

Effective Teacher Professional Development: Middle-School Engineering Content*

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The research outlined in this paper looks at a teacher professional development program designed to prepare middle school teachers to teach an after school engineering/technology LEGOTM robotics unit. Thirteen Massachusetts public middle-school teachers participated in a summer professional development programme during the first two weeks of August 2005. Many of these teachers had not had any formal training in teaching engineering/technology. This paper looks at aspects of the professional development course that worked and those that did not by considering confidence surveys, researcher observations and teacher interviews.

Keywords: professional teacher development; engineering education; robotics; after-school programme; middle school

THE CHALLENGE OF CHANGE

TECHNOLOGY is increasingly becoming an integral part of today's society. With advances in technology, the integration of computers into our everyday lives, and more professions dependent on technically skilled workers, there has been an increased pressure on our education system to respond. With many jobs requiring technical skills, students will require a K-12 education that involves a strong science, technology, engineering and mathematics (STEM) curriculum to prepare them for college and/or employment. The Massachusetts Department of Education (DOE) now takes on the challenge by including engineering standards in their statewide curriculum frameworks for K-12 education[1]. This is new and potentially very exciting; however, most teachers have never had any formal engineering coursework, which makes it doubtful that students will receive the engineering content that Massachusetts is mandating. Even with teacher workshops, on-site assistance and other teacher resources, some teachers still do not implement the content in the classroom. It may be that the teachers still do not feel they have sufficient content knowledge, or confidence, or desire to teach this content, which leads to the question:

'What important aspects should there be in a teacher professional development programme that enable middle-school teachers to teach an after-school LEGO robotics programme?'

This paper looks to shed some light on this question and lay groundwork that a larger, more

in-depth study can build upon. This paper will discuss what engineering in the middle-school classroom consists of, the current state of implementation, the design and development of a professional teacher development programme, and the results from this programme.

Middle-school engineering content

The middle-school teachers considered here come from Massachusetts' public schools. In this paper, the middle-school engineering curriculum is defined as that which will be taught by these teachers as required by the *Massachusetts State Science and Technology/Engineering Curriculum Frameworks* [1]. The frameworks outline standards to be included in technology and engineering curricula for grades k-12. The frameworks describe the nature of engineering as, 'Engineering strives to design and manufacture useful devices or materials, defined as technologies, whose purpose is to increase our efficacy in the world and/or our enjoyment of it [1, p. 4]'. Within this context, the major strands of content material included in grades 6–8 are:

1. Materials, Tools, and Machines
2. Engineering Design
3. Communication Technologies
4. Manufacturing Technologies
5. Construction Technologies
6. Transportation Technologies
7. Bioengineering Technologies.

The curriculum used by the teachers in this study focuses on the following strands of the engineering and technology frameworks: the Engineering Design Process, Communication Technologies,

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Manufacturing Technologies and Bioengineering Technologies. These strands are applied to a LEGO robotics design project where the students will use the engineering design process as defined by the Massachusetts State Curriculum frameworks [1] while using the aforementioned technologies to create a final design project. The development of and further description of this curriculum are outlined in more detail later.

'Constructionism' in teaching engineering

Engineering, as previously described, includes the design and manufacture of products. It makes sense, therefore, that a curriculum designed to teach the principles and practice of engineering should include hands-on design projects where students build artifacts or products. Papert [2] describes such a hands-on learning environment as constructionism. This philosophy of education gains its roots from Piaget's constructivism, where the learner is described as actively constructing knowledge as opposed to knowledge simply being transmitted from teacher to learner. Constructionism includes not only cognitive construction by the learner, but also, as one of the major tenets of the philosophy, the learner constructing a real-world or virtual-world (in the case of computer programming) artifact. Papert argues that the physical hands-on, object-oriented nature of constructionism reinforces and deepens students' understanding. Many studies have since shown that hands-on, real-world learning environments are beneficial to students attitudes and learning [3–8].

While this hands-on or constructionist environment can be beneficial to learners, teaching in this environment can be challenging for a teacher in the classroom. This study will look at how professional development is able to address this challenge for teachers in a classroom environment.

Need for professional development

Whether it is learning the engineering content, the pedagogical approach, or the classroom management aspects of teaching engineering, there will be an undeniable need for professional development for teachers in this new subject area. Teaching in a more learner-centred, hands-on, project-based environment will require that teachers have an in-depth knowledge of the subject area [9]. Historically, there has been little to no engineering/technology education through high school. Most middle-school teachers teaching STEM subjects would have majored in a particular science or maths and have never been exposed to much engineering content. This lack of technology/engineering experience calls further for the need of engineering content development for middle-grade teachers. The Massachusetts State Curriculum Frameworks also acknowledge that there is a need for professional development plans in order

to implement a technology/engineering curriculum [1].

Hopkins [10] says it is crucial to include experiential and hands-on activities in teacher professional development. He insists they need to experience what the students may experience and be able to learn how it will actually be done in the classroom before they take it into the classroom. This would also appear to address one of the most common questions that arise after professional development workshops and training, namely, how do I do this in the classroom [9]?

