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Engineering an Integrated STEM Education for Teachers

Dr. Danial J. Neebel PE, Loras College

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(Work-In-Progress)

Abstract

There is a strong movement in K-12 education toward integrated STEM curricula (Science, Technology, Engineering, and Mathematics). This paper describes an engineering course in robotics that is part of Master of Arts in Education. The program seeks to truly integrate the STEM fields and provide educators with sufficient training so that they may motivate and challenge their students.

Introduction

The physical world around us cannot be described by a single discipline. Each STEM discipline has its own way of looking at the physical world. Traditional education seeks to break the world into separate academic disciplines. Consider the world of Robotics, traditionally an engineering discipline. Robots interface with the world around them and become part of a world that is not concerned with categories or disciplines. The purpose for which the robot was created determines the discipline. The creator of the robot may have been a physicist, a mechanical engineer, a computer scientist, a mathematician, or even a psychologist. The disciplinary labels of those involved in robotics are not as important as the skills, knowledge and methods [1] [2] [3] used to create the robot. According to Stohlmann, et. al., integrated stem education is an excellent way to improve students' performance in science and mathematics. Stohlmann, et. al. also state that better and more preparation and support for teachers is necessary to leverage integrated STEM curricula to improve student learning. [4]

What is STEM?

Koonce, et. al. provide a quantitative review of what disciplines industry and academics refer to as STEM disciplines [5]. Their conclusions were that there are significant discrepancies between industry and academics. Certainly definitions vary among academicians. We provide below in **Error! Reference source not found.** our own view of the individual STEM disciplines.

What is Integration?

In education, integration is often experienced through problem-based learning. Problem-based Learning, PBL, lends itself well to engineering education as engineers apply Math, Science, and Technology to solve problems. The many separate disciplines come together for a common purpose. In the course described in this paper, robotics engineering is used to solve problems and create a context for learning. This context then motivates us to deepen our learning from various disciplines to solve the problem at hand [1].

As mentioned earlier the goal is to acquire skills, knowledge, and methods from the variety of STEM areas. However, disciplines still exist in post-secondary education and to similar extent in the job market. Therefore, students must also understand where the bodies of knowledge originate. Understanding the viewpoints and techniques of individual STEM disciplines is an important step to motivating further study. Students can then go on to secondary and post-secondary education with a clearer view of where they are headed. According to Honey, et. al. educators must be explicit about what disciplines are involved and where each plays a role. [1]

Administration and faculty at Loras College saw a need to provide educators with a stronger more integrated understanding of STEM. To this end, faculty have developed and Loras College now offers a master's degree in integrated STEM education. This Masters program is designed to provide practicing teachers and informal educators with the tools necessary to bring the STEM disciplines into their classroom. The program targets K-8 teachers, but is available to all teachers. This paper presents one of the courses, a course covering the methods of engineers through robotics as an application.

An Integrated STEM Education Master of Arts Program

The program described here is framed around a definition of STEM from Vasquez et. al.: "…an interdisciplinary approach to learning that removes the traditional barriers separating the four disciplines of science, technology, engineering and mathematics and integrates them into real-world, rigorous and relevant learning experiences for students." [6] The Integrated STEM Masters is a program focused on the theory and practices of delivering meaningful learning opportunities in STEM and related disciplines with the understanding that integrated STEM allows students the skills and perspectives necessary to deal with the problems of the world in which we live. The degree program is for teachers in the elementary grades through high school and informal educators. The program presents STEM Education as appropriate for all students, not just the best and brightest.

- Place-based STEM education
- Curriculum Inquiry in STEM
- Scientific and Engineering Practices
- *Robotics Engineering
- Issues in STEM Education
- STEM for ALL
- Using Research to Improve Teaching/Learning in STEM
- Mathematics and Technology as Interdisciplinary Topics
- Action Research Project Part I and II
- How Students Learn
- Assessment for Teaching/Learning in STEM
- Teachers as Researchers: Communication of Action Research findings

Figure 1: Ordered list of courses in the Integrated STEM Education Masters

The faculty in the Integrated STEM program are from the education, biology, chemistry, engineering, computer science, and mathematics programs. The vast majority of the curriculum is delivered online. Courses are listed in Figure 1. There is not a division between content based courses and methods courses. Application is stressed in each course. Students reflect upon how what they are learning can help improve their own curricula and teaching. Although, some courses are team taught, the course presented hear is not.

