DOCUMENT RESUME

ED 470 975 TM 034 603

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TITLE Using Simulations To Improve Cognitive Reasoning.

PUB DATE 2001-04-00

NOTE 7p.; Paper presented at the Annual Meeting of the American Educational Research Association (Seattle, WA, April 10-14, 2001).

PUB TYPE Reports - Evaluative (142) -- Speeches/Meeting Papers (150)

EDRS PRICE EDRS Price MF01/PC01 Plus Postage.

DESCRIPTORS *Cognitive Processes; *Computer Simulation; *Middle School Students; Middle Schools; Skill Development; *Thinking Skills; *Virtual Reality

ABSTRACT

This study investigated changes in students' cognitive reasoning as they analyzed the dynamics of a rainforest ecosystem (El Yunque) in the aftermath of a hurricane in Puerto Rico. Students explore the virtual rainforest to study what happened to a type of frog after the hurricane. The culminating event is a simulation in which students manipulate the environmental conditions to recreate the dynamics of the frog population after the hurricane. Subjects were 54 students from a sixth grade class. Students answered reflective questions at the end of each activity, and their responses were coded to indicate the levels of cognitive reasoning shown. A main effect for project phase was found, indicating that there is a statistically significant difference between students' levels of cognitive reasoning at each phase. Student responses after using the simulation contained the highest level of student cognitive reasoning. This finding points to the possibility of using dynamic simulations in situations where the underlying concept is itself dynamic. (Contains 1 table and 15 references.) (SLD)

Using Simulations to Improve Cognitive Reasoning

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NASA Classroom of the Future™

Proposal to AERA 2001
SIG: Advanced Learning Technologies

Introduction

From 4th to 8th grade, the international ranking of US students in science performance on TIMSS drops from the ranks of the top-performing countries to the level of mediocrity. TIMSS researchers explain this result by arguing that "what you teach is what you get" (Valverde & Schmidt, 1997/1998). In the case of US middle schools, the presentation of a large volume of concepts at a superficial level results in students who have difficulty integrating concepts and applying that knowledge to solve complex problems. A similar analysis of NAEP results (Bruer, 1993) indicates that students are not learning the higher-order thinking abilities that the National Science Education Standards (NRC, 1996) recommend for all students.

In this paper, we investigate changes in students' cognitive reasoning as they analyze the dynamics of a rainforest ecosystem in the aftermath of Hurricane Georges in Puerto Rico. Students are transported virtually to the Caribbean National Forest (or El Yunque as it is more commonly known) to learn what happened to the coquí frog after the hurricane. They explore images of the rainforest to discover where the coquí live, what they eat, how they reproduce, and who eats them. This exploration is followed by directed reading of the engaging *Coquí Chronicle* that provides explanations to the questions explored in the previous activity. The culminating event is a simulation environment in which students manipulate the environmental conditions of the rainforest in order to recreate the dynamics of the frog population in the aftermath of Hurricane Georges. It is our hypothesis that the simulation environment will support students in their development higher levels of cognitive reasoning.

Simulation Environments

Simulations are powerful tools for helping students understand dynamic systems. They generally fall into two broad categories—experiential or symbolic (Gredler, 1996). In experiential simulations, students become one of the characters in the simulation. They assume the roles and responsibilities of that character. Students make decisions within the simulation from the vantage point of that character and experience the consequences of their decision. With decreasing costs for hardware, the use of virtual reality environments for experiential simulations is becoming more popular. With an emphasis on realism, experiential simulations provide concrete representations of reality.

On the other hand, students using a symbolic simulation manipulate the virtual environment from outside of the simulation (Gredler, 1996). The representation of reality is usually mediated through a symbol system, such as graphs of simulation output or diagrams of simulation processes. Students using symbolic simulations maintain a vantage point that is more detached than experiential simulations. There is less empathy with a character in the simulation and the representation of reality is more abstract. The El Yunque learning environment used a symbolic simulation of the population of the coquí frog. Students could manipulate parameters related to number of predators, availability of food, and availability of nesting sites. The simulation displays the expected population levels over the 20-month period following Hurricane Georges.

There are two lines of research that informed the design of the symbolic simulation in the El Yunque learning environment—dynamic visuals and learner control. Symbolic simulations often provide dynamic visual output as students manipulate input parameters. Research on the use of dynamic visuals indicates that positive learning outcomes result when the visuals relate to concepts that are inherently dynamic (Anglin, Towers, & Levie, 1996). The visuals focus students' attention on the salient features of the dynamic concept. In the case of El Yunque, students need to understand the dynamic nature of the rainforest environment in order to accurately predict population levels over time. The simulation displays the output in graph form. The graph changes dynamically based on the input parameters, thus focusing students' attention on the relationship between the input parameters and the population levels of the coquí.

