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ABSTRACT

One of the most pressing issues in education is the importance of creating learning contexts and communities that are based on children's thinking in science and enhancing their understanding of pertinent concepts. In this research study, fifth grade students (N=20) were asked to design a game teaching younger students about the ocean environment. The games developed by the students were examined along with the electronic interactions among the game designers and the classroom consultants who were a group of more experienced students in the same school. The analyses of the games showed that there was a strong connection between the content integration and the science-oriented theme of the game. The analyses of the electronic interactions indicated that students made early decisions about where to focus their discussions and initial attempts to discuss science content were redirected to focus on programming issues. The effect of the game programming context and the high level of creative control accorded to students on the type of science content integrated into their games and the nature of their electronic interactions is discussed. It was concluded that this project-based learning environment heightened motivation and commitment. Contains 32 references. (JRH)

Issues in Project-Based Science Activities: Children's Constructions of Ocean Software Games

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INTRODUCTION

One of the most pressing issues in education is to create learning contexts and communities that are based on children's thinking in science and enhance their understanding of pertinent concepts. Recent efforts in science education have promoted project-based activities as an alternative to work-sheets and teacher-centered instruction (Brown, Ash, Rutherford, Nakagawa, Gordon & Campione, 1993; Gordin, Polman & Pea, 1994; Ruopp, Gal, Drayton, & Pfister, 1993; Scardamalia, Bereiter & Lamon, 1994). Project-based activities, in theory, promote learning that integrates different subject domains, enhances student motivation, supports the development of metacognitive strategies, and fosters student cooperation (Blumenfeld et al., 1991).

There is little empirical research about project-based activities that can help educators define the various parameters for implementing successful learning environments. With these few examples, there is a need to define how individual differences in students' cognitive skills and motivation can affect learning outcomes. There is a need to redefine teaching approaches, activities, and materials as the teacher takes on activity-based learning. There is a need to explore how computational media can be integrated into the classroom and support students' learning. A central parameter concerns the level of control accorded to children in pursuing their research interests and determining the features of their final project.

The current study presents one application of project-based activities to help upper elementary students learn about one eco-system, the ocean. Traditionally, students explore ecological ideas by studying facts and observing living systems. In our study, we asked students to design a game teaching younger students about the ocean environment. This particular approach is grounded in constructionist theory, which postulates that learning takes place best when the learner is actively building an external and shareable artifact (Harel, 1991; Papert, 1980, 1993). Programming is one way to do this. In programming ocean games, children can represent their ideas and thoughts about ocean creatures, oceanographic geology and food chains using multiple media: text, graphics, and sound. We chose the game context because of its motivating nature for children (Lepper & Malone, 1987). In contrast to most educational approaches, in which children learn while *playing* games, here children learned while *making* their own games (Kafai, 1995) by directing their energies on the content area of oceans.

We conducted a four- month study with a class of 20 fifth graders in an inner-city public elementary school (Evard, 1994). At the end of the project, we gathered the completed ocean games. We first examined the nature of the ocean games and then sought to understand children's efforts to incorporate content about the ocean environment into the games. In addition, we documented and examined the electronic interactions among the ocean game designers and the classroom "consultants," who were a group of more experienced students in the same school. In our results section, we discuss the how the project unfolded for the students. We focus, in particular, on how the game programming context and the high level of creative control accorded to students in this project affected the type of science content integrated into their games and the nature of their electronic interactions. By examining the games and the electronic exchanges, we get a sense of the students' inquiry into science and programming issues. The unusual nature of our task, i.e., making ocean games compared to traditional research reports, allows us to highlight some of the potential problems and provide us with insights for future classroom implementations.

REVIEW OF RESEARCH

Recently, a small number of curriculum innovation efforts have implemented project-based research activities across various subject areas: history (Carver, 1992; Lehrer, 1992), mathematics (Harel, 1991; Kafai, 1995), biology (Brown & Campione, 1992; Scardamalia, Bereiter, & Lamon, 1994), atmospheric sciences (Gordin, Polman & Pea, 1994). These efforts have been triggered by debates and criticisms of traditional classroom research and tasks as being "inauthentic," or too far removed from the learning that occurs outside of classrooms (Resnick, 1987; Lave, 1988). While there is a lot to be learned from analyzing and comparing these different interventions, for this study we will examine more closely two project-based activities that share a set of common features: students' age, collaboration, computer use, and science content. We will focus on features of the interactions in the learning environment and the final products created by students.

The "Community of Learners" (COL) project developed by Brown and Campione (Brown & Campione, 1992; Brown, Ash, Rutherford, Nakagawa, Gordon & Campione, 1993) has students choose particular themes for their research projects. Students then collaborate in teams in assembling a classroom report in the manner of a jigsaw puzzle, each team being responsible for respective domains and informing other class members. Instruction is interwoven throughout the research activities. The final result is a report of teaching materials that contains the accumulated findings of all the project members. The "Computer Supported Intentional Learning Environments" (CSILE) effort implemented by Scardamalia and Bereiter (Scardamalia et al., 1992; Scardamalia, Bereiter & Lamon, 1994) starts students off with posing a series of text-based and knowledge-based questions about their topic of research. These questions then serve as guidelines for their research investigations. During their research, students make use of a communal database that allows them to deposit research results and to interact with other students (of the same or other classrooms) through e-mail exchanges. Eventually students are able to annotate posted research resports and link them together in appropriate manner, reflecting the interconnected nature of their subject domain.

