Engaging Middle School Students in SEAD Learning Through Smart Product Design

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ABSTRACT
In this paper we illustrate the results of an open-ended SEAD (science, engineering, art, and design) course engaging middle school students in design of smart products and services. Students engaged in integrative activities that had them researching and developing viable products, while considering the business, engineering, and design aspects. Final presentations of each team's product prototype, design process, and business plans were presented to a group of local business executives to critique on value proposition, viability, and market opportunity.

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K-12 education; product design; prototyping

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

General Terms
Design

INTRODUCTION
Challenging students to think outside the box and develop critical and creative thinking skills is an essential goal for educators responsible for preparing these students for the 21st century workforce [2]. Transdisciplinary teaching and open-ended product design courses give students the opportunity to develop and expand these skills while increasing student engagement and motivation. Making students partners in their learning, rather than passive recipients of information, is a crucial element of learning [1].

The design process with open-ended outcomes is a strategy intended to allow students to move through phases of creative and critical thinking, including ideation, selective judgment, and refinement of their product [2]. As students work through several iterations of their own designs, analytical and evaluation measures can be used to address needs or problems not otherwise discovered in a single iteration. Along the way, skills in creativity and critical thinking are honed and content knowledge enhanced.

We offered 7th and 8th grade students a course in smart product design to gain a deeper understanding of sensors, physical prototyping, and business and marketing concepts. Students developed their smart product around the theme of improving their environment. We will discuss our experiences and perceptions of the learning experience for students and describe the outcomes. We will also highlight the challenges and successes as viewed by the researchers, teachers, and students involved.

This paper examines the critical roles played by school administrators, teachers, and researchers in identifying characteristics of exemplary courses developed to cultivate creative and critical thinking skills within K-12 education. While the identified challenges created some unnecessary hurdles, constant iteration on the course design and the interaction and the exchange of ideas among the parties involved, ultimately resulted in active engagement and demonstration of creative and critical thinking skills in the smart product design course.

COURSE OVERVIEW
The smart product design course was designed as a 15-week class offered to 7th and 8th grade students at a private school in a small city close to the university. Twelve students originally enrolled in the course, but due to various conflicts, nine students completed the term; three girls and six boys. The class was offered the last period of the day, Monday through Friday. Two days a week the class time was extended beyond the school day, giving the students an additional hour.

Staffing
During the extended class periods, two graduate students traveled to the school to provide workshops on business concepts, design, and engineering. There were two school faculty/staff members associated with the class. The classroom teacher was a veteran science teacher with over 40 years teaching experience. Their school staff member was the Director of Technology, who became the lead instructor for the course when the graduate students were not available. The Technology Director had no formal educational experience or training in teaching, but was an active member of the school community and very involved in classes. His input was valuable from two aspects; one as a technology resource, the other as the a means of providing consistency for the class. On the

days the graduate students were not present, they maintained contact with the students through Google Hangouts.

Student Expectations

No specific prerequisites were required for this course, however there were several key traits expected of the students that were described in the syllabus:

The ability to work individually as well as in teams. While the projects in this class were team-based, students would often be provided individual tasks that support the work of their group. This would require the students to our own their own outside of the group, and then report back what they had found out.

To be comfortable with ambiguity. The course was focused on teaching a design process, not necessarily in developing a particular product. For the students, this meant that the form and character of their final products were not known from the outset. This uncertainty could be difficult for students as they had to research, analyze, iterate, and discover what their final projects would be.

Be open-minded and accepting of change. Students were asked to present their ideas, as well as receive constructive criticism of those ideas from classmates. The process of sharing and critiquing allowed students to improve their product ideas throughout the class. The students were encouraged to repeatedly work on ideas and to not accept the first solution they developed.

Maintain a good attitude, participation. Give the small number of students in the class having everyone present was critical to progressing through the class. Activities and modules, such as the ones in Table1, could not be repeated if a student was absent or late to class. Also, as this course was a new experience, both for the researchers and the school, we did not focus on student grading to measure achievement, but largely their engagement with the class.

Activities and Modules

Participation in the course was voluntary. At the start of the school year, the students and parents were given a letter describing the course as well as a course syllabus. The course syllabus mapped out the course description, learning objectives, and basic outline of activities. The first week introduced the topics of sketching, research, and sharing. During weeks 2-6, activities examined opportunity identification, concept generation, evaluation, and selection of a product. Weeks 7-15 included design development, prototyping, and business plan development. Important deadlines were noted and communicated throughout the course. The final presentation was an explanation of the design and iteration process and unveiling of their products to area business leaders. After the team presentations, business leaders, students, and educators held a discussion on the experience and what was gained.

Activities were designed to introduce content to students and give them experience using research strategies, documentation tools, engineering tools (sensors, circuits, etc.), and relevant applications. Collaborative and team building skills were progressively honed as the weeks passed. Students worked on communication and teamwork skills through maintaining a positive, supportive attitude and practicing the acceptance of the ideas of others. Frequent "play" periods were provided, where students were supported while experimenting with sensors, lights, prototyping with cardboard and other materials, and being encouraged to take risks and think big. Breaking down barriers and developing bonds between the participants was encouraged through numerous critique sessions, where students analyzed and offered each other constructive feedback (see Table 1).

