AC 2008-2498: FIRST YEAR ENGINEERING STUDENTS' INITIALS IDEAS FOR SOLVING COMPLEX PROBLEMS

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First Year Engineering Students' Initials Ideas for Solving Complex Problems

Abstract

This study is part of a larger ongoing study to explore the use of mini authentic challenges as anchors for inquiry in large lecture sections of first year engineering students.   Anchored inquiry into authentic, complex problems continues to grow as an effective instructional method for developing engineering problem solving and technical skills. As a precursor to lecture, students log onto an online module that presents a challenge statement. The online module provides a text field for students to *generate initial ideas* about how to solve the challenge and *generate questions* about what more they need to learn.   Then they *review* multiple perspectives provided by experts and *compare* these ideas with their initial thoughts. This generative experience is designed to orient students with the relevant information presented in lecture and with questions about what they need to learn in lecture. Some challenges have students evaluate complex systems as part of the process of generating ideas. This descriptive study explores what novice engineering students notice in complex systems relative to a problem solving goal. In this case the challenge was a troubleshooting activity that could be solved with a simple adjustment to one of the components. However, many students choose to make the problem a redesign problem of a completely different area of the system. These results illustrate that first year engineering students can approach complex challenges prior to instruction. They can identify the underlying problems based on their general understanding of the structure and function. Their lack of understanding of the how to determine the behavior of the system may be the cause of their inability to appropriately define the problem. The range of students' responses can be analyzed as formative feedback to support instructors' refinement of lectures to meet the needs of the students.

Keywords

Introduction

First Year Engineering (FYE) students are academically bright yet demonstrate a large variance in experience with engineering problem solving.   Specifically, students can manipulate mathematical operations for specific cases, but they have difficulty using data or equations to evaluate the performance of a complex system. In addition, they demonstrate difficulties representing complex systems in a way that supports their comprehension of a problem and the identification of potential solutions for a given situation. These specifics are important when we think about new pedagogical approaches to learning that involve learners starting instruction with a complex challenge. This paper presents results from a descriptive study designed to

illustrate first year students' ability to comprehend complex problems and generate ideas to inform their problem solving process prior to direct instruction. Specifically, the question is "What do FYE students notice in their evaluation of a problem involving a complex system?" Also, "What are students' perceptions of their ability to approach complex problems prior to direct instruction?"

The following sections provide a brief background of anchored inquiry as an effective instructional method. This includes a short description for how to present a challenge using an online module. The methods section provides a short description of the process and analysis used to categorize learners' responses and a short survey students completed. The final section outlines the implication of this study on instructional design with technological learning environments blended with classroom experiences.

Background

The First Year Engineering (FYE) course on Engineering Problem Solving and Computer Tools is mandatory for all incoming engineering students (approximately 1700 students a year). The course is designed to provide critical knowledge and skills students will need during their program of study at the university. Such knowledge includes systematic problem solving strategies (e.g. problems in design, troubleshooting and analysis), teaming, graphical and mathematical modeling and reasoning with data. Another content specific component of the course is to develop learners' programming skills; MATLAB is the most widely used language by instructors and researchers at the university. Therefore, students learn to develop programming and algorithm design skills as part of the course. The large cohort of students is divided into four sections; one of the sections is taught by the author. Students attend two lectures a week prior to going to a 2 hour lab. The lectures provide an introduction to new concepts that are applied and expended on later in the lab. Students develop their problem solving skills of open-ended, ill structured problems through an experimental curricular approach for STEM (Science Technology Engineering and Mathematics) learning called Model Eliciting Activities (MEA)[1]. An MEA presents a complex challenge that requires the development of a mathematical model as part of the solution. Students work in teams outside of class and lab to solve these complex challenges. Each team will solve three to four of these MEAs during a semester. Teams have two opportunities to generate a report and receive feedback from their peers and the teaching assistant (TA) on their solutions. This provides students with the opportunity to see other teams' solutions and develop important critique and communication skills. The ill-structured and open-ended nature of these problems results in a wide range of possible solutions. Assessment and evaluation of these performance tasks currently can only be done through human intervention.