Experiential workshops are not the sole answer. Far too many one-off workshops or seminars lack continuity or follow-up and lead to wasted time [11]. Many describe some sort of ongoing support structure as critical to teacher professional development [9, 12, 13]. Teachers will need to have a time or place to ask questions, voice their concerns and issues, or get feedback. Or, as Daloz (2000) describes, teachers need an opportunity to take committed actions to allow them to expand and grow in this new content area in a way that makes the most sense for them.

Harcombe (2001) describes an extremely well thought out professional development programme she developed for her Model Science Lab. This programme had rich content summer workshops that included teachers teaching the content to other teachers posing as students. The teachers were exposed to all the different activities and lessons that would be done in the classroom. They were also provided with opportunities to meet every school day as peer groups to discuss what was working or not working. The research and programme development team would also periodically provide further development throughout the school year. Overall, the programme was successful in implementing a constructivist-learning environment in urban science classrooms in Houston, Texas.

While it would make sense to try and emulate what Harcombe did with her programme, it is likely not as feasible as one would hope. Her programme had strong grant funding, college professors and college students in addition to the support of the school. This type of support would likely not be available to implement an engineering curriculum broadly throughout a state.

Call for further research

If it would not be feasible to implement a resource-intensive teacher professional development programme, then what is doable and still effective? There is a need to investigate and research this topic further. What are the critical factors in having teachers confident enough to implement change in the classroom? What is the minimum engineering knowledge teachers must gain to teach the subject effectively in the classroom? These are a few of the questions we attempt to address in this study.

THE TEACHER PROFESSIONAL DEVELOPMENT PROGRAMME

Background

The teacher professional development programme described in this paper is a joint effort between Northeastern University, Tech-Boston a part of the Boston Public Schools (BPS), and Tufts University's Centre for Engineering Educational Outreach (CEEEO). An Information and Technology Experiences for Students and Teachers (ITEST) grant through the National Science Foundation (NSF) provides the funding. The purpose of the programme is to create a LEGO[®] robotics after-school programme for middle-school students that will include Massachusetts State Curriculum Framework standards, and to then prepare middle-school teachers to teach it. The professional development programme took place on the Northeastern University campus during the first two weeks of August 2005.

Curriculum development

The authors developed and tested the ten-lesson LEGO robotics unit used. The lesson plans were developed by first piloting them with four teachers. They led the lessons modelling the instructional practices they wished the teachers to integrate in their classroom. The teachers then led the lessons in their classrooms and provided feedback on how to improve the lessons. After receiving this feedback, the lessons were further refined. At this point, the authors led the unit in two eighth grade classrooms. The resulting student feedback and classroom observations helped to finalize the unit for use in the summer professional development workshop.

Two-week professional development workshop

The two-week professional development experience for teachers was then designed around the preparation of teachers to teach the aforementioned 10-lesson robotics unit in an after-school environment. The concern was that teachers not only learnt the unit, but also how to introduce the programme successfully into their schools. In addition to the student lessons, teachers were given additional background content on difficult concepts such as gears and ROBOLAB programming. Experts from various fields were brought in to round out further the experience of the teachers (i.e. university professors, experienced teachers, outside consultants, etc).

The second week consisted of a practicum with students in the morning followed by additional workshops in the afternoon. The teachers spent mornings teaching the robotics unit to a group of 4–6 students. Teachers and students were allowed a total of ten hours to complete the unit; they were given one LEGO robotics kit per group of 2–3 students, access to the Internet and the ROBOLABTM software. On the last day of the programme, students presented the assistive

devices they had created to the entire group. In the afternoon, teachers discussed successful strategies they had used with students and what additional training, resources, materials, etc. they needed. Teachers also shared challenges they had faced and the group worked together to brainstorm potential solutions. The following day teachers reported back on whether or not the proposed strategies had worked for them.

METHODOLOGY

What happens next?

The teacher professional development programme along with the after-school programme are part of a larger study where teachers will be followed-up throughout the school year and student outcomes will be measured. The scope of this paper is limited to aspects of the two-week's programme which were successful in the eyes of participating teachers and the instructors. The data discussed in this paper came from confidence surveys administered to the teachers, content tests administered to the teachers, observations by the instructors and follow-up interviews conducted with the teachers two to three weeks after the two-week professional development course.

Population study

Table 1 shows the breakdown of the participating teachers' demographics.

Implementation of the professional development workshop

In the first week, the professional development plan was followed closely. Teachers participated in scheduled workshops with guest presenters, and were led through the robotics unit lesson by lesson. Each morning and afternoon was punctuated with the ritual of giving feedback and reviewing the feedback of the day before. During the second week, the initial professional development plan was loosely followed, as teachers needed support and information in a different way than had been anticipated. The mornings were spent with students instructing them in robotics. In the afternoons, teachers debriefed each other about what worked, what did not and how to solve issues they were having with their students. The initial plan had been to continue the teachers' professional development with more lessons on advanced building, advanced programming and CAD. However, the teachers needed immediate support on specific questions they and/or their students could not solve. Afternoons were spent troubleshooting robots and programs, learning building techniques and engaging in team building exercises. Finally, teachers spent a portion of each afternoon preparing for the next day's lessons.