Activity	Purpose
Physical Prototyping	Iterate on physical form of their product and evaluate.
Lemonade Stand	Experience decision-making and introduce business concepts of product, price, and marketing.
Round Robin	Offer students the opportunity to freely propose and critique ideas. Development of constructive criticism.
Public Critique	Give students experience in documenting processes and publicly communicating their ideas.
Business Plans	Determine what, why, how, and to whom to market their product, and at what price.
Storyboarding	Visually depict their product and how it works.
Sketch	Explore potential design ideas and interactions.
Field Trip	Allow students to experience first hand being in a higher education, academic environment; tour engineering and design studios and meet with faculty.
Kiva	Open ideation space to generate new ideas and possibilities, partnered with university undergraduate students to help with ideation and critique.
Arduino Play	Gain an understanding of the ability of computational materials and how they can influence design choices.

Table 1. Course Activities

REFLECTIONS

Researcher Perspective

The overall experience was extremely valuable to researchers, students, and instructors. Though not without its issues and constraints, the smart product design course was successful as assessed by student gains. Insight was also acquired on the impact of teacher and administrator mindset, timely communication between school administrators and researchers, teacher training, allocation of space, time limitations, and accessibility of technology to students on educational outcomes.

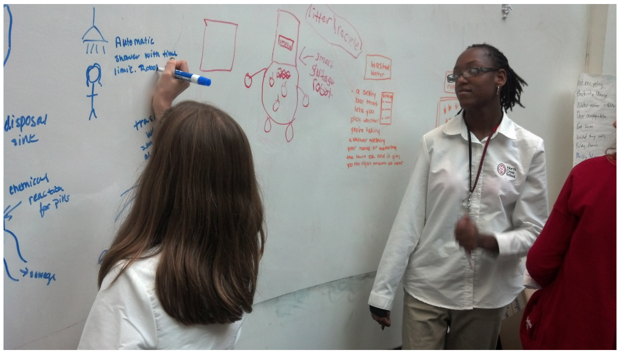

Figure 1. Students ideating during field trip to the University

Student gains were measured through weekly self-evaluations and peer critiques. Students privately documented their thoughts about the class and their own contributions as well as those made by their teammates every Friday. Consistent evaluation allowed the graduate students to make changes to the course and give students ownership. While the course was based on an undergraduate product design course, it quickly became evident that pedagogical modifications were necessary in order to give our middle school students more support and direction.

In addition to student gains and participation, use of technology helped with student engagement and commitment to their projects. Students used their iPads to complete a number of tasks including weekly evaluations, file sharing using Dropbox, just-in-time research, and access to applications relevant to the design process. Documentation was easy as they took pictures and videos, made sketches, and kept journals throughout several iterations of their design.

While students made mostly positive gains, the researchers also focused on how logistics played a part in the overall experience. As with any experience in a K12 school, issues and constraints were present. Some of the most common being communication, space allocation, scheduling, and limited time. However, these constraints were offset by flexibility and cooperation between all parties involved.

Administrators at the school were supportive of the overall goals of the course, but were viewing the concept of smart product design as something comparable to a curriculum for a robotics course. This lack of clarity became problematic in recruiting teachers, mainly because it was viewed as a STEM (science, technology, engineering, and mathematics) course rather than a course designed to involve most disciplines, even the arts. Thus, teachers unfamiliar with robotics and engineering were reluctant to become involved. It was also problematic in helping parents appreciate the wealth of opportunities a smart product design course could offer their child as much of the focus on standards, college applications, and student advancement relies heavily on experiences with STEM rather than SEAD. Our vision of the smart product design course was not limited to robotics, rather included a business and design aspect not usually present in such courses. Ultimately, a science teacher and the Director of Technology were assigned as co-facilitators.

Upon initial contact with the school itself, the collaborative (between school and university) concept included two weeks of teacher professional development. This was to occur in the summer prior to fall implementation of the class. However, timing issues between the two institutions prevented the training from being done. Although the experience was ultimately exciting and fulfilling for both instructors, lack of professional development created initial feelings of anxiety and frustration. Once the routine was established and student engagement was apparent, these feelings dissipated.

As is vital to any design process, space to ideate and build was somewhat problematic. The assigned room was not the room of the teacher involved, so student work had to be erased and removed, and stored daily. As a result, however, students became resourceful as they figured out ways to keep track of their work by taking pictures of the white board notes with their iPads and using available office space as storage areas.

Although 15 weeks was dedicated to the class, time became an issue. Because the class met at the end of the day, students often checked out of school early for various reasons, other teachers pulled students to make up work in other classes. Thus, absenteeism became a concern. Once again students turned to their technology and those who were absent began using their iPads to communicate with the class when they were out for illnesses, and even on evenings and weekends. They used email and Facetime to stay connected and exchange ideas. One student was sick for an entire week but was committed to attending class everyday via Facetime. As team leader she felt it was important to stay in contact with her teammates and contribute as much as she could.

