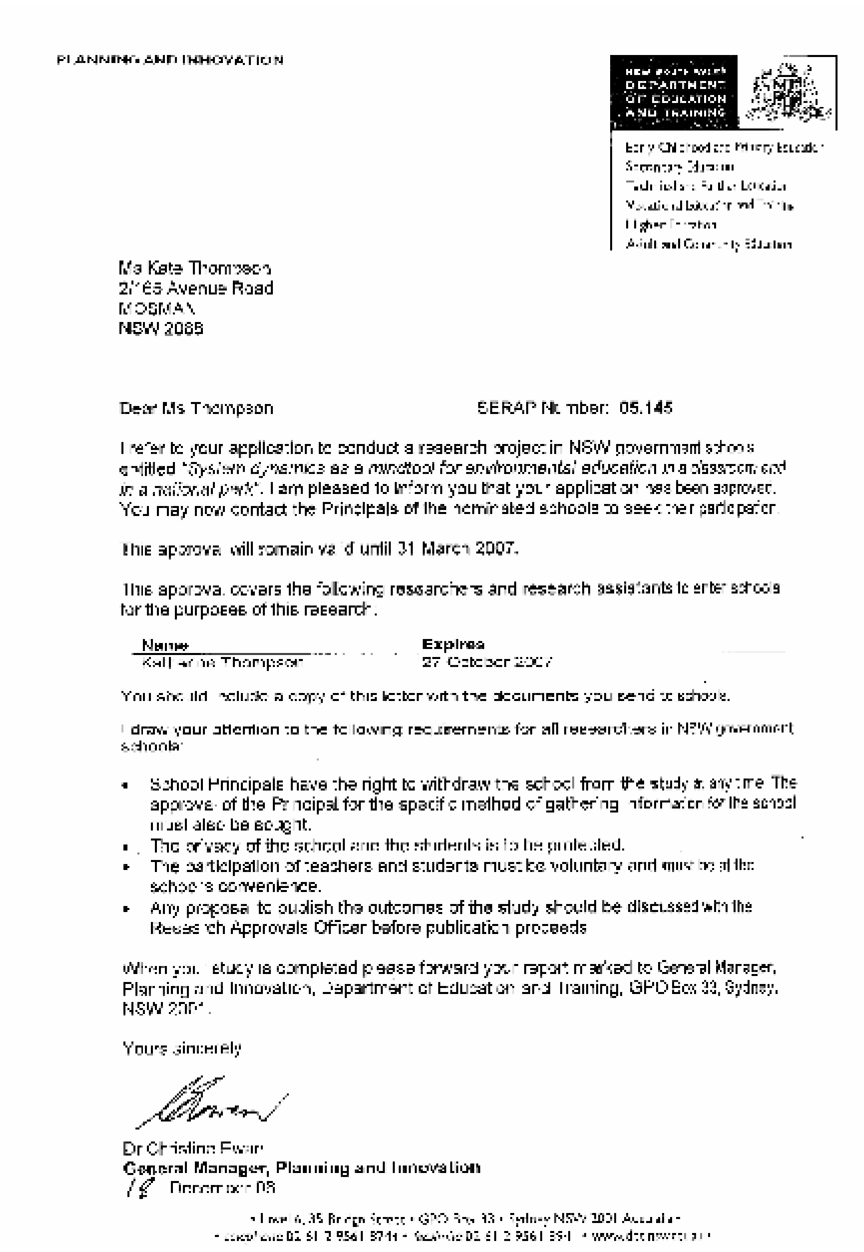
(7) A report and a copy of any published material should be provided at the completion of the Project.

Yours sincerely

Associate Professor J D Watson
Chairman
Human Research Ethics Committee

Encl. Parental (or Guardian) Consent Form
[illegible]
Parent and Guardian Information Sheet
Participant Information Sheet
[illegible]

APPENDIX 10: ETHICS APPROVAL: DEPARTMENT OF EDUCATION AND TRAINING, NSW



PLANNING AND INNOVATION

NEW SOUTH WALES
DEPARTMENT
OF EDUCATION
AND TRAINING

Early Childhood and Primary Education
Secondary Education
Technical and Further Education
Vocational Education and Training
Higher Education
Adult and Community Education

Ms Kate Thompson
2/165 Avenue Road
MOSMAN
NSW 2088

Dear Ms Thompson SERAP Number: 05.145

I refer to your application to conduct a research project in NSW government schools entitled "*System dynamics as a mindtool for environmental education in a classroom and in a national park*". I am pleased to inform you that your application has been approved. You may now contact the Principals of the nominated schools to seek their participation.

This approval will remain valid until 31 March 2007.

This approval covers the following researchers and research assistants to enter schools for the purposes of this research:

Name	**Expires**
Katherine Thompson	27 October 2007

You should include a copy of this letter with the documents you send to schools.

I draw your attention to the following requirements for all researchers in NSW government schools:

- School Principals have the right to withdraw the school from the study at any time. The approval of the Principal for the specific method of gathering information for the school must also be sought.
- The privacy of the school and the students is to be protected.
- The participation of teachers and students must be voluntary and must be at the school's convenience.
- Any proposal to publish the outcomes of the study should be discussed with the Research Approvals Officer before publication proceeds.

When your study is completed please forward your report marked to General Manager, Planning and Innovation, Department of Education and Training, GPO Box 33, Sydney, NSW 2001.

Yours sincerely

Dr Christine Ewan
General Manager, Planning and Innovation
18 December 06

Level 6, 35 Bridge Street • GPO Box 33 • Sydney NSW 2001 Australia
Telephone 02 61 2 9561 8744 • Facsimile 02 61 2 9561 8941 • www.det.nsw.edu.au

APPENDIX 11: SCRIPT

Hello everyone. My name is Kate Thompson and I would like you to call me Kate. I'm a PhD student at the University of Sydney, and the work that you do today will help me out with my PhD project. A PhD is a degree at university, that you do after you've done your first degree, and you do the one project for about three years. I did my first degree in environmental science. For my PhD, I want to find out how students your age learn about environmental systems. The first thing that I'm going to ask you to do is to fill in the background information questionnaire that's in front of you. This asks information about you, and about your attitudes and thoughts toward science and the environment. This is because some other people think that there are relationships between attitudes towards the environment and how students learn about the environment. If I ask you these questions too, then analyse the results, I may be able to see if these people are right. Also, if there are any strange results that I get at the end, then I can look back at this information I asked you in the beginning and see if any of that explains the results.

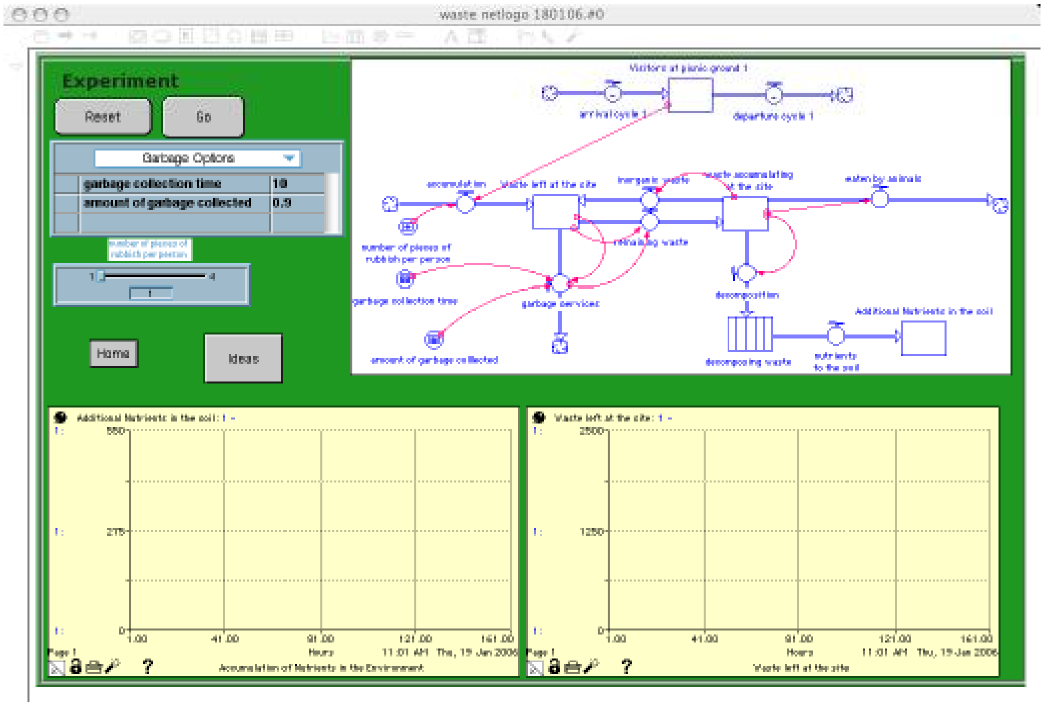
So, can you all fill out the background questions and then I'll collect them and tell you about the next section. Please don't talk to your friends about the answers, if you have any questions then put your hand up and I'll come over and help.

