Exploring the learning potential of an Artificial Life simulation

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Abstract

CULUTRE is an Artificial Life simulation that aims to provide primary school children with opportunities to become actively engaged in the high-order thinking processes of problem solving and critical thinking. A preliminary evaluation of CULTURE has found that it offers the freedom for children to take part in process-oriented learning experiences. Through providing children with opportunities to make inferences, validate results, explain discoveries and analyse situations, CULTURE encourages the development of high-order thinking skills. The evaluation found that CULTURE allows users to autonomously explore the important scientific concepts of life and living, and energy and change within a software environment that children find enjoyable and easy to use.

Keywords

Computer-assisted instruction; Artificial life simulation; Primary school education; Higher-order thinking

Biographical Notes

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1 Introduction

This paper describes the CULTURE system, an educational software package for children aged between eight and twelve years of age. CULTURE is an Artificial Life simulation developed by the authors to allow users to explore first-hand the important scientific concepts of energy and change, life and living, and feedback and continuity. The software allows students to create a world of artificial creatures and, through the choice of parameters, control how these creatures will behave.

Through exploring dynamic simulations, CULTURE aims to provide children with opportunities to become actively engaged in the processes of problem solving and critical thinking, thus encouraging the development of high-order thinking skills. The aim of the research outlined in this paper is the determine the extent to which CULTURE

- actively engages children, and
- encourages the use high-order thinking skills.

Active engagement of children is important for a number of reasons. Firstly, educators of young children believe that children learn best when they are actively involved in learning experiences [1]. This belief is based on developmental theory that advocates that learning does not just involve the passive reception of information, but rather is an active process that involves the active construction of knowledge [2][3][4]. In addition, the degree to which a computer system has the potential of extending the user's intellectual performance greatly depends on the extent of the user's active engagement with the system [5]. It is not only what the students are interacting with but also how they do it.

In order to encourage the use of high-order thinking skills, CULTURE is designed to provide an environment that actively engages the user. Higher-order thinking, as defined by Patterson and Smith (as cited in [6]), "occurs when a person is engaged in active and sustained cognitive effort directed at solving a complex problem and when the person makes effective use of prior knowledge and experience in addressing the problem". Educators have long found that children learn more effectively when there is an emphasis on experimentation, problem solving, self-directed learning and co-operation [1]. Accordingly, CULTURE is designed to encourage children to solve problems in a self-directed learning environment. These problems are designed to fit with Resnick's [7] definition of higher-order thinking, as they are complex and non-algorithmic, and they involve uncertainty and can yield multiple solutions.

CULTURE has been designed, based on theories of development and learning outlined above, to offer the best possible opportunities for children to become actively involved in experiences that involve the use of higher-order thinking skills. The system may be best described as an interactive learning environment (as defined by [8]) in that it is designed to

- regulate the locus of control between the student and the system,
- accommodate task-based methods that support conceptual understanding through the provision of illustrative feedback, and
- encourage learner-controlled investigations and problem solving.

An artificial life simulation was chosen for a number of reasons.

1. Such a system allows children to take control of the learning process and in doing so derive meaning from, and be able to apply, concepts they have had the opportunity to explore.

2. The study of ecological systems such as those present in CULTURE - life and living, and energy and change - has educational value beyond the ecology discipline. Ideas like self-organisation, feedback and emergence are important concepts in fields ranging from economics, to engineering, to anthropology [9]. Models of living systems provide a basis for understanding many other systems and phenomena in the world. In addition the study of an ecological system provides learners with a familiar environment. Most young people are familiar with many of the concepts related to the survival of plants and animals and this prior knowledge and experience is valuable for a number of reasons. By providing students with a system that build on their real world knowledge and experiences, an artificial life simulation offers intrinsic motivation [10]

and, when combined with problem solving, assists in the development of higher-order thinking skills (Patterson and Smith, 1986, as cited in [6]).

3. Artificial life systems are essentially made up of many simple elements that interact in complex ways. The simple elements are easy for children to create and program; yet the emergent patterns of interactions can be quite complex. In order to predict the way in which their world will evolve under a particular set of creature parameters, children need to develop theories, discover the inadequacies of these theories and develop better theories.

