Robotics and Discovery Learning: Pedagogical Beliefs, Teacher Practice, and Technology Integration

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Much educational software is designed from a specific pedagogical stance. How teachers conceive of the pedagogical stance underlying the design will affect how they use the technology; these conceptions may vary from teacher to teacher and from teacher to designer. There may be a conflict between the designer's pedagogical beliefs inscribed in the educational technology innovation itself, and the teacher's pedagogical beliefs, which may affect the teachers' ability or desire to use the educational technology innovation. The purpose of this study is to contribute to our understanding of this issue by examining teachers' reflections on teaching and learning robotics through the discovery learning method. Data for the study were collected at a teacher professional development workshop series and at a robotics fair. A total of 20 middle and high school teachers participated in the study. Our findings indicate that teachers' perceptions of student learning needs influence their pedagogical practice and that these perceptions and practices may be affected through teaching and learning with discovery learning-based educational technologies. Teachers developed a strategy aimed at creating and managing a pedagogically productive tension in students. They also devised two modes of learning alongside students. Implications for future research regarding technology integration are discussed.

Data from the U.S. Department of Education indicated that there is one instructional computer for every five students in the United States (Parsad & Jones, 2005). In addition, more and more teachers report they feel increasingly prepared to teach using educational technology (U.S. Department of Education, 2000). Despite these developments, researchers continue to record an underutilization of educational technology in K-12 settings (Bauer & Kenton, 2005; Cuban, Kirkpatrick, & Peck, 2001; Windschitl & Sahl, 2002). Indeed, Bauer and Kenton reported that though teachers feel confident to use technology, their actual observed use of technology in the classroom may be characterized as random and occasional. Furthermore, teachers who do integrate technology tend to use it for communication purposes or for low-level activities such as word processing or searching the Internet (Barron, Kemker, Harmes, & Kalaydjian, 2003; Cuban et al., 2001).

Reasons for the underutilization of educational technology range from lack of teacher preparation time (Cuban et al., 2001; Ertmer, Addison, Lane, Ross & Woods, 1999; Windschitl & Sahl, 2002), to lack of equipment (Ertmer et al., 1999) to a lack of institutional support (Cuban et al., 2001; Johnson, 2006; Windschitl & Sahl, 2002). Ertmer et al. (1999) have termed these structural issues as first order barriers to technology integration. More recently, researchers have begun to take a close look at what are described as second order barriers to technology integration. Second order barriers are ones that relate to teachers' intrinsic beliefs, attitudes and practices about teaching and technology, including teachers' pedagogical beliefs about the role of technology in the curriculum (Ertmer et al., 1999). For example, introducing a student-centered technology into a teacher-centered classroom may present unwelcome challenges to the teacher regarding her perceived role as the knowledgeable authority in the classroom (Lin, 2001). Indeed, technologies that require a teacher to employ a method of teaching they do not already use may have difficulty being adopted (Windschitl & Sahl, 2002). Whereas, teachers who choose to use a technology that aligned well with their pedagogical beliefs were generally successful at integrating technology into their classrooms (Zhao, Pugh, Sheldon, & Byers, 2002). There is some evidence to show that teachers tend to select educational software and technology tools that align with their own pedagogical views (Niederhauser & Stoddart, 2001). These results suggest the importance of teachers' pedagogical beliefs to successful technology integration. However, there are relatively few studies that focus on this relationship (Ertmer, 2005).

The purpose of this study is to contribute to our understanding of the relationship of teachers' pedagogical beliefs to technology integration by examining teachers' reflections on, and experience with, the teaching and learning of robotics educational technology through the discovery learning method.

Pedagogical Beliefs, Teaching Practices, and Technology Integration

Researchers report that teachers who gain experience and expertise with integrating technology in the classroom undergo a shift in their instructional methods from instructionist and teacher-centered to constructivist and student-centered (Becker & Ravitz, 1999; Levin & Wadmany, 2006; Sandholtz, Ringstaff, & Dwyer, 1997). It is argued that this change in pedagogical method may lead to a change in pedagogical belief that is facilitated in part by the use of powerful technology tools in the classroom such as computers, and also by the student learning outcomes teachers observe as a result of using a new technology, instructional method, or curriculum (Guskey, 2002). This view of pedagogical transformation is countered by researchers who have found that many teachers who integrate technology into their classrooms do not change their teaching practices (Cuban et al., 2001), and that those who do change their practices do not see the alteration as influenced by the technology itself, but as a consequence of school policy, participation in an academic course of study, or insight gained through personal reflection (Dexter, Anderson & Becker, 1999; Windschitl & Sahl, 2002).

A further possibility suggested by some researchers is that individuals who are interested in constructivist and student-centered methods, but have yet to find a way to implement these methods in their classrooms, are aided in this endeavor by computer technology (Ertmer et al., 1999). In this view, the transition in pedagogical practice occurs as the result of an interaction between the teachers' pedagogical beliefs and the use of technology as an enabling agent. There is evidence to suggest that teachers' pedagogical practices do not always align with their pedagogical beliefs. For example, Unal and Akpinar (2006) found that science teachers in Turkey reported holding more constructivist pedagogical beliefs than they were observed using in their classroom practice. This is not surprising as teachers report feeling constrained to use teacher-centered and instructionist methods by institutional forces, such as mandated outcomes on standardized tests (Pedersen & Liu, 2003).

An important aspect of this debate about the nature of the relationship of technology usage to pedagogical transformation is the fact that educational technology tools themselves are not "functionally neutral" (Zhao et al., 2002). In other words, certain technologies are better suited to certain activities. In fact, much educational software is designed from a specific pedagogical stance. However, how teachers conceive of the pedagogical stance underlying the design will affect how they use the learning environments, and these conceptions may vary from teacher to teacher and from teacher to designer. For example, Pedersen and Liu (2003) identified four distinct definitions of student-centered learning among the 15 teachers using a digi-

tal, student-centered, science-learning environment called Alien Rescue. Clearly, practitioners do not always share theoretical definitions and the distinct definition an individual holds may well affect her implementation of a given digital learning environment or educational technology tool. Pedersen and Liu also found that these same teachers have different ideas about what constitutes facilitation in a student-centered learning activity. Some teachers enacted facilitation through providing a lot of structure and direction to students, while others took a far less directive approach by scaffolding student progress through questioning techniques. Therefore, the functional and pedagogical intention of the designers and developers of digital learning environments may go unrealized when placed in the hands of teachers who do not share the same epistemological frame.

