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Integration overload? Learnings from making a new link between mechanical engineering classes

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Integration Overload? Learnings from making a new link between two mechanical engineering classes

Introduction

Curriculum integration by way of connecting content among individual courses can benefit engineering education. It supports the development of both reductive and integrative skills needed for problem solving. It also promotes organization of knowledge and application to diverse situations that are characteristics of developing expertise [1], [2], [3], [4], [5]. The work presented in this paper is part of a program in the Mechanical, Aerospace, and Nuclear Engineering department at Rensselaer Polytechnic Institute, supported by a National Science Foundation Revolutionizing Engineering Departments (RED) grant. The program's central focus is curriculum integration and the collaborative teaching culture required to sustain it. A similar effort at Colorado State University reformed the approach to engineering education in the Electrical and Computer Engineering Department by distributing "thematic content" that connected different courses and "emphasizing knowledge integration" [6]. Challenges in adapting this approach at the author's department include scaling up to a larger program, addressing asynchronous timing of when students take classes, and sustaining the program past the pilot phase. One approach to addressing these goals and challenges is modular activities that can be adopted by instructors and embedded into courses. It was in this context that several faculty and learning experts collaborated to develop an activity that integrated knowledge from two typically unconnected mechanical engineering courses.

Methods

Activity Design: A Modeling and Control of Dynamics Systems (ModCon) course provided a scenario representative of the challenges in developing integrated curriculum in our department - a large class required by majors from all programs who were taking the course as either juniors or seniors. A small-scale activity with minimal disruption to the existing course content enabled rapid assessment of feasibility, effectiveness, and sustainability — the likelihood that the activity would persist in future semesters. This was achieved by replacing an existing exercise with a new problem that included the desired features for integration and assessment.

The original exercise had occurred in week five of the course, after students had learned about modeling dynamic systems with ordinary differential equations; applying Laplace transforms to represent the model as a transfer function; and analyzing characteristics of step responses for first and second order systems. The baseline course content covers modeling of mechanical, electrical, and electromechanical systems, and most assignments involve systems in these domains. The original exercise asked students to model a mechanical system and then solve for physical parameters to achieve specified performance. The exercise had been presented as an in-class assignment.

The new activity, on the other hand, involved a thermal system. One challenge was that not all students in the course would have taken a heat transfer course. The following strategies were used to address this:

- Providing targeted material for reference and review

- Emphasizing concepts from thermodynamics
- Scaffolding through the modeling phase of the problem
- Encouraging peer collaboration
- Allowing access to any other available resources

The ModCon instructors consulted with instructors of thermal and fluids courses to emphasize the application of the First Law of Thermodynamics to develop the governing system equations, since most student would have taken a thermodynamics course as a sophomore. The thermal and fluids faculty also prepared reference material based on content from the thermodynamics course, posted on the learning management system page for the ModCon course. Key information from the reference material included equations for the First Law of Thermodynamics, change in internal energy, and heat loss from convection. The problem was presented as follows:

> Consider that you need to design an experimental set up to be used as a testbed for a novel miniature temperature sensor. This new sensor is meant to be used for *in situ* monitoring of a fabrication process. This means the sensor is embedded on a work-piece while the fabrication process is running. See a diagram of the sample-sensor system in Fig. 1

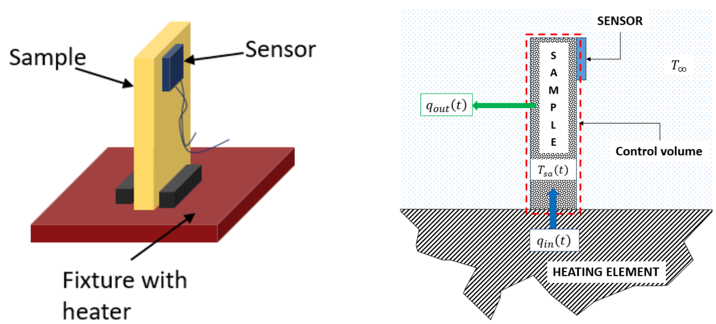

Figure 1: Diagrams given to describe the thermal modeling problem.