Such an environment allows children to explore "what if…" questions and this exploration can be a useful foundation for many process-oriented learning experiences. Through exploring artificial life concepts children are offered opportunities to build models so they can examine specific phenomena. It is anticipated that such investigation activities will develop naturally from exploration activities: students will be motivated to find out why the creatures in their artificial world thrive or languish. Investigation evolving from exploration activities can provide the intellectual and emotional connections students need to find the activities motivating and meaningful [11].

Accordingly, CULTURE has been designed to give users with the opportunity to make *inferences*, *validate* their results or methods, *explain* their thoughts and discoveries, and *analyse* situations. An evaluation of CULTURE has been conducted to assess the extent to which these four skills higher-order thinking skills were fostered in primary school children. For the purposes of this research, these skills are defined thus:

- *Inferring* - making a predictive statement or conclusion, based on observation and reasoning.
- *Validating* - deciding, through investigation, the accuracy or quality of a hypothesis, inference or result.
- *Explaining* - communicating perceptions of cause and effect.
- *Analysing* - breaking a situation down into its component parts. [12]

2 A Description of CULTURE

Within CULTURE students are able to create and modify "living" computer organisms. It is a world of ZOIDs and SPOTS. The software allows users to create a place for different species of ZOIDs to live, and to determine the properties of each species of ZOID, the environment in which they must survive, and the availability of a nutritional food source. CULTURE has an intuitive interface aimed at enhancing ease of use, providing continuous visual feedback. Figure 1 is a screen shot of a CULTURE simulation running.

2.1 ZOIDs

ZOIDs are the dynamic objects within the environment. They have the ability to move in search of food. SPOTs are the primary source of food for the ZOIDs. There are a number of ZOID attributes that may be set by the user. Some of these attributes, like the ZOID's name, colour and shape, have no effect on interactions within a simulation, while others have substantial impact on the interactions that occur. These include the ZOID's preferred food, ability to find food, life span, and energy requirements. The energy requirements of a ZOID that the user is able to define are:

