

Students' and Instructor's Impressions of Ill-structured Capstone Projects in an Advanced Electronics Lab

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Abstract. During spring 2010 six students enrolled in an advanced electronics lab worked in pairs on ill-structured capstone projects. They designed electronic circuitry to automate experiments that were completed in a previous advanced physics lab. Some ill-structured features of these capstone projects included open-ended goals, limited guidance from the instructor and the possibility of multiple solution paths. Semi-structured interviews were conducted with both the students and the instructor of the class, before and after the students worked on these ill-structured capstone projects to gauge the participants' expectations of the projects before they began and their views about these projects after they were completed. We report on the pre- and post-project impressions of the students and instructors regarding this ill-structured learning experience.

Keywords: ill-structured problem solving, capstone projects, upper-division laboratory, physics education research.

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INTRODUCTION

There are a variety of ways of characterizing problems. Problems can be characterized based on the methods and strategies used to solve a problem. The structure of a problem is also among the characteristics that distinguish problem types. Problem structure can be considered to vary from well-structured to ill-structured along a continuum [1]. Well-structured problems are well constrained with all elements of the problem specified explicitly. As a result well-structured problems have well defined initial and final states and clearly defined solution paths from the initial state to the goal state (i.e. solution). In contrast, ill-structured problems are vaguely defined with some elements of the problem unknown thus ill-structured problems may have multiple solutions and multiple solution paths [1, 2, 3]. At Kansas State University, students enrolled in an advanced electronics lab course titled Physical Measurements and Instrumentation (PMI) work on ill-structured capstone projects during the latter half of the semester.

In this phenomenological study, we conducted individual semi-structured interviews with both the instructor and the students in the PMI advanced electronics lab. The goal of these interviews was to gauge the participants' expectations of the capstone project experiences before they began and their views

about these projects after they were completed. Specifically, we sought to address the following research questions in this study:

- Q1. What are the students' and instructor's learning expectations from these ill-structured capstone projects?
- Q2. What do the students say they learn after they have completed these ill-structured capstone projects?

PMI CAPSTONE PROJECTS

The PMI course covers analog and digital electronics as well as LabVIEW programming. This course is offered to undergraduate physics majors but occasionally graduate students take this class. For the undergraduate students, the prerequisites to this course are the Modern Physics Lab (MPL) and the Advanced Physics Lab (APL). The MPL and APL courses cover typical modern physics experiments.

Students enrolled in PMI spend the first half of the semester learning about basic analog and digital circuits and circuit elements together with an introduction to LabVIEW programming. In the second half of PMI, students work on ill-structured capstone projects. In these ill-structured capstones the students apply their newly learned knowledge of electronics and LabVIEW to design circuitry that automates an

experiment that was previously learned in the MPL or APL. There are several experiments that students can choose from for their capstone project. The students in this study worked on one of the following three experiments as their capstone project:

1. Measuring the Speed of Light (SOL)
2. Saturated Absorption Spectroscopy (SAB)
3. Superconducting Quantum Interference Device (SQUID)

In the SOL capstone, students were required to design and build circuitry to measure the speed of light given. They were provided with a fiber optic cable, a laser diode, a photodiode and a variety of electronic components that they had learned about in the first part of the PMI course. Students in the SAB and SQUID capstone projects first reviewed the SAB and SQUID experiments by redoing the measurements that they had done in the previous advanced lab. Then the students were asked to come up with ideas to improve the measurements being done in these experiments. These ideas were required to involve a substantial application of the electronics knowledge that they had learned in the first part of PMI.

Some features that make these capstone projects ill-structured include their open-ended goals, the limited guidance provided to the students, the possibility of multiple solution paths and consequently multiple solutions depending on for example, the electronic components that the students choose to use as well as the trade-offs they make regarding the design specifications of the project.

METHOD

Six students were enrolled in the PMI course during the spring 2010 semester. Semi-structured interviews were conducted with both the students enrolled and the instructor of the class, before and after the students worked on these ill-structured capstone projects. These interviews were aimed at gauging the students' and instructor's expectations for the capstone projects before the students began and their views about these projects after they were completed. For this paper, part of the data collected through these interviews is summarized and discussed. The interviews were transcribed and open coded to look for emerging themes.