> Derive the transfer function $G(s) = \Theta(s)/Q_{in}(s)$ for this system. Here, $Q_{in}(s) = \mathcal{L}\big(q_{in}(t)\big)$ which is the input in watts, and $\Theta(s) = \mathcal{L}\big(\theta(t)\big)$ which is a temperature differential in Kelvin. Knowing that the temperature sensor to be tested has a time constant of $\tau = 1.5$ seconds, design the bench top sample such that the thermal dynamics of the sample system are 10 times slower than the sensor. This ensures that the temperature change can be accurately and finely resolved by the sensor. Choose from the following list of possible materials and briefly justify your choice.

The assignment provided a table with five possible materials that included their thermal conductivity, specific heat, density, and cost. In this manner, the new activity was enhanced by posing a more open-ended realistic design problem without a single correct answer. Collaboration was allowed in class, with students who had not taken heat transfer yet encouraged to work with a peer who had taken, or was taking, the course. Students were also encouraged to use any resources at their disposal, including but not limited to the posted reference material. During the modeling phase when heat transfer knowledge was most pertinent, class time was divided into intervals corresponding to specific milestones. In each interval, students were encouraged to work through the solution themselves. At the interval end, progress was ascertained and appropriate hints were discussed. This scaffolding was intended to promote equitable progress within the limited time.

Assessment: Survey questions were used to evaluate the students' experience with, and the effectiveness of, the new activity. The pre-assessment survey had students score the following on a 1-6 Likert scale: 1) I am able to explain the first law of thermodynamics verbally; 2) I can explain how different forms of energy are related to the temperature of a system; 3) If provided with some review material, I think I will be able to write down a mathematical model of how the temperature of a system changes over time. The post-assessment survey put emphasis on collecting a mix of quantitative and qualitative data about 1) resources used and their usefulness; 2) difficulty of the knowledge integration exercise; 3) usefulness of the initiative as a whole.

Qualitative responses to survey questions were analyzed using principles of thematic analysis [7], [8]. The first and second author separately examined student responses to extract initial themes. Survey responses were also input into both Microsoft Copilot and ChatGPT with the prompt, "Summarize themes in the following student responses to a survey." The output was used to verify themes identified by the authors. If an additional theme emerged from Copilot or ChatGPT, the authors used a keyword search to confirm adequate supporting data from the raw responses before including it as a theme. Artificial intelligence is being recognized as a tool for analysis of qualitative data, with recent studies describing benefits, limitations, and guidance [9], [10], [11]. The first author coded all responses to correspond to the thematic categories, ranked frequency of themes, and used the results to draft the summary in the Results and Discussion sections.

Iteration: This activity was piloted in Spring 2024 by the first author, and iterated in Spring 2025 by the second author. In the pilot semester, the entire activity was conducted in one class period. In the second semester, the activity was split into two parts over two class sessions — a modeling part, and a design part. The survey and wrapper questions were refined in the second semester. The design portion was made even more open ended, with the material selection component added to the problem.

Results and Discussion

Results presented here are from the second semester that the activity was implemented when 219 students were enrolled in the course. Table 1 summarizes 200 students responses from the pre-assessment survey which was applied one class session prior to the in class exercise.

Table 1: Pre-assessment survey results

Scale – (low to high)	1	2	3	4	5	6
Content familiarity	1%	10%	16.5%	38%	21.5%	13%
Problem solving confidence	2%	7.5%	14.5%	40%	27.5%	8.5%

Figure 2 summarizes 169 responses from the post-assessment survey at the end of the exercise.