Recently we introduced the use of mini-challenges as a pre-lecture activity to develop a "time for telling"[2]. Simply stated, that people can be told something when they are prepared to hear it. For example, imagine times when you've been working on something, but just can't figure out how to proceed. This experience becomes an anchoring event for you because many of the components of the structure and function of the problem are now apparent to you. Then when someone tells you some needed information, you have a kind of "Aha" moment and the pieces start coming together. Why can't a lecture experience be a similar kind of "Aha" moment? The

author's research team continues to work on how to accomplish this in an introductory engineering course.

One instructional model for accomplishing this goal is anchored inquiry[3]. Anchored inquiry is in the family of problem based learning and other inductive learning environments.[4] The particular approach used in this study emerges from the challenge-based method[5] used in the VaNTH[6] engineering research center (ERC) using the technology tools developed by the ERC [7]. In this model, students are posed a challenge before they attend lecture. The challenge is related to the big ideas to be presented in next lecture session. Students are asked to generate ideas about how to solve the challenge and questions about what more they needed to know to better understand the problem and identify potential solutions to the challenge. In some situations they are also given multiple perspectives of the challenge based on experts' thoughts and then asked to update their initial thoughts. Lecture begins the students' journey toward learning more about the big ideas underlying potential solutions to the problem. Other learning activities help to build their skills for specific procedures or conceptual understanding they will need. They will also receive formative feedback along the way to help them monitor their progress toward achieving their learning objectives. This approach has been successfully used in other undergraduate learning venues.[5]

The instructional approach is founded on learning theories and instructional approaches for effective learning enviroments[8]. The work in this study moves toward further bridging theory to practice and identify a method for capturing the qualities of students' learning and using it to guide the implementation of the instruction.

Methods

Nine learning modules have been constructed to introduce first year students to descriptive statistics, function discovery, numerical analysis, teaming and ethics to name a few. This study used a challenge involving a closed loop control system to introduce numerical analysis (maximum, minimum, roots of an equation) and review function discovery (e.g. linear regression, exponential relationships). The problem provides an excellent foundation to develop a mathematical model of a system's performance. The objective for the module is to use functional analysis tools in MATLAB on a mathematical model to predict when a maximum in a system is reached, or when a system passes through a specific value. The instructional activities consist of two major phases to anchor students' learning experience in an inquiry challenge.

Presenting the challenge
Students were presented a challenge facing a bioengineering graduate student, Sandy Wilson, who designed a simple incubator system with a proportional controller shown in Figure 2 and a systems response graph in Figure 3.

Her experiment requires repeatedly opening the door to sample the cells. When the door is closed the systems' return to the desired temperature is less than as indicated by the overshoot in temperature at 4 seconds in Figure 3.
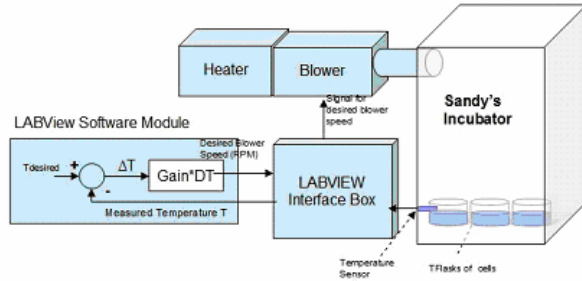
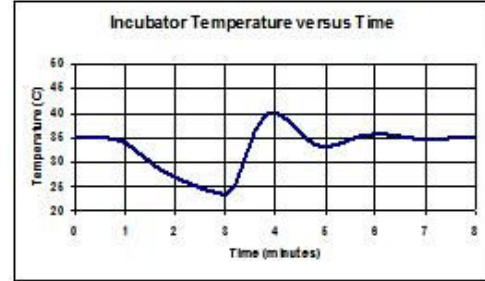**Figure 1 - Incubator System and closed loop response**

Figure 2 - Closed loop response

Students access the online module through the Blackboard Learning Management System (LMS) that organizes and delivers course materials. The module is presented in a web form with open fields where students can respond to two major questions and a survey question-

What questions do you need to investigate in order to better help Sandy?
What ideas do you have for Sandy on how she can improve the performance of her system?

Please respond to the statement "This challenge description is too difficult for me to comprehend."