In order for me to see what differences there are in the ways that you all learn about environmental systems, I have to see how what you know or understand changes. So, I'm going to give you what's called a pre-test and a post-test. The pre-test is a test given to you before you have a look at the materials, the post-test is the test given to you after you look at the materials. That way, I can not only compare you to each other (taking into account that information I asked you in the background questions) but also compare you to yourselves. This test will be exactly the same. So, rather than asking you to write the same things twice, I'm going to collect your pre-tests after you've completed them and photocopy them. When you do the post-test, I'll give you this photocopy and you can make any changes to your earlier answers that you'd like to.

So, now can you do the pre-test. Remember, please don't talk to your friends about the answers. If you don't know the answer to a question, please write that, or select "I do not know" as an option. That's important as far as my study is concerned, because if you didn't know something at the beginning, but you did after you look at the materials, then that's important.

Now that you've done all the paperwork for now, you're going to look at the materials. In order to investigate the different ways that you learn about environmental systems I'm going to give you different things to look at. We call these *representations*. All of you will get to read a text-based description of the environmental system I've chosen. Some of you will look at a system dynamics model, and some of you will look at an agent-based model, and some of you will look at both. You will half an hour to do this, and then I will give you the post-test again, and ask you to do two more things.

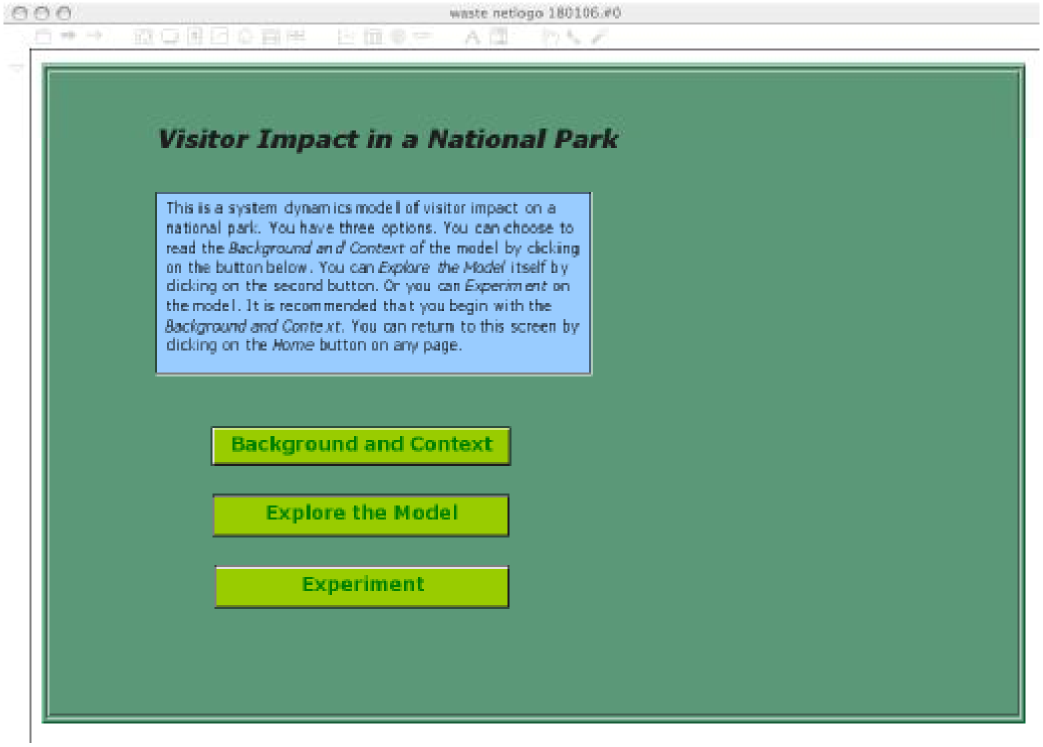
Before then, I need to give you a few instructions. The system dynamics model looks like this:



Garbage Options

garbage collection time	10
amount of garbage collected	0.9

There are certain variables that can be manipulated. The time that the rubbish is collected and the percentage of rubbish that is collected. By changing these two variables and watching the graph here, you should be able to make conclusions about the system. You start the exercise on this screen

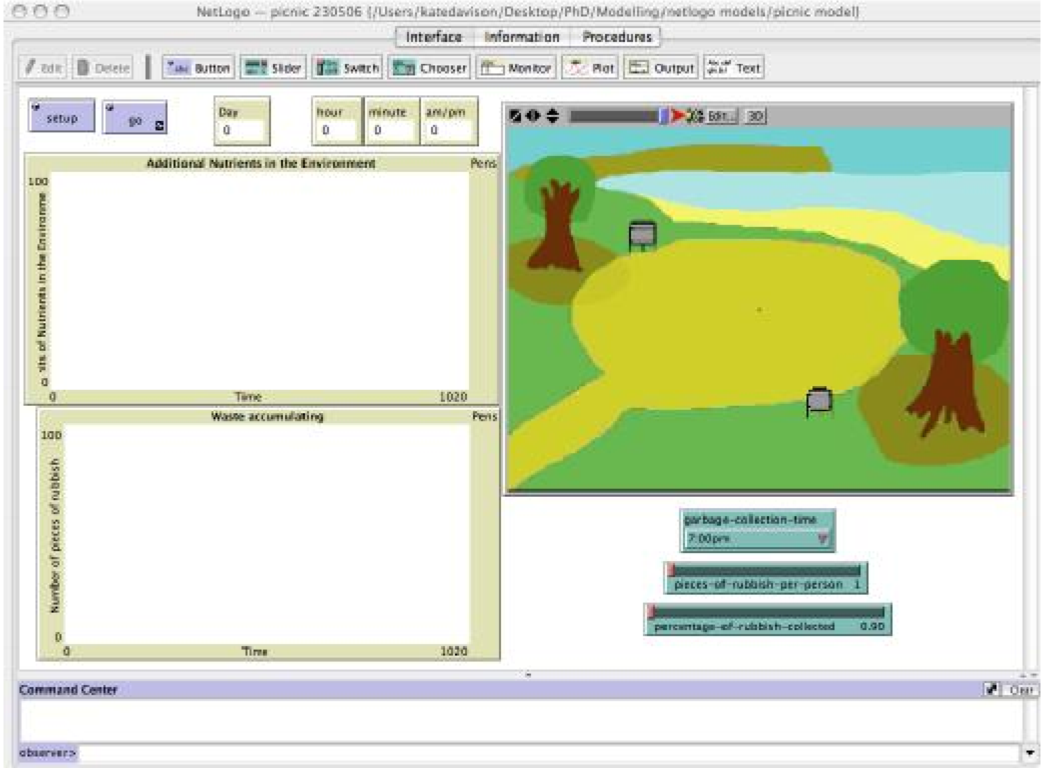


Visitor Impact in a National Park

This is a system dynamics model of visitor impact on a national park. You have three options. You can choose to read the *Background and Context* of the model by clicking on the button below. You can *Explore the Model* itself by clicking on the second button. Or you can *Experiment* on the model. It is recommended that you begin with the *Background and Context*. You can return to this screen by clicking on the *Home* button on any page.

with the text description, and you can navigate through the model using the buttons here.