The open-ended survey question about difficulty revealed several major themes. First, many students struggled with gaps in prior knowledge, due to not having taken or retained content from heat transfer or thermodynamics. According a pre-survey, 48% of responding students had not taken heat transfer yet. Second, some students found it difficult to integrate knowledge from additional courses, especially when this integration was not a regular part of their learning experience. A number of students indicated feeling overwhelmed about having to pull in outside topics when they were already struggling to grasp the topics in the ModCon course. Third, the inherent difficulty of a more complex, open-ended problem rewarded some students and frustrated others. Lack

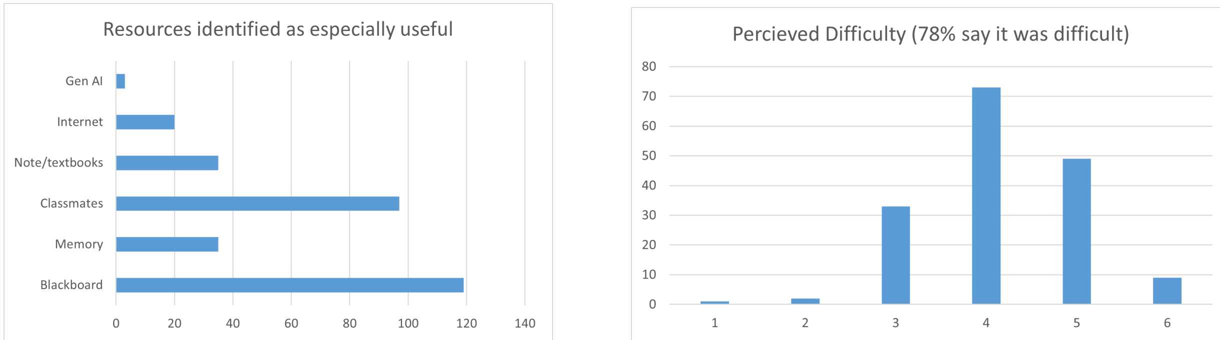

Figure 2: Summaries of responses to select wrapper questions.

of clear constraints or parameter values made it hard to know how to start or proceed. However, many students found the problems ultimately solvable despite being hard to start. Some students found the problems intellectually stimulating despite the difficulty. A few students felt uniformly confident about the problem, saying it was "just right", "relevant" to class, or "well-defined". Some students appreciated the design-problem aspects of part two, specifically referring to selection of materials and dimensions, and consideration of cost.

From the open-ended question about how helpful the exercise was, several themes emerged regarding the value of the activity, including that it 1) provided exposure to integration between different topics, 2) helped learn the material from ModCon, 3) reinforced knowledge from Thermodynamics or Heat Transfer, 4) practiced application of concepts to a real world engineering problem. Additionally, students recognized the value of practicing complex problems that require critical thinking, system-level perspective, and a systematic approach. Several students specifically stated that the exercise likely helped prepare them for their engineering career.

Although students benefited from the design nature of the activity (the triumph), the challenge of drawing on heat transfer knowledge discouraged many students (the tragedy). Strategies including emphasis on thermodynamic principles, access to various resources, and providing hints at intervals throughout the modeling process were not enough to overcome this gap. It is possible that more clear and deliberate scaffolding could facilitate a thermal modeling problem in future iterations. Students seemed overwhelmed by needing additional knowledge on top of learning material in this notoriously difficult class. This dilemma of balancing integrative content with discipline specific learning was discussed in [1]. However, ModCon already builds on numerous other courses from the mechanical engineering curriculum, from electronic instrumentation to dynamics. Going forward, instructors intend to better leverage the existing potential for knowledge integration in the course through improved pedagogical practices that promote transfer and organization of knowledge. The instructors also plan to modify more problems throughout the course to feature open-ended design questions as was done with this activity. Finally, future evaluation of the activities would benefit from assessing learning artifacts such as model correctness or common error patterns.

From the department level perspective, this activity was successful in stimulating collaboration among faculty in different sub-disciplines as well as infusing improved teaching and assessment practices through consultation with learning experts. In addition, results of this activity inform a more nuanced approach to emphasizing interconnections in the curriculum, as suggested by prior studies [12], [13], [14].

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