☐ Strongly Disagree ☐ Disagree ☐ Agree ☐ Strongly Agree

*Reviewing Multiple Perspectives*

Once students submitted their responses, then they were given 4 perspectives from people who have solved similar challenges. Students are asked to compare these individuals' responses with their own. These perspectives are similar to responses we've obtained from other students during earlier implementations of the module.

We asked several people familiar with systems like the incubator to comment on their analysis of the problem and what they would think about as they began solving this problem. See how they compare with your initial thoughts.

Jennifer Wilson, **Junior in Mechanical Engineering**
My first thought to prevent overheating is to set up the blower to turn-off before the temperature reaches a desired temperature. However, I think the temperature would simply peek near the desired temperature and then cool down to the turn-off temperature. Then the heater would cycle on and off keeping the temperature at the lower turn-off temperature.
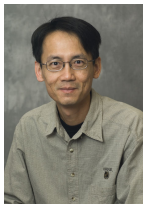
Joe J. J. Lin, **Engineering Education, B.S.I.E., M.S.I.E.** Click for bio
"Currently the slope of temperature between time= 3 to 4 minutes is very steep. However, if we control the blower right, the slope should become less and less steep when the temperature approaches 35 C. So the problem is either the controller's adjustment is not frequent enough, or the blower was not controlled properly. "
This makes me think... "Was the blower speed adjusted frequently enough? Did we use the proper 'Gain' value to adjust the blower speed?"

***Dr. K. Newburg, PhD.*, Biomedical Engineering**
I think Sandy has put together a great test apparatus. I'm pleased she was able to make use of our extra parts. To improve her set up she might want to construct a simple mathematical model of the system and then run an analysis to determine the best Gain for the controller. She could run a quick test to determine how fast the system heats up to the maximum temperature and how long it takes to cool off with the door closed. With this data I think she could make a mathematical model.

***Rupesh K. Agrawal,* B.S.M.E., M.S.M.E.** Click for bio
As I define the problem we need to provide a system which can monitor the temperature while sampling to stabilize the temperature requirement and keep less variation from sampling. I think some of the things we need to record is temp and time duration while sampling and record speed of blower when the temp stabilizes after you start the system. This analysis will develop a system with better feedback to record blower speed, time and temperature to keep the temperature below 35 C and exceed for more than 5 sec (considering safety factor and unforeseen event)."

Students also responded to a short survey.

How do your ideas compare with these people's perspective?

⬜ Very Different ⬜ Different ⬜ Similar ⬜ Very Similar

In this module, how useful are these perspectives at helping you notice important ideas related to solving this problem?

⬜ Not helpful ⬜ Somewhat helpful ⬜ Helpful ⬜ Very helpful

What have you noticed that you didn't notice before?

Please select the response to these statements that best describe your experience with this module. Rate from – Strongly Disagree, Disagree, Agree, Strongly agree

- This challenge description is too difficult for me to comprehend.
- This challenge was interesting to me.
- I can see myself solving this kind of problem in the future.
- I think it is helpful to work on challenges like this before we read the book or go to lecture.
- I like problems that make me think.
- The video on open loop system response presented gave me ideas about how to use MATLAB and LabView.
- The video on open-loop system response presented is interesting.

Please share any comments you have about this module.
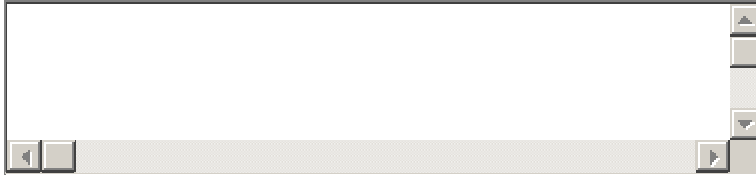
Students' responses are stored on a secure server.   The results were downloaded from the server and analyzed.

Analysis

This study focused on students' ability to generate ideas for solving Sandy's incubator problem. Open coding was used to explore the data for concepts then categorize those concepts based on patterns, similarities and differences. Table 1 summarizes the major categories of students' responses to the initial question "What ideas do you have for Sandy on how she can improve the performance of her system?" The table provides several examples of students' responses used to define that coding category.