Constructionism, Robotics, and Discovery Learning

Constructionism is a theory of learning proposed by Papert (1991). Similar to Piaget's theory of constructivism, constructionism posits learning as "building knowledge structures" (p. 1). However, unlike Piaget's theory, constructionism does not privilege abstract reasoning as the only route to high-level intellectual understanding. Rather, constructionists argue that individuals use a number of highly personal and concrete methods for developing these high levels of understanding in a domain (Turkle & Papert, 1991). Papert (1980) claims that computers are an excellent example of an educational tool that allows students to develop and use these highly personal and concrete routes to higher-level understanding.

A number of computerized educational technology products have been developed based on Papert's theory of constructionism. Chief among them is the programmable brick created by Resnick and Martin (1991). This programmable brick, also called the robotics command explorer (RCX), is at the heart of the popular educational robotics system, Lego Mindstorms. The constructionist design of the RCX allows students to develop highly personal and concrete ways of learning in the robotics domain. Such learning may be facilitated when a discovery learning method is used. For example, two research teams have found that the discovery learning method is effective for fostering the development of content knowledge, problem-solving skills, and cooperation in students studying robotics (Chambers & Carbonaro, 2003; Suomala & Alaajaski, 2002).

Discovery learning is defined by Ormrod (1995) as "an approach to instruction through which students interact with their environment by exploring and manipulating objects, wrestling with questions and controversies, or performing experiments" (p. 442). Robotics is a tool-rich environment that lends itself to exploration through manipulation of the tools such as the

RCX, the sensing devices, the Lego pieces, and through using Robolab, the programming software language understood by the RCX. In addition, it is very common for robotics activity to be organized around the solving of a particular programming challenge, and for students to engage in experimentation as they attempt to solve the challenge (Sullivan, 2008). In solving challenges, students wrestle with questions related to design and programming issues. It is important to note that while robotics learning is often focused on the solving of a specific problem, there are always multiple ways to correctly solve the problem. Therefore, students of robotics are in a continual process of discovery. There is always more to learn and new and different approaches one can take to solving the same problem.

Ormrod's (1995) student activity-based definition of discovery learning is elaborated by Hammer's (1997) definition, which further delineated the role of the student and the teacher:

> Like all popular terms in education, *discovery learning* has taken on a range of meanings, but most often it refers to a form of curriculum in which students are exposed to particular questions and experiences in such a way that they "discover" for themselves the intended concepts. The student's inquiry is usually "guided" by the teacher and the materials, such as through "Socratic" questions, because no one expects them to arrive on their own at ideas it took scientists centuries to develop (p. 489).

Discovery learning in the context of this study follows both Ormrod's definition of the characteristics of activities students engage in while involved in discovery learning and Hammer's definition as it regards both the role of the student as an active inquirer and the role of the teacher as a Socratic guide to student inquiry. One final distinction should be made here regarding the definition of discovery learning. Mayer (2004) distinguished pure discovery learning from guided discovery learning. According to Mayer, pure discovery learning involves only the assignment of a problem to students. In this view, the teacher provides no help and has no role other than to make the assignment. Mayer defined guided discovery learning as: "the student receives problems to solve but the teacher also provides hints, direction, coaching, feedback, and/or modeling to keep the student on track" (Mayer, 2004, p. 15). It may appear that Hammer's definition of discovery learning leans towards a guided discovery learning approach. However, in this study, the workshop leaders only offered guidance through Socratic questioning—they did not provide hints, direction, coaching, feedback, or modeling. Hence, the term discovery learning is used.

While the discovery learning method is both a definitionally (Hammer, 1997; Ormrod, 1995; Papert, 1980) and empirically (Chambers & Carbonaro, 2003; Suomala & Alaajaski, 2002) valid approach to teaching robotics it may not be a method of teaching that is readily embraced by classroom teachers. Levin and Wadmany (2006), studied changes to pedagogical practice adopted by seven elementary school teachers engaged in a year long technology-based professional development project. They found that only one of the teachers took up the discovery learning method. In this study, Levin and Wadmany situated the method of discovery learning conceptually as a radical constructivist epistemology. Such an epistemology may not be widely shared by teachers. And for those teachers who do subscribe to radical constructivist beliefs, it is not at all clear that they will be able to enact teaching methods derived from such beliefs (Pederson & Liu, 2003; Unal & Akpinar, 2006).

One reason for teachers' lack of interest in the discovery learning method may include the amount of time involved in allowing students to explore. Dean and Kuhn (2007) noted that discovery learning, as opposed to direct instruction, is a process that unfolds over time. It is possible that teachers feel pressed for time and that such a concern may add to the tension they feel regarding using a teaching method such as discovery learning versus a more traditional approach to covering the content (Bauer & Kenton, 2005; Hammer, 1997)

Therefore, even though the discovery learning method appears to be an excellent approach to teaching and learning robotics, it may be a method that teachers have trouble adopting. However, anything less than an exploratory approach to learning robotics would substantially undermine the value of the learning experience itself. Recall, the RCX was designed based on the constructionist principles of highly personal and concrete approaches to building knowledge structures; constructionist methods like discovery learning allow for such approaches. The dilemma thus defined includes the conflict between the designer's beliefs about teaching and learning inscribed in the educational technology innovation itself, and the teacher's ability or desire to use the educational technology innovation.

In this study, we sought to explore this dilemma from the teachers' points of view. We were interested in understanding teachers' views on learning robotics through a discovery learning method. Our questions concern how teachers experience learning robotics through the discovery method and how they think about teaching robotics with this method. We were also interested in how well they learned the robotics content using the discovery method.

METHODS

Setting and Participants

The data for this study were collected as part of a grant-funded teacher professional development project undertaken through a university and community college partnership in the Northeastern United States. The grant was funded by the state of Massachusetts as a part of their Commonwealth Information Technology Initiative. The goal of the grant is to bring information technology experiences to students in schools to better prepare them for work in the information technology sector. The major goal of the workshop was to provide teachers with an opportunity to learn robotics and to implement a robotics curriculum in their respective schools. An important aspect of this goal was to foster reflection on how robotics might be integrated into the teachers' respective curriculums. Teacher participants received a $500.00 stipend for their participation in the project.

The cofacilitators of the workshop consisted of the first author and a community college professor who teaches robotics. Both of the facilitators have a high level of proficiency with Robolab and the Mindstorms system. The first author also has a high level of understanding of pedagogical approaches and instructional designs for teaching and learning with educational technologies. Both facilitators were present for all sessions.