The agent-based model looks like this:



garbage-collection-time 7:00pm

pieces-of-rubbish-per-person 1

percentage-of-rubbish-collected 0.90

You can change the same variables as in the system dynamics model, and you can view the same graphs. You can read the text description by clicking on the *information* tab. If you change a variable you need to press the *setup* button before you start the simulation. You can pause anytime by pressing the *'go'* button, and you can manipulate the speed here.

You all have paper to make notes on as you go. You will have half an hour to look at whatever model, text or combination of these that you have. Please only look at your own computer screen and if you have any questions just put your hand up and I will come and help. I'll give you a warning when you have five minutes until the end. Ok, you can start.
You have five minutes.

Ok, time is up. The first thing that I'm going to ask you to do is this. This is just one double sided piece of paper. On the first side I want you to write down a description of what you think was happening in the national park. This is so I can figure out what you've learnt in your own words. So imagine you're explaining to someone what the environmental system was all about, and write down that description on the front of this piece of paper. On the back is space for you to draw a concept map. This takes account of different students' abilities to explain concepts. I'll give you ten minutes to do this.

Thanks everyone, that's been ten minutes. Now I'd like you to go through your pre-test again and make any changes to your answers from before you learnt about the system. Your answers may be exactly the same, if this is the case, just write "see above" or something like that in the box. If you'd like to make a small change then you can add something, or if you'd like to make a major change, there's room to do that too. You have 10 minutes to go through.

And now, the final thing I need to ask you to do. This is a very short evaluation questionnaire. This is for me to see what you thought of the whole experience. It shouldn't take you very long at all.

Ok. Thank you so much for coming today and helping me out with my study. Once I have some results, which will happen when I have done lots of sessions like this one, I will get in touch with your teacher and let them know where you can access the results online if you're interested.

Thanks again.

Appendix 12: Tests for Normality of Learning Outcomes

	Skewness	Kurtosis	Kolmogorov-Smirnov[a]	
	z_{skewness}	z_{kurtosis}	Statistic	Sig.
Total scores				
EK_{pre}	−0.90	−0.17	0.18	**.20***
EK_{post}	−0.17	0.52	0.23	**.20***
$\text{EK}_{\text{change}}$	**2.61**	**3.09**	0.29	.05
SDK_{pre}	−0.28	−0.77	0.14	**.20***
SDK_{post}	0.08	−0.36	0.14	**.20***
$\text{SDK}_{\text{change}}$	1.34	0.74	0.23	**.20***
FAT	0.58	−0.79	0.20	**.20***
Key questions				
Q5_{pre}	1.00	0.15	.21	**.20***
Q5_{post}	0.29	−0.95	.19	**.20***
$\text{Q5}_{\text{change}}$	0.86	−1.51	.39	**.00**
Q6_{pre}	−0.82	−0.93	.25	.15
Q6_{post}	−0.18	−1.02	.18	**.20***
$\text{Q6}_{\text{change}}$	1.59	0.58	.28	.07
Q7_{pre}	−1.05	−0.18	.21	**.20***
Q7_{post}	−1.36	1.29	.19	**.20***
$\text{Q7}_{\text{change}}$	**2.72**	**3.41**	.29	**.04**
$\text{Q8–15}_{\text{pre}}$	−0.11	−0.80	.16	**.20***
$\text{Q8–15}_{\text{post}}$	0.55	0.39	.26	.11
$\text{Q8–15}_{\text{change}}$	0.81	−0.01	.22	**.20***
Q16_{pre}	0.00	−0.81	.19	**.20***
Q16_{post}	−0.71	−0.78	.24	.20
$\text{Q16}_{\text{change}}$	**2.59**	**2.16**	.44	**.00**

	Skewness	Kurtosis	Kolmogorov-Smirnov[a]	
	$z_{skewness}$	$z_{kurtosis}$	Statistic	Sig.
Describe	0.73	-1.51	.29	**.04**
Issues	1.35	0.18	.32	**.02**
HLT	1.85	2.27	.34	**.01**

Note. EK = environmental knowledge score. SDK = system dynamics knowledge score. FAT = final assessment task score. Q5 = knowledge about introduced animal species. Q6 = knowledge about introduced plant species. Q7 = knowledge about human impacts on an ecosystem and associated timescales. Q8-15 = general system dynamics knowledge. Q16 = applied system dynamics knowledge. Describe = *Describe* section of the final assessment task. Issues = *Issues* section of the final assessment task. HLT = *Higher Level Thinking* section of the final assessment task. $_{pre}$ = pre-test score. $_{post}$ = post-test score. $_{change}$ = change in the score between the pre-test and post-test. Bold typeface indicates data deviates from normal distribution

[a]df = 8

*p is at the lowest boundary

.

APPENDIX 13: TESTS FOR NORMALITY OF USE OF THE MODELS

	Skewness	Kurtosis	Kolmogorov-Smirnov	
	$z_{skewness}$	$z_{kurtosis}$	Statistic	Sig.
Screens				
Exp$_{SDM}$	-.06	-1.50	0.23	**.20***
Exp$_{ABM}$	-1.43	-0.24	.25	.15
Exp	-1.09	-0.23	.19	**.20***
Inf$_{SDM}$	1.17	-0.13	0.20	**.20***
Inf$_{ABM}$	2.53	2.47	.31	**.02**
Inf	0.05	-1.52	.26	.13
OT$_{SDM}$	**2.59**	2.15	0.44	**.00**
OT$_{ABM}$	**3.12**	**3.76**	.37	**.00**
OT	2.19	1.83	.23	**.20***
ETM	**2.99**	**3.75**	0.32	**.20***
Activities				
‘go’$_{SDM}$	0.53	-1.14	.21	**.20***
‘go’$_{ABM}$	-0.36	-1.49	.32	**.02**
‘go’	0.38	-0.92	.20	**.20***
IF				
SbS	0.54	-0.15	.26	.11
Ideas	0.54	-0.15	.26	.11
npr$_{SDM}$	1.03	-0.02	.21	**.20***
npr$_{ABM}$	0.36	-1.49	.32	**.02**
Npr	2.15	2.13	.25	.15
prc$_{sdm}$	0.95	-1.20	.30	**.04**
prc$_{ABM}$	0.83	-1.14	.30	**.04**
Prc	0.00	-0.81	.11	**.20***

	Skewness	Kurtosis	Kolmogorov-Smirnov	
	$z_{skewness}$	$z_{kurtosis}$	Statistic	Sig.
gct_{SDM}	0.70	-0.53	.21	**.20***
gct_{ABM}	0.52	-0.83	.25	.16
Gct	0.92	0.41	.20	**.20***
TA_{SDM}	0.37	-1.30	.21	**.20***
TA_{ABM}	-0.29	-1.23	.19	**.20***
TA	0.01	-1.00	.19	**.20***
ABM	0.03	-1.49	.26	.12
SDM	-0.03	-1.49	.26	.12

Note. . Exp = proportion of time spent on the *experiment* screen. Inf = proportion of time spent on the *information* screen. ETM = proportion of time spent on the *explore the model* screens. OT = proportion of time spent *off task*. Go = number of times the model was run. IF = number of times explore the model in full was selected. SbS = number of times explore the model step by step was selected. Ideas = number of times the ideas option was selected. Npr = frequency of changes to the number of pieces of rubbish. Prc = frequency of changes to the percentage of rubbish collected. Gct = frequency of changes to the garbage collection time. TA = total activity. ABM = proportion of time spent on the agent-based model. SDM = proportion of time spent on the system dynamics model. $_{SDM}$ = on the system dynamics model. $_{ABM}$ = on the agent-based model. Bold typeface indicates data deviates from normal distribution.