Results

All students could generate a response for this challenge and almost all the students identified that too much heat (or temperature) was the source of the problem.   Students' definition of the problem and their strategies for approaching the problem were novel, but they were not necessarily appropriate (i.e. efficient). Table 1 illustrates the three major categories of their responses organized by the goals they generated. The majority of students focused on making changes to either the insulated box or the procedure for sampling the cells to limit the time the door was open. Or they focused on the blower/heater system. They understood that the rapid rise in temperature could be a problem; therefore, she would need to manually switch the blower system on or off. Only a few students discussed reducing the gain in the controller to reduce the overshoot.   Also, only a few students asked questions about the function of the LABView Software Module and what role it might play in the control of the system. We believe that one reason for this is students have little experiences evaluating systems and do not explore all connections.

Figure 4 is a summary of the results from the short survey after completing the module.

Table 1 – Categories of initial ideas provided by students

Goal - 1. Control the amount/rate of heat energy entering the heat chamber.	
Category – feature and solution	**Example of student response**
A – Adjust Gain A1 - Defines automatic control system	A- My first suggestion is that the blower and heater gradually slow as the difference in temperature approaches 0. Also, "Gain" should be increased while the door is open to compensate for the rapid cooling. A1 – program blower so that it doesn't heat too much, this will take trial and error to find exactly how much

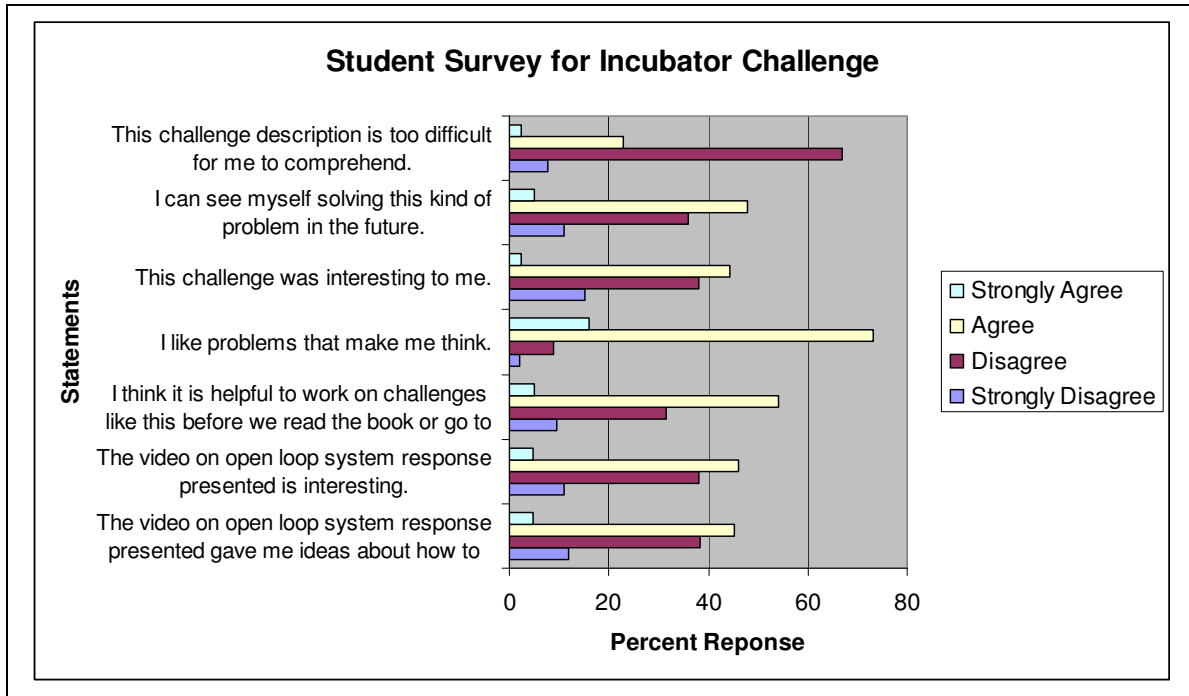|	the blower must heat to get the incubator temperature just right.
B – Temperature Switch – control cuts off or reduces speed at some preset threshold temperature	Have the temperature shut down when it gets close to the desired amount and then turn back on to constant the temp so it stays at the desired temp.
C- Blower, long slow warm up cycle	Incremental steps up
D – Heater system, replace	- Change the heater. - I think Sandy could try and find a heater with more varied temperature settings and change her program to