Project activities occurred in three phases. Phase one consisted of a teacher professional development workshop series, phase two was implementation of the robotics curriculum in individual schools by the workshop participants, and phase three—intended as the project culmination—consisted of a one-day robotics fair. The workshop facilitators were available by email to assist teachers in the implementation of the robotics curriculum in their respective schools during phase two. However, none of the teachers took advantage of this assistance. Data for the study were collected at the teacher professional development workshop series and at the robotics fair. A total of 20 middle and high school teachers participated in four professional development workshops over a two-month period. Twelve of these teachers also participated in the robotics fair that occurred approximately two months after the workshop series ended. These teachers were interviewed at the robotics fair. The eight teachers who did not attend the robotics fair were later contacted by email in which four questions were posed as follows:

1. Did you try out robotics with your students in any way after the January, 2006 robotics workshop (after school or in class?)

2. If so, how did you teach the topic (e.g., direct instruction, student-directed exploration, etc.)

3. If you did not teach robotics, why not?

4. If you did teach robotics, why did you choose not to attend the robotics fair held in May, 2006?

Two of the eight teachers responded to the email. Of these two, one reported that she was precluded from implementing the robotics curriculum in her school by the administration. The second teacher was able to implement the curriculum and her comments were analyzed with the interview data and are reported in the qualitative results section of the article.

The teacher participants represent a purposive sample. Of the 20 teachers who participated in the workshop series, 40% (N=8) were high school teachers and 60% (N=12) were middle school teachers. The sample consisted of teachers of Mathematics (N=7), Science (N=5), Computers (N=2), Technology (N=2), Special Education (N=2), and Electronics (N=1). Sixty-five percent (65%) of the teachers were female and 35% were male. The majority, 85%, identified themselves as Caucasian, with only 10% African American and 5% Hispanic/Latino/a. Participant ages ranged from 26 to 60; the majority, 60%, were between 36 and 50. All of the teachers taught in high-needs school districts as defined by the state of Massachusetts.

Pedagogical Approach

A discovery learning approach, as previously defined, was used in teaching this workshop series. A minimum amount of direct instruction was provided to the teachers. The curriculum included four three-hour workshops. During the first session teachers were given a number of resources with which to commence their own learning processes. These resources included the Lego Mindstorms Robotics Kit—including a book that provided detailed visual instruction for building specific types of vehicles, Robolab software—including tutorials or "training missions" regarding how to program in Robolab, and three commercially available Robotics learning texts. In addition to these resources, teachers were taught how to use the context-sensitive help function in Robolab. In subsequent sessions, the facilitators provided brief direct instruction about the following topics: (a) the five components of a robot; (b) gears and gearing; (c) robotics and problem solving; and (d) robotics and science inquiry. In addition, teachers took home a public television produced documentary DVD regarding philosophical issues related to robotics. This documentary was discussed in the third workshop session.

Working in pairs, teachers solved a series of increasingly difficult robotics challenges given by the workshop facilitators. The first challenge was to program the robot to make a square by executing four equally spaced 90-degree turns. The second challenge was to program the robot to follow a black

oval line on a white field using light sensors. The third challenge was to program the robot to move around objects using touch sensors. While the goals of the robotics activity were provided to the teachers in the form of challenges, the means of achieving the goals were left to the teachers. Provided with resources, the teachers were meant to explore and experiment with the robotics environment in keeping with the discovery learning method. Following Hammer's (1997) description of the role of the teacher as a guide in a discovery learning approach, the two facilitators provided a minimum level of guidance to the teachers through a Socratic questioning technique. In this technique, students are not given direct answers to queries, but are guided to think further about their questions and potential means of answering the questions.

Research Design

We used pre-post test designs as well as qualitative methods to gather data in this study. The pre-posttests (described next) measured changes in both teachers' robotics content knowledge and teachers' self-assessment of their level of proficiency regarding aspects of teaching and learning with robotics. We also gathered data related to teachers' perceptions of teaching and learning with robotics through their participation in an online reflection activity conducted at the end of each workshop session, and through interviews conducted with the 12 teachers who attended the robotics fair.

Pre and Posttests of Robotics Content Knowledge

The first author and the cofacilitator created the pre and posttests of robotics content knowledge (Appendix A). The tests were administered before the first workshop and after the last workshop. The tests were identical and consisted of twelve questions that pertained to the areas of instruction and discussion covered by the workshop facilitators as well as general knowledge that may be gained through interacting with the robotics materials. Cronbach's alpha was calculated to measure the reliability of the instrument. The reliability was found to be low $\alpha=.65$. The low reliability may be related to either the small number of test items, the possibility that more than one construct was being measured, or poor test items (Wells & Wollack, 2003). Further analysis revealed that two of the test items failed to discriminate between high scoring and low scoring students and were, therefore, poor test items. When these test items were excluded from the analysis, Cronbach's alpha was reported at $\alpha=.74$, an acceptable level for classroom tests (Wells & Wollack, 2003). The two non-discriminating items were excluded from the pre-posttest score analysis. A paired samples *t*-test was conducted to compare the mean scores from pre to post on the remaining 10 test items.

Scoring of the pre-post content test

t was possible to earn a total of 23 points on both the pretest and the post-test. In most cases, one point was given for each correct answer. However, some of the questions required multi-part answers. Each of the parts in the multi-part questions received one/half point if answered correctly. For example, question number four asked the participants to identify the five components every robot has. A totally correct response to this question received 2.5 points.

Pre and post self-assessment survey

The authors of this article developed the self-assessment instrument (Appendix B). The questions on the survey reflect both the skills needed for the teaching of robotics and technology-teaching competencies as identified by the National Educational Technology Standards (International Society for Technology in Education, 2002). The self-assessment survey was used to (a) help participants assess their beginning levels of knowledge and skills, (b) help participants identify areas they might want to strengthen, and (c) assess end of workshop gains in competency. The survey was administered before the first workshop and after the last workshop. The reliability of this instrument was determined using Cronbach's alpha. High reliability was found at $\alpha=.96$. Descriptive statistics, means, and frequencies were determined for each item within the self-assessment and aggregate scores were compared.

Qualitative Data Collection—Online Reflections and Teacher Interviews

A learning management system was used in the workshop series. It served a dual purpose as both a central repository for course materials and additional web resources, and as a means of data collection regarding participant learning reflections. Since our primary research interests concern teachers' experiences with and views on the discovery learning method as a robotics teaching and learning approach, we designed open-ended reflection questions that we thought would help to reveal these views. At the end of each of the four workshops, participants were asked to log in and respond to the following three primary questions on the online discussion:

1. What did you learn today?

2. How will you apply this learning?

3. What concerns do you have regarding using robotics in your class-room?

Most of the workshop participants responded to the reflection questions at the end of each week. There are three teachers who each missed one week of reflections because they needed to leave the session early. There-

fore, there were a total of 177 responses gathered from the online discussion board.

