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PROJECT-BASED LEARNING FOR EXPERIMENTAL DESIGN RESEARCH

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ABSTRACT
Project-based learning has been illustrated to be an effective means of teaching students many of the "real-world" issues that arise during the course of engineering projects. However, project-based learning tends to have a product-centric focus. This paper describes an experimental run of a project-based learning program with a research-oriented focus, named "X-PBL." In this project, four college undergraduates were tasked with developing artifacts to interrogate a research question of their own design. This paper outlines the motivation and details the logistical organization of this project, concluding with a qualitative assessment of how the research focus changes the character of project-based learning in engineering design.

Keywords: Project-based, design research, engineering education

1 ENCOURAGING ENGINEERING RESEARCH

Although universities are the centers of academic research and development, engineering undergraduates have often sheltered from the hubbub and excitement of guided research. This is an unfortunate oversight, since engineering research has the potential to expand student horizons, to increase motivation for higher-level education, to augment the students' ability to perform scientific inquiry, and to impress upon the student the importance of cooperation and communication. It is thus desirable to integrate engineering research into undergraduate research programs. [1]

It is important to distinguish the open-ended engineering research proposed here from the "laboratory class" research most undergraduates are exposed to; in open-ended research, neither the questions, nor the methodology, nor the answers are pre-ordained. Many universities address the need to encourage engineering research at an undergraduate level through programs like the Undergraduate Research Opportunities Program at the Massachusetts Institute of Technology, where the student participates in various phases of research activity as a junior colleague of a faculty member. [2] Such programs are a strong resource for students who seek out specific opportunities, and prolonged participation will create exposure to the research community and the underlying process. However, these programs are based on an apprenticeship model; student experiences vary widely depending on the faculty mentor and the phase of research the student happens to become involved in. In order to incorporate engineering research into the undergraduate curriculum, it is desirable to develop a more structured approach to introducing undergraduates to the trials and tribulations of engineering research.

2 AN EXPERIMENT IN EXPERIMENTAL PROJECT-BASED LEARNING

2.1 Overview

This paper describes a variant of project-based learning ("PBL"), which we have termed "X-PBL" to signify its focus on experimental research. Project-based learning has been championed as a means to help students synthesizing existing technical knowledge and developing an appreciation for the logistical issues present in any design project. Although the moniker encompasses a wide variety of programs, project-based learning in engineering is generally modeled after industrial engineering projects. [3] The goal of the X-PBL program was to leverage our experiences with such product-centric educational endeavors to introduce engineering undergraduates to the world of academic research in design engineering. Rather than focusing on technical issues and engineering requirements, students contend with developing research questions and tracking emerging technological trends. They evaluate ideas based on potential academic impact rather than on cost or market-based product viability, and are asked to deliver research findings rather than functional artifacts or systems at the end of the project. By engaging students in experimental research early on, X-PBL aims to teach students to ask new kinds of questions and to explore new kinds of issues—questions and issues vital to innovation in engineering design.

2.2 Description

Just as traditional project-based learning is like a microcosm of industry engineering projects, so is X-PBL a microcosm of academic research projects. The pilot X-PBL project was run in the context of a larger interdisciplinary research project on Interactive Workspaces, focused on how information technology could be used to enhance educational collaboration. [4] The students engaged in the X-PBL program joined an existing research community of graduate students engaged in different aspects of the overall project, were mentored by a graduate student advisor, and were guided by a faculty member at a high level through the following tasks:

* developing a research focus
* performing ethnographic research
* benchmarking prior research
* finding specific research questions
* designing artifacts for interrogation
* designing experimental studies
* analyzing information
* presenting results

2.3 Project Constraints and Resources

Because the engineering research projects performed in this domain are often performed in groups, the X-PBL project was team-based. The four undergraduates, only two of whom were acquainted with one another before the project began, were told that they could divvy up tasks and focus on different aspects of the project, but that they needed to develop common goals and to negotiate a shared budget of USD$2000. In addition, the scope of their projects was limited by a twelve-week time frame. This time restriction was important not only for pragmatic reasons but also encouraged the students to pare their inquiry down to its most essential elements.