Goal - 2. Reduce the amount of heat lost in the system during sampling.	
Category – feature and solution	**Example of student response**
E – heater, run when door is open	Don't turn the heat off when she works on the sample so the temperature does not fall too far down
F – change procedure	She should find a more efficient way to sample the cells.
G – Chamber - redesign	Use a small door so heat loss is minimal, program blower so that it doesn't heat too much, this will take trial and error to find exactly how much the blower must heat to get the incubator temperature just right.

Goal - 3. Actively remove heat from the system (e.g. A/C, or exhaust system).	
Category – feature and solution	**Example of student response**
H- Add heat reduction system	introduce a more efficient cooling system in order to avoid the rapid initial heating overshoot

Discussion

This study illustrates several important characteristics of learning, instruction and the potential of technology to support the presentation of interesting challenges and gathering of rich data related to students thinking about engineering situations. First, the results demonstrate students' ability to generate ideas about systems they are unfamiliar. Second, students' responses can be coded into a specific set of categories. The incubator challenge illustrated that students target three different goals for improving the system. Two of the goals were not as appropriate as adjusting the gain of the system. This is not surprising that first year students are unfamiliar with control systems and introducing them to this simple system can prepare them for analyzing future systems. As instructors we could hope that they would notice the controller component and raise a question about its function and behavior. However, at this stage of their education they are not noticing the system as a whole. Therefore, **first year engineering students may need multiple opportunities to learn how to evaluate a complex system**.

Student Survey for Incubator Challenge

Statements (y-axis)
- This challenge description is too difficult for me to comprehend.
- I can see myself solving this kind of problem in the future.
- This challenge was interesting to me.
- I like problems that make me think.
- I think it is helpful to work on challenges like this before we read the book or go to
- The video on open loop system response presented is interesting.
- The video on open loop system response presented gave me ideas about how to

Legend:
- Strongly Agree
- Agree
- Disagree
- Strongly Disagree

X-axis: **Percent Reponse** (0, 20, 40, 60, 80)

Figure 3- Survey results after module, before lecture

Future studies will investigate the potential of giving students multiple opportunities to evaluate systems throughout the course. An achievable goal would be for students noticing all the components in a system, attempt to evaluate the function and behavior of these components. This new awareness will facilitate their ability to generate questions about specific components when they are uncertain about its function and its behavior in the system.

Students' responses provide instructors with an idea of what they understand and what more should be discussed in class. The range of the students' responses will depend on the open-endedness of the challenge and the accessibility of the challenge to students' level of comprehension. The historical database of students' responses cataloged around governing principles of the system and students' noticing can increase our efficiency for giving formative feedback to our students. Also, as more and more responses are collected, we develop a rich profile for how students approach the library of challenges we design. Therefore, we should be able to anticipate the needs of students relative to how they process complex systems.

The result from the short survey illustrates students' willingness and interests in working on problems that make them think. Students agree that they control loop problem was accessible to them; however, the class was split on how interesting it was to engage in. We can strive to design challenges that are interesting to all students, but this may be a difficult goal to achieve with a large class consisting of multidisciplinary students. Finally, it's interesting to see that some students report a split in their perception that beginning with the challenge prior to lecture is helpful. More work needs to be done to determine the source of this division.

Additional studies are being conducted to evaluate how these online modules provide experiences for preparing learners for class time Aha moments. For example, some students are primed with questions because they will reference the modules directly. The content of their

questions are either about comprehending the challenge or questions about one of the multiple perspectives. By entering these questions into the system the instructor has an inside advantage for providing information for these questions which increases the chance of an "Aha" moment.

We are also interested in the developmental trajectory of learners' ability to generate ideas and questions about complex systems and how they represent them. The technology provides an important method for engaging our large population of students. Base on the survey for this challenge the majority of the students favor its use. We need to use a more diverse set of problems to capture the interest of all the students.

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