The approach chosen for this study is called "Learning Science Through Design" (LSTD) and asks students to develop educational computer games on a given topic area (Kafai, 1995). Students usually work for several months, as in the two other approaches, conducting research, programming screens and interactions creating stories and dialogues around their science area. Throughout the project, students meet from time to time with their prospective users to evaluate their games in progress and are allowed to examine each others' games. In addition, students use a boadcast message system to communicate with more experienced game designers about content and programming issues. In the end, all students have designed an educational game that teaches something about the ocean environment.

All three of these project-based science activities share certain features: They focused on the subject area of biology/ecology, functioned in upper-elementary school classrooms, developed through collaborative peer interactions, and extended over the long term. There are, however, some distinctions among them, including: how much the project activities were integrated with science teaching; how much the collaborative interactions were structured in advance; and, how students used the computer to report on their research results.

Both COL and CSILE focused on integrating science instruction and project activities. In LSTD no such integration effort was made. Before starting the game design, students had prepared research reports on ocean environments but there was no additional science teaching accompanying the design activities except for teacher-student interactions during the computer time alloted to the project.

All projects made extensive use of collaboration to facilitate and enhance students' learning. In COL students made use of features found in the jigsaw method (Aronson, 1978) and reciprocal teaching (Brown & Palincsar, 1989) to interact and communicate with each other. In CSILE students functioned as editors and critics to each other when accessing reports and notes produced by other students. In LSTD students collaborated with who and when they deemed it necessary (Kafai & Harel, 1991a) and exchanged messages with a class of game design consultants (Kafai & Harel, 1991b). In addition, they met once a month with their prospective users, a class of younger students from the same school. The "level of agency" (Scardamalia & Bereiter, 1992) or "bandwidth of competence" (Brown, 1992) accorded to students in their interactions varied in both projects. Both, COL and CSILE, structured not only the social interactions but also their timing.

Another difference lies in the way students used the computer to report their research results. In both COL and CSILE, students were using word-processors to produce research reports and teaching materials. In CSILE, students were also able to input their products into the communal databases, annotate and link them together. In LSTD students were not using an application but creating an application by programming educational games. While it is clear that in the context of the LSTD projects, students learned programming in addition to learning science, it was also hypothesized that this particular process would enhance their science understanding in special ways by facilitating the inclusion of dynamic events (see also Harel & Papert, 1990). In a recent shift in science research, visualization and simulation methods have become recognized research approaches (Hestenes, 1992). The different production methods also resulted in different final products. In COL and CSILE students created research reports and teaching materials; students in LSTD created an instructional game.

To summarize, the projects, although overlaping in important aspects, differed mostly in regard to the levels of control accorded to students, the nature of the task and its employed production methods. If the continuum of level of control is described as ranging from child-centered to teacher-centered approaches, it is apparent that LSTD situates itself closely to the child-centered side. Approaches such as COL and CSILE may be placed at the mid-point of the continuum (Rogoff, 1994). Using the ocean game designers as a case in point, we will examine the implications of different degrees of freedom given to students in their interactions. Furthermore, we will also look in which ways the given project task impacts students' thinking and learning about the content matter.

RESEARCH PARTICIPANTS AND CONTEXT

The LSTD game design project was conducted with a class of 20 fifth-grade students who were programming games in Logo to teach other students about the ocean. The class had 12 boys and 8 girls from mixed ethnic backgrounds ranging from ages ten to eleven. Before the project started, each student selected an aspect of the ocean environment for a research project. Subsequently they decided whether to include the research results in their game design or not. All the students had programming experience in Logo, although they had to learn more sophisticated programming concepts as they created their games. The students met every day and transformed their classroom into a game design studio for about four months, learning programming, writing stories and dialogues, designing ocean environments and its inhabitants, considering interface design issues, and devising teaching strategies. Several "focus sessions" presented opportunities for the teacher and researcher to initiate discussions around issues and ideas relevant to all game designers. For example, issues about games, students' experiences playing games, ocean themes, what they learned, and programming ideas among other topics were discussed on these occasions.

The collaborative structure of the project provided ample opportunities for the game designers to discuss their games with their classmates, to show it to their potential users, and to a wider public. In addition, students used a discussion group in an electronic bulletin board system called NewsMaker that was installed on the local network (Kortekass, 1994). The discussion group was conceived as a tool for helping novice programmers get assistance from both their peers and older, more expert student programmers (Eward, 1994). It functioned much in the mode of a Usenet group in that all the posts were available to all the students. Individual electronic mail was not possible.