One of the challenges of the X-PBL project is that there is no one proscribed "right way" of doing engineering research; indeed, one of our goals was to show the students the degree to which creativity and good judgment are required in the course of research. The X-PBL students had at their disposal various tools and facilities already affiliated with the Interactive Workspaces project and with the Center for Design Research, where they were working. The team was not told explicitly what was available to them, but was informed that they need only ask other researchers both on and off their project about anything they were interested in. This was done not only to simplify administration, but also to reinforce the open-ended nature of their project and to encourage resourcefulness in the team members.

3 CASE STUDY

The following is a detailed description of the student team engaged in our X-PBL project. The team consisted of four female undergraduates, three of whom had just completed their first year of undergraduate in mechanical engineering and one of whom had just completed her third year. The students worked over the summer, and had the benefit of being able to focus solely on the research project.

3.1 Orientation

One key aspect of engineering research is that it happens within the context of a research community. To introduce the undergraduate student team to the community at the Center of Design Research, we had a small party and asked the student team to bring food and to send e-mail invitations to their fellow researchers. We strove to rapidly integrate the students into the community, inviting them to meetings, talks given by visiting researchers. The students were asked to start of their work by going around and asking graduate students what they were doing in their research, and how they were approaching their respective projects.

We also emphasized the importance of keeping good records of their ideas and their process as they engaged in their research project, suggesting to the student that they each go out and get a logbook. The team went beyond our suggestions and created a design weblog, or "blog" where they posted day-to-day updates on their work and ideas.

In addition, we suggested early on that they choose a name for their group and project, to make it easier to refer to their work. After talking to various graduate students, and noticing that many project nicknames either began in an "i" to signify "interactive" or ended in an "X" to indicate that something was experimental or unknown, they playfully named themselves "iX" to indicate that they were going to make an "interactive something."

3.2 Developing a Point of View

Since the student team was responsible for choosing their own research project, we gave them pointers about how to select something worthy to work on. We adopted the product-design term "point of view" to describe to the students how they needed not only to find a worthwhile research focus, but also to develop a unique perspective on their topic. We stated this early, but also gave the team plenty of time during the following two phases of work to narrow in on what they planned to do.

3.3 Ethnography

The team decided first of all to focus on interactive furniture. Several researchers suggested that they perform some ethnography to examine how people interact with normal furniture to start out. The iX team studied people and groups that interacted with conventional tables through observation and photographs around our college campus, at restaurants, during business meetings, in bookstores and through books and furniture catalogues. They observed that generally tables have four functions: storage, rest-and-gesture, social focus, and display. They decided to concentrate on the display and social focus aspects of table use, as these were the areas where technology might best enhance to furniture.

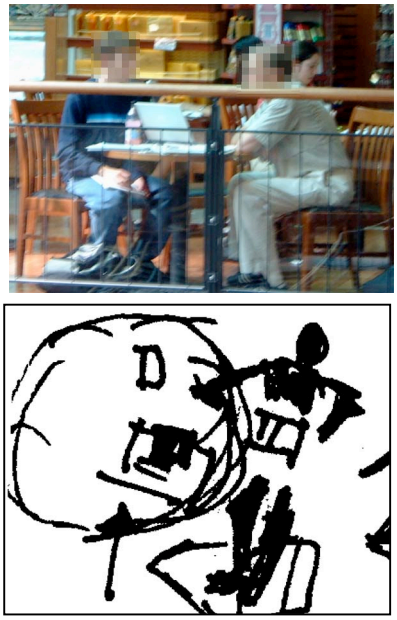

Figure 1. Social focus created by table. Photo above. Logbook sketch, below.

The iX team noticed that people like to spread out information on tables, for example to organize documents or look at pictures. However this also creates a problem of being able to reach and gesture on items displayed that are far away on the surface. Also, a table supports multiple orientations. When people surround a table, it is impossible for everyone to have the same view of the table's contents. Thus, when trying to share information, people will gather together on one side of the table so that they can also share a point of view. If a document is placed between two people, it implies that it belongs to both of them. By increasing the size and scale of the document, it can be placed among more people and therefore allow for shared ownership between a greater number of people.

