EXPLORING THE NARDOO –DESIGNING SIMULATIONS THAT SUPPORT IMPROVED LEARNING OUTCOMES FOR STUDENTS STUDYING ISSUES OF MANAGEMENT OF A WATER CATCHMENT

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ABSTRACT

Whole catchment management of water resources is a complex process requiring students to develop an understanding of systems and processes which operate at over extended timeframes at both a macro and micro environmental level. The development of models and simulations of such systems affords an opportunity to overcome these constraints through the provision of 'risk free environments' in which the user may hypothesise and test cause and effect relationships. This provides the potential for students to gain a better understanding and the processes at work and thus improving the overall learning outcomes. This paper reports on the development of the international award winning interactive multimedia based CD ROM simulation package, *Exploring the Nardoo*, which is based on a constructivist approach to learning . It models an inland river catchment and the changes which occur through time as a result of human interaction with the environment through the presentation of a series of problems related to the consequences of this interaction. The software contains several purpose built interactive simulations which provide the opportunity for students to fully control the inputs and outputs. They target specific issues associated with water management in such environments. They were designed in accordance with contemporary theoretical principles in terms of both pedagogical and user interaction issues with regard to modelling the real world effectively so as to provide an authentic environment in which the user may construct knowledge and understanding of complex processes. Each of these simulations is a powerful exploratory tool, which provides support for the solution to one of the embedded problems by mimicking a 'real world process' which forms an integral part of one of the problems encountered in the Nardoo River Catchment. Through multiple representations of data, the simulations greatly enrich the 'quality' of the problem solving process for students, allowing them to become immersed in a 'real' situated process, manipulating the various causal parameters and testing hypotheses without a 'real' consequence or risk and in a time frame which is convenient to them. The paper also reports on the outcome of a study designed to test the efficacy of the assertion that with careful design, interactive simulations which mimic complex ecological processes can provide the opportunity for improved learning outcomes and the development of a deeper understanding of the underlying relationships.

KEY WORDS
Simulation, Water Catchment Management, Cognitive Tools, Situated Learning, Algal Bloom, Constructivist learning environments, Educational Multimedia

INTRODUCTION

Our water resources represent a finite resource on which an ever increasing demand is being placed through such avenues as rising population, the intensifying of both industrial and agricultural use and an ever

increasing degradation of the structures and processes through which nature itself recycles this finite commodity.

The interaction of people with the environment impinges not only on the quantity and quality of the water resources available to them, but also on the successful management of catchment areas. The success or otherwise of this management can only be improved significantly through the development of a greater public awareness of the problems and issues faced by those who are responsible for water resources and catchment management.

Community awareness of the need to manage water resources, particularly on a whole catchment basis is generally poor. This situation arises out of a lack of community understanding of the relationship between the state of 'health' of the overall catchment and the activities of the community in and around the catchment at both a local and individual level
"Market research by the New South Wales Department of Water Resources has supported these assertions through feedback from community workshops and public responses to draft policy releases and discussion papers" (Wright et al. 1994).

The key issues which need to be addressed in order to raise public awareness and facilitate a change in the communities attitude and commitment to water resource management include;

•   the need to develop an understanding for a balance between supply and demand,

•   the realization of the need to minimize of resource degradation and the need for ecological and economic sustainability,

•   the understanding and embracing of possible solutions to problems related to water management issues,

•   an acceptance of both a personal and collective responsibility for sustaining water quality and availability. Corderoy et al. (1998)

EXPLORING THE NARDOO

At all levels of society, greater demands are being placed on education systems to produce citizens who can use knowledge in new domains and different situations. Learning to think critically, to analyse and synthesis information to solve problems in a variety of contexts and to work effectively in teams are crucial skills for students, and yet there is little evidence that our education systems are developing these skills

Jonassen and Tessmer (1996-7), among others, have questioned the commonly used taxonomies of learning that are the basis of our curriculum documents, proposing that engaging in a greater range of learning outcomes than isolated intellectual skills is essential for meaningful learning in our children.

In parallel with this push for renewal, the integration of technologies which allow the representation of ideas in many different media forms through information and telecommunication technology, and specifically computers, into the educative process offers instructors unique opportunities to individualise instruction, place learners in open ended student–centred investigations, and for instructors to shift from their traditional instructor role to the role of mentor and co-learner.

