ROBOTICS ACTIVITIES AND CONSTRUCTED PROBLEM SOLVING: CREATING SPACES FOR LEARNING/DOING

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The case of students solving complex tasks for autonomous robots is explored as an example of the dynamic of learning/doing. Related to the interdependence, emergence and form of classroom dynamics, as discussed by Davis et al. (2000), and to the complexity of relationship, systems and meaning dynamics as described in Fleener (2002), learning/doing extends traditional notions of constructivist learning by considering the social and cognitive spaces of learning and doing as a complex system of relationship, meaning, and activity.

FOCUS OF THE PAPER

In Engaging Minds, Davis et al. (2000) discuss the complexity of the interdependence, emergence, and form of classroom dynamics, including the web of relationships among teaching, learning, and curriculum. We will offer a glimpse of their vision of a dynamic learning environment by describing how students, engaged in robotics activities, create spaces of meaning for mathematics learning and discourse. Focusing on learning rather than teaching, as do Davis et al. (2000), while emphasizing meaning-making as a hermeneutical and social process of relationship, meaning and system, we will consider how rich activities may provide opportunities for "recreating heart" – reviving schools as places of learning/doing.

THEORETICAL FRAMEWORK: LEARNING/DOING DYNAMIC

Foucault (1986) developed the notion of knowledge/power as the inextricable relationship between knowledge and power. According to Foucault, "power can never be the property of an individual" (Appelbaum, 1995, p. 39), and knowledge, as well as power, are aspects of the social dimension. Knowledge/power, then, is something separate from either individually and is the dynamic between the two. Similarly, neither learning nor doing can be separated from the social dimension or from one another. Learning/doing, like Foucault's knowledge/power relationship, is a structural dimension of the social context. This relationship extends the constructivist notions of learning beyond the cognitive realm to include the active embodiment of knowledge as a complex of relationships.

The logic of relationship can be found in Dewey's logic as inquiry (Dewey, 1938), and Whitehead's process philosophy (Whitehead, 1929). A logic of relationship understands that all that is and that we know is in interdependent, dynamic relationship. Nothing exists, posits Whitehead, that is not in relationship. The logic of systems challenges fragmented, piecemeal approaches to meaning and purpose, considering the form of systems per se. Inextricable relationships within systems cannot be studied apart from the complex web of relationships that give the system its identity and purpose. Chaos, complexity, and complex adaptive systems approaches explore system dynamics from this perspective of interdependence and connectivity. Finally, a logic of meaning, as first explored by Wittgenstein (1953), suggests that meaning structures themselves do not exist and cannot change until we change the language we use to describe our world.

We cannot re-vision schooling while maintaining our traditional ideas about teaching, learning, and knowing. Until we change the ways we talk about what it means to know mathematics, we cannot hope to recreate classrooms where the very soul of mathematical inquiry, as a process of discovery and invention rather than consumption or transmission of inert facts, is possible. The learning/doing dynamic captures the complexity of learning as active, social, and contextual processes.

This paper presents a description of a team of students engaged in creating an autonomous robot. The nature of their problem solving efforts, both in programming their robot to solve particular tasks and in their creation of tasks for their robot to solve, will be explored using case study methodology. From the perspectives of meaning, relationship and systems, the students' construction of an autonomous robot will exhibit the interdependence, emergence, and form of a learning environment that engages the minds (Davis et al., 2000) and souls (Fleener, 2002) of these students as dimensions of learning/doing.

RELATED LITERATURE: OPPORTUNITIES FOR LEARNING/DOING

Seymour Papert (1980) was among the first to envision the potential of students' programming robots to transform schools. His Logo environment, he argued, supported Piaget's notions of students' needs to actively construct mental structures through experimentation, experience, and activity. He hoped that by programming turtles in his virtual Logo environment, students would themselves become mathematically empowered by gaining confidence in their abilities to do mathematics, deriving new understandings of and appreciations for mathematical relationships, and engaging in problem solving and reasoning activities to achieve complex tasks.

The early Logo virtual environment was extended with the invention of the floor "Turtle" in the 1980's. Mirroring the moves of the Logo turtle on the screen, the floor turtle was linked to the computer so students could solve problems in three-dimensional space. While the move from two-dimensional virtual space to three-dimensional "meso" space (Berthelot & Salin, 1994) greatly enhanced the opportunity for students to experience the movement of the turtle as an "object to think with" (Papert. 1980, p.11), the tasks to be solved and the inability to instill in the Turtle it's own abilities to "think," limited the impact of Logo in either its virtual or three-dimensional applications.