School Faculty Perspective

In interviews with the two staff members facilitating the product design course, the overarching theme that resonated with both was the increase in maturity and the students' problem-solving abilities. Both viewed the gains as an overall increase in the level and type of thinking. Students were not only thinking at a different level, they could articulate their thinking processes to each other. Teacher Z described it by saying, "seeing the difference in them between when they started and when they finished...there was a maturity level difference....they were thinking more conceptually". Student engagement was also high on the list of observable outcomes. Students maintained enough passion and motivation about their products to analyze, evaluate, improve, and communicate continuously, even after school hours. Teacher S described it as, "the successes the students came through, not so much in the final product, the presentation, but the comments they shared with the people who were evaluating. It was the comments that I heard, kids say, this is why I participated in this and here is what I gained from doing it. The kids who cared enough about it to have formulated in their mind what it was that they hoped to gain and what it was they got and could articulate that, to me, that is a measure of success". The students' use of technology was another noticeable outcome. The use of the iPad as a tool to document, research, communicate, and share ideas was a bonus and not anticipated. Learning to use other technologies, such as sensors

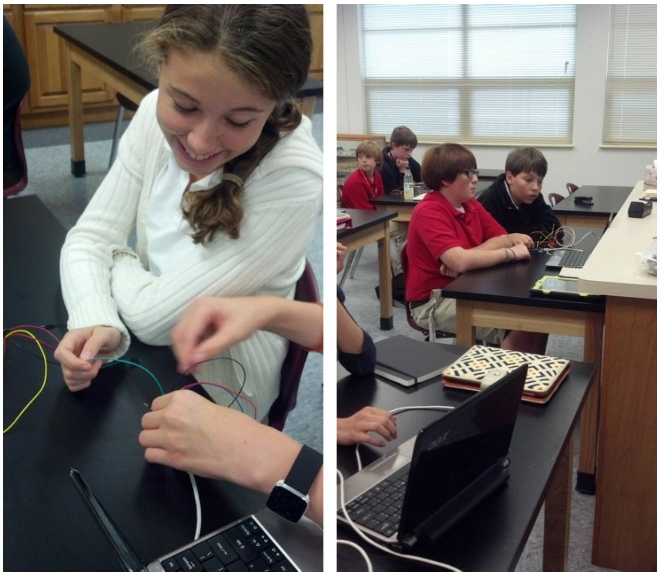

Figure 2. Students experimenting with Arduinos and sensors

and Arduinos was expected and achieved.

The facilitator with the science and teaching background observed the need to retool the curriculum to better match middle school pedagogy. Some material was covered faster than most middle school students could grasp. Her knowledge of the students and the student evaluations allowed us to go back and revisit areas that needed attention.

Student Perspective

The most compelling evidence of student learning came from the students themselves as they discussed their products and the class. This discussion occurred after their final presentations with local business leaders. The local business leaders were given time to ask students about the process and the students articulated their perspectives quite well. When asked why this class was different than their other classes, Student C replied, "*we really had to switch it around, and we had to think of how we could move forward instead of having the teacher tell us what to do*".

When discussing the use of their iPads, Student I explained, "*to design your product it just opened up a whole new door of how you can actually make something on your Ipad, ... then you can go and print it and you actually have a physical prototype. And that's just been like a cool learning experience in this class*".

The student's grasp of how things worked was obvious as they demonstrated their products and fielded questions from the audience during the final presentations. They exhibited poise, confidence, and a level of articulation not often seen in middle school students. Student T explained the division of labor within the teams as, "*We had like a certain area that we were focused on because the main aspects were business, engineering, and design. And we kind of signed up for which one we were interested in and tried to split it up evenly, with one person being design, one person being business, one person engineering...[but] we could all work together*". Student I elaborated by saying, "*Everyone was doing engineering, everyone was doing business, and everyone was looking for a design to decide what in the world this product should look like. It was a great collaboration of all of us*". Even the obligatory few students that we thought might have missed the point, stepped up to the plate when presenting.

As students discussed the parts of the class they liked, they called attention to the value of open-ended projects and choice. They spoke about the different aspects of the course, rather than a class having one focus, such as science or math. They enjoyed the integrative nature of the class. Recognition that all content areas were equally important was evident. The ability to choose an area of expertise, such as the design aspect, the business component, or the engineering, made the experience individualized, even though they gained knowledge and expressed a new respect for all aspects.

CONCLUSIONS

There were many valuable lessons learned from this experience. The importance of aligning higher education and K-12 schools in terms of schedules and logistics was clear. Allowing enough lead time for proper teacher training is critical in assuring that teachers and researchers are clear on their roles and comfortable with the content and how best to present it.

Although issues of assigned space and scheduling are obstacles, they are surmountable. A room dedicated to making, and the uninterrupted time to do so are optimal. However, we also learned to work within the constraints we are given. Quite often, the lesson we learn from the constraints are just as valuable as those we learn had the constraints been removed.

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