The current level of sophistication of interactive multimedia applications provides an incentive for designers to produce software which fully utilises the capabilities of such applications. This is particularly evident in many of the simulation based packages being developed today which exhibit a tendency to move away from the earlier reliance on a 'pre-set', 'fixed and repeatable outcome' model which provided a very simple approximation of the real world that it was trying to mimic.

The software package *Exploring the Nardoo* is an interactive multimedia CD-ROM based 'constructivist' learning environment which attempts to provide a realistic, 'risk free', 'open ended', information rich environment in which the student can explore the issues associated with water resource management and human habitation on a whole catchment basis.

The package simulates a navigable, inland river catchment environment representing four time zones of the rivers' development, from a pristine state through to the present day.

The Four Time Zones represented are:
- Zone 1: The Pristine state
- Zone 2: Early Development (1940's - 50's)
- Zone 3: Later Development (1960's - 70's)
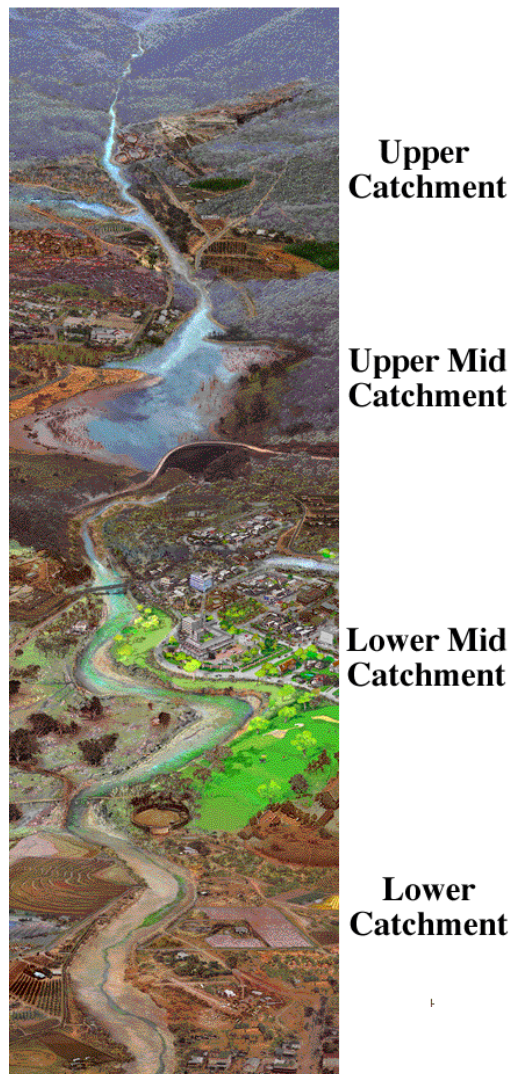- Zone 4: The Present Day (See Figure 1)

Figure 1. The Four Regions of Time Zone 4

Within each of these time zones, the river catchment is divided into four regions along its length, from the upper catchment through to the mature river plain.

The package uses a geographic metaphor which contains a Water Research Centre and a navigable river environment and it presents the issues associated with inland Australian rivers and how they are effected by farming, industrial activity, settlement and water use demand. The metaphor for the knowledge structure is a navigable river that contains biological, chemical and physical data. Four time zones representing roughly equal time spans of the rivers' development, from a pristine state through to the present day are available for the student to freely explore. Within each of these time zones, the river catchment is divided into four regions along its length, from the upper catchment through to the mature river plain.

The issues, scenarios and problems presented within this interactive landscape represent complex ecological processes which in nature can act over tens of years and could not normally be experienced by an individual.

The package has been designed to facilitate access by learners to a complex information landscape by:
- providing an adaptive navigation system and coherent information metaphor that requires little or no explanation. Thus the learner can rely upon the expected range of operations and functions which are available in the expert's world.
- supplying accessible and useable tools to allow access to the scope of supporting learning resources presented in a variety of representational forms (such as video and graphic representations of concepts and simulations) and to make measurements and investigate the properties of phenomena.
- providing a hierarchical set of problems to solve. Each problem is based on the information embedded in the landscape, thereby, creating meaning from an otherwise disparate set of resources.