We looked at the instructor's answer to the following question:

a) What learning outcomes do you anticipate the capstone project to have?

We also looked at students' answers to the following questions:

b) What do you expect to learn by doing this capstone project?

c) What did you learn from the capstone project?

RESULTS & DISCUSSION

The six students enrolled in the PMI course during the spring 2010 semester worked in pairs on one of these ill-structured capstone projects, with a pair of students working on one of these three projects.

Initial Expectations

When asked about the anticipated learning outcomes, both the students and the instructor expressed expectations to relearn the concepts relating to the experiments that the capstone project involved as well as the capstone experience being a great opportunity to apply the students' newly learned electronic knowledge in the context of an actual experiment. When asked to articulate the purpose of the capstone projects, the instructor remarked, "Well, the main purpose is to hopefully tie everything together like I mentioned in class ... Some students didn't know what a capstone project was ... so I talked about the capstone in terms of an arch and so a capstone, what it does is ... it is really the main structural point in some respects, and if you don't have it the whole arch falls apart. And so it is to build on what they learned already but tie everything together. So hopefully they got that and that's the kind of the way I see it here too. But it's even beyond this class; right ... it's to tie in the stuff they learned from the other two laboratory classes - the advanced lab (APL) and the modern physics laboratory (MPL)."

When asked in general about his expectations of students' learning the instructor remarked, "Well, in some respects they are not going to learn much because they are going to relearn things... but that remains to be seen. I think they are going to learn a lot of little things. Hopefully they will deepen their knowledge of what they have already. So for example like, with the speed of light experiment what new will they learn? They'll learn about laser diodes, photodetectors and things like that ... they'll learn about an optical fiber. So those are new things and that might be of interest. And I think it depends on the experiment...."

The instructor also pointed out some specific details about what he expected the students to work on including some circuits that he expected the students to learn about and build in order to improve the measurements being done in the specific capstone project that the students chose to work on. For example for the SAB project, the instructor's expectations were that "once they have done the experiment, to come up with some addition to the

experiment to help with the data acquisition. So that could be, at the bare minimum, some automation or even better yet, develop some new aspect of the experiment to help measure something, for example like line width or absolute peak or things like that.”

For the SQUID project, he stated, “What I am hoping is they can build something to help improve the data acquisition on a couple of things, either the temperature, resistivity as a function of temperature or measuring the induced flux. ... To measure the induced flux by using what's called a flux lock loop. The flux lock loop is again a servo and that's something I want them to learn.”

Finally, for the SOL project, he stated, “Basically, what I want them to do is ... do a better measurement of the delay between the pulses, so what they are supposed to do is generate a light pulse, put it down a fiber and do a good measurement of the delay ... I want them to do that not with the O-scope and not with the NI ELVIS but actually build a circuit that counts it (the time delay). This is all based on stuff done in class. So in principle nothing in the electronics is that new besides the optics, the photodiodes and photo detectors, those things are new.”

Students’ comments regarding their expectations focused on their chosen capstone project. One of the students who had chosen Saturated Absorption Spectroscopy, remarked, “I really hope that I can

apply the electronics ... I hope this capstone project will help me with the experience of building something to enhance something else because in research you always need to think of things to make experiments better, more easier to do it, and get more accurate readings. So hopefully this can help me to build up more in my research as well.”

A student who had chosen to work on the SQUID project remarked, “Hopefully I will relearn the SQUID experiment and the physics behind it ... then also how to build something that will actually have a specific function in an actual experimental environment. I think it will be a good learning experience in that way.”

A student who had chosen to work on Speed of Light remarked, “I think it actually gives you a real situation that you use what you previously learned in the first part of the class. Because right now we did all the little tricks but we don’t know what the tricks are used for. And to actually use them in an experiment, I think the main thing I will be able to learn is just going to backup what I already know. It shows that the first half of the semester wasn’t just things you learned because you are in this class but, you can actually apply it.”

The instructor’s and students’ initial expectations are summarized in Table 1.

TABLE 1. Instructor’s and students’ expectations about specific capstone projects.