[a]df = 8

**p* is at the lowest boundary

APPENDIX 14: ANSWERS TO THE FINAL ASSESSMENT TASK

Q1. WHAT VARIABLES DID YOU ALTER? WHAT HAPPENED TO THE SYSTEM WHEN YOU ALTERED THE VARIABLES?

Code and Group	Response
S020, SDM group, ILE	get to experiment with the different times and work out the general curves. The dram matic differences between the curves when altering the number of pieces of rubbish per person. Provided graphs
S027, ABM group, CLE	I altered the percentage of rubbish collected to 100%. Instead of a little rubbish left over each time the rubbish collector was there, there was no rubbish. Overall amount of rubbish decreased, but the pattern (of the graph) of the amount of rubbish did not change. Provided graphs.
S033, ABM group, ILE	time when collecting garbage, amount of garbage per person. Sometimes there would be more nutrients added sometimes less. No graphs provided
S037, SDM & ABM group, CLE	The later the garbage collection time the more rubbish is accumulated. The less garbage collected, the more nutrients in the environment. The more rubbish per person, the more rubbish accumulated. Provided graphs
S038, SDM & ABM group, CLE	Altered "garbage collection time", "amount of garbage collected" and "rubbish per person". As the number of pieces of rubbish left behind increases, accumulated nutrients increases. The later the collection time and the more garbage that is collected, the less accumulated nutrients remain. No graphs provided
S039, SDM & ABM group, CLE	Garbage collection time – later it is, the less number of nutrients in the soil. Amount of garbage collected – the less collected, the more nutrients and more waste accumulated. Pieces of rubbish left per person – increase in number of overall rubbish = more nutrients + waste. No graphs provided.
S045, SDM group, CLE	Garbage collection time (later) – less nutrients in soil, less waste. No graphs provided.
S047, ABM group, CLE	variables altered – garbage collection time, pieces of rubbish per person, percentage of rubbish collected. Additional nutrients increased while the accumulation of wastes generally decreased. Graphs provided.
S048, SDM & ABM group, CLE	When the garbage was collected at 7pm and at 5pm. It seemed similar but the amound of nutrients was more when the rubbish was collected at 7pm. Graphs provided.

Code and Group	Response
S050, SDM group, ILE	The garbage collection time - as it increased, the number of additional nutreints decrease the number of wastes left at the site increased (at the beginning) greatly but at the end of the day decreased. Number of pieces of rubbish per person - As it increased, the accumulation of nutreints in the environment also increased as well as the wastes left on site. When the 2 variable were both increased, both the nutrients in the environment and the wastes left on site were smaller than if just if the number of pieces of rubbish per person was increased. No graphs provided.
S052, SDM group, ILE	Altered the garbage collection time and rubbish per person. The best results for lower nutrient addition came when garbage collection time was 7:30pm. No graphs provided.
S053, Text group, CLE	the time the garbage collector came, the percentages of the rubbish collected, pieces of rubbish per person. Graphs provided.
S061, ABM group, CLE	the time (from 5:00pm to 7:00pm) - people starting coming later (not as much waste at start). Rubbish per person (from 1 to 4) - rapid increase in wastes. % of rubbish collected (from 100% to 90%) - more nutrients into the environment. Graphs provided.
S062, ABM group, CLE	Garbage collecting time - people come later/earlier. Pieces of rubbish/person - more / less organic wastes. % of rubbish collected - less / more unit of nutrient added, more / less animals eating organic rubbish. Graphs provided.
S067, ABM group, ILE	Graphs provided
S069, ABM group, ILE	Garbage collection time, rubbish left per person, percentage of garbage collected. When less rubbish was collected, there was a sudden increase in nutrients in the environment. With so much rubbish, the system (rubbish bins) were almost always full. Graphs provided.
S073, SDM & ABM group, CLE	garbage - collection time. I gave less time for rubbish to accumulate. Pieces-of-rubbish-per-person (had more to collect). Percentage-of-rubbish-collected (had less left over). Graphs provided.
S076, SDM & ABM group, ILE	(1) altering amount of garbage left behind. With just one piece, additional nutrients to the soil rises as in graph A. as rubbish pieces increased the constant part of the graph remained on the next park followed approx. same trend. Same for "waste left at site" (B). (2) altering time of garbage collection. as time became higher trend followed a decreasing version of trend described above. (3) altering the amount of rubbish collected. as the percentage collected increased the graphs followed the same trends followed in A and B except they decreased. Graphs provided.
S077, Text group, CLE	Rubbish collection time changed from 5pm to 7pm. As the sheet says, there is a steady increase in the departure of visitors between 5pm-7pm. At this time, (at the end of the day) more visitors are dropping off their rubbish than before 5pm. If the time is changed to 7pm, more rubbish is collected and consequently, less rubbish is left overnight to decompose (and add more nutrients in teh ecosystem) and less rats (introduced species) come to eat the decomposible rubbish. percentage of rubbish collected changed from 0.95 to 0.9. less rubbish would be collected than normal. more nutrients in ecosystem. more introduced species in the park. No graphs provided.

Code and Group	Response
S078, SDM & ABM group, ILE	garbage time, amount of garbage collection. Graphs provided.
S079, SDM group, CLE	1. Garbage collection time - later times - less additional nutrients and less waste left at site. 2. Amount of garbage collected. 3. More rubbish per person - increase in additional nutrients. No graphs provided.
S080, SDM group, CLE	garbage collection time, amount of garbage collected. Later times equals less nutrients in soil. This is because more rubbish was collected at later times. More rubbish equals more nutrients. No graphs provided.
S081, SDM group, CLE	garbage collecting time, amount of rubbsih collected, rubbish per person. The later the rubbish was collected, the more rubbish was left at site and more nutrients was in the soil. More rubbish per person icnrease when garbage collection does not change. Graphs provided.
S082, SDM group, CLE	the garbage collection time, additional nutrients in soil and the amoutn of garbage collected - waste left at site, and rubbish per person - waste left at site. Graphs provided.
S083, SDM group, ILE	Number of pieces of rubbish per person; the additional nutrients in the soil increased as more rubbish was left by each person. (after resetting) the time rubbish was collected; the later the rubbish was collected the lower the amount of additional nutrients. No graphs provided.
S087, Text group, CLE	Variable changed: time garbage collector comes, from 5pm changed to 7pm. This would result in more of the garbage removed, and less left behind to take an impact during the night until the next day. [the amount of garbage collected, 95% at 7pm, would be more than 95% at 5pm, as amount of people leaving at the end of the day and dropping of their rubbish increases.] Percentage of rubbish collected each time decreases from 0.95 to 0.9, then amount of rubbish left behind would increase, having more impact on the ecosystem. No graphs provided.
S091, ABM group, ILE	Variables altered - time garbage collected, piece of rubbish collected per person, percentage of rubbish collected. Day 1 - the highest number of rubbish was 293. Day 2 - it dropped to 52 and went up to 112. Day 3 - dropped to 13 and went up to 134. Day 4 - dropped to 18 and went up to 57. day 5 - dropped to 14 and went up to 54. day 6 - dropped to 10 and went up to 100. day 7 - dropped to 8 and went up to 29. no graphs provided.
S098, SDM & ABM group, ILE	I changed the time the garbage was collected to 7:00pm the percentage of rubbish collecte to 100% and the pieces of rubbish per person to one. The waste accumulating spiked the highest on day one and a lot lower on the other days. The additional nutrients in the environment graph stayed at zero till it rose slightly at the start of day five and stayed level. in the picture they was decomposing rubbish around the bin. No graphs provided.
S099, SDM & ABM group, ILE	I changed the garbage collection time to 7pm, the pieces of rubbish per person to 2 and made 0.95% of rubbish collected. On day one, we had the most pieces of rubbish and the highest number of rubbish was 293. Day 2 we had 92 pieces. Day 3 we had 134. day 4 was 46. Day 5 was 53. day 6 was 85. and day 7 we had 35. no graphs provided.
S101, SDM & ABM group, ILE	Garbage collection time, rubbish per person, rubbish collection time. Rubbish that was not being collected increased. Feral animals and native animals came into the area. No graphs provided.