The research took place in an inner-city public elementary school in Boston. One part of the school is an experimental site of the MIT Media Laboratory, which was established eleven years ago and investigates the implementation and rituals of a computer culture. The school houses 15 classrooms with approximately 250 students and has 110 networked computers. The computers are arranged in four circles in the open areas surrounded by the classrooms with additional computers. While this feature distinguishes the school from usual classrooms, the student population is characteristic of an inner-city school with a high percentage of Hispanic and African-American students. The most distinctive features of the regular classroom activities are that all the students have daily access to the computer and they use mostly the Logo programming language to create their own software in contrast to using pre-designed program packages.

METHODS OF DATA COLLECTION AND ANALYSES

A combination of qualitative methods was used to document the students' ideas, thoughts, and progress in game development. Interviews were conducted to gather students' interest, ocean knowledge and evaluation of video games. During the project, the students participated in research activities by keeping notebook entries and saving log files to provide additional information for the researcher. At the end of the project, we had established a portfolio for each student consisting of daily notebook entries created by the students describing design plans, progress and problems; video interviews with the children conducted after the project; and, the game software.

For the purpose of this paper, we analyzed the final ocean games, designer notebook entries and electronic exchanges among students. To examine the nature of the ocean games and the content integration of the ocean environment into the games, the games were coded by researchers focusing on game themes, graphic and narrative complexity, content inclusion, and pedagogical strategies. In addition, we analyzed the logfiles of the broadcast messages for continuous exchanges. A more detailed analysis of the quantity and quality of messages exchanged during the first three weeks of the project has been conducted by Eward (1994).

RESULTS

We begin the presentation of results with an overview of the games created by the students and will follow up with an in-depth analysis of beginning electronic interactions, the content integration and pedagogical strategies included in games. All twenty students designed and implemented an ocean game. All the students situated their games in the ocean environment: 14 games were adventure-themed with a character overcoming underwater obstacles, five resembled quiz shows, and one involved role-playing and simulation. Most games engaged the player through a question-and-answer format, with 12 games asking questions about the ocean in a random way and eight games asking questions organized around a specific ocean theme: fish names, predator-prey relations, the coral reef, the continental shelves, or the ocean floor, for example.

Some aspects of the games were clearly inspired by television and video games. Ellen's lead character in her game, "Sea Quest," was Capt. Bridger, a likely reference to Lloyd Bridges of the "Sea Quest" television program. Some of the feedback appeared to be inspired by violence-themed video games. In Ted's game, for example, players met with various ugly endings: bleeding to death, an unsettling encounter with a bomb, bites by various fish. "The grouper bit you!" and "The clownfish hurt you!" Sam also employed this terrorizing tactic: "Shark got you!", "Octopus got you," and "Your submarine has hit the island and you are blown up under the water." Similar comments or endings were used mostly by boys. This reference to commercial games and media is a pervasive feature in many games designed by children (Kafai, 1996).

Some students became quite caught up in the drama, incorporating cinematic elements, such as scrolling text, animation, and elaborate scene-setting in both text and graphic images. In Ted's game, he explains at the game's outset that the player is a diver exploring the coral reef for treasure, then he segues into an opening animated sequence, showing a helicopter hovering over the ocean. In Saul's game, "Welcome to the Marines," he opens with scrolling text explaining that the player is an expert marine diver, then shows an animation of a grey ship sailing across a screen of blue waves, stopping, then letting a diver plunge over the side. This is the official starting point of the game.

Despite this clear interest in drama, only seven students went on to develop a full narrative. Most relied instead on short "teaser" lines designed to play up the mystery and excitement of the ocean world, but without any real follow-through in the traditional narrative sense. In the opening lines of his game, "The Deep Ocean," Juan reminded players that scientists "know more about the moon than we know about the ocean floor." In "Ocean Keys," Lorraine adopts the tone of an advertiser saying: "Welcome to Ocean Keys, the fabulous game of excitment, danger, and seaweed!![sic]" This lack of narrative stands in contrast to observations made in another game design project, in which students designed fraction games (Kafai, 1995). In this context, the majority of students adopted the narrative format at some point in the course of the game design. Some students also employed sophisticated rhetorical elements such as false or multiple endings to keep the players' attention.

Students' Electronic Interactions. We reviewed the electronic exchanges among the student programmers to see how students' representation of the game design task developed. We focused on the content of their exchanges for the first six days of the project when students were still feeling their way into the project and we classified these exchanges along three dimensions, according to their primary content: science content, programming content, and personal matters. We also traced the discussion threads to see how the electronic interactions progressed and to see what types of discussions were facilitated or stymied by the electronic environment

Our review showed that the children used the system to get their game design task done. Even though many of the 196 posts during this first six days were lively, and there was no shortage of good-natured teasing, this social banter remained grounded in the subject of programming. There was only 1 science content-related discussion thread. By the sixth day, there were three threads that critiqued the quality and content of the electronic interaction. And there were also 5 random personal comments that did not evolve into threads. These personal comments went along the lines o "I want to know what you think about this programe? I think it's cool and fun," (sic), and "You really look like (child's name) don't get mad because I said this."