The first question was designed, in part, to examine the extent to which teachers believed themselves to be learning using the discovery method. The second question was posed to understand how the workshop may or may not affect teachers' pedagogical practices. We reasoned that asking teachers how they would apply what they had learned would prompt reflection on both pedagogical practices and pedagogical beliefs, particularly in regard to technology integration (Zhao et al., 2002). The third question was asked to help frame the overall experience the teachers were having with the robotics workshop.

Semi-structured interviews were conducted at the robotics fair with the teachers who implemented robotics in their respective schools. The interviews lasted from 15-20 minutes. The interviews concerned student learning and robotics project implementation in the teachers' respective schools. An interview protocol was designed to gather data in two areas: (a) teachers' reflections on student learning, participation, and interactions; and (b) teachers' accounts of implementation, integration with existing curriculum, and difficulties and benefits. The two authors and a graduate student (familiar with the project and trained in the interview protocol) conducted the interviews.

Qualitative Data Analysis

At the end of the workshop series, all participant reflections on the questions were downloaded and saved. After the robotics fair, all interviews were transcribed. Three individuals, the first two authors and an educational technology graduate student familiar with the project, separately analyzed the reflections and interview data. Using the method outlined by Rossman and Rallis (2003), analysis of these data consisted of an iterative process of reading and re-reading the postings and interviews to identify the emergent categories present in the teachers' reflections and reported experience. After each of us had analyzed the data, we met to discuss the analysis, and to come to a consensus regarding the common, overall categories. Disagreements were resolved through discussion. The first author then analyzed these categories to determine the themes and subthemes reflected in our analysis of the data. The second author then reviewed and ratified these themes and subthemes.

RESULTS

Pre-Posttest Robotics Content Knowledge

The pre and posttests of robotics content knowledge scores were tabulated. The mean score for the pretest (M=2.23, SD=1.95) was significantly different than the mean score for the posttest (M=10.43, SD=3.61), t (19) = 9.797, p =.001 (two-tailed), Cohen's d = 2.82. The participating teachers' robotics content knowledge increased at a statistically significant rate as a result of taking part in the robotics workshop series and the effect size was large.

Table 1

Aggregate Self-Assessment Pre and Post Scores by Percent

		No Proficiency I have no knowledge of these concepts	Low Proficiency I have only a general knowledge of these concepts	Moderate Proficiency I am very familiar with these concepts	Strong Proficiency I have taught others these concepts
Proficiency in hands-on robotics curriculum planning	Pretest	55%	40%	0%	5%
	Posttest	0%	20%	70%	5%
Proficiency in the use of problem solving skills with robotics	Pretest	60%	35%	5%	0%
	Posttest	0%	20%	60%	20%
Understanding of the connections between robotics and inquiry	Pretest	50%	35%	15%	0%
	Posttest	0%	25%	75%	0%
Understanding of the connections between robotics and design skills	Pretest	35%	40%	25%	0%
	Posttest	0%	15%	70%	15%
Understanding of the philosophical issues related to robotics	Pretest	20%	60%	20%	0%
	Posttest	0%	15%	75%	10%

Pre-Post Self-Assessment Surveys

Analysis of the pre-post self-assessment survey also showed marked changes between scores in all of the key areas. The mean score for the pre-test (M=1.59, SD=.28) was significantly different than the mean score for the posttest (M=2.7, SD=.19), t (19) = 16.286, p =.001 (two-tailed), Cohen's d = 4.54. Table 1 provides an aggregate summary by percent of pre and posttest scores.

As the data in Table 1 indicates there is a consistent positive upward trend between pre and posttest scores. Every participant at a minimum achieved a general knowledge of all concepts; most participants, 60% to 75% in all categories, reported becoming very familiar with these concepts.

Qualitative Results

Three themes and eight subthemes emerged from the analysis of the online reflections and the interviews. The main themes are:

1. frustration with the discovery learning method

2. teacher competency

3. curriculum analysis.

When the teachers discussed their frustration with learning robotics through the discovery learning method they focused on: (a) concern about student frustration; (b) a desire for more direct instruction; (c) strategies for adapting the discovery learning method; and (d) using the adapted discovery learning method. In discussing their concerns about their own competency in teaching robotics teachers focused on: (a) learning strategies; (b) student learning outcomes; and (c) teachers and students learning together. And finally, in analyzing robotics as a curriculum, teachers discussed: (a) obstacles to implementing robotics as part of the regular school curriculum. We discuss each of these findings in turn. Pseudonyms are used throughout.

Frustration With the Discovery Learning Method

Teachers criticized the discovery learning method as frustrating and slow. They expressed their own feelings of frustration with the process and expressed concern about the potential for student frustration. Fifteen of the teachers discussed feeling frustrated by the pace of learning, the lack of explicit instruction, the amount of information given, and the difficulty of the robotics content. For example, Randy remarked: "One of the frustrations I have had is that there needs to be a simpler chart that tells what all of the tools do. I have been exploring using several of the tools but can't really find out what the tool does until you place it in a program and then open the help menu." And Michelle added, "I will have a better understanding of the

frustration level of my students after working today to try to program and running into difficulty. Having some success was helpful but then running out of time was again frustrating." This comment was echoed by Gerald who noted, "Without any education on which icons do what, it can be very time consuming figuring out how to program."

Concern about student frustration. Of the 15 teachers who criticized the discovery learning method, 10 generalized their own learning experience and frustrations to the learning needs of their students. In other words, they spoke of their own frustrations in terms of how they would pedagogically alleviate the projected frustration of their students. For instance, Deanna stated:

> My partner and I discussed how frustrated the students would be to spend so much time on learning one small feature that greatly affects progress. Personally, I'd help them through some of these steps since it prevented us from learning more. We knew we had to use a particular feature but didn't know how to use the keyboard (ex. click on the hand symbol versus the pointer).

Indeed, their experience with the discovery learning method prompted them to reflect on, and identify with, the learning frustration their own students occasionally displayed in their respective classrooms. Carolyn articulated this insight:

> I learned the frustration my students sometimes feel. I needed a jumping off point. Jeremy [one of the workshop facilitators] helped us with our program and that support was really what I needed. Sometimes as a teacher I want to tell students to just do it, get started with something and go from there. Yet, today I felt that paralyzing frustration of not knowing where to start. This taught me to have something prepared for students that might need some support, which I would say I would do that in a regular math classroom. Perhaps it was merely the experience of walking a mile in someone else's shoes.