Code and Group	Response
S105, ABM group, ILE	5:00pm garbage collection time, 1 piece of rubbish per person, 90% rubish collected on day one the number of pieces off rubbish was the highest at 120.7 pieces of rubbish. On day 2 it went down to 110.7 pieces, by day 7 it had lowered up to only 13.6 pieces. Graphs provided.
S106, Text group, ILE	No graphs provided.
S109, SDM group, ILE	I altered how much rubbish per person and also the amount of garbage collected. No graphs provided.
S110, SDM group, ILE	as the number of rubbish left by the people that came to this National Park increased, the graph at the very start was at its highest but then later on in the day, the rubbish levels decrease. No graphs provided.
S111, SDM group, ILE	I altered the amount of garbagge collected, the collection time. The graph came up with colourful lines. No graphs provided.
S113, Text group, ILE	The amount of rubbish collected amount of people in the park, different days when the rubbish is collected, different times when the rubbish is collected, different amounts of organic and inorganic rubbish left behind, different foods eaten, amout of bbqs in use, rubbish eaten by animals. the system can change by the amount of rubbish collected and the time it was collected because the more poeple there are, the more rubbish is left behind, or is needed to be picked up by the garbage truck, and in turn, more animals that get attracted to the area, and the more amount of nutrience that is put into the ground which can effect the ecosystem because the animals can choke out the other species of native animals. No graph provided.
S116, SDM group, ILE	I altered the garbage collection time, and the amount of garbage collected as well as chanign the amount of rubbish left per person. I changed each of these variables twice and this showed me that when the garbage collection time was at 7:30pm, more rubbish was collected, and there were less additional nutrients found in the soil. also when the rubbish per person was a 4 there was a high amount of of waste left at the site. Graphs provided.
S118, Text group, ILE	I altered the time the rubbish was collected. By making the time the rubbish was collected later it means there would be less people in the park to place rubbish in the bins after it has been collected. Therefore more rubbish will be collected and less waste left in the park. if there is less waste then less animals will come and eat it. therefore elading to more rodents and introduced species. No graphs provided.
S119, SDM group, ILE	I altered the amount (from 1 to 2) of rubbish per person, the garbage collection time (from 18 to 20) and the amount of garbage collected (from 0.9 to 1). The added nutrients in the soil increased, and so did the amount of waste left at the site, compared to the original settings. No graphs provided.
S120, SDM & ABM group, ILE	the amount of garbage collected, the collection time and the amount of rubbish per person. The grass started to change colour and the organic waste started to decompose.

Q2. WHAT ARE THE MANAGEMENT ISSUES THAT ARE INVOLVED IN LOOKING AFTER THIS AREA OF THE NATIONAL PARK?

Code and Group	Response
S020, SDM group, ILE	sustainability of the environment, waste management.
S027, ABM group, CLE	waste management. Trying to maintain a clean environment for the animals that inhabit the national park and keeping vegetation clean and healthy. Figuring out the best alternatives to keeping the amount of rubbish as low as possible is also important.
S033, ABM group, ILE	when to collect rubbish
S037, SDM & ABM group, CLE	rubbish collection, introduced species, bushfires, land management, management of biodiversity.
S038, SDM & ABM group, CLE	The amount of waste which is left behind by the visitors have to be managed. So the garbage collection time has to be organised.
S039, SDM & ABM group, CLE	cost, waste disposal, amount of visitors left by visitors and its impact on native species.
S045, SDM group, CLE	waste management, collection of waste
S047, ABM group, CLE	ensuring that visitors are not littering (thus impacting the whole of the environment negatively), thus waste management is vital. Air quality, land/water management should also be taken into account.
S048, SDM & ABM group, CLE	The waste produced by park users. People bringing in introduced species – rats – cats. Other issues relevant for Nparks – erosion – land management, salinity, water management – algal blooms.
S050, SDM group, ILE	the garbage collection time and managing the amount of wastes left behind by visitors.
S052, SDM group, ILE	managing the amount of rubbish per person or at least providing them with more bins to reduce littering; garbage collection – times, ways to increase amount of garbage collected so everything gets collected.
S053, Text group, CLE	cost of upkeep, transport of cleaning services, rubbish, burning wood
S061, ABM group, CLE	waste
S062, ABM group, CLE	making sure that people are aware of the disposing rubbish correctly by placing signs. Waste issues.
S067, ABM group, ILE	What time the garbage is collected, what percentage of the garbage is collected. Other issues – how much garbage is left behind per person, how many people visit, how much scavenging animals eat, how many scavenging animals there are.

Code and Group	Response
S069, ABM group, ILE	When to collect garbage, how much to collect, starting and closing times of the park, how much garbage can be brought by each person, how many bins in the area.
S073, SDM & ABM group, CLE	--
S076, SDM & ABM group, ILE	park opening and closing hours, situation of picnic sites, quality of rubbish collectors, frequency of rubbish collectors, installation of animal proof bins.
S077, Text group, CLE	Waste management (Rubbish collecting times, estimating the amount of rubbish to be collected.), management of introduced species, management of fire safety, management of visitors (their pets etc).
S078, SDM & ABM group, ILE	the garbage co-ordination, time collection, ammount.
S079, SDM group, CLE	the frequency and efficiency of rubbish collection. The regulations regarding littering. Determining areas open to the general public for picnicking etc.
S080, SDM group, CLE	waste management for visitors and the ecosystem.
S081, SDM group, CLE	time of garbage collection and number of people collecting the rubbish, therefore amount of rubbish collection.
S082, SDM group, CLE	the time rubbish is collected and amount of rubbish that is collected.
S083, SDM group, ILE	making sure the rubbish is collected; monitoring the number of people going in and out of the park (kind of like crowd control); making sure people abide by the rules so as to protect the animals.
S087, Text group, CLE	pollution due to rubbish left behind (waste management), firewood amount in park, introduced species control (pets).
S091, ABM group, ILE	garbage collector
S098, SDM & ABM group, ILE	the collection of rubbish, the amount of bins in the park.
S099, SDM & ABM group, ILE	garbage collection
S101, SDM & ABM group, ILE	inconsistent rubbish collection (not picking up enough rubbish)
S105, ABM group, ILE	garbage collecting.
S106, Text group, ILE	The management issues that are involved in looking after this area of the national park are the garbage collectors, emptying the bins.

Code and Group	Response
S109, SDM group, ILE	keeping the national park clean and litter free, providing more rubbish bins. Everyone is to clean up after themselves.
S110, SDM group, ILE	keeping the national park clean and hygienic. The amount of rubbish should be decreased and their should be more bins.
S111, SDM group, ILE	controlling the amount of rubbish, keeping the park clean.
S113, Text group, ILE	The time that the garbage truck comes, the amount of bins placed around the area, keeping the amount of introduced species down.
S116, SDM group, ILE	What time the national park opens and what time it closes, when the garbage is collected, inhabitants of the park.
S118, Text group, ILE	time the rubbish is collected, time the park closes, type of things allowed into the park eg pets bikes, sporting equipment etc, the areas people are allowed in, what parts visitors allowed to drive through.
S119, SDM group, ILE	opening/closing times of the park, rubbish collectino times/ amounts, inhabitants of the park, park resources (e.g. water)
S120, SDM & ABM group, ILE	rubbish collection, controlling the amount of rubbish collected, keeping the park clean

Q3. WHAT DECISIONS WOULD YOU MAKE IF YOU WERE THE MANAGER OF THIS PARK?