Focus on Science Content. The specific trajectory of the one science content-related thread is illuminating. The researcher who oversaw the Newsmaker system noted that the students chose to exclude science content from their discussion early on: "This distinction between the science content of their games and the questions related to Logo programming was the first line drawn by the students..." (Evard, 1994, p. 83). This lack of science discussion might have contributed to the lack of science content engagement in a significant number of the games. The thread began when Jaime asked on the third day: "How many mammals live in the ocean?" There were nine responses. Five of them were attempts to answer the question, in which other students either tried to help their classmate reframe the question or actually offered information. Two responses could be classified as "silly" attempts to answer the question. And two more could be classified as refusals. One of the refusals came from the teacher, who rarely posted in the electronic environment. Evard notes that the teacher posted the message after being approached by several students. Her post read:

> "Is this question about how to design your game? Or is this a question about information you need to know to create your game? Who is responsible for doing the research about your topic? Your classmates or you?
>
> I suggest that to answer this question, you leave the computers and go into the classroom and consult the many books about the ocean which are there. If the answer is not in one of these books, I suggest you continue your research at the library."

In the remaining three days after this post, students continued to respond to Jaime's request, but no one else ventured to ask another science content question. The decision to remove science discussion from the electronic environment seems to stem from a view that other students should not be doing research for each other. This decision seems to reflect a deeply entrenched value of the classroom culture, namely that you do not ask your classmates for help because that is perceived as "cheating" or "shirking" or failing to learn by "doing it yourself." Similar observations have been made by researchers in other projects that used public exchanges to foster science learning (Jackson et al., 1994).

Focus on Programming Content. A different development was documented in the exchanges about programming issues. The programming discussion threads generally related to knotty questions about how to create sound effects or make characters talk, how to assemble geometric shapes into lifelike characters, and how to create certain animation sequences. Evidently, the student programmers were quite caught up in the challenge of bringing their creations to life.

One of the more intricate programming discussion threads concerned a que n posed on the third day by two different students, Juan and Ted, about making the turtle "repeat a wave" without making a circle. This generated 10 responses, five of which were either misfires or "don't knows." Of the remaining five, four offered differing solutions to the problem, including one that suggested getting the teacher to help. A fifth one recommended that the student talk to a classroom student expert who had performed a similar repeat procedure using a fish. Given the complexity of this problem and the sense that few students knew how to solve it, it is interesting that the posts never evolved into a back-and-forth discussion about how to resolve it. One explanation might lie with the limitations of the Newsmaker software. Unlike discussion forum threads that are indexed by initial post, Newsmaker did not permit tidy organization of the discussion threads. All the posts were presented in a scrolling format down the screen. As such, it was probably difficult to track a particular discussion. Since there was no personal electronic mail capability, it was also difficult for the questioners to organize the responses. Another possible explanation is that the students saw the electronic context as a place to get quick answers and quick responses, not to engage in deliberation or debate.

Focus on Social Conventions. The structure of the electronic exchanges evolved over these early days. Students experimented with ways to communicate in this medium. Several of the conventions of face-to-face conversation emerged in the electronic environment such as saying "I don't know" and "thank you" in response to questions and answers. Conventions of letter-writing also emerged, such as signing posts, "Yours sincerely." The students gradually developed, by trial and error, their own interactional "ground rules" for the Newsmaker environment. Some types of interactions, such as "I don't know" were discarded by the electronic community because they were viewed as clutter.

One benchmark of the restructuring process that occurred over these first few days is reflected in the responses to the very first post: "How do you make a new shapes page?" It received 15 responses, making it the longest thread of the time period under study. Of those 15 responses, seven offered essentially the same solution over and over again, five were misfires where one message was resent repeatedly by the same student, two were "don't knows," and one was a "can't do it" message. By contrast, a post that emerged on the fifth day concerning how to remove a box from the corner of the screen received a more efficient string of responses. Of the six responses, none of them were "don't knows" or misfires, and five of them explained the box couldn't be removed or offered some possible ways of minimizing it or getting rid of it. One post served as what conversational analysts would call an "agreement token," with a student simply chiming in with another's suggestion.

By the sixth day of the system, messages that did not offer information, were off-topic or unclearly stated, or just plain rude, were singled out for criticism: "Answers like 'I don't know' don't make a lot of sense," as one student wrote. "I think that some of the answers that are given are rude and impolite. Newsmaker is not a place to talk about what happens during the day, it is a place to ask questions and get answers," wrote another. In addition, by the fifth and sixth days, more students were using Newsmaker to link classroom "experts" with classmates needing assistance: "Talk to (Jose). You two are in the same boat. (Pardon the pun)." The positioning of students in different roles was also a part of the other project-based learning environments, COL and CSILE. The difference is that in these contexts, the teachers assigned the roles in advance; in LSTD, the roles of expert and novice evolved through the student electronic interactions. As Evard (1994) noted in her analysis of the first three weeks of electronic communications, students also determined what exchanges were best done face-to-face and best done on-line. They preferred not to type out long procedures in the Newsmaker environment, but to schedule times so they could discuss the procedures in person: "I can't write out the whole procedure right here because it's too long, but maybe I can print it out and give it to you on the bus."