The Robotics Engineering Course

The Robotics Engineering course is organized so that each topic revolves around a project area and not so much around a discipline. Each week students investigated and tried various elements of programming (technology), electrical and mechanical engineering, use of mathematics, and some small amount of physical science. Along the way they wrote microcontroller programs, built electrical circuits and mechanical systems, and applied a variety of sensors common in robotics. The students applied the engineering design method in a culminating project using robotics to solve a problem of their own choosing. The learning outcomes of the course are given below.

Students will demonstrate the ability to:

1. Employ the engineering design process to design and create a prototype.
2. Write a computer program using flow control constructs and procedures.
3. Explain analog and digital interface techniques using a variety of environmental sensors.
4. Construct and program an autonomous robot with simple navigational abilities.
5. Reflect upon a project to practice skills of critical thinking, decision making, self-learning, and the engineering design process.

As already mentioned, the course described is organized into a sequence of projects. Each project is designed to allow the students in the course to demonstrate their grasp of a particular area of robotics. For example, one of the first projects requires the students to construct their robot from a kit. Not everyone is mechanically inclined so this exercise is not as trivial as it sounds. Other projects required students to test the effectiveness of a specific sensor given changes to the electrical circuit connected to the sensor. In that project students learned about how the sensor system operated and the programming needed to interface the software and the hardware. Other projects involved: program control logic with timed events, bringing mathematics and computer science together; driving LEDs bringing physics and electrical engineering together; Servo motor control bringing electrical and mechanical engineering together to see how rotation can be translated into linear motion. All this needs to be squeezed into seven weeks.

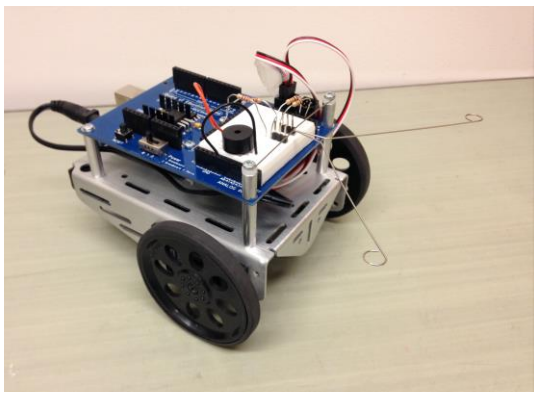

Figure 2: Robot with whiskers installed at the end of week 2.

The short duration of the course means students must get their robot up and running quickly. Figure 2 shows the robot platform; the Arduino-based Board of Education Shield Kit from Parallax. Parallax provides an online tutorial covering programming and building the kit [7]. The following describes the weekly assignments and provides a summary of the final projects.

Schedule

- **Week 1: Brains and Brawn.** The first week is spent on the fundamental aspects of programming (Brains) and building the robot (Brawn). Students construct the robot and write a program for the robot to traverse a predetermined route. Students also do some circuit building with LEDs and resistors connected to Arduino outputs to provide signals concerning what the robot is trying to do. The first week culminates in with a project to make the robot to travel in a geometric pattern such as a square or a triangle. Students turn in a video of the robot running through the predetermined path and the program that drives the robot. STEM areas touched upon in the first week are mechanical engineering, electrical engineering and technology.
- Week **2: Navigation by feel.** The second week students learn more about programming structures such as loops and arrays as data structures. Arrays are employed to hold a sequence of robot commands: drive forward, turn right, etc. Then for loops are introduced as an easy way to step through the commands. Students also begin to learn about digital input

and they add “whiskers” to their robot. The whiskers and learn how a contact closure can be interfaced to the microcontroller. The whiskers are a simple contact closure with a pull-up resistor tied to a digital input pin. The weekly project is to program the robot to navigate by whiskers including the ability to recognize and recover from getting stuck in a corner. STEM areas in this week are technology for programming, physics of forces applied to the whiskers, electrical engineering for the wiring of the circuits.