The problem-solving challenge for students to become active participants in the learning process is presented on entry to the metaphorical environment, the data collection facilities allow collection of a full range of media forms and simulators allow the user to ask questions and investigate possible answers to those questions.

By providing a metaphor relating to the real world, students are encouraged to apply scientific concepts and techniques in new and relevant situations in this ecology-based application, throughout the problem-solving process. In so doing, the learner is likely to become more interested in developing questions, ideas and hypotheses about the learning experiences encountered. As an alternative teaching/learning strategy in the development of inquiry and problem solving techniques, this package incorporates high quality visual materials in the form of graphics, sound, text and motion video together with scientific measuring tools to aid in the construction of understanding.

Each region in the visual representation of the river environment contains an embedded investigation, to follow and resolve. These problems challenge the user to become an active participant in the learning process. This problem-solving approach is introduced to the user at the beginning of the program as they enter the simulated Water Research Centre. The Centre is populated with guides who introduce you to the learning environment and the information access metaphors and who also provide metacognitive support for the problem solving process through hints and problem solving strategies specific to each investigation.

Of particular significance within the package are a flexible set of cognitive support tools which provide the student with the ability to interrogate, manipulate and extract information in a manner supportive of learning through a constructivist approach. One of these tools, the simulator, is the focus of this paper and the study it reports on.

SUPPORTING LEARNING WITH COGNITIVE TOOLS

Within constructivist frameworks, cognitive tools can help learners organise, restructure and represent what they know. It was considered that a series of cognitive and possibly metacognitive tools could be developed to support the perceived needs of the learners and incorporated into our design processes.

Jonassen and Reeves (1996) have summarised the foundations of cognitive tools research and have identified the following key principles in the context of multimedia design:
- Cognitive tools will have their greatest effectiveness when they are applied to constructivist learning environments.
- Cognitive tools empower learners to design their own representations of knowledge rather than absorbing knowledge representations preconceived by others.
- Ideally, tasks or problems for the application of cognitive tools should be situated in realistic contexts with results that are personally meaningful for learners. (p. 698)

Cognitive tools that support the user have been shown by Jonassen and Reeves (1996) and others to enhance the learning process and to support the users' investigations. If students are to truly create their own meanings and understandings of the phenomena they encounter, designers need to not only incorporate user tools which will enable them to present their findings using the full array of resources contained in the packages, but also support their investigations with powerful cognitive tools.

The cognitive tools in the *Exploring the Nardoo* package include a Personal Digital Assistant (PDA) and a Simulator, which "provide the users with highly interactive simulations of some of the more 'critical' issues for inland river catchments. The simulations complement the embedded problems by providing "links with the 'real world' experience and by creating an environment in which the user may develop and practice higher order cognitive skills" (Corderoy et al. 1996)

THESIMULATION TOOLS

For students to 'test' ideas, three simulators have been incorporated: a Personal, Home Water Use simulator a 'whole catchment level' water demand Dam Management simulator and a Blue Green Algal Bloom simulator (Figure 2). Each of these simulators is a powerful exploratory tool, which provides support for the solution to one of the embedded problems by mimicking a 'real world process' which forms an integral part of one of the problems encountered in the Nardoo River Catchment.

They greatly enrich the 'quality' of the problem solving process for the user by providing unhindered access to act and become immersed in a 'real' situated process, manipulating the various causal parameters and testing hypotheses without a 'real' consequence or risk and in a time frame which is convenient and manageable for them and "and enabling the learner to ground their cognitive understanding in their action in a situation" (Laurillard 1996).