In the last decade, Papert's vision has been revisited as computers have become more powerful and accessible. While research on the impact of students' programming, per se, has not been definitive, current research (see, e.g. Kaput, 1992) re-examines how general-purpose programming may be valuable as tools for problem solving. Yelland (1995), for example, suggests solving problems through programming may promote higher order thinking skills, develop flexible and creative thinkers, and strengthen problem-solving abilities.

Current research on brain dynamics supports approaches to learning that include rich contextual problems allowing for multiple levels of and approaches to understanding. Richardson's book (2000) The Making of Intelligence suggests traditional constructs of intelligence that reduce it to either genetic endowment or environmental factors fail to capture the complexity of the dynamics of active engagement and multiple levels of representations that occur as we interact in rich environments.

Still unexamined, however, is how students' efforts to program autonomous robots capable of interacting with their environments, may challenge traditional notions of problem solving and extend ideas about learning. No longer programming the turtle to solve a particular task, students must explore how to make their robots "think" – how to program a robot to interact with its world in order to solve tasks. More authentic, the challenge becomes not how to set the robot in motion but, rather, how to instil in the robot the ability to take in sensory data as information about its environment and react and respond in ways that still allow the robot to accomplish a particular task. It may be that by moving between spaces of self and robot, thinking and doing, students are afforded opportunities for engaging in what Foucault describes as technologies of the self: "models proposed for setting up and developing relationships with the self, for self-reflection, self-knowledge, self-examination, for deciphering the self by oneself, for the transformation one seeks to accomplish with oneself as object" (Peters, 1999, p. 12). Beyond the cognitive dimension alone, working with robots that are capable of sensing light, touch, and other environmental dynamics, students are afforded opportunities to engage in learning/doing.

METHODOLOGY

The students described in this paper participated in an after-school robotics club, and were members of a middle school team that competed in the Spring 2001 Botball competition. Botball is a six-week K-12, national robotics competition sponsored by the KISS Institute of Practical Robotics (www.kipr.org). Teams that enter receive two small processors (a Handyboard and a Lego Mindstorms RCX processor), software (Not Quite C for the RCX and Interactive C for the Handyboard), various sensors for both processors, and Lego parts for constructing their robots. The teams must design, build and program robots using the C computer language to compete against other teams' robots in a competition arena.

Our case study explored how these students came together and approached creating and solving problems for their robots as they learned about robot construction and programming. We used categories described by Davis et al. (2000) as our interpretive framework for exploring the complexity of learning/doing afforded by the robotics activities of this group. Thus, interdependence, emergence, and form (see Davis et al., 2000) were the multiple lenses through which we examine the problem solving activities of this group of students.

RESULTS: TEACHING ROBOTS TO THINK

Our Botball team organized into three groups: one robot team for each of the two processors and a web design team. Each group further divided into teams of builders and programmers. The builders constructed the mechanical structure of the robot. They had to figure out how to integrate the processor, motors and sensors into their designs while working with the programmers to determine design features that were necessary to interface with program objectives. The programmers wrote the computer code to coordinate the robot's actions. Recognizing and anticipating environmental characteristics were aspects of the problem solving space that required discussion among both builders and programming groups. After the Botball competition, the BOTS club continued to meet, creating and solving their own robotics problems.

The robotics club met every week after school for the remainder of the semester. All but one student remained active after the competition while several new students joined the club. The students determined procedures for deciding what tasks they wanted their robots to accomplish. Club sponsors, including two of the co-authors of this paper, facilitated club activities. Student sense-making activities included problem posing, anticipation of environmental and design features, and explaining, listening, justifying, facilitating and probing each other's ideas. The adult facilitators enabled sense-making activities rather than providing solution strategies or setting parameters for problem posing and/or solutions (Wood, 1999). This approach is consistent with Cobb and Steffe's (1983) teaching experiment where the teachers assume the role of participant observers, engaged in student activities through their own listening, querying, and interactions as students work toward problem definitions and solutions. This research approach is particularly relevant in robotics activities as a case where the teachers seldom have a single "best" approach in mind. Creativity as an aspect of solution strategy is supported by the richness of the potential of robotics activities.