Within symbolic simulations, the ability to manipulate input parameters and obtain immediate feedback through dynamic visuals allows teachers and designers to provide greater learner control. Though research involving learner control has mixed results in general, there seems to be evidence that learner control is particularly valuable for complex tasks (Williams, 1996). Avner et al. (1980) found that students using highly "interactive" learner control showed a greater degree of high-level skills. This suggests that the more control a student has in a complex environment, the more abstract their thinking may become. The symbolic simulation in the El Yunque Learning Environment encourages this type of learner control.

Measuring Cognitive Reasoning

SOLO, an acronym for the Structure of the Observed Learning Outcome, is a response model developed by Biggs and Collis in the late 1970s (Biggs & Collis, 1982). Since that time more than one hundred studies have been undertaken, both to apply and extend the model (Pegg, 1992). In summary, SOLO provides a framework upon which the underlying structure of the answer to a stimulus question can be inferred from the response given. Coding a student's response using the SOLO model depends on two features: *mode of thinking* and *level of response*. Of the five modes of thinking, one is relevant to this paper—*concrete symbolic*. In that mode, a person thinks through the application of a symbol system, such as written language. This is the most commonly targeted mode of thinking in middle-school and high-school classrooms.

Within each mode of thinking, there are three general levels of response. In the *unistructural* level of response, the student uses only one piece of relevant data and so the response may be inconsistent. In the *multistructural* level of response, two or more pieces of data are used without any relationships represented between them. No integration occurs of the data and some inconsistency may be apparent. In the *relational* level of response, all data are now available, with each piece woven into an overall mosaic of relationships. The whole has become a coherent structure. There is no inconsistency within the known system. The SOLO framework was used to code student responses from the El Yunque Learning Environment.

El Yunque Learning Environment

Hurricane Georges rocked the island of Puerto Rico in September 1998. The rainforest looked like a war zone in the aftermath of Hurricane Georges. Most of the trees were knocked down and those still standing were stripped of their leaves entirely. To many residents on the island, the condition of El Yunque was seen as tragic, especially since the rainforest appeared to have been close to full recovery after Hurricane Hugo, which struck the island in August1989. Many residents would be surprised to find out that hurricanes are a necessary component of the biodiversity of El Yunque. Historically, El Yunque has been struck by a hurricane every 50 years. At this frequency, the rainforest can maintain a balance between old growth species and pioneer species. Scientific models predict that more frequent hurricane patterns would favor pioneer species and less frequent patterns would favor old growth species.

We were funded by a Small Grant for Exploratory Research from the National Science Foundation to develop a prototype of the El Yunque Learning Environment. Helping students discover the dynamic relationships of a complex ecosystem is the main learning goal. Hurricanes create a disturbance to the flora of El Yunque, which ripples through the fauna of the rainforest. In the prototype software environment, students investigate the dynamics of the coquí frog. The learning environment provides a model of scientific inquiry that guides students through the following phases: 1) exploration, 2) background research, 3) data management, and 4) data analysis.

There are three activities that comprise the exploration phase. Students begin by exploring Web sites related to Hurricane Georges. Next, students explore a 3D image of the rainforest. They can zoom in to marked locations to see panoramic images from the rainforest. Finally, students can explore an illustrated representation of the rainforest to observe where the coquí lives, what they eat, how they reproduce, and who eats them. In the background research phase, students return to these same questions by reading the *Coquí Chronicle*. In the data management phase, students are provided with a graph of baseline population numbers. They enter their prediction of population dynamics after Hurricane Georges and compare their predictions with the actual data. The learning experience culminates in the data analysis phase when students alter levels of prey, food, and reproductive habitats and see how the results compare to the actual data. It is our hypothesis that as students move through the investigation activities they will respond at increasingly abstract levels.

Method

Participants

Subjects include 54 students from a sixth grade class in a small parochial school. Gender breakdown is 58.8% male, 41.2% female. Students spent five class periods in Spring 2000 exploring the El Yunque Learning Environment during regular class time.

Materials

Post Activity Questions

The students were asked to answer a reflective question at the end of each activity for a total of ten questions. The questions were grouped according to the phase of the investigation: Exploration, Background Research, Data Management, and Data Analysis.

Level of Cognitive Reasoning

Student responses were coded according to the SOLO framework. We were able to identify two categories of levels of response. The first category was levels of response related to the features of the rainforest and species within the rainforest. The second category was levels of response related to descriptions of how those features change over time. We ranked the levels of response related to temporal descriptions as more abstract than levels of response related to features only.

Below are the codes that were assigned to the individual's response to the 10 questions that assessed the student's level of cognitive reasoning during the investigation.