Table 1. Breakdown of teacher demographics

Gender	female	male		
# teachers	6	7		
Race	African American	Caucasian	Hispanic/Latino	Undisclosed
# teachers	6	4	1	2
Experience	1–5 years	6–10 years	10–20 years	20+ years
# teachers	5	2	3	3
Subject taught	technology	maths	science	language arts
# teachers	5	4	3	1

Source: Authors.

RESULTS AND DISCUSSION

Hands-on opportunity

When asked what aspect or aspects of the two-week professional development best prepared them to teach the after-school LEGO robotics unit, a number of teachers mentioned the opportunity to work with the materials and experience of each lesson was critical for being prepared. The first week of the summer workshop was designed to have the teachers work just as their students would with the lessons and materials. In addition to working with the lessons, the teachers received additional content and experiences related to the topics in the unit. One teacher described what best prepared them as, ‘. . . the hands-on and being able to do a lot of the activities . . . the whole process gives me the confidence now that if I get stuck again I am much better prepared to find the solutions . . .’ Similarly, another teacher touted the hands-on experience: ‘it [hands-on experience] sort of grounded us and from that experience we can go forward and certainly it isn’t something I would have tackled without the experience’.

It was also clear, through observing, that the teachers were engaged with the materials and learning at a rapid pace by being able, as part of the hands-on process, to test and retest their ideas and designs.

Seeing other teachers do it

During the practicum in the second week, the teachers and their student groups engaged in the 10-lesson unit in two large rooms. This was not by design; space limitations did not allow each group to have its own room. An unexpected benefit of this arrangement was that it allowed teachers to observe other teachers’ styles, approaches, struggles and successes. One teacher commented, ‘I was looking at the different people and their teaching styles and saying, ‘I like the way he did that’, or ‘I hope I didn’t do that.’ Teachers never get a chance to do that.’ Having teachers in the same room served as a way for teachers to reinforce their own methods. Another teacher commented on how witnessing other teachers teach had him

‘recognizing there are other ways to do things and there is no wrong or right way and there are just different paths as long as you get to the same destination’.

Observations during the practicum also pointed to the value of the shared space. Teachers were clearly watching other teachers and other student groups working through the unit and using what they saw in one group with their group. At times, teachers would ask other teachers for assistance and a teacher would leave the group for a while and assist. A number of times Rick, who had discovered great ways to use the different LEGO gears, showed another teacher how to use a particular gear mechanism to create a certain type of motion. The shared space also allowed the three instructors to be more readily available to those teachers who had questions during the lessons. Since this was looked on as an opportunity to experiment with new lessons, questions to and support from the instructors were encouraged. While it was not an intentional design item, using large rooms with a number of teacher-student groups worked very well to enhance teacher learning and confidence, or as one teacher put it, ‘. . . having a lot of people in the same situation around you made it easy.’

Analysis of confidence in teaching engineering content

Overall, the two-week professional development was successful in improving teachers’ confidence in their knowledge of and in teaching engineering principles. The teachers were asked to assess whether they were very confident, moderately confident, slightly confident or not confident where each rating was given a point value, 1 for not confident up to 4 for very confident. From the first to the last day of the workshop, teacher confidence increased significantly from 2.17 to 2.92 ($p = .002$), nearly a full point on a 4-point scale. There was also an increase in their confidence in teaching engineering principles from 2.58 to 2.92. The less substantial increase in teaching engineering principles is likely due to the teachers’ teaching experience. Seven of the teachers had 10

or more years of teaching experience, and a number of them mentioned in their follow-up interview that their confidence was due to this. Also, interesting to note was that teachers' confidence decreased when faced with teaching computer principles and skills. This is most likely due to the fact that the teachers had seen the ROBOLAB programming language for the first time.

CONCLUSIONS

The goal of preparing middle-school teachers to teach an after-school LEGO robotics unit with technology/engineering content appears to have been achieved. All the teachers who participated said they were going to teach this unit either in an after-school or in-school setting. Aspects of the two-week professional development study that impressed teachers and researchers were walking through the curriculum step by step with the instructors, allowing the teachers plenty of hands-on experience with the materials and soft-

ware, creating a safe environment for the teachers to practice teaching the unit, allowing teachers to observe other teachers teach the unit. The teachers felt it was important to be able to become familiar with how the unit would be taught and for them to be able to 'play' with the materials beforehand. Surprisingly, having the teachers work with their students in a large room amongst the other groups was an aspect that enhanced the teachers' learning and confidence with the unit.

For the future, work will be done to adapt teaching styles to better match the inquiry-based, hands-on learning environment the researchers wanted to create for the students. Teaching styles were difficult to change radically in only two weeks, and other strategies need to be looked at to accomplish this goal. The researchers will also be following-up with additional professional teaching development opportunities throughout the school year. For future programmes, it will be important that the teachers recruit their own students for the second week practicum as having that relationship ahead of time enhanced the learning experience for teachers and students.

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