More able users are provided with the facility to solve problems at a deeper level through the testing of their own "what if" scenarios. This can, during the course of solving problems… "facilitate more detailed exploration and learning by;
- allowing the user to take readings at a sight and study the changes as the simulation runs,
- allowing the monitoring of all parameters while the simulation is running, with the aim of exploring the relationships between them" (Corderoy et al. 1993)
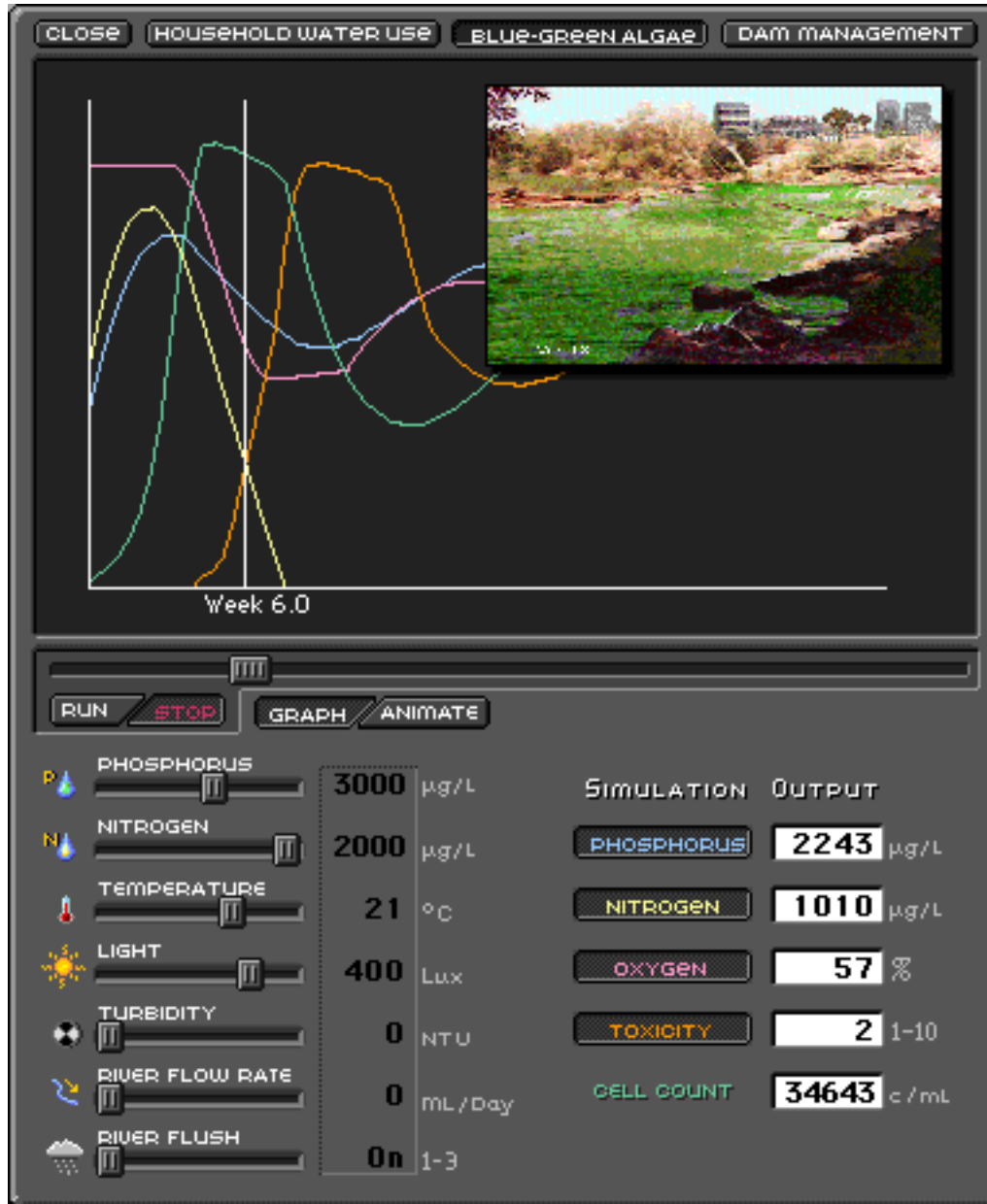
Figure 2. The Blue-green Algal Bloom simulator.

The innovative incorporation of multiple forms of feedback in these simulators has added to their power as tools for learning. Data input is simply achieved and the values are displayed in windows during the simulation, allowing the user to check them against the outcome of the simulation. Likewise output data from the simulation is also visible at all times and the format in which it is displayed is user controlled. Pure numerical data is displayed in the output data windows, while the main screen of the simulator may be toggled between a graphical display and an animation of the process.