Desire for more direct instruction. Ten teachers indicated that the frustration they were feeling related to a lack of direct instruction. These teachers expressed the need for more instruction, more handouts, more lecture on programming, more guidance, and longer labs. For example, Randy wrote: "If this course were done again, I would like a brief lesson at the start of each class exploring commonly used devices like looping and branching."

While Michelle indicated, "I needed more directions regarding the icons for programming." And Anita commented, "I think that I am just an individual who needs to see how things are done before applying it."

Strategies for adapting the discovery learning method. Teachers expanded on this desire for more instruction in their thoughts about how to apply what they had learned in their teaching. They identified specific strategies that they would use to adapt the discovery learning method to pedagogically address potential student frustration. Several strategies were mentioned ranging from providing explicit instruction, to controlling student frustration through information management, to providing more guidance to students as they work on the problem. Ten (10) of the 20 participants elaborated on the adaptive strategies they would use in teaching their students robotics. One such strategy is to strike a balance between discovery learning and direct instruction through the amount of information given to students. Ann discussed this strategy in her reflection:

> Feeling very frustrated trying to program the robot to follow a black line in a circle, I would probably give more guidance to the students. Maintaining a balance between giving too much information and not enough information to the students so that they will learn but not get too frustrated.

Jason commented similarly, "The experience today will make me more aware of how much information I give my students and how frustrated they might get if not given enough information. The frustration level needs to be there, but controlled." Meanwhile, Deanna intends to provide more instruction, "I want my students to feel successful so I am going to have exercises for them to do each time they meet with me." And Danielle remarked, "I will hope to alleviate frustrations with a sense of humor."

Other strategies discussed included becoming personally mindful of the students' experience, offering positive reinforcement, and emphasizing the playful aspects of the activity.

Utilizing the adapted discovery learning method. Thirteen of the teachers reported implementing the robotics curriculum with their students. And each had done so using the discovery learning method. However, they employed the method with their own adaptations including giving advice, providing direction, and motivating students. Jason discusses his approach with his students:

> Um, trying to not get involved too much. And then just deciding how much guidance they need, trying to get that frustration level so that it wasn't too high, so they wouldn't give

up. I didn't participate a lot in helping them. I would watch them, and if I thought they were getting really frustrated, then I would sort of give them some advice. But as far as the building of it and what they were doing, it was all their own.

Another adaptation was directing student work. Sarah discussed her endeavor to direct the students' choice of project for the robotics fair.

I presented to them the options for the fair, and had them choose as a group which one they wanted to do. And the girls chose the groovy bot, and the boys chose the sumobot. And I sort of like tried to urge them to do the…more of the book one, just because it would be easier to have them do that. And I thought they would be more successful, but they didn't want to, so I wasn't going to push them to do something they didn't want to do.

And Fred reported on the feedback he gave a student on his project as a form of coaching or motivating instruction.

We can't just do our usual, but go after it. Especially one boy, he said he finished his project in one session. The beginning of the second, he saw the program, understood it, got it all to work. He was done in one and a half of the four sessions. I told him, "Part of your project is hand operated, you have to push the people into the ride to make it work, that's old time, old school stuff. Let's make it more robotic."

Teacher Competency and Student Learning

The third theme that emerged from the data collection focused on teachers' concerns about their own mastery of the technology. Even though the teachers' knowledge about robotics had improved, based on the pre-posttest results, they still expressed concern in their written reflections regarding their competency as teachers of robotics. Elizabeth expressed her concern thusly:

I haven't introduced the robot to my class, yet. I felt I needed to understand more before I could give them a go at it. I'm still really worried that I won't be able to troubleshoot problems as they come up…I am most concerned that still being very much a novice, I may not be able to clearly explain certain processes to my kids. I hope I can help them effectively.

This was a concern for 10 of the 20 teachers who took part in the study. For example, Sarah commented, "I do have concerns that they will get frustrated and not want to persevere, and that I won't have the knowledge to scaffold them effectively." This sentiment was echoed by Darlene, "One of my continued frustrations is not knowing enough if the students get confused."

In addition to feeling worried about their own competency, teachers also reflected on the positive ways they would handle their lack of expertise with their students. For instance, Gerald remarked, "I will explain to students that I recently learned something that I had no prior experience with and ask them to help with the continual learning process." And Laurie noted, "The students will probably know more than me! When I ask them to help me they will be reinforcing their knowledge."

Learning strategies. The teachers commented on learning strategies they used in the robotics workshop and on how they might help their students use these same strategies. The primary learning strategies articulated by the teachers were trial and error and asking questions of other teachers; they also mentioned note taking and the use of the context sensitive help resource available in Robolab. For example, Michelle noted, "I learned how to problem solve using trial and error, asking questions and using the ctrl H key when trying to program." And Sarah remarked:

> This session demonstrated the benefits of just "playing" with the program without too much guidance from "experts." We were forced to figure it out through trial and error, and as a result, learned much more from the experience. I will remember that when working with my students.

While many teachers reflected on the trial and error nature of learning in solving a robotics challenge, Elizabeth took this understanding a step further and derived a key pedagogical insight into learning in robotics. An important aspect of learning in the design process is dealing with failure; it is through failure that one can learn to create better designs (Lewis, 2006). This insight unfolded over the second, third, and fourth week of the professional development workshop for Elizabeth as follows:

> Week Two—I learned a great deal today. One of the most important things I learned was that the mistakes I was making were just part of figuring out what I needed to know. Because I know so little about the topic of robotics, it was very frustrating in a way. But, as soon as I gave up trying to figure everything out all at once, the process became fun.

Week Three—One of the ways I will use this is to help my kids learn through trial and error. It is definitely a process of making mistakes and analyzing to make changes. This has been a helpful reminder for me as well.

Week Four—The thing I will apply most to my kids and my teaching practice is that so much of this and so much of science is that it is a lot of trial and error and a lot of making mistakes. The most important thing is to learn something from those mistakes and try to change things accordingly in the future.

Student learning outcomes. Even though teachers expressed concern about their own level of competency with the content and their ability to help their students, once they implemented the curriculum, they reported positive learning outcomes for students. Teachers discussed student learning primarily in terms of problem solving, the collaborative nature of the enterprise and students' enjoyment of the process.