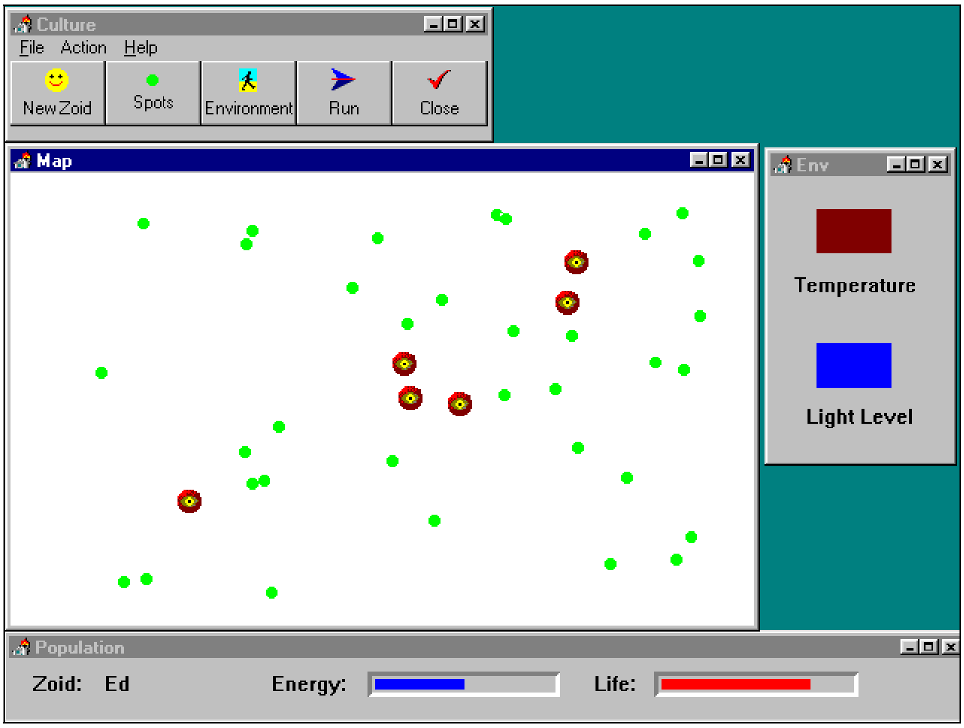

Figure 1: A CULTURE simulation running with one species of ZOIDs

- the level of energy with which a ZOID will be "born",
- the amount of energy a ZOID uses to move from one point to another,
- the level of energy required for reproduction, and
- the energy cost of reproduction.

Each new type of ZOID included in the system, identified by a different colour and shape, represents a new "species" of ZOID in the system. All members of a given species have the same attributes. Given a set of attributes the ZOIDs will behave (eat, move, reproduce, die) and interact. Differing emergent behaviours, stemming from the alterations of these attributes, may be easily observed by the user of the system.

2.2 SPOTs

SPOTs are the static beings in the CULTURE environment: they do not move. They are the default food of ZOIDs. Users of CULTURE are able to define the life span of a SPOT and its nutritional value when eaten. The user may also specify the environmental conditions (temperature and level of light) in which the SPOTs prefer to "grow". SPOTs appear within the world depending on these conditions. A user may specify that SPOTs favour hot, dark areas, in which case the SPOTs are most likely to appear in regions that are hot and dark.

2.3 The Environment

At any stage during a simulation session, the user is able to customise the environmental conditions of the CULTURE world. Any one point in the environment is capable of having more than one defined environmental attribute. The user is provided with the facility to chose one of three lighting levels, light, shade or dark and one of three temperature ranges, cool, warm or hot. Therefore, users are able to specify cool dark regions, hot warm regions etc. These variations may be painted onto an environment canvas and are represented as different colours. This ensures that the different environmental conditions can be easily identified.

3 Evaluation Methodology

A total of sixteen children in their third year of primary education from a local suburban school participated in the study. They were aged between 7 years 9 months and 8 years 8 months. The children worked in pairs during the evaluation, as studies show that children given the opportunity to work together co-operatively have opportunities to share ideas, explain their thinking, provide help to peers and take responsibility for their own learning [6][13]. There is also evidence to suggest that co-operative learning is helpful in both promoting problem solving and enhancing planning strategies of learners [14]. In addition, working with pairs is a useful evaluation strategy, as children are more likely to discuss and explain what they are doing with their peers as they work through evaluation exercises. These pairs were chosen by the teachers who where instructed to chose children of average ability who enjoyed working together. All had some experience with computers, but not in using CULTURE. The subjects completed two exercises using the CULTURE software system in 45 minutes. They also completed a brief questionnaire.

The children first worked through an introductory worksheet. It aimed to familiarise children with the system interface and explain objects within the CULTURE world (ZOIDs, SPOTs and the Environment) and their associated attributes. During this time a task checklist was completed by the experimenter as a means of recording the participants' level of success while proceeding through the exercise.

3.1 Skills Assessment

The main aim of the evaluation was to determine whether the CULTURE system facilitated the use of problem solving and critical thinking skills. Children were required to make changes to ZOID, SPOT and Environmental attributes in order to achieve specified goals. The exercise was divided into three parts.

3.1.1 ZOID Initialisation

Participants were required to create a species of ZOIDs that would live for a long time and have lots of babies. In order to achieve this goal they were told to select the values of three attributes

- energy used during reproduction,
- energy required to reproduce, and
- life span.

3.1.2 SPOT Initialisation

The children were asked to create SPOTs that live a long time, were not very good food for ZOIDs and liked to live in warm, light areas. In this instance they were told to select the values for

- life span,
- nutritional value,
- temperature, and
- light level.

As this was their first experience at creating their own CULTURE simulation, the participants were not given a choice about the attributes to be altered. Once they had determined the values for these attributes, they were asked to run the program, observe the events on the screen and answer two questions - "Did the ZOIDs live a long time?" and "Did the ZOIDs have lots of babies?".