Code and Group	Response
S020, SDM group, ILE	more resources to keep the environment as stable as possible, more rubbish bins, easier access to the popular areas.
S027, ABM group, CLE	I would find out the best way to control the amount of rubbish in the park and to keep the amount of rubbish as low as possible.
S033, ABM group, ILE	to collect 100% of the rubbish, and collect it at 7:00pm or collect garbage more frequently. If this way followed it would reduce the amount of rats, but the amount of nutrients added to the environment is also reduced.
S037, SDM & ABM group, CLE	I would collect 95% of the rubbish at 6:00pm everyday.
S038, SDM & ABM group, CLE	Leave garbage collection till closing time. If garbage is collected beforehand, newly put rubbish will remain – accumulation for the next day.
S039, SDM & ABM group, CLE	do garbage collection earlier so that it will lead to more nutrients in the soil, but not too early so that the rubbish re accumulates before closing.
S045, SDM group, CLE	time that waste is collected. Amount of waste collected.

Code and Group	Response
S047, ABM group, CLE	establish a fine system, where when a visitor litter, s/he is fired for it. Build more bins, collect rubbish more frequently. Develop brochures / signs about The impact of litter and pollution on our environment.
S048, SDM & ABM group, CLE	Try and educate park users about the issues. Collect all rubbish more often.
S050, SDM group, ILE	--
S052, SDM group, ILE	make garbage collection at 7:30pm. Encourage people to take certain pieces of rubbish home. Make bins more efficient so rubbish doesn't spil/easier to take 100% of rubbish out. E.g. using rubbish bags or bigger bin.
S053, Text group, CLE	make policy - take own rubbish with you when you go home. Make garbage collector come at 7:30pm or later. Make garbage collector collect all inorganic materials
S061, ABM group, CLE	collect rubbish more often or build more bins to put the rubbish in.
S062, ABM group, CLE	make sure that garbage collections are more frequent. Providing more bins. Make sure garbage collectors collect 100% of the rubbish. Hire patrol officers to reinforce littering consequences.
S067, ABM group, ILE	have the garbage collected later so that more rubbish is collected because people often stay late, and have 100% of the garbage collected. Some still gets left behind so the nutrients from the decay of the organic matter are still gained.
S069, ABM group, ILE	more rubbish bins to encourage no littering policy, more percentage of rubbish collection.
S073, SDM & ABM group, CLE	--
S076, SDM & ABM group, ILE	I would close the park earlier, allowing rubbish collectors to collect before nightfall and the arrival of animals. I would only hire very effective rubbish collectors. I would also situate picnic areas in large open areas where littering is easily spotted by rangers.
S077, Text group, CLE	change the collection time for the rubbish from 5pm to 7pm and make sure that the rubbish efficiency is higher. Make sure that visitors know of the rubbish rules and regulations in the park (e.g. scoop up dog droppings, no littering and no bushwalking off the track).
S078, SDM & ABM group, ILE	not collect all rubish every day - 95% late rubish collection.
S079, SDM group, CLE	1. Employ the garbage collector to come at 7:30pm to decrease the amount of waste left at the site, hence the number of additional nutrients (also, ensure maximum efficiency). 2. Ask visitors to dispose of no more than 2 pieces of rubbish to keep nutrient/waste levels low.
S080, SDM group, CLE	I would try to let there be more nutrients absorbed in the soil. The garbage collection I would choose at 5:30pm and a percentage of 95% with the assumption of one rubbish per person.

Code and Group	Response
S081, SDM group, CLE	when rubbish was collected, amount of workers, days rubbish can be collected more often.
S082, SDM group, CLE	to collect the rubbish more regularly and collecte more rubbish. I would also put fines for people caught littering.
S083, SDM group, ILE	Have organic and inorganic bins separately so that all the waste that cannot be decomposed is collected and decomposable waste can be 'composted' so the park still gets the additional nutrients. Monitor that people are not taking too much fire wood, or walking in special habitats; as well as making sure people use the bins.
S087, Text group, CLE	apply limits for firewood collection, later rubbish collection times, owners to scoop up pet droppings, have on leash so they won't destroy the natural park environment.
S091, ABM group, ILE	more bins, more rubbish collectors.
S098, SDM & ABM group, ILE	to put some more bins in that have lids and to collect the rubbish at the cloestest time to the park closing.
S099, SDM & ABM group, ILE	have a recycling system, where all organic waste can be decomposed and put back into the park so as the vegetation can still get nutrients.
S101, SDM & ABM group, ILE	have a consistant timeing for rubbish collection. See that every day 3 times a day a rubbish collection run is completed.
S105, ABM group, ILE	more rubbish collecting, more bins.
S106, Text group, ILE	decisions that I would make if I were the manager of this park is to make different type of recycle bins.
S109, SDM group, ILE	if someone is seen littering they would be fined/prosecuted straight away.
S110, SDM group, ILE	add more bins and an actual seating and eating place for people to eat.
S111, SDM group, ILE	more rubbish bins, with dog poopy bags. Picnic tables with bins really close by.
S113, Text group, ILE	I would make the collection of rubbish two time a day, set up animal traps to kill of introduced species like rats, mice and feral cats, put in more bins.
S116, SDM group, ILE	open the park at 11am and close it before the rubbish was collected. So if the rubbish is collected at 6:00pm the park could close at 5:30pm.
S118, Text group, ILE	make rubbish collecting later so less rubbish is thrown away after the collector has arrived. Not allow animals into the park - or keep animals on leash at all times. Make people pay more so they are less wanting to come ina nd I get more money!

Code and Group	Response
S119, SDM group, ILE	arrange for 2 garbage collections per day
S120, SDM & ABM group, ILE	more rubbish bins, doggy poop bags, compost bins for organic waste, recycling bins etc.

Q4. IF THIS DESCRIPTION OF THE NATIONAL PARK WAS MORE DETAILED, WHAT DO YOU THINK WOULD HAPPEN NEXT? WHAT ARE THE POSSIBLE PROBLEMS THAT COULD OCCUR FOR THE ENVIRONMENT?

Code and Group	Response
S020, SDM group, ILE	from added nutrients, there could be more introduced species of animals, more non-native species taking over the natures.
S027, ABM group, CLE	ran out of time
S033, ABM group, ILE	The animals will become more dependent on the food scrapes and the natural cycle of the ecosystem will be interrupted.
S037, SDM & ABM group, CLE	--
S038, SDM & ABM group, CLE	An abundance of nutrients at the park. More rubbish is accumulated as not all the rubbish is collected every day.
S039, SDM & ABM group, CLE	more introduced species of animals (such as mice) are attracted by the food - competition with native animals.
S045, SDM group, CLE	birds, eat picnic food / food from bin, add waste, plants grow that are unaactive, e.g. "tomato tree"
S047, ABM group, CLE	there would be more additional nutrients and waste accumulation is still present. Some problems that may arise are pollution to plants + water, thus animals that depend on them may become ill, and flora growth may be shunted.
S048, SDM & ABM group, CLE	More rubbish would have built up and released more nutrients and attracted more introduced species.
S050, SDM group, ILE	--
S052, SDM group, ILE	--

Code and Group	Response
S053, Text group, CLE	the animals can eat something bad for them, eg wipes - chemicals in them, bad food (off). The animals will relocate to somewhere else due to excessive noise etc. The habitat (trees and grass etc) will suffer from wood burning etc. air pollution from burning.
S061, ABM group, CLE	I don't know
S062, ABM group, CLE	more Co2 - trees would be overworked. Global warming. Smelly national park because of rotting litter.
S067, ABM group, ILE	nutrients in the soil could cause plants to grow. Depending on how much of the garbage is collected, the garbage could accumulate unitl it becomes a big issue.
S069, ABM group, ILE	I think the park would become full of introduced species (eg rats) because of the amount of organic waste left. Possible problems = littering could affect tourism appeal, blockage of water supply = inhabited by introduced species.
S073, SDM & ABM group, CLE	--
S076, SDM & ABM group, ILE	the steady rise in the amount of nutrients in the soil might mean that some forms of vegitation growing close to the picnic sites may become "too dominant"? The pieces of rubbish left at the site is not a particular worry as this seems to level out.
S077, Text group, CLE	--
S078, SDM & ABM group, ILE	long term effects of feral animals and their impact on the native animals. The build up of rubish over time.
S079, SDM group, CLE	additional nutrients could be introduced into water/river systems through run off causing algal blooms and eutrophication. Remaining litter may be eaten by animals and cause them to get sick, depleting numbers.
S080, SDM group, CLE	there may be mre plant growth because of the amount of nutrients in the soil. We need to take into account the animals which might benefit from this added growth.
S081, SDM group, CLE	the amount of rubbish can impact on the environment by making soil containing more nutrients which will prmote growth, but more rubbish can harm natural habitats for animals in short term.
S082, SDM group, CLE	the habitats of plants and animals or numbers of certain species will decrease.
S083, SDM group, ILE	the "not collected and non-decomposable" waste will accumulate over time. Animals may be harmed if they eat some of the waste left around / in the bins. Excess of nutrients from the decomposing waste.
S087, Text group, CLE	I don’t understand the question.