Six of the 12 teachers who attended the robotics fair reported that the primary learning outcome they observed in their students was learning how to solve problems. The teachers emphasized different aspects of problem solving in their comments ranging from learning the iterative nature of design problem solving to persistence in problem solving—even when it is difficult, to translating an idea into a problem solution. Deanna discussed the rewards related to the problem-solving activity of her students:

It's the problem-solving part. It was watching them have an idea, and learning that that has to translate into the program, and then to see it work. And I don't think they run into that frustration level in day-to-day learning in the school. That: Well how do you do it? The teacher is not telling me how to do it, it's not working, it's not working. When they couldn't even get it to turn because there were six legs. That is, I think, a unique part that they got more reward when they accomplished it than they feel day-to-day at school. They are not putting up that much of a struggle, I think, when they go from classroom to classroom. So, I think that's a unique part of it.

Fred reported a similar experience with his students:

But the one's who did this, it surprised even them, they stayed with the problems when they got really hard. They fixed the

project and made it work. You know 40 drafts of a paper. You know with problem solving like this, "why isn't it working? what's wrong? well let's try something else." They stayed with it. And they came after school to do this and came on a Saturday, gave up a Saturday, this was a powerful experience for them, and for me I learned a lot.

Eleven teachers discussed students working together. For the most part, the teachers reported that students worked well together. For instance, Ann noted:

They did work together, they were exchanging ideas quite often. They would make suggestions and then try that and if it worked that was fine and if it didn't they would go back." And Martin commented: "Ricky and Lisa didn't know each other before hand, before they started doing this, and so then they started working together and it was interesting because they didn't say a lot to each other, but they helped each other along with the projects.

However, there were also reports of students who did not collaborate. For example, Gary noted that while the younger students in his class worked together, the older students worked individually:

My freshman that is here today—Eddie—and one of the other freshmen seemed to work together pretty good. The juniors I noticed were kind of on their own with it. One would work on it for a while and then he would get so far—and then he would go onto something else. Then another junior would pick up on it and he would start working on it. So there wasn't a lot of teamwork in that respect.

Gary, who teaches in a vocational high school, also reported that his students were not as enthusiastic about the robotics project as he would have hoped. This may have been due to the fact that, in the vocational setting, students have lots of opportunities to engage in hands-on learning. However, his observation is the anomaly regarding student enjoyment. Nine of the twelve teachers interviewed at the robotics fair remarked on the high level of interest and enjoyment they observed in their students as they worked on their robotics projects. Martin remarked: "They had a great time doing it, they really enjoyed it." Meanwhile, Dolores, a middle school special education teacher, found her students' interest to be remarkable:

It was amazing just to see them working together and wanting to get these pieces to form something that was real functional for them. The interest was unbelievable—it was very amazing their dedication to come after school. I didn't do it during school time—it was after school and the fact that they did show up shocked me. The fact that the five of them were willing to show up after school amazed me.

Teachers and students learning together. A separate aspect of the teacher competency issue was the experience of teachers learning alongside students. Six of the 12 teachers interviewed at the robotics fair remarked on this phenomenon. Since the learning curve with robotics was fairly steep for the teachers, they did not necessarily have all of the answers to student questions. To handle their own lack of unfamiliarity with the technology, some teachers adopted a style of teaching that may best be thought of as modeling how to approach a problem. For instance, Laurie reported the following: "I read the books too, to look up things. They saw me having to look up things so they were comfortable doing the same. I would tell them I don't know what this is—let's figure it out."

The use of the discovery learning method with robotics does appear to alter the traditional, knowledge-based, hierarchical relationships found in many classrooms, if only out of necessity. If the teacher, in fact, is not a knowledgeable authority with the technology, they will have to take a different approach to using the technology in their classroom. In this case, that approach was one of learning alongside students. Indeed, the teachers discussed the ways in which their students' knowledge of robotics became comparable to, or more advanced than, their own. All of the teachers viewed this as a positive experience for everyone. Fred discussed it in these terms:

I think one thing that was unique for them (the students) was seeing their teacher having to struggle with the same problems they were having. And trying to figure it out together, knowing that they couldn't just sit back and wait for me to solve it because I wasn't that much more advanced than they were and I was doing trial by error each step of the way. And if they were focused on what we were trying to figure out that they could have the key input at times. "No, I think if we turn it around it will work better, if we move the gear over here, it will work better."

Curriculum Analysis

When the interviewed teachers were asked about integrating robotics into their regular curriculum, all of them saw a direct connection with their curriculum. Teachers noted physics connections, math connections, language arts connections, engineering connections, and general problem solving connections. Jason discussed the interdisciplinary nature of robotics:

> Just to work the gear ratios, and torque of motors, and how much it would pick up and what you would get; those types of math and science topics, and working it that way. So, I definitely see something that we could both use in the curriculum, probably do it interdisciplinary. I would want to do this in math, I want to see the connection to some of the science, just with either levers, or gear ratios and the different torque, speed that you turn, speed that you turn what [sic] around. There's just a multitude of things you could do with that connection. And then…also get in on writing about it, so the connection with language arts also.

Obstacles to implementing robotics as part of the regular school curriculum. Despite these interdisciplinary curricular connections, seven of the 12 teachers who implemented the robotics curriculum reported that they felt robotics fit best as an after-school activity. The reasons for this ranged from the time consuming nature of the activity, to the amount of money needed for the kits, to the difficulty in keeping all of the Lego pieces in the kits. Indeed, all of the teachers who implemented the robotics curriculum did so as either an after-school program or as a special in-school activity for certain students offered during the academic support and study hall periods. This is not necessarily surprising, as teachers had a minimum of one and a maximum of three robotics kits available to them. When asked about integrating robotics into his technology course, Randy framed the problem in this way:

> Yes and no—I mean certainly the activity is great—it just takes a long time. I have my kids for 45 days so I think there are a couple of problems. It takes a long time. If I ran this as a project for all the kids, I would never get the regular curriculum accomplished. I do have something that I need to do there and it takes a long time. Obviously, there is also the issue of how many of these kits do I need during one term? If I have 80 kids that probably means even if I put them in big groups—it means that there will be like 20 kits and that is a tremendous amount of money to buy the kits.

Time and money obstacles to the integration of technology in the curriculum are well-known first order barriers to technology integration.

DISCUSSION

As Mellado (1998) noted, "given material has certain associated beliefs and traditions about how best to teach and learn it" (p. 199). The discovery learning method is associated with the teaching and learning of robotics by virtue of its constructionist theoretical underpinnings. This strong theoretical link between the discovery learning method and robotics has been bolstered by research indicating the efficacy of the method for teaching robotics (Chambers & Carbonaro, 2003; Suomala & Alaajaski 2002). The results of our study support these previous findings as the pre-posttests showed a significant increase in content knowledge and in a feeling of proficiency with teaching robotics over the course of the four workshops.