3.1.3 ZOID Modification

This part of the exercise required the children to restart the program and make some changes to the ZOID species they had created. They were asked to change two of the three values they supplied in ZOID initialisation in order to make this species die quickly. In this instance they were allowed a choice of which attributes they would change.

The children were finally required to run the program, see what happened and answer the question "Have lots of ZOIDs died?" and briefly describe what they saw happen.

4 Results

4.1 Skills Assessment

The aim was to establish the extent to which CULTURE promoted the use of high order thinking skills such as *inferring*, *validating*, *explaining* and *analysing*. Data used for this analysis include

- the parameter values participants recorded on worksheets,
- the responses given by participants to statements and questions, and
- observations made by the experimenter.

4.1.1 Inferring

The Skills Assessment Worksheet asked participants to select values for ZOIDs and SPOTs in order to achieve a specific outcome. Participants were required to make a series of predictions based on the values they selected. They had a certain amount of knowledge about the ZOIDs and SPOTs and were required to examine these values, reflect on the result they required and form a hypothesis about the values that they needed to supply in order to achieve this result.

ZOID Initialisation

ZOID initialisation required participants to supply three values for ZOIDs to create a species that would live a long time and have lots of babies. Table 1 below provides a list of the values the each of the eight groups supplied. The users were asked to predict appropriate values, based on their knowledge and through reasoning, to achieve the desired goal. In this instance, by selecting a small value for energy used during reproduction, a small value for energy required to reproduce and large life span value, children could create a species of ZOIDS that lives a long time and has lots of babies. The shaded values indicate responses that resulted in a failure to produce the desired outcome.

	Group Number							
	1	2	3	4	5	6	7	8
Energy used during reproduction	5	10	0	30	50	25	1	0
Energy required to reproduce	100	20	1	60	30	20	1	0
Life span	8000	50	1000	100	100	730	100	1000

Table 1: Results of ZOID initialisation exercise.

SPOT Initialisation

For this exercise, participants needed to select four values to create SPOTs that live for a long time, are not very good food for ZOIDs and like living in warm, light areas. Table 2 shows the participants' responses to this exercise. Five of the eight pairs correctly inferred that by selecting a large life span value, a low nutrition value and warm (W) and light (L) environmental conditions they would produce the required outcome. The shaded values indicate responses that resulted in a failure to produce the desired outcome.

	Group Number							
	1	2	3	4	5	6	7	8
Life span	8000	105	100	95	40	409	800	1000
Nutrition	1	8	1	15	100	10	5	500
Temperature	W	W	W	H	W	W	W	C
Light level	L	L	L	L	S	L	L	L

Table 2: Results of SPOT initialisation exercise.

ZOID modification

This exercise required participants to change two of their ZOID values from the previous exercise in order to create a species of ZOIDs that died quickly. The results of this exercise are summarised in Table 3. The easiest way to achieve this result was for participants to select a low life span value. Seven of the eight groups selected a value below 30, thus ensuring that the aim of the exercise was met. The ideal response for this exercise was the creation of a ZOID species that used a lot of energy to reproduce, had a high energy required to reproduce value and a short life span. It was encouraging to see that two groups (Group 3 and Group 5) supplied all these appropriate values. The shaded values indicate unexpected responses.

	Group Number							
	1	2	3	4	5	6	7	8
Energy used during reproduction	100	1	100	33	1000	17	40	1
Energy required to reproduce	0	4	100	67	1000	25	50	1
Life span	20	2	5	30	4	21	9	100

Table 3: Results of ZOID modification exercise.

4.1.2 Validating

Data collected during the study indicated that CULTURE did provide opportunities to validate hypotheses. The participants were required to run simulations after they had decided on appropriate ZOID and SPOT attributes and examine the results.

Following the ZOID modification exercise, participants were asked whether lots of ZOIDs had died and were required to briefly describe what occurred.