Concrete Symbolic – Features (Cycle 1)

- Unistructural 1 - the student mentions only one feature.
- Multistructural 1 – The student mentions more than one feature.
- Relational 1– The student uses another location as a model to help organize the features found in a rainforest or features typical to a hurricane.

Concrete Symbolic – Casual (Cycle 2)

- Unistructural 2 – The student mentions one casual or temporal connection.
- Multistructural 2 - The student mentions two ore more causal or temporal connections.
- Relational 2 – The student describes a similar model in order to organize the causal description of the rainforest and its contents. The student goes on to relate another theme that would link the features and processes together. This would involve knowledge the student would have gained about another environment and using it in the context of the rainforest.

Results

A repeated measures analysis of variance was performed on the level of cognitive reasoning that was demonstrated by students. A main effect for project phase ($F(1,21)=40.49$, $p<.0001$) was found indicating that there is a statistically significant difference between students' level of cognitive reasoning at each phase. Table 1 shows the frequency of responses made by the students for each project phase.

To make pairwise comparisons across project phases, paired sample t-tests were performed. Results indicate that student responses after using the simulation contained the highest level of student cognitive reasoning as compared to the other phases (data analysis > exploration > research background = data management). Figure 1 shows how level of cognitive reasoning varies as a function of project phase.

Implications

As indicated by performance on TIMSS and NAEP tests, it is very difficult to teach students complex learning outcomes. This is consistent with previous research using the SOLO framework to evaluate student learning outcomes from multimedia learning environments (McGee e. al., 1999). During the exploration, background research, and data management phase, students were investigating content through a static medium. Their overall level of cognitive reasoning remained at the level of the first cycle, with a focus on features. After using the simulation environment, the overall level of performance raised to the second cycle, with a focus on changes to features over time. This finding points to the possibility of using dynamic simulations in situations where the underlying concept is itself dynamic. Future research work will focus in more detail on what features of the simulation environment contribute towards the positive increases in cognitive reasoning levels.

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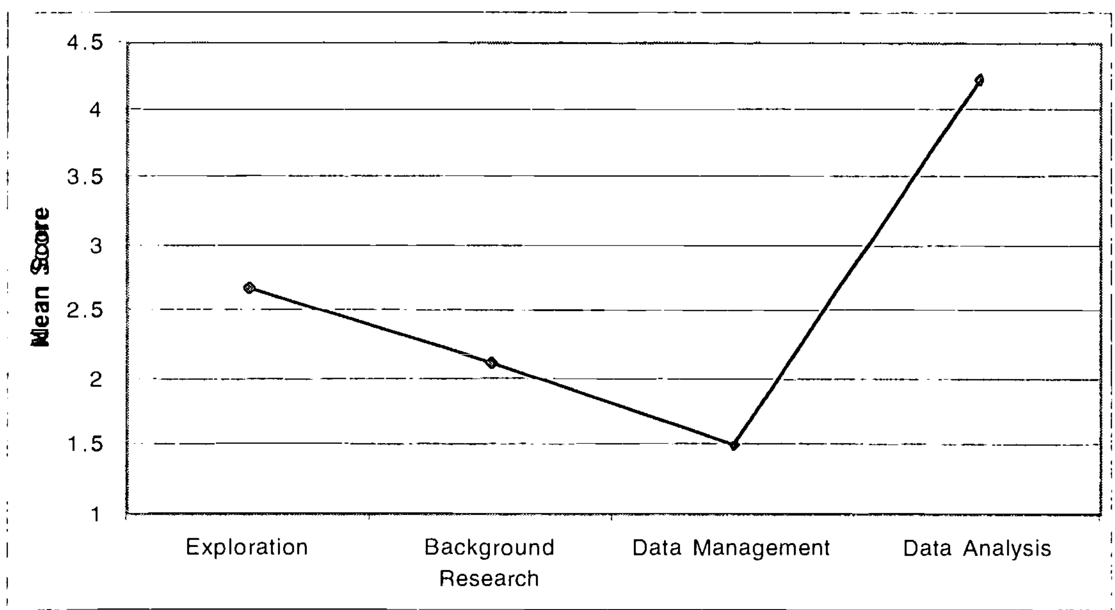
Table 1:

Percent of Student Responses by Project Phase

	Exploration	Background Research	Data Management	Data Analysis
Cycle 1 U	7.14	35.14	65.38	8.33
Cycle 1 M	53.57	25.68	26.92	6.25
Cycle 1 R	1.79	0.00	0.00	0.00
Cycle 2 U	26.19	16.89	7.69	25.00
Cycle 2 M	11.31	4.73	0.00	60.42
Cycle 2 R	0.00	0.00	0.00	0.00

Figure 1:

Level of Cognitive Reasoning as a Function of Project Phase



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