Our aim in using the discovery learning method in this professional development robotics workshop was to model the teaching approach that we believe is the most congruent with the pedagogical intent of the designers of the technology. Modeling a teaching approach in a technology-based professional development workshop is risky if the approach is one that may not resonate with teachers' pedagogical beliefs or practices. As Niederhauser and Stoddart's (2001) work showed, teachers tend to adopt technologies that align with their pedagogical beliefs. If teachers are introduced to a technology using a pedagogical method that they do not ascribe to, there is a risk that the teachers may reject the use of the technology on pedagogical grounds. And indeed, we found that despite the strong learning outcomes achieved, the teachers who took part in this robotics workshop were critical of the discovery learning method. However, this criticism did not translate into outright rejection of the method. Of the 14 teachers whom we were able to follow-up with after the robotics workshop, 13 adopted most of the elements of the discovery learning method in presenting the robotics curriculum. This may well have been due to the teachers' own achievement in the robotics workshop. However, it also indicates that teachers are open-minded about pedagogical practices and they appear to be willing to try a new practice, even if they are initially critical of it. This information is important for those providing professional development on educational technologies that were designed to introduce new and novel approaches to learning. It indicates that even though previous research shows that teachers prefer to use educational technologies that align with their own pedagogical beliefs (Zhao et al., 2002), they are also willing to experiment and try something new. Therefore, professional development efforts may do well to introduce

new pedagogical approaches with the confidence that, though they may be criticized, they will also be tried (albeit with a few adaptations).

For example, the teachers in this study criticized the discovery learning method as frustrating and slow. They expressed the concern that their students would also feel frustrated with this method of learning. Indeed, avoiding or mitigating student frustration was a common theme in the teachers' reflections. In thinking about these issues, the teachers elaborated on specific teaching strategies they would use to adapt the method to lessen the possibility of student frustration including explicit instruction, controlling student frustration through information management, providing more guidance, emphasizing the playful aspects of robotics, and encouraging students. The enumeration of these strategies suggests that teachers' pedagogical practices are strongly influenced by their perception of student learning needs. Indeed, such a finding was previously reported by Hammer (1997). Our results support Hammer's finding.

As noted, we found that though the teachers were critical of the discovery learning method during the professional development workshops, those who implemented the robotics curriculum reported using the method with their students. The reason for this may be that people tend to teach topics the way they were taught them (Hodson, 1988). However, the teachers also reported adapting the method by providing more guidance and instruction when they judged student frustration to be at an unproductive level. In many ways their strategic adaptations moved the method from a discovery learning approach to a guided discovery learning approach as defined by Mayer (2004). For example, as noted in the results section, the teachers provided feedback (Jason's advice to students), direction (Sarah's direction to build a robot from a book example), coaching (Fred's challenge to his student to make his project more robotic), and modeling to the students (Laurie's use of a reference book to solve problems), all characteristics of a guided discovery learning method.

Furthermore, teachers reported observing positive student learning outcomes including problem solving, learning to work together, and enjoying learning as a result of being involved in the robotics project. Deanna noted that the students got the opportunity to really struggle with a problem in a way that they rarely get to in the classroom. She saw the resolution of the problem as a powerful learning experience for the students. Interestingly, the very issue most of the teachers were concerned about—student frustration—appears to have been the issue that led to a great sense of achievement for the students, as reported by Deanna and others. It was the opportunity to struggle with a problem and to depend on oneself and one's student peers for the resolution of the problem that resulted in a rewarding feeling of accomplishment for many of the students. As Deanna noted, this is not

a typical classroom experience. Students are not usually given open-ended, challenging problems to solve on their own, as they were in this instance. It is possible that the teachers in this study were initially concerned about student frustration, based not only on their own frustration, but also on their beliefs about typical student learning in the classroom, which may not include an understanding of struggling and feeling frustration as potentially fruitful learning states. However, it appears that the robotics teaching and learning experience may have allowed teachers to re-examine their perceptions about student learning needs as evidenced in Elizabeth's comments about the importance of failure, as framed in a trial and error approach, to learning in science and technology.

In concert with this re-examination, the critical analysis and subsequent adaptations of the discovery learning method may also have allowed the teachers to experiment with pedagogical practices they might not normally employ. Specifically, the teachers reported exploring the practice of inducing and managing a productive tension between students struggling with the robotics problem on their own and becoming so frustrated as to give up. As Jason and others noted, based on their own experience with the discovery learning method, it became important to be able to judge when to give students guidance and when to stay out of the process. The experimentation with pedagogical practice reported by the majority of the teachers in this study appears to bolster the argument that teachers tend to shift their pedagogical practices when using technology. Moreover, the insight that students' learning needs include the opportunity to struggle with a problem, even to the point of failure, is an interesting pedagogical idea that may have been induced, in part, by participation in this robotics project.

In line with these observations are teachers' experiences with, and responses to, competency in teaching robotics. While the teachers felt concerned about their own expertise with robotics, they managed this concern through adopting a learning-together approach. This strategy was necessitated by virtue of the steep learning curve involved in mastering robotics. Sometimes this "learning alongside" took the form of the teacher modeling an approach to problem solving, as in Laurie's case—other times "learning alongside" meant students taking the lead in solving the problem as Fred discussed. In either case, this relative flattening of the classroom hierarchy is characteristic of student-centered learning environments. Therefore, this finding also supports the theory that teachers' pedagogical practices may change as a result of teaching with technology, if only because the learning curve for new technologies is so steep that to use them in the class means to learn along with the students. Indeed, the teachers in this study viewed this flattening as very positive for students. Hence, it is possible that teachers' pedagogical beliefs regarding student-learning needs may also be affected

by these experiences. It is important to note here that the data reported in this study is primarily self-report data. The results are based on the teachers' reflection and recollection of their experiences with teaching and learning robotics. Given the speculative nature of this data—the results should be viewed as tentative and future research should follow-up these initial results.

Finally, all of the teachers saw a connection between robotics and the curriculum, particularly math, science, and technology, but also language arts. Despite this fact, the majority of teachers saw robotics primarily as an after-school activity. The reasons given for this revolve primarily around the first order barriers of time, classroom management and financial issues. This finding is worrisome for two reasons: (a) it leaves empowering and engaging learning experiences for informal learning environments, which not all students may have access to; and (b) it indicates that those who design powerful educational technologies may never see them integrated into the classroom.