Group 1 “Millions – They had a lot of babies and died”
Group 2 “One ZOID had three babies and then they all died”
Group 3 “We had one Fearsome and it died in 5 secs”
Group 4 “They still have babies but not many and they die quickly”
Group 5 “One ZOID died in one second”
Group 6 “There’s lots of them, soon some of them die and reproduce”
Group 7 “They had lots of babies but they all died out quickly”
Group 8 “ Had lots of babies, then died”

These comments show that CULTURE provides participants with the facility to validate their hypotheses. The participants have shown a clear understanding of what is occurring and as a result are able to accurately assess the results of the simulation.

4.1.3 Explaining

An example of participants *explaining* a CULTURE simulation has been identified in the section above. While validating their results, participants are also involved in explaining what has happened. This is just one of the many instances of children involved in explaining while using CULTURE.

In observing the groups as they completed the exercises the experimenter often noticed examples of peer tutoring – where one of the group members grasped the concepts more quickly than the other and explained and justified to the other group member values that had been chosen. In three separate pair groupings one group member grasped the energy level concepts better than the other did and in each instance this member was able to explain the ideas of cause and effect. An example of this is when two children were engaged in a discussion about the value they should use for "energy required to reproduce" in the ZOID initialisation exercise.

Child 1	"See, if you make that 50 they'll have babies straight away."
Child 2	"No, no, lets make it 100."
Child 1	"But see here (pointing to initial energy level), if you do that they'll have to find food."
Child 2	"OK, make it 50."

4.1.4 Analysing

As an initial investigation into the effectiveness of CULTURE, the worksheets were designed to provide a scaffold from which the participants could work comfortably. As such the worksheets do not provide explicit opportunities to analyse an entire simulation. However, observations indicated that with further use participants would be able to analyse situation and determine a complete set of appropriate ZOID attributes without assistance.

There were two examples of pairs changing values once they had run a simulation and realised that they had not achieved the desired result. Both pairs made changes that were subsequently effective in achieving the desired result. These observations suggest that validation, followed by analysis, provided a means by which participants could refine their hypotheses. CULTURE provided users with a platform to further test their theories. One of these pairs updated their ZOID energy levels in the ZOID initialisation exercise, decreasing the energy used during reproduction to achieve the desired result. This is the obvious path to achieving the required result.

The second pair changed the SPOTs nutrition value from 1 to 50 in response to their ZOIDs species not reproducing. They were able to use quite complex reasoning to determine that reproduction would increase in the situation they had created if the ZOIDs were able to find food with good nutritional value, thus increasing their energy levels more rapidly. In this instance, the children were able, through construction of a mental model of the CULTURE world, to analyse the situation, and rather than predict the outcome, select a value that they felt sure would produce the desired result.

In addition, there was an example of a pair that felt comfortable enough with the simulation to change ZOID attributes that they were not asked to alter. This pair changed the ZOID search distance during the ZOID initialisation exercise in order to increase their ZOID's chances of living a long time and having lots of babies. This pair, using their mental model of the simulation, analysed the situation by breaking it down into its component parts and realised that changing this value would provide ZOIDs with greater reproduction opportunities through the ability to find food sources more readily thereby increasing their energy levels.

4.2 Assessing Levels of Engagement

One of the key objectives of the CULTURE software is to encourage the development of high-order thinking skills through *active engagement* while participating in activities that require sustained cognitive effort. By letting the children work in pairs it increased the opportunities for the children to socially construct their understanding of the system. The observations conducted throughout the evaluation indicated that children did, in fact, work together on tasks, and were involved in discussing and debating strategies, co-operatively planning the creation of their CULTURE world and jointly assessing simulations. While there were examples of pairs where one child was working while the other observed proceeding (Group 2), where one of the pair was the dominant partner (Group 3 and Group 7), the majority of pairs worked co-operatively on tasks, with both children actively engaged in the exercises.

The introductory worksheet was used primarily to assess the CULTURE interface through observing the participants as they created a simple CULTURE world.