The predominance of programming issues in the electronic discussions also reflected students' focus in the game design process. As the following analyses of ocean content integration into the games shows, students found it difficult to reconcile the two tasks of programming a game and learning about the ocean environment.

Ocean Content Integration in the Game World. From a point of view of ocean content integration, the games could be classified as "rich," "moderate," and "minimal." Rich refers to games where the student incorporated more than four facts, developed a theme, and attempted to integrate the facts. The number four was selected as a threshhold because, within the small universe of 20 games studied, it represented a clear point of distinction. Anything beyond four supported a pattern of content integration. Moderate refers to games where the student referred to fewer than four facts or fish names and did not attempt to interrelate the information. Minimal refers to games where the students used one fact or a few fish names, at best. Following this classification scheme, seven of the games could be considered rich, seven, moderate, and six, minimal.

Continuing this analysis to see if there was a correlation between the organizational strategy used by the game designer and the level of content integration achieved, we find that five games organized around a theme were rich, while the other three themed games were moderate. One of the themed games contained minimal content. By contrast, two of the random question games attained rich status, three attained moderate status, and five were classified as minimal. These correlations suggest that students are more likely to achieve higher levels of content integration when they have a theme around which to organize their games (see Figure 1).

Another analysis rates the game designer's focus on graphics on a five-point scale: animation and graphics (5); animation only (4); still graphics only (3); limited pictures/graphics/mazes (2);

and, a couple visual elements only (1). Three students attained a rating of 5; one a level of 4; nine a rating of 3; two a rating of 2; and one a rating of 1. Four of the students' games could not be categorized because we lacked access to the full games because of programming glitches. We reviewed these games via their programming code only. Correlating these graphic scores with content ratings, we find a fairly even distribution of content levels to graphic scores. The three students at level 5 graphics represent each of the content attainment levels. Most students settled at the level 3 graphics level, and again, they represented each of the three content attainment levels fairly equally. Finally, each of the content attainment levels was represented at the lower end of the graphic scale.

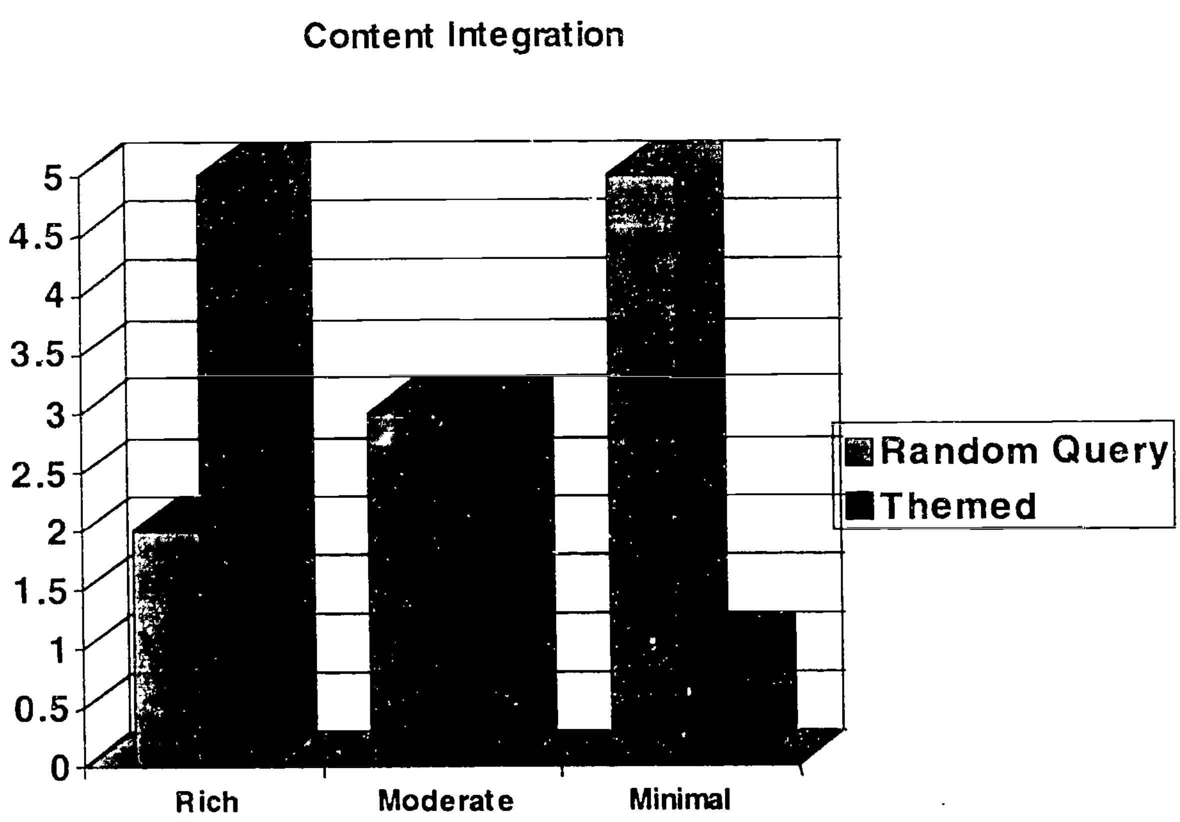

Fig. 1: Distribution of content integration in ocean games.