THE STUDY

The study reported on in this paper focused on the simulation tool mentioned earlier and the testing of its educational effectiveness. The simulation tool provided an effective and realistic replica of a real world

system, in this case, the complex natural process of algal bloom development and their implications. This tool was an integral part of the water management software package *Exploring the Nardoo*. Harper et al., (2000).

The study was based on two assertions with regard to the educational effectiveness of simulations in educational environments. First, that to be effective simulations need to have been designed in accordance with contemporary theoretical principles in terms of both pedagogical and user interaction issues with regard to modelling the real world effectively so as to provide an authentic environment in which the user may construct knowledge and understanding of complex processes. Second, that students using such simulations will have better learning outcomes and develop a deeper understanding of the relationships between the variables involved than those who are exposed to a more conventional approach in terms the representational media adopted, available resources and teaching methods.

Students using simulations, designed in accordance with contemporary theoretical principles, will have better learning outcomes and develop a deeper understanding of the relationships between the variables involved than those who are exposed to a more conventional approach in terms of resources and teaching methods. In the design process, consideration was given to both pedagogical and user interaction issues with regard to modelling the real world effectively so as to provide an authentic environment in which the learners could construct their knowledge and understanding of the complex ecological process under study.

Methodology
The methodological approach adopted for the study was of a classic experimental design (pre/post test) and based in the Scientific Paradigm. The data set on which the analysis of the study was based, was collected using researcher designed instruments which included:
- A Knowledge Acquisition Schedule (KAS) - a measure of learning outcomes;
- A Cause and Effect Schedule (CES) - a measure of the development of an understanding of relationships between contributing variables, and;
- A User Perception Schedule (UPS) - Additional data (parametric) to gather user perceptions of the learning experience with regard to the pedagogical approach and user interaction in terms of the users preferred learning style.

The subjects in the operational population comprise 118 of the entire student enrolment (138) for the subject EDUS 301 "Science and Technology Investigations" within the Faculty of Education at the University of Wollongong. This subject is a 'Pre Service' course for students training to become teachers. Burns (1998) suggested that sampling entire natural groups such as this is a common practice in educational research and that it retains the principal of randomness while providing flexibility in research design which may otherwise be curtailed through institutional pressures.

The students were all enrolled in a program of study to enable them to practice within Primary Schools in New South Wales. The subject prepares students to teach in the area of the Primary Science and Technology Syllabus. Being 3rd year students, the mean age was around 21 years. Approximately 15% of the students in the group were classified as mature age students. Their science/ecology background, (what they studied in the Science strand in senior high school) was varied. In this study the majority have, through their study of biological based or biased studies, a practical familiarity with the basic principles of ecology.

The Procedure
At the outset, in an introductory session which was conducted during a scheduled lecture period prior to the commencement of the experiment, students in each group were given general information about the scheduled prescribed assessment task, the nature of the package which they were going to use in completing the task and an outline of the time line.

Both the experimental and the control groups were exposed separately, to a 1.5 hour orientation session to introduce them to the *Exploring the Nardoo* package, During this session they were given some verbal information about the software to be used such as its central theme and its overall structure. The researcher used an on-screen walk through for each of the major sections of the package, describing what they were, how to use them and where they fitted within the overall scheme of the learning environment *Exploring the Nardoo*. Care was also taken to ensure that the students were aware of the extensive resources in various media formats available to them. Time was also spent in discussing functionality issues such as, extraction of data from the system, saving files, reloading and working on them away from the experimental site. The students were told that the work sessions would be run in pairs and that they were free to choose their own partner. The students pair were able to spend some 40-50 minutes gaining 'hands on experience' with software during their introductory session. Each pair of students was given its own 'appropriate' CD version of *Exploring the Nardoo*. Naturally, the actual conduct of the orientation session was slightly different for each group, as the experimental group needed to be made aware of the simulation tool which was not available in the software version used for the control group.

Each of the groups was given the pre-treatment instruments to complete before the start of the orientation session and the format for this initial collection of pre-treatment data session was then given a copy of the assignment task ready for the next session.
The subjects in both the Control and Experimental group were given a total of 6 hours hands on (2 x 3 hours sessions) to complete the task as well as the initial 40-50 minutes hands on orientation. This orientation period appeared to provide sufficient training in the use of the software so that the 6 hours spent working on the task was quality time with respect to task completion. At the next lecture session, (4 days after the last experimental session), the subjects handed in their completed task as an assignment and in the last part of the lecture period completed a Post-Test KAS and a Post-Test CES which were identical to those completed before the experiment started except that they had the identification as Post-Test.