- **Week 3: Navigation by light.** This week the students learn about measurement of ambient light levels. One such measurement uses a phototransistor. This requires the use of the analog to digital converter in the Arduino. This works well for dim light, but not so well for brighter ambient light. To increase the range of light measurement, the students use the photo transistor to discharge a capacitor. The faster the discharge time, the brighter the light. The STEM areas involved here are technology for programming, electrical engineering for the circuit, physics for the phototransistor device, and mathematics to describe the discharge rate of the capacitor.
- **Week 4: Measuring quantities and calibration:** So far, sensors have been fairly simple, touch, light sensitive, etc. The fourth week includes the use of Infrared LEDs and an Infrared detector. The IR detector comes from the manufacturer tuned to respond best to 38 kHz. This means it is primarily a digital sensor in that it can only detect a 38 kHz modulated IR signal. However, some rudimentary measurement of distance can be done by varying the frequency of the signal output of the infrared LED. In one activity students use the variation in sensitivity as a rough means to determine distance from an object. Although highly inaccurate, this simple measurement of distance allows students to explore the concept of proportional control. A program using proportional control causes the robot to move faster when farther away from objects and back up if too close to an object. There is also an activity to demonstrate how ambient light fixtures can “fool” the IR detectors.

  Weeks 5 through 7: The Engineering design process. At the end of the fourth week, students begin to brainstorm ideas for a project by looking for problems that need solutions. The first step is to identify a need. The entire design process presented to the students is shown in Figure 3 and is from “Engineering Fundamentals and Problem Solving” by Eide, Jenison, Mashaw, and Northup. [8]

1. Identification of a need.
2. Definition of the problem
3. Search – what have others done
4. Criteria and constraints:
5. Formulate Alternative Solutions
    - Stage 1: Brainstorm
    - Stage 2: Development
    - Stage 3: Prototype (one design)
    - Stage 4: Test
6. Analysis – Mathematics and Science
7. Decision – Does solution work?
8. Write Design Specification
9. Communication – Tell Everyone

Figure 3: The engineering design process.

- **Example final projects (pictures and descriptions)**
    - **Cirbot:** The Cirbot assists in teaching geometry to 5th grade class. The robot raises and lowers a pen to draw a given geometric object. The 5th grade students were able to help debug the robot and present what they had learned from the activity in a video.

- **Dog Feeder:** One student felt a need for a device to refill the dog food dish. The student designed a device to refill the dish when it was empty for a prescribed amount of time. In this case four hours.
- **Teacher Tracker:** Robot that tracks a teacher's movement from front to back of room carrying video camera. The device made use of the SWIVL robot to carry a tablet device that takes video of a presenter. The SWIVL robot turns to face the teacher and the Arduino-based robot moves the SWIVL robot along a track to follow the teacher around the classroom.

Assessment and Summary

With no formal assessment data is ready at the time of this writing, some reflection of the instructor is offered instead.

What worked well: The use of video clips are extremely important in online learning. Students who can see examples worked by the instructor are better prepared to solve their own problems. Instructors who can see the problems a student is having with a robot are better equipped to help students debug their own project.

What did not work so well: As with typical face-to-face classroom, interaction between students and with the instructor is very helpful in learning. Teamwork is difficult on robotics project when students are not in the same locale. The challenge becomes how to encourage communication among students and the instructor. Online courses tend to operate asynchronously. Using video snippets to communicate helps, but video chat would be much more helpful. Video chat should be initiated by the instructor, rather than waiting for students to request a time.

Finally, as mentioned earlier, further work is needed to better align course projects to the Next Generation Science Standards.

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