These findings suggest that sensitivity to graphic design is a variable that is fairly independent of content concerns. There was a similar distribution when relating narrative structure to richness of content. In general, the seven students who employed narrative were evenly dispersed along the three content attainment categories; same for those who did not employ narrative. These results suggest that sensitivity to narrative is a variable that is fairly independent of content concerns.

Pedagogical Strategies. We also examined the nature of pedagogical strategies employed by students in their games as an indicator of what kind of learning environments the students created for their intended users. Most of the games employed question-answer formats. Students usually used multiple choice questions, true-false questions, and an advance organizer technique, where they presented factual information at one point in the game, then tested the player later. To a lesser extent, students tried to make the information easier to wade through by personalizing certain facts, phenomena, or fish. They latched onto familiar or surprising concepts, and drew analogies.

In "Under-Sea Adventure," Rhonda selected facts that accentuated the surprising differences and similarities between life on land and life in the sea. Pea crabs, she said, are no bigger than peas. Blue baby whales weigh 5 tons and drink 132 gallons of mother's milk each day. Pistol shrimp snap a large claw to startle their prey, then kill it.

Sometimes students anthropomorphized the fish, like Tonya, who said the male gourmis "push you around" and "think they own everything." This approach has been cited in the research literature (Hatano & Inagaki, 1987) as one approach many students choose in their developing understanding of biology concepts by creating analogies to human behaviors. A more sophisticated analogy was employed by Saul to introduce the player to the concept of continental shelves. Saul reminded his game player that when "someone walks on the beach," the continental shelf grows larger through accretion of sand pushed by these footsteps.

Only one student, Austin, took this kind of strategy to the level of near simulation. In his game, he asked the player to select a role to play among five fish: little skate, sand lance, American lobster, squid, and alewife. Then, the player encountered various fish and was asked to decide whether to eat it, chase it away, ignore it, escape shallow, or escape deep. Through feedback after each encounter, Austin attempted to teach the player about the logic of the food chain: "Well, that was a waste of time! That fish was harmless! Don't waste energy like that!"; "Yummy! That was a good meal! If only every fish could eat that well!"; and, "Hey! That was perfectly good food! Next time, maybe you'll get it straight!" After watching his game go through a few dry runs with younger students, Austin said that, given the chance to improve his game, he would incorporate more hints about food chain logic next time.

It is apparent from this analysis, that most students created conventional drill-and-practice games, with the exception of Austin, reflecting little of the open-ended learning environments they experienced themselves (Lehrer, 1992). One of the possible explanations refers to the dominance of models of teaching and learning as they are propagated in commerical and cultural media. For example, many educational games available on the commercial market or designed by teachers emphasize drill and practice and retention of facts. In most instances the game itself is disassociated from the content to be learned. Another explanation is that open-ended learning environments are harder to invent. A game structure that allows players to advance when they answers questions is conceptually simple: The content challenges are fully factored out of the game context. The fact that all the students were novice programmers might have contributed to this solution.

But the impact of cultural stereotypes was also demonstrated by the violent feedback that some students used to shape the player's experience of the game. Four students opted for violence or cutting the game short when the player got a wrong answer, like Mario: "You have hit a reef and killed many fish. Start over." The four students who opted for violent feedback all offered only minimal content in their games. These four students, all boys, also tended to rate higher in the graphic content of their games, incorporating graphics and animation when possible. These results suggest that these students wanted to re-create a flashy video game rather than engage in the educational aspect of the exercise.

Seven students preferred simple feedback that merely informed the player if the answer was correct or incorrect. Usually these games said, "Try again!" if the answer was incorrect. Three of the students preferred more personalized feedback, where there was distinct tone and voice to it. Austin, for example, would say, "Yuck! What revolting food! Next time, leave those for someone else who needs them." Tandy took her feedback to a high level of personalization, taunting the player: "Are you crazy? Are you sure you want to finish?" Ellen interspersed her feedback from Capt. Bridger with evil textual "laughs" of delight when the player got a wrong answer. Only one student, Rhonda, provided feedback through a running score.