4.2.1 Ease of Use

The participants experienced very few problems using CULTURE. On the whole they found the software simple to use. The intuitive screen design allowed users to access with ease the menus and dialogue boxes they needed to use to create and run a CULTURE simulation. Although there was an initial need to support participants, observations indicated that they became competent quickly and during the second exercise showed high levels of independence. Three statements on the questionnaire were designed to establish how easy (or difficult) the participants found the CULTURE interface to use. Responses to these statements indicate that a majority of the participants found the system intuitive and easy to use (see Figure 2).

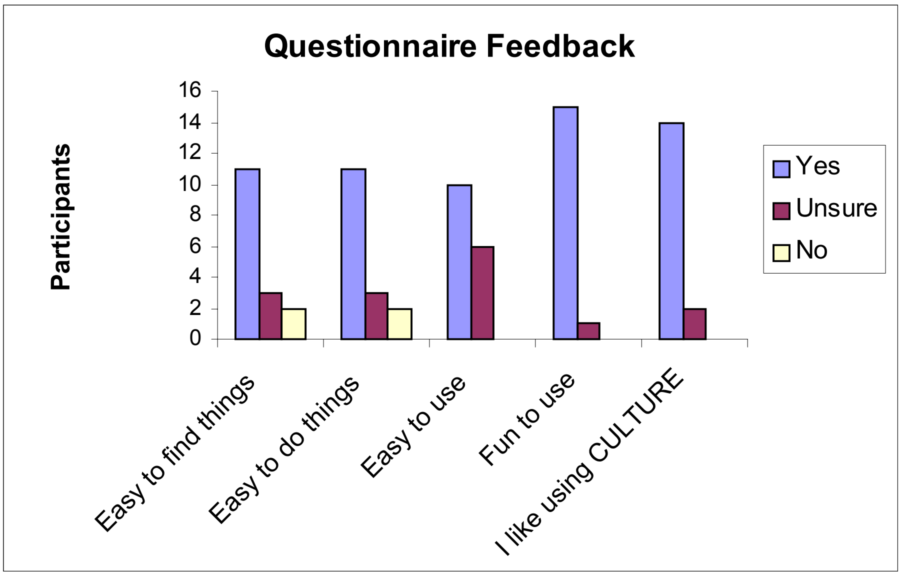

Figure 2: Questionnaire Results

4.2.2 Level of Enjoyment

Participants were asked if they found CULTURE fun to use and if they like using CULTURE. Results indicate that the children for the most part enjoyed using the CULTURE system (see Figure 2). Additional observations made by the experimenter and comments made by participants on the questionnaire support this outcome and suggest that enjoyment stemmed primarily from a high level of engagement while using the software.

"I like seeing ZOIDs die."
"And I liked the SPOTs getting eaten."
"It was fun because it showed the circle of life."
"It was very fun, interesting and entertaining."

4.2.3 Likes and Dislikes

The questionnaire required the participants to list some of the things they liked and disliked about CULTURE. In an analysis of the participants' positive comments about the system, it appears that their enjoyment stemmed, to a large degree from their ability to control the actions of the ZOIDs. Thirteen participants listed some things they liked about the system. Of these, nine mentioned the creation of ZOIDs and the ability to change their attributes. Four of the participants mentioned creating and changing the SPOTs, while three listed changing environmental attributes as one of the reasons they liked the system.

Positive comments included:

"We were allowed to change the ZOIDs"
"We could paint on the screen"
"How you make ZOIDs"
"How you make SPOTs"
"That you could change the species"
"I like how I can choose the things about the ZOIDs"
"Running things"
"We get to make our own ZOIDs and SPOTs"

There were comments that indicated that the participants would have liked more control over the simulation. Statements like "It would be good if we could move them (ZOIDs)" and "It would be good to change the shapes of SPOTs" made by participants while using the software support this view. The questionnaire responses made at the end of the session also provided an insight into the ways that CULTURE could be improved. Some of the things the participants listed that they didn't like about CULTURE included:

"You couldn't change the SPOTs"
"I don't like SPOTs"
"The SPOTs could be different in things such as colour, shape and size"
"I didn't find painting easy"
"Deciding on the energy they use"
"There should be more action"

These responses support the view that on the whole the children enjoyed using the system. Some minor interface adjustments and an increased level of control (especially over the SPOTs) are the two major ways, according to the children, in which the software could be improved.