As the students in the robotic club learned to work with their robots and use them to accomplish particular tasks, it became clear that there were multiple dimensions to their problem solving. The complexity of the activities in which they engaged can be captured by examining their efforts from the perspectives of the structure of problem solving efforts, interdependence of activities, and emergence of meaning as aspects of learning/doing.

Structure of Problem Solving Approaches. Initially, determining the task for the robots to accomplish was the responsibility of the organizers of the competition and the facilitators of the club, especially during team competition. As students became more adept at working with the robotics components, they began to take responsibility for defining their own tasks. Whether the tasks were defined by the facilitators or by the students, however, there were specific components of the problem solving process that were identifiable.

For example, whether the task was simply to get the robot to move forward and knock down an object, follow a straight line using sensors, or negotiate a maze, students had to design their robot for movement and appropriate sensory inputs, program the computer to use the sensory data the robot received through the various sensory input devices, and write a program that allowed the computer to use this data and take the appropriate actions. Decomposing the problem into these structural characteristics was just one aspect of successfully programming their robot to complete its tasks, however. Anticipating environmental complexity was a problem solving feature beyond the structural dimension of task completion.

Interdependence of Activities. The mechanical or structural features of programming their robots to accomplish tasks were not separate from learning to respond to and anticipate aspects of the environment in which the robot acted. The interdependence of learning to interface with and respond to the complexity of the learning environment, including learning to respond to and anticipate obstacles to task completion, were seamless with learning the mechanics of programming, robot design, or sensory interfacing. Thus, an important feature of the richness of the robotics learning environment seemed to be the complexity of tasks necessary for problem solutions. The students couldn't first concentrate on the mechanics, then focus on the problem for the robot to solve. Linear problem solving approaches (Polya's approach, for example) were not viable for solving the tasks these students were tackling. Neither "top-down" nor "bottom-up" strategies seemed to work as students' problem solving efforts fluidly oscillated between the mechanics of problem solving and the strategies of problem solving.

Learning to navigate was a complex activity that exemplifies this dance between mechanics and inspiration, knowledge and creativity. Students initially approached the problem of robotic navigation by programming the drive motors to propel the robot for a specified time. Backward or turning motions were conceived as reversing or differentially turning motors at each wheel. The students typically started with dead reckoning to determine the length of time necessary for motors to run. Gear slippage and loss of power in the batteries, however, created drift and affected the distance and direction travelled, resulting in missed targets and errant robot motion. Students learned to anticipate these problems and developed strategies that reflected an understanding of motion as an interaction with the environment and not simply movement through space and time. Thus, for example, students typically solved this problem by using the encoder sensor to determine wheel revolutions allowing for more precise determination of movement distances. Later approaches incorporated the range sensor allowing the robot to determine relatively precise distances from objects. This later approach extends robot motion from a calculation of distance to an intelligent response to its environment.

Emergence. While attending to the larger problem solving task, students learned to communicate with one another as well as with the robot. The interdependence of mechanical and inspirational aspects of problem solving is extended as new meanings and skills are gained. As problems with solution strategies became apparent, opportunities for accommodating these difficulties qualitatively extended the learning opportunity. These emergent understandings were facilitated by the learning/doing interface.

Learning/doing became apparent to us as students alternated among skill development, creative problem solution, brainstorming, mechanical engineering, and programming. Within each problem context, there were multiple events of emergence accompanied by routine activity. Without emergence, however, problem solving efforts were stymied or reached a plateau.

IMPLICATIONS: THE SOUL OF LEARNING

Davis et al. (2000) suggest "teaching is about affecting perception" rather than "helping students to know what they don't know" (p. 26). The importance of the robotics activities was not in solving particular tasks, or even in the process of solving the tasks. Instead it was in changing how the students looked at their world, problems, and communication. By trying to anticipate how the robot would experience its world and creating a program that would allow the robot to respond appropriately, there were multiple opportunities for the learning/doing complex to unfold.

Just as Whitehead (1929) rejected Newton's idea that the most basic, fundamental reality is entities in space and time, elevating relationship as the essence of all being, so this robotics case illustrates that learning is not about "knowing," "thinking," or "communicating" but is about knowing-relationships, thinking-relationships, and communication-relationships. Learning/doing captures the dynamic of these multiple relationships as our students' problem solving efforts changed when they stopped looking for solution (things) but instead started seeing problems as rich environment-interpretation interactions.

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