Instructor’s Expectations	Students’ Expectations
<ul style="list-style-type: none"> • Relearn the physics behind the experiments and deepen their knowledge of the involved concepts. • Build on the electronics knowledge they learned in the first part of PMI. • Learn about and build circuits to improve the measurements done in the experiments e.g. a servo loop circuit to lock laser to sub-Doppler features and building a counter circuit to measure time delay to calculate speed of light in an optical fiber. 	<ul style="list-style-type: none"> • Relearn experiment and physics behind the experiment. • Apply learned electronics knowledge to an actual experimental measurement.

Comparing the expectations of the instructor and students we find that the instructor was focused on students relearning some of the ideas in greater depth and also learning skills pertaining to the project. However, the students were more focused on learning some general skills and applying what they had learned. The instructor appears to focus on getting the students to build certain specific circuits, while the students, who are probably unaware of the details of the task, are more open-ended about their expectations.

Student Reflections about Capstones

Overall, students report their capstone project experiences to be positive ones. The students talked about how the capstone projects helped them relearn and see concrete applications of previously learned ideas and mentioned some general skills and knowledge they felt they had learned from their capstone experience. Students reported learning physics conceptual knowledge as well as some laboratory skills. Looking at the transcripts of the student responses to question c) “What did you learn from the capstone project?” we find that their responses fit within the following three themes: 1)

Physics concepts, 2) Electronics and 3) Experimentation.

A student expressed how the capstone project had helped them relearn and solidify their understanding of the physics concepts in that experiment by stating that “it was a good thing to do, I relearned some things that I did in the Advanced Lab and I kind of understand them better now that I have had other classes ... from E&M, and that kind of stuff, like in the SQUID how the electrons interact with the lattice in the superconducting state, also that is from quantum mechanics too. So having learned some of that, it's easier to understand how the super conducting works. And then a little bit of solid state physics also for the Josephson's junction and things like that.”

Another student remarked, “I learned the servo control technology and how those circuits worked and those are really common circuits in laboratory environments ... and since I already kind of knew how the SQUID worked I kind of relearned that new information but I feel that I have a stronger grasp of it now ... like when I took advanced lab when I was a sophomore I hadn't done any quantum mechanics besides just the square well and ... so I actually kind of understand how the SQUID works on a quantum mechanic level, which I had no idea before, so that was kind of new information.”

To demonstrate an electronics learning outcome a student remarked, “...I've learned a lot about having experience with circuits and just learning new circuit elements. We tried to use a timing chip for a clock which we didn't cover in class, I think digital counters and how to cascade them together ...” and another student stated that “from the capstone project we built a servo circuit, which is new for me and is new for our lab time, we didn't talk about it or study it in our lab ... building the servo circuit helps to lock the laser so we also learned about locking the laser ...”

Other student responses expressed experimentation learning outcomes. For example a student stated that “As far as experimentation goes, I learned a lot about troubleshooting and doing dummy tests to make sure things work ... I mean I have been taught since ... I have been working in the JRM [research] lab for two years. And so whenever something is wrong you learn to just break it down into smaller pieces and this was a good opportunity to solidify that. So just break it down into its smallest pieces and put things together from there.” Another student stated that “From the experiment itself I think I learned about the Michelson Interferometer, experimentally how to handle and work with it.”

SUMMARY & FUTURE WORK

We have investigated students' and instructor's expectations and students' self-reported learning outcomes of working on ill-structured capstone projects. We find that the students' and instructor's initial expectations for these capstone projects were mostly the same except that the instructor appears to focus on getting the students to build certain specific circuits, while the students, who are probably unaware of the details of the task, are more open-ended about their expectations. At the end of the capstone projects students articulate specific benefits of the capstone experiences which include the opportunity to revisit and relearn what they had learned previously, acquiring general laboratory skills, seeing concrete applications of previously learned electronics knowledge in experiments and gaining deeper insights into the physics of these experiments. Overall, these learning outcomes can be categorized into three themes: 1) Physics concepts, 2) Electronics and 3) Experimentation.

In the future we plan to investigate the actual details of how the students go about solving these ill-structured projects and what kind of difficulties the students encounter in that process by analyzing the audio and video recordings of in-class observations of the students working on these ill-structured capstone projects.

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