Code and Group	Response
S091, ABM group, ILE	--
S098, SDM & ABM group, ILE	the comming of non native animals to the park.
S099, SDM & ABM group, ILE	increased nutrients levels, animals feeding on litter leading them to become dependant on it as a source for food.
S101, SDM & ABM group, ILE	the environment could become more polluted.
S105, ABM group, ILE	--
S106, Text group, ILE	--
S109, SDM group, ILE	heavier pollution, animals dieing due to swallowing rubbish.
S110, SDM group, ILE	more and more litter would be produced which can spread unhygienic diseases to animals that feed there and for humans who go to eat there.
S111, SDM group, ILE	if there was a lot of litter, animals may come and die.
S113, Text group, ILE	there would be an over population of introduced species and native species would become more and more rare until they all DIE!
S116, SDM group, ILE	--
S118, Text group, ILE	more rodents come and eat the rubbish - feral animals (cats) are attracted to the rodents and they eat them, causing an increase in feral cats. Possums and other natural animals are endangered
S119, SDM group, ILE	I don't know… what a weird question.
S120, SDM & ABM group, ILE	--

Q5. IMAGINE YOU ARE THE MANAGER OF THIS NATIONAL PARK, AND YOU HAVE TO WRITE A REPORT FOR YOUR BOSS WHO HAS NEVER BEEN TO THE PARK BEFORE. DESCRIBE THE PARK, WHAT HAPPENS IN THE PARK, WHAT THE MAIN ISSUES ARE, AND THE CONSEQUENCES OF THE DIFFERENT MANAGEMENT OPTIONS.

Code and Group	Response
S020, SDM group, ILE	The state of the National Park I'm am currently in management of requires several lines of attention. The park is a popular spot for young families to enjoy picnics all year round. As you are probably already aware of the environmental issues that people can have on the environment. The amount of rubbish that are deposited in the bins are collected at 5pm everyday. I believe this still creates room for the other waste to seem into the environment through animals and therefore added nutrients to the environment.
S027, ABM group, CLE	ran out of time.
S033, ABM group, ILE	The park seems very popular among the public. Many people go there. The park is a favourite site for families to go picnicing. As a result a large amount of rubbish is accumulated each day. This causes rats, but the organic rubbish decomposes to form nutrients for the environment. Recently we have decided to collect 95% of rubbish in the garbage bins at 7:00pm each day. This way organic rubbish is allowed to accumulate to decompose in the nutrients. We decided to collect rubbish as 7:00pm because that is around closing time. The problem is, because we collect on 95% there are still some rats.
S037, SDM & ABM group, CLE	The park is a wonderful place and open to anyone who would like to visit. We get visiters from all around coming to simply enjoy their time outdoors with their friends and family. This means that we also get a lot of rubbish and litter throughout the day, most of which is conected, the rest left to decompose and return nutrients to the soil. There is a small dilemma however, as to when to collect the rubbish and how much exactly to collect. Collecting more would not allow for decomposition of organic substances, feeding nutrients to the soil. However, collecting less would increase the amount of inorganic materials in the environment which could be of harm to local animals and have serious consequences for the near end for future.
S038, SDM & ABM group, CLE	Most people came in at about noon. The place becomes crowded and the amount of waste left behind by the visitors begin to increase. Therefore the amount of waste left over at the end of the day increases. Right now 95% of garbage is collected however if it is possible to get to 100% it would be for more advantageous. When rodents come out at night and search through the bins, they take some non-organic waste out of it. These things are unable to decompose and the amount of rubbish will gradually increase.

Code and Group	Response
S039, SDM & ABM group, CLE	Most people visit the park between 11am and 2pm to generally have a picnic and a walk to enjoy our unique landscapes. But there are also environmental impacts as well. Our visitors leave rubbish behind, which can attract foreign species of animals into our balanced ecosystem. The rubbish presently is collected at 5pm every day but by changing the times, we can change the impacts in the park. Collecting later in the day decreases the number of nutrients and decreases the number of waste left over. Collecting too early means the rubbish has the opportunity to reaccumulate thus leading to nocturnal introduced species being attracted. Earlier collection also leads to more nutrients in the soil, which can be a breeding ground for foreign vegetation.
S045, SDM group, CLE	Park is fairly small, it thrives on tourism Main issues are concerning waste disposal – o What time waste is collected, and o Amount of waste collected The issues affect the population of mice and rats (and consequently, feral cats) in the park. They also affect the types of plants that thrive, as organic waste contributes to the nutrients in the soil; some plants thrive on certain nutrients. Foreign plants may also be encouraged to grow, due to the organic waste. By increasing the amount of waste collected, there is less nutrients left for the soil By collecting waste at a later time, more waste is collected and less nutrients are left for the soil If both options are taken again, less nutrients, and better control of rodent population.
S047, ABM group, CLE	This National Park is at risk of certain issues, and the most serious of which is pollution not all visitors abide to the 'No littering' rule, and not all rubbish are placed in bins, but grasslands and in water areas. This effects the whole of the National Park environment – the atmosphere, hydrosphere, flora and fauna, and there natural features interact with each other, thus problems turn to plagues of problems as rubbishes in grasslands and lakes will decrease in quality (in terms of cleanliness). It will also affect the health and well being of the fauna that inhabit this national park, and extinction may result from the irresponsibility of humans. This also applies for the growth of plants. The decrease in air/water/land quality and health of flora/fauna means an imbalanced system, an unhealthy environment.
S048, SDM & ABM group, CLE	The park is coastal and used by many people. The park is used mostly for picnics. This means issues arise relating to litter and introduced species such as cats and rats. These issues can be managed by stopping people dropping litter, changing the time litter is collected and how much is collected. This can be a problem because of the cost involved. However if it is left unchanged rats are attracted which in turn attracts cats which hunt native animals. If a greater percentage litter is collected and people drop less rubbish, the amount of litter in the park is less. This means there are more nutrients.

Code and Group	Response
S050, SDM group, ILE	The park is currently in good condition and is open to the general public. However the general public have a tendency of littering and using inorganic products whilst in the park participating in activities such as picnics and bushwalking. The main issue of the park is the accumulation of litter and the inorganic products we have no problem with but the later the rubbish is collected, the less nutrients the part gets from the organic products but more of the wastes are being collected and keeping the park clean.
S052, SDM group, ILE	The park is currently open to the public to have picnics and used as an area for recreational activities such as walking the dog. The detrimental affect of these activities is the accumulation of rubbish that adds nutrients to the soil. At present a garbage collector collects the rubbish at 5pm, 2 hours before closing time. He usually picks up 90% of rubbish leaving approximately 10%. Though the amount of rubbish varies each day, rubbish is an unnatural substance that should be removed as much as possible to maintain a cleaner environment.
S053, Text group, CLE	Currently the Alison National park has been fairly productive, profit and economy-wise and has been very supportive of environmental improvement strategies. The park has bbq facilities, bathrooms, picnic area and regular garbage collecting. The main issues of concern is the impact of running this area on the earth environmental-wise and this is becoming evident through the data we have been keeping. So, an idea is proposed to limit this, by making sure no inorganic materials are left behind at the park, and this will hopefully stabalize the ecosystem's food chain. However, currently only 90% of inorganic materials are being collected and this can have a gradual change in our environment. I also propose to change bbq maintaining methods by using electricity (rooted from methods besides burning) to maintain the bbq's fuel source. This will hopefully change the environment positively by releasing no greenhouse gases.
S061, ABM group, CLE	I don't know
S062, ABM group, CLE	the national park when it is not visited by people having picnics, is a serene and green place. It is glowing with trees, a river, picnic area and plants.
S067, ABM group, ILE	The park is a national park with water elements and lots of tourist appeal. A lot of people visit the park at first, but this number decreases as it goes along. Garbage collection is the main issue. It is best for the garbage to be collected later and for 100% of it to be collected. If some garbage is left behind, however, the organic components will decompose, adding nutrients to the soil.