DISCUSSION

In our analyses of the LSTD project, we focused on the intertwining of social aspects, as exemplified in students' electronic interactions, with the individual constructions of the educational games designed to teach younger students about the ocean environment. In our analyses of electronic interactions, it became clear that students made early decisions where to focus their discussions: initial attempts to discuss science content were redirected to focus on programming issues. At the same time, students established social conventions on what they considered acceptable contributions or not. The analyses of the games showed that there was a strong connection between the content integration and a science-oriented theme of the game. Students took advantage of the many degrees of freedom accorded to them in the design of their games. On the other hand, the investigation of pedagogical strategies indicated that many students were not willing to give the same latitude to their players in the design of their ocean learning environments. In the following discussion, we want to cast a wider net by examining the level of control accorded to students in their interactions and the given project task that seemed to impact students' learning experience in important ways.

Levels of Control in Interactions. Learning Science Through Design, as contrasted with the other two project-based learning environments discussed in this paper, offers children a high level of creative control over the production of an artifact. Under this learning framework, children are hypothesized to learn at a deeper level when they create a representation of their knowledge, feel "ownership" of a product, and know they will share their product with other people. Although the actual products created in this environment do not consistently attest to learning science at a deeper level, the electronic mail discussions lend some support to this hypothesis:

1. The majority of discussion threads remained on point.
2. The children established their own interactional ground rules.
3. The children attempted to help each other frequently.

These findings suggest that the type of project-focused engagement educators hope to instill in students was developing within the LSTD project-based context. Unfortunately the ocean games community did not incorporate the science content into its electronic discussion. Based on the commitment and complexity of the electronic discussions about programming and the resulting success of many of the students' games as programming feats, it appears that if the students had chosen to bring science into the discussion -- or if they had been encouraged to -- then perhaps more the games would have incorporated deeper levels of science content.

In our analysis of the game programming environment as a context for project-based learning, we discovered various similarities and differences in outcome between the LSTD approach and two other well-known project-based curriculum designs. Both CSILE and COL focus on the culture of inquiry that exists in the classroom, grounding their approach in Vygotskian ideas about collaborative learning and the zone of proximal development. In both of these environments, the idea of having an audience of peers is critical to fostering deeper, more self-directed and personally meaningful inquiry. The LSTD approach offers another twist on collaborative learning -- one that lets children represent their knowledge by creating an artifact to share with other peers.

If the CSILE and COL projects illustrate ways of incrementally giving children more control over their inquiry, then the LSTD project represents a learning environment that gives children the highest level of control. Based on our results, we have to conclude that such an environment was highly motivating for the children, but also somewhat overwhelming. A number of children chose to focus almost exclusively on the "bells and whistles" of the technology. Another group of children sought shelter, so to speak, in the familiar worksheet-style pedagogy of the traditional school classroom. As understandable as such responses are, they are problematic in the educational context. Ultimately, these results suggest that the LSTD context, as formulated in this project, fails to create a *consistent* context for a deeper level of subject inquiry.

Perhaps in the future, the LSTD method needs to structure the electronic exchanges around content more along the lines described by both Scardamalia and her colleagues in the CSILE project and Brown and her colleagues in the COL environment. In these projects, children were encouraged to ask questions and seek answers from their classmates. Such interactions were viewed as an essential component of "authentic" learning because they helped students learn to frame questions, answer questions, and, in short, "learn to learn," (Brown et al., 1993, p. 190). Expertise can be distributed, as Brown says, around the classroom, and different students are responsible for covering certain areas for the group.

> Participants in the classroom are free to appropriate vocabulary, ideas, methods, and so on that appear initially as part of the shared discourse and, by appropriation, transform these ideas via personal interpretation.

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(Brown et al., 1993, p. 192)

In our learning environment, hindsight shows us that Jaime's query about the number of mammals in the ocean might have been handled more effectively. This question might be categorized as a "wonderment" question by Scardamalia and her colleagues (Scardamalia & Bereiter, 1991). At heart, Jaime's question was not so much an effort to get other children to do his work as an effort to find a way to describe the vast breadth of creatures that fill the mysterious void of the ocean. If it had been treated as such, the exchanges might have gone differently. Students might have discussed alternative ways of communicating this breadth or built upon his basic concept by suggesting that other categories be added to "mammals." The difficulty of discussing science content in electronic exchanges has also been noted in other project-based learning environments. In the evaluation of e-mail exchanges concerning the gathering of weather-related data in the "Kids as Global Scientists" project, Songer (1995) also commented that less than 10% of all exchanges related to the science issues; many other exchanges were more of social nature. Still, we feel that the electronic environment probably would have accommodated such a discussion based on the richness of the electronic exchanges we saw concerning programming issues.

Level of Control in Project Task. One central feature of project-based learning is that students are usually working on complex tasks that go beyond worksheet exercises answering questions. In all three approaches, students were engaged for many weeks in the production of their research reports (CSILE), teaching materials (COL) and educational software games (LSTD). If we adopt the perspective of Barbara Rogoff, that lessons may be placed along a continuum ranging from teacher-centered to child-cen-ered, with the mid-point being a "community of learners" approach, then the LSTD approach situated itself closely, perhaps too closely, to the child-centered side (1994). In the game design situation, it was apparent that students had many more degrees of freedom to decide in which ways their game could relate to ocean content. As the results indicated, the majority of games could be classified as having low and medium content integration. These game designers tended to employ two approaches: (1) constructing narrative adventures involving fantasy elements such as divers, undersea treasures, bombs and dangerous fish, or (2) using traditional worksheet-style question formats and word search games to transmit a few random, scant facts about the ocean environment. These games demonstrated little systematic knowledge of the ocean from a scientific perspective.