5 Conclusions

This preliminary, focussed evaluation of CULTURE indicates that the system provides opportunities for children to be actively engaged in the processes of inferring, validating, explaining and analysing. The evaluation established that CULTURE requires that children actively use the processes of problem solving and critical thinking. CULTURE successfully encourages the development of high order thinking skills. It is important to remember that higher order thinking should not be solely characterised by correct answers, but also by the fact that the combined complex thinking of a pair of children produced an interesting result and increased the probability of a correct response [6]. Time and again this was observed to be so during the evaluation of CULTURE.

The participants' enjoyment of the software was shown to stem primarily from a sense of control over the software. The intuitive user interface provided users with a high degree of autonomy as they manipulated objects within the CULTURE world. Motivation and interest in the simulation was consistently high. The evaluation indicates that CULTURE is software to which the children can make positive emotional connections.

The results of this preliminary study show that the CULTURE Artificial Life simulation allows children to take control of learning processes within a minimally restrictive environment that encourages user freedom in the exploration of open-ended problems. The field of Artificial Life shows great educational promise in its ability to provide meaningful, loosely constrained, interactive learning environments that could be used across a number of curriculum areas. It has exciting potential which extends beyond that which has been described in this paper.

Further investigation should be carried out to determine the extent to which CULTURE has educational value beyond the ecology discipline. It is believed that CULTURE could be used across a number of different curriculum areas – from mathematics and science though to social sciences.

Acknowledgements

We would like to acknowledge the financial support of a University of Queensland Postgraduate Research Scholarship. We would like to thank those Grade 3 teachers and students at Ironside State Primary School, Queensland, who participated in the CULTURE system evaluation. Their enthusiastic contributions were much appreciated.

References

[1] Yelland, N. (1997). Technology: changing the way we think and learn or maintaining the status quo? Australian Educational Computing, 12 (1), 3-8.

[2] Fischer, K. W., & Lazerson, A. (1984). Human development: From conception through adolescence. New York: W. H. Freeman and Company.

[3] Clements, D. H. (1986). Effects of LOGO and CAI environments on cognition and creativity. Journal of Educational Psychology, 78 (4), 309-318.

[4] Flavell, J. H. (1992). Matacognition and cognitive monitoring: A new area of cognitive development inquiry. In T. O. Nelson (ed.), Metacognition – Core Readings (pp 3-8). Boston: Allyn and Bacon.

[5] Salomon, G., Perkins, D. N., & Globerson, T. (1991). Partners in cognition: Extending human intelligence with intelligent technologies. Educational Researcher, 20 (3), 2-9.

[6] Sherwood, C. (1990). Computers and higher order thinking skills. In A. McDougall and C. Dowling (eds.) Proceedings of the 5th World Conference on Computers in Education (pp 1081-1085). North Holland: Elsevier Science Publishers.

[7] Resnick, L. (1987). Education and learning to think. Washington DC: National Academy Press.

[8] Akpinar, Y., & Hartley, J. R. (1996). Designing interactive learning environments. Journal of Computer Assisted Learning, 12, 33-46.

[9] Resnick, M. (1994). Learning about life. Artificial Life, 1 (1-2), 229-241.

[10] Wood, D. L. (1990). The characteristics of intrinsically motivating early childhood and special education software. In A. McDougall and C. Dowling (eds.) Proceedings of the 5th World Conference on Computers in Education (pp 719-724). North Holland: Elsevier Science Publishers.

[11] Helgoe, C. (1994). LEGO thinking. The Computing Teacher, 21 (8), 26-27.

[12] Department of Education, Queensland. (1981). Syllabus and guidelines for teachers of primary science. Brisbane: Department of Education Queensland.

[13] Meloth, S. M., & Deering, P. D. (1994). Task talk and task awareness under different co-operative learning conditions. American Educational Research Journal, 31 (1), 138-165.

[14] Kapa, E. (1999). Problem solving, planning ability and sharing processes with LOGO. Journal of Computer Assisted Learning, 15, 73-84.