Code and Group	Response
S069, ABM group, ILE	The park is visited by approximately 100 people per day, it is a popular site for picnicking. At the park, visitors bring rubbish can be restricted by [?] (about 50% organic and 50% non-organic) and management chooses when to collect rubbish and how much to collect. Main issues = as above. Consequences = more rubbish = more introduced species, more nutrients in the environment, full bins most of time. Less rubbish = opposite Early collection time = more rubbish Late collection time = vice versa.
S073, SDM & ABM group, CLE	--
S076, SDM & ABM group, ILE	National Park Report. This national park is one which receives many visitors who come here to picnic. Our main issues are the efficiency of the garbage collection, the severity of the littering and the time of garbage collection. In respone to these main issues it can be seen the park is most efficiently run if 100% of garbage is collected, littering is restrained as much as possible and collections are carried out as late as possible.
S077, Text group, CLE	The national park is complex system, further complicated by human activities, for example; picnicking of visitors in the national park. The arrival and departure of visitors to the park greatly affects the biotic and abiotic environments. As visitors arrive (around noon) they bring foreign articles (food, rubbish etc) into the park and as they depart (steadily between 1pm-5pm and peaking at 5pm-7pm), the deposit the rubbish into our rubbish bins. The current rubbish collection time is 5pm, just before the peak departure time. If the rubbish collection time was moved to 7pm and the rubbish collecting efficiency increased, the visitor impact on the park is lessened. For example; less food would be left in the bins overnight, meaning that less non-native animal species would be drawn to the park (e.g. rats, mice, feral cats), also less nutrients would be introduced to the environment. Less foreign plants would be introduced as seeds, etc are introduced into the park.
S078, SDM & ABM group, ILE	The park is by a lake and is often a popular spot with many people. The main impact of these people is litter. There are several ways of handling this and the key issues are how much rubbish they leave, the time it is collected and how much is collected. The time it's collected effects the amount of nutrients that go into the soil. If it is collected well before the park shuts more rubbish goes into the bin before the day finishes and there is more nutrients available for decomposition. The amount of rubish left behind just increases or decreases the amount

Code and Group	Response
	of rubish within the system.
S079, SDM group, CLE	The park is quite popular with the general public as it has pleasant picnic facilities. The majority of visitors arrive at around lunch time and leave between 5 and 7pm. Unfortunately, picnic activities introduce both organic and inorganic wastes to the park. If left to decay, the organic materials can introduce additional nutrients into the soil, leading to algal blooms and other such effects in local river systems. In order to minimise these harmful effects, it would be wise to employ a garbage collector at 7:30pm as this ensures the majority of rubbish left by visitors is collected, hence less rubbish is left to decay overnight and possibly be consumed by animals. Regulations to limit the amount of rubbish disposed of by each person will also decrease additional nutrient levels and the amount of remaining waste.
S080, SDM group, CLE	The park is filled with many trees, bushes, flowers and rocks. Also, there are a lot of wildlife which live in the park. There are usually picnics, bushwalks and various family occasions in the park. Main issues are to protect the environment from visitors.
S081, SDM group, CLE	Boss, As manager of this National Park I have been aware of the everyday happenings in and around the area. I have to inform you that this park has regular visitors with the amount of visitors peaking during the working week. The rubbish will accumulate, therefore I strongly urge you to hire more staff to accommodate the demand for rubbish collection. The rubbish does not affect the environment as ‘additional’ nutrients within the first few days of the week, but by the end of the week it is clear that extra nutrients are in the soil, making the soil very fertile. This will promote growth but too much growth will cause over abundance and imbalance in the park.
S082, SDM group, CLE	Littering. The national park attracts many tourists each day and with the tourists come rubbish. To keep the park’s ecosystem functioning as well as it possibly can we can choose what time to collect the rubbish and how much rubbish is collected. If we choose to collect the rubbish later the additional nutrients left in the soil increases and waste left at site increases however after 9:00pm the additional nutrients in the soil start decreasing. If the tourists leave more rubbish per person than rubbish collected then more waste is left on the site.
S083, SDM group, ILE	The National Park is often filled with people having picnics, on school tours, or bushwalking groups. This means there must be a steady limit of people permitted in so as to prevent major disruption to the parks ecosystems. One of the problems the park faces is the waste left on site. Waste is collected daily however not all of it is always removed. This means small amounts of waste are slowly accumulating. Another issue is the time the waste is collected. The later it is removed from the park, the more that is left over. The waste mentioned is a combination of organic and inorganic wastes so the decomposition of the waste as a whole is varied.

Code and Group	Response
S087, Text group, CLE	The national park is a popular, and often busy place, with many visits from the ppublic everyday of the year. Visitors for picnics mostly come during lunch time, and only a few arrive before 11:00am and after 2pm (although some still do). There is a steady number of these people leaving between 1pm and 3 pm, and then this increases between 5pm and 7pm. The park closes at 7:30pm. On certain days we have more visitors than others such as the weekend, however school holidays may not mean that more visitors are in the park. The main issues that we face in the park are waste management, firewood collection, and impact of introduced species on the natural/native environment (people who bring their pets). At the moment our garbage collector comes at 5pm to collect the rubbish, but with different timeslot that he can come at, say, at 7pm, this would mean more garbage collected and less impact on the environment.
S091, ABM group, ILE	
S098, SDM & ABM group, ILE	there needs to be more rubbish bins but the rest of the things in the park are fine their was only one animal that ate out of the bin and everything runs smoothly.
S099, SDM & ABM group, ILE	--
S101, SDM & ABM group, ILE	--
S105, ABM group, ILE	--
S106, Text group, ILE	--
S109, SDM group, ILE	This is the national park, this park is full of nature's gifts: trees, plants, insects, birds. The greenery is beautiful, families enjoy coming here for picnics or just a day to relax. One of the main issue is people littering and not cleaning up after themselves. Some consequences of this include animals mistaking rubbish for food, and choking on the rubbish.

Code and Group	Response
S110, SDM group, ILE	The National park would consist of a lake, a place to hire boats, playground equipment, an arrange seating place and bbqs. The lake would be useful for people to fish or just enjoy the water. People can hire boats and either fish on the boat or just enjoy being and floating on water. The playground equipment would be good for the children and the arranged seating place would be for people who are going to eat there or have a bbq. The would also be grass so people could also decide to sit on the grass and eat. The main issue is the amount of rubbish. To fix it, I would place more clean bins that don['t smell or attract pests and insects.
S111, SDM group, ILE	--
S113, Text group, ILE	--
S116, SDM group, ILE	The garbage is collected at 7:00pm, becaues the park closes at 6:30pm, before that time there would still be a lot of garbage left which could create problems for the park.
S118, Text group, ILE	--
S119, SDM group, ILE	The park is a fairly clean environment, but there are a afew issues within the environment, including; Visitors will normally have picnics, walk their pets, have barbeques etc. Inorganic rubbish accumulation – rubbish bins are collected once a day, but littering causes an issue. Altering the number of times rubbish is collected will result in less inorganic matter accumulating.
S120, SDM & ABM group, ILE	--