RESULTS AND FINDINGS

The processing of the data obtained from the study had several phases. Data from the User Perceived Value Schedule was initially subjectively assessed and then coded for parametric analysis. This coding was done using a scoring pattern based on a 5 point Likert scale. The compilation of the parametric data from the pre and post tests, Knowledge Acquisition Schedule and the Cause and Effect Schedule was followed by the use of Statview 4 for the Macintosh (1992) to conduct 2 way repeated measure ANOVA analysis.

In terms of the KAS, both the control and experimental group showed an increase in their pre vs. post mean scores. The control group's post KAS mean score when compared to the pre KAS mean score showed a 2.5 point improvement while the experimental group's post KAS mean score when compared to the pre KAS mean score showed a 4 point improvement. Since the design of the package was such that factual knowledge about the process was available in many representational forms, this was not unexpected. More importantly, the experimental group's post KAS mean score compared to the control group's post KAS mean score showed a 3 point difference. A repeated measures
ANOVA ($F_{Critical\ 1,116}$ = 3.92 and $\square$ = 0.05), Treatment vs. pre/post KAS mean scores, conducted on the data yielded an $F_{Obtained\ 1,116}$ = 7.325 and $\square$ = 0.0078.

The conclusion to be drawn from this is that the control and experimental group's improvement in the post KAS score (a measure of learning outcomes) resulting from access to the package *Exploring the Nardoo* (including the simulation tool for the experimental group) is reflected in an improvement in the learning outcome for both groups. However in terms of the knowledge component of the experience, there was a significant difference between the post KAS mean scores for both groups, the experimental group's scores

changing significantly more than those of the control group. One must therefore reject the H_o and conclude that the simulation tool may have had a positive influence on the acquisition of knowledge about algal growth.

In terms of the CES, a similar pattern emerged. Both groups showed an improvement on their pre treatment mean scores as in deed would be expected with exposure to the rich learning environment.
The experimental group's post CES mean score when compared to the pre CES mean score showed an 8 point improvement while the control group's post CES mean score when compared to the pre CES mean score showed a 3 point improvement. A repeated measures ANOVA ($F_{Critical\ 1,116}$ = 3.92 and $\square$ = 0.05), Treatment vs. pre/post CES mean scores, conducted on the data yielded an $F_{Obtained\ 1,116}$ = 66.7 and $\square$ = < 0.0001. This result would compel one to reject the H_o (no significant difference in performance).

The conclusion to be drawn from this is that the control and experimental group's improvement in the post CES score (a measure of development of understanding of relationships) from having access to the package *Exploring the Nardoo* (including the simulation tool for the experimental group) is reflected in an improvement in the understanding of relationships between contributing factors for both groups. However, in terms of the development of an understanding of the relationships involved in the process, the experimental group's post CES score was significantly better than the control group's and this reflects a significant advantage afforded the experimental group by having access to the simulation tool.

Analysis of the data obtained from the User Perceived Value Schedule (UPS) not only provided supportive evidence for the findings from the two parametric instruments but also proved a rich source of information on the more general aspects of simulation design.
Generally, both the control and experimental group participants had the perception that using *Exploring the Nardoo*, provided them with a more interesting and profitable learning experience than traditional methods of studying ecological and land management issues. The experimental group participants also suggested that the simulation tool was an integral part of the package and experience particularly in terms of it providing them with the flexibility to alter both the input parameters and output at will, providing them with a tool to gain a better understanding of the process rather than just better factual knowledge.

CONCLUSION

In terms of the assertion that students using simulations designed in accordance with current theoretical principals will have better learning outcomes and develop a deeper understanding of the relationships between the variables involved than those who are exposed to a more conventional approach in terms the representational media adopted, available resources and teaching methods, this study was able to demonstrate improved learning outcomes and development of understanding of relationships and provide corroboration of the effectiveness of the simulation tool.

