AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #28139

Facilitating Cross-Course Connections & Knowledge Transfer between Engineering Thermodynamics and Mathematics (WIP)

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Abstract

It is well-established that students have difficulty transferring knowledge and skills between courses in their undergraduate curriculum. In order to assess the ability of students to transfer ideas between their classes, the connections students make between integral calculus and other subjects was tested in a thermodynamics class. In this pilot study, students were posed the classical thermodynamics problem of boundary work, which requires the application of calculus skills to solve. After a first attempt to solve the problem with no instructor guidance, students were given a relevant calculus problem in order to activate their prior knowledge. After solving this calculus problem, students were given a second attempt at solving the initial thermodynamics problem. Student responses to each of the problems were scored. Prompting students with the calculus question was successful in showing students the need to integrate to solve the problem of boundary work but did not significantly improve their overall problem-solving success. Many students did however state that they felt they had the skills required to solve the thermodynamics problem. Suggested barriers