They also observed that when reading a newspaper or presenting information on a laptop, the display surface is often vertical. However, if writing on a piece of paper or typing on a keyboard, it is necessary that the input surface be horizontal. From this they generated a hypothesis that horizontal surfaces work better for input, whereas vertical surfaces are better for output.

3.4 Benchmarking

As the iX team began to focus their work on interactive furniture, fellow graduate students made numerous suggestions of other relevant research projects they should check out. This familiarization with existing research gave students a clearer picture of what had and had not already been done by those in the larger research community, and helped them learn to appreciate the important role that journal papers and conference proceedings play in research.

By chance, the iX team attended a lunch-time talk to the Interactive Workspaces group by a visiting researcher from Mitsubishi Electric Research Laboratories working on the Diamond Touch interactive tables. [5] They were excited to see that her findings on

how people used shared interactive tables matched their own observations, particularly about the problems of information orientation on desk surfaces. In addition to this work, the students also drew much inspiration from Nadia Kahn's Furnichat project [6] and PARC's Experiments in the Future of Reading [7]; this work helped the students develop their point of view that they were trying to develop an interactive table "with spirit."

3.5 Idea generation

The iX team brainstormed numerous possible applications for an interactive table. They decided that a table "with spirit" would have a specific identity or purpose. The iX blog lists over 100 different ideas for their project. Many ideas, such as tables which could record events and identify the speakers at a meeting, and glasses that provide extra information in a meeting, were determined to beyond the capabilities project members, the tools on hand and the time constraints of the project. Other ideas only appealed to a subset of the team members. However, as these discussions progressed, it was clear that collaboration was a major theme, as was the challenge of getting a shared perspective on the topic at hand.

From these brainstorms came the idea of the MapNews Table, which is an interface for navigating and viewing news from around the world. They argued that news affects everyone, but people traditionally receive news individually. The MapNews Table could provides a focus for a communal dialogue on current event; their goals would be to see how different design decisions in terms of input and output techniques might influence collaboration. In choosing this concept, they also considered other applications that could potentially benefit from this type of interface include planning, presentations, and games.

Not all of the team members were uniformly enthused about this main idea. The senior team member wanted to work on something larger in scope by herself. This dissatisfaction was expressed by "dropping out" of the conversation, failing to show up for meetings and categorical rejection of brainstorming concepts. The graduate mentor was unable to convince this member that she either had to scale her work down, join the other team members on their project, or present a persuasive case for her own idea. Unfortunately, this is very much a real-world phenomena in working with teams. Several graduate researchers counseled different remedies, but ultimately, since the separatist team member was not amenable to numerous other forms of compromise, it was determined that she should work on her own separate project.

3.6 Realization

The iX team fleshed out details of their design by creating a storyboard for the usage,/ MapNews table presents passersby with a map of the world. Users can select one of 192 different countries, by pointing at the country on a physical map on the table. The country name is displayed at the top of the table on the beveled display. The main vertical display then shows an English-language news site from the selected country. Users can then navigate through the website by using a trackball which rested on the MapNews table.

Figure 2. MapNews Table

In constructing the MapNews Table, the iX team faced all of the challenges of a hands-on engineering project. The iX team made use of both commercial and in-house technology. Modified eBeams [1] built into the puck allow the user to click directly on the map. The Event Heap Server (developed at the Stanford iRoom [2]), provides the ability to "multibrowse", displaying the name of the selected country in a webpage projected at the back of the table, and displaying the news site on the large display. Major design decisions made by the team included what technology to use, whether to use a projected map or a physical map, how to size the interface to encourage collaboration, and what granularity to present the information in.

3.7 User testing

Since the goal of the design research project was to learn something new, the iX team needed to quantify how various aspects of the MapNews Table's design affected group interaction patterns. They devised a user study to contrast groups using a laptop and the MapNews table when the groups were engaged in news-oriented tasks. The iX team recruited nine groups of three people to participate in the studies.