IMPLICATIONS AND CONCLUSION

Our research indicates that teachers' perceptions of student learning needs may influence their pedagogical practice. It also appears that these perceptions and practices may change through teaching and learning with discovery learning-based educational technologies. This is particularly important in light of the original concerns posed in this study. If teachers' pedagogical beliefs and practices dictate their adoption of new educational technologies, it is extremely important to understand that these beliefs are subject to change. In other words, successful and widespread technology integration may rely on finding ways to help teachers' pedagogical beliefs evolve to include such notions as the usefulness of struggle, frustration, and failure in student learning. In a symbiotic relationship, this belief evolution may be facilitated by using pedagogical practices such as creating productive tension and taking a learning together approach in pre-service education technology courses and in in-service professional development workshops. Indeed, it may be vitally important to discuss the learning together approach as a necessity of the continually changing face of technological innovation. Expecting teachers to be masters of a given technology before using it in the classroom may hinder such use. Whereas, adopting the notion that a technology can be used in the classroom as both the students and teacher come up to speed in the use of it is completely reasonable and may foster the use of technology.

In light of our findings, future research may focus on how productive tension may be created and managed by classroom teachers using new edu-

cational technologies. In addition, further exploration of the ramifications and manifestations of the learning together approach will be useful for those interested in successful technology integration.

Finally, in regard to the finding that teachers felt robotics would best be taught in an after-school setting, further investigation is necessary. Teachers may be more willing to alter their pedagogical practice to align with the pedagogical intentions reified in the educational technology product itself if the context of implementation is an informal one. With less at stake, teachers may be more willing to experiment. Future research should explore the contexts in which teachers may be willing to use technologies that stretch their pedagogical practices and interrupts their perceptions about the learning needs of students. When teachers see technology-rich environments—designed to enable open-ended inquiry and self-directed learning—as essential to student learning, such technology may have a chance to be integrated into classrooms.

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Notes

Acknowledgements

Appendix A

Content Assessment

Please briefly respond to the following questions. If you are not familiar with the topic please indicate this.

1. How is Gear Ratio defined?

2. What is an idler gear? How does it affect the gear ratio?

3. Distinguish between a crown gear and a bevel gear.

4. What are the five components that all robots have?

5. Give two reasons why it is important to avoid *stalling* the electric motor.

6. Draw a short program (5-7 icons) using robolab iconography, and then write out what the program will do.

7. What was P3's biggest achievement and what/who is P3's famous child (so to speak)?

8. What is the goal of the Robocup founders?

9. Why is robot design (appearance) so important, according to some robotics experts, notably Kitanu?

10. What is sub-goal analysis?

11. What are the five main steps in conducting a scientific inquiry?

12. What is the difference between domain general and domain specific problem solving strategies? Give an example of each type of strategy as applicable to problem solving in Robotics

Appendix B

Summary Profile of Knowledge and Skills

	1. Proficiency in hands-on robotics curriculum planning	2. Proficiency in the use of problem solving skills with robotics	3. Understanding of the connections between robotics and inquiry	4. Understanding of the connections between robotics and design skills	5. Understanding of the philosophical issues related to robotics
Proficiency/ Understanding					
Strong Proficiency/ Understanding	13-16 ☐	13-16 ☐	13-16 ☐	13-16 ☐	13-16 ☐
Moderate Proficiency/Understanding	9-12 ☐	9-12 ☐	9-12 ☐	9-12 ☐	9-12 ☐
Low Proficiency/ Understanding	6-8 ☐	6-8 ☐	6-8 ☐	6-8 ☐	6-8 ☐
No Proficiency/ Understanding	4-5 ☐	4-5 ☐	4-5 ☐	4-5 ☐	4-5 ☐
Pretest Scores	Record your pretest score here	Record your pretest score here	Record your pretest score here	Record your pretest score here	Record your pretest score here
Posttest Scores	Record your posttest score here	Record your posttest score here	Record your posttest score here	Record your posttest score here	Record your posttest score here

Appendix B Continued

1. Hands-on robotics project curriculum planning				
1.1 Knowledge of how to integrate robotics into my curriculum	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowledge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
1.2 An understanding of where and when to use robotics in the classroom	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowledge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
1.3 Knowledge of how to plan and implement robotics projects using technological design	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowledge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
1.4 Knowledge of how to teach problem-solving and collaboration skills using robotics	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowledge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
1. Add the numerical values of your responses and record the total here. (Maximum score: 16)				

Appendix B Continued

2. Robotics and Problem Solving Skills				
2.1 Use of specific problem solving skills in solving robotics problems	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowledge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
2.2 Use of general problem solving skills in solving robotics problems	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowledge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
2.3 Use of robotics technology to facilitate higher order and complex thinking skills	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowledge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
2.4 Use of robotics technology to improve critical thinking and knowledge construction	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowledge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
2. Add the numerical values of your responses and record the total here. (Maximum score: 16)				

Appendix B Continued

3. Robotics and Science Inquiry				
3.1 Relationship of technological design issues to science inquiry process	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowledge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
3.2 The use of the science inquiry process to debug programs	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowledge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
3.3 Knowledge of methods of design and documentation of technological processes	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowledge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
3.4 The use of collaborative team work in meeting robotics challenges	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowledge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
3. Add the numerical values of your responses and record the total here. (Maximum score: 16)				

Appendix B Continued

4. Robotics and Design Skills				
4.1 An understanding of the relationships of robotics components	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowl-edge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
4.2 Understanding of basic programming in robotics (input/output/process-ing, parallel processing, iterations)	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowl-edge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
4.3 Creating and building stable structures with lego or other materials	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowl-edge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
4.4 Creating diagrams or drawings of structural designs	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowl-edge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
4. Add the numerical values of your responses and record the total here. (Maximum score: 16)				

Appendix B Continued

5. Robotics and Philosophical Issues				
5.1 An understanding of the uses of robotics in society	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowledge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
5.2 An in-depth understanding of the relationship between robotics and artificial intelligence	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowledge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
5.3 Understanding of technological change and the ethical challenges this creates for society	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowledge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
5.4 An understanding of the safe and responsible use of robotics in the classroom	☐ (1) I have no knowledge of these concepts	☐ (2) I have only a general knowledge of these concepts	☐ (3) I am very familiar with these concepts	☐ (4) I have taught others these concepts
5. Add the numerical values of your responses and record the total here. (Maximum score: 16)				