The data collected from the Knowledge Acquisition Schedule (KAS) indicated that use of the package *Exploring the Nardoo* resulted in significantly improved acquisition of factual knowledge for both the control and experimental groups. This was not unexpected as the overall design of the software was such that all students had access to extensive multi-format information on all aspects of algal blooms and the investigation was designed so as to be *independent* of the algal bloom simulation tool. The fact that the experimental groups KAS mean scores showed a significantly greater increase than those of the control group would suggest that using the tool also supported factual knowledge acquisition.

Analysis of the Cause and Effect Schedule (CES) data suggests that the simulation tool also facilitated a deeper understanding of the processes and the relationships between causal factors for the students who had access to the simulation tool. On examination of the data in terms of the degree of improvement between

pre and post CES mean scores for the two groups, it is apparent that as in the case of the KAS mean scores, the students using the simulation tool not only improved their CES mean scores, but improved them by a significantly greater margin than those in the control group. This outcome adds support to the assertion that when students have the opportunity to test and re-assess their mental models of complex systems, the processes and relationships at work, in meaningful learning environments and supported by appropriate tools, there is a potential for improved learning outcomes and the development of deeper understanding.

The data collected from the User Perceived Value Schedule (UPS) indicated that the students had the perception that they learned more using this package than if they had used a more traditional method. It also indicated that many of the students believed that the highly visual nature of the package was a significant factor in their learning and that placing the learning in a familiar context helped them understand a complex process. In terms of the simulation design, analysis of the UPS data provided ample support for the argument that, in terms of standard design parameters the simulation design was effective. Students reported that they were happy with the level of control, the ease of use and the overall functionality of the simulation tool. Of particular interest is the general perception among students who used the simulation tool that the ability to flip between representational modes for data output was an important factor in their learning and understanding and that having the ability to change variables and test the effect was a key factor in their development of a deeper understanding of the underlying processes and relationships. This study supported the assertion that, the design of the delivery tool is as important to the overall learning outcome for students as the way in which it is used in a classroom.

REFERENCES

Burns, R.P. (1998). Introduction to Research Methods. Addison Wesley Longman. Melbourne.

Corderoy, R.M., Harper, B.M., & Hedberg, J. G. (1993). Simulating Algal Bloom in a Lake: An interactive multimedia implementation. Australian Journal Of Educational Technology. 9 (2). Summer: pp.115-129.

Corderoy, R.M., Wright. R,. J., Harper, B.M., & Hedberg, J. G. (1996). Exploring the Nardoo: Simulating & Reporting on Ecological Processes. Conference of the Australian Science Teacher's Association. Canberra. July 7-12.

Corderoy, R.M., Harper, B.M., Hedberg, J. G. & Wright, R.J. (1998). Exploring the Nardoo- The development and Implementation of an Interactive Simulation Package for Whole Catchment Management. Environmental Management: Engineering the Water-Environment and Geo-Environment. Proceedings of the 2nd International Conference on Environmental Management (ICEM2). Sivakumar & Chowdhury (Edits). University Of Wollongong. Australia. Elsevier pp. 623-631.

Harper, B.M., Squires, D. & Mcdougall, A. (2000). Constructivist Simulations: A New Design Paradigm. Journal of Educational Multimedia and Hypermedia. 9 (2), pp 131-149.

Jonassen, D. H., & Reeves, T. C. (1996) Learning with Technology: Using Computers as Cognitive Tools. In D. H. Jonassen, (Ed.) Handbook of Research on Educational Communications and Technology. New York Simon & Shuster Macmillan, pp. 693-719.

Jonassen, D. H., and Tesssmer, M. (1996-7). An Outcomes-Based Taxonomy for Instructional Systems Design, Evaluation, and Research, Training Research Journal,. 2, 11-46.

Laurillard, D. (1966) The Changing University. Paper #13. ITFORUM   http:// www.tile.net./tile/ listserv/itforum. html. University of Georgia..

Wright, R., J., Harper, B., M., and Hedberg, J., G. (1994). An Interactive Multimedia Package on Inland Water Catchment in Collaboration with the Department of Water Resources. Design Statement: Milestone One Report. (Unpublished). Interactive Multimedia Unit, Faculty of Education, University of Wollongong.

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