The groups varied in terms of gender mix, ages, and levels of acquaintance between group members. The first task asked groups to find different countries perspectives on specific current events. The second task was more open-ended, asking groups to summarize the five top news stories in a specified region of the world. Half of the groups performed the first task using a laptop with a web browser, and the second half performed this task using the MapNews Table. The groups then switched to use the other interface for the second task; the experiment was designed to counteract order effects in the tasks. Each group was given a brief tutorial on the functionality of the MapNews Table and had five minutes of free time to acquaint themselves with the interface before using it for their tasks. The iX team took pictures and made observations through the duration of each session, and afterwards gave users surveys.

The iX made a number of observations about the use of the MapNews table that would greatly inform future work in large-scale interfaces. For instance, they found that the MapNews table made it easier to transfer input control between users by passing the puck, thereby relieving the "backseat driver" phenomenon found on the laptop. Perhaps as a consequence, people generally visited more sites and countries on the Map Table.

Quantitatively, the iX team's results indicated that the MapNews Table encourages group participation and unity more so than on a laptop. Group members were far more likely to agree with the statements that they "agreed with the final answer" (4.4 ±0.26 vs. 3.9±0.20 on a 5-point Likert scale, 90% confidence level) and "would enjoy working with this group using this interface again." (3.6 ±0.34 vs. 3.0 ± 0.35) for the tasks where they were using the MapNews Table than tasks where they were using the laptop. In addition, their results indicated that the MapNews Table is a better tool for groups searching for news than a laptop, with all but one of the respondents stating that they preferred the MapNews Table to the laptop.

4 EVALUATION

The X-PBL pilot run was a qualified success. Team members received hands-on experience with a research project, and were exposed to a much larger research community in the process. The iX team students themselves were very enthusiastic in their feedback about their experiences. One student commented that she was so caught up in working on the project that she did not notice until after the project was over that "the experience was more valuable than the product in the end." In the year following the pilot, the iX team members often reported back that their experience gave them an advantage in their classes. They also indicated that their experience influenced their decisions about what courses and electives they subsequently took. Three of the four team members went on to pursue research positions for the following summer. Fellow graduate students expressed a lot of wonder about the enormous amount accomplished by the team in the course of a few short months, and felt that they had all benefited from the retrospection about the research process engendered by the questions of the iX team

One area where the project had problems was in extending the positive experience to all of the students in the group. The one student who opted out of the main project had difficulty motivating herself to develop a single focus for the summer, found it challenging to put into words the problems she was encountering and ended up not finishing any project at all. This situation emphasizes to us the benefits of collaborating with others in attempting something new and challenging, and of staying engaged in a research community when working on one's own. We are interested in finding different ways to help manage the team dynamics so that future research teams do not splinter in this same way.

5 CONCLUDING REMARKS

Several factors contributed to the success of our pilot run of X-PBL: a broad community of friendly and accessible graduate students and professors [8], a wide variety of tools and materials on hand for rapid prototyping, easy access online to documentation of prior research and, of course, motivated students. What was not necessary, surprisingly, was prior technical knowledge; all of the technical skills used by the students were acquired during the course of their research project. Testimony from the students and faculty involved in the program suggest that the program a lot to illuminate shared understanding of research, and generates increased interest in pursuing graduate studies.

X-PBL shows promise as a way of introducing engineering design students to engineering research. The experience of participating in research accomplishes many of the same things that traditional project based learning does: it teaches students how to identify and specify engineering problems, how to source necessary information and

materials, how to work with others to accomplish a larger task. However, X-PBL emphasizes the challenges in formulating specific questions and plans of attack in an open-ended field, and puts a particular emphasis on scholarship and innovation. This variation X-PBL provides can help to enrich the variety of the undergraduate engineering design experience [9]. Ongoing work in X-PBL will refine the program requirements and provide more quantitative data with respect to the program impact on undergraduate and graduate research experience [10].

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