By contrast, those students achieving rich content integration situated their games in a specific ocean locale: coral reef, ocean floor or continental shelf permitting students to construct a miniature ecosystem, linking animals to ocean geology and habitat conditions. But even here, students do not push the full possibilities in their designs. Consider the following example of one game that used predator-prey relations. The student tapped into the player's knowledge of how certain sea creatures related to several other types of sea creatures. As some researchers have pointed out, the predator-prey relation is a good starting point but does not necessarily lead to a more sophisticated understanding of food webs (Gallegos, Jerezano and Flores, 1994). Students ultimately need to develop an understanding of the food web where there are numerous relationships.

While content integration proved to be a problematic case for students when given the choice, we could oberve the children's attraction to games in the high levels of personalization in each of the ocean games. Students pursued more personalized themes and approaches: drawing analogies between marine and terrestial animals, anthropomorphizing marine animals, and highlighting "fun facts". As strategies, these approaches embody both assimilative and accommodative mechanisms, but are limited by their less than scientific or systematic view of the ocean environent. This points to an important issue in project-based activities: Students need to develop those personal "hooks" to maintain their motivation for a long term project. The games employing anthropomorphizing and analogizing strategies attempted to bring the subject matter closer to the player's and designer's experience. The question, then, is whether making games (at least in the way they were used in

LSTD) are good and productive environments for learning about science. This question relates to the issue of creating "authentic" learning tasks for children.

There are essentially two positions in this debate: one is is to adopt a stance that says "do as scientists do", the other is "learn how scientists do". Brown et al. (1993) adopted the later stance and argued that engaging young students in similar practice as real scientists would be hoping for too much:

> "Even without an appreciation for daily life in grade school, the armchair philosopher must see the impracticality of suggesting that children be encultured into the society of historians, biologists, mathematicians, and literary critics. This may be the desired state of first-rate graduate school education, but it is surely not a reasonable expectation for grade school . . . We argue that schools should be communities where students learn to learn." (Brown et al., 1993, p. 190)

The "community of learners" approach acknowledges that a classroom can only approach authenticity. A classroom has been described as a self-consciously structured environment built "around the children's interests in ways that will involve them in meaningful activities connecting with the skills and values of adulthood," (Rogoff, 1994, p. 3). The LSTD context was patterned after the model of a high-tech game design student more than a science lab. Viewed from this perspective, we can argue that the game programming context shows potential for moving students toward more scientific learning practices, but perhaps needs more self-conscious structuring from adults to highlight the "science" over the "game." In real life game design studios, after all, there is a specialization of expertise: the programmers program and the content experts develop and research content.

Although we did not conduct formal assessments of what the children learned in this environment, we can summarize our observations of what they appeared to learn. Most of them clearly learned the practice of programming, which requires them to think in a procedural, logical way and break down different tasks to their component parts. The game context also provided students an opportunity to begin exploring a more scientific view of the ocean environment, such as the biological relations of predator-prey and miniature eco-systems. One promising area that was not explored in these games, but that might in future applications, is using this computational environment to move children toward more authentic use of cutting-edge scientific tools, such as computer simulations and visualizations (Kaufman and Smarr, 1993). Perhaps using the game context could be viewed as a way to link a graphic world that is quite familiar to students -- video games -- to a graphic world quite new to the students -- scientific visualization.

CONCLUSION

The LSTD learning context stood on the margin between popular culture and scientific culture, more akin to a high-tech game design company than a science lab. It was a context that leaned heavily toward a "child-centered" approach and might have benefited from more structure to enhance the integration of science content. In our learning environment, we saw children practicing particular skills that will be useful in helping them become effective learners in the future: asking each other for help in problem-solving, finding ways to present information, and developing an understanding of programming procedure. We saw children grappling with ocean information and trying to incorporate it into a context that is familiar to them: games. We saw children achieving rich content integration by situating their games in specific ocean locales, permitting students to construct miniature ecosystems, linking animals to ocean geology and habitat conditions. We saw other children achieving rich content integration by pursuing more personalized themes and approaches: drawing analogies between marine and terrestial animals, anthropomorphizing marine animals, and highlighting "fun facts".

We also saw that this project-based learning environment heightened motivation and commitment, pushing the students to their personal limits, as one student expressed at the end of the project:

> "I really expected even though the teacher told me that it would take months and months and months to finish the game, I really did expect to do it, like start it, in one week and finish it up the next week. ... I just went like: Oh, this will be easy. All it will be, is a little bit of this, a little bit of that, and a little research, and I'll be finished. But it didn't turn out that way because I had to spend a lot of days on research and programming. There were tons of problems, like one time my turtle was messed up. Plus I had to make all the graphics and everything. So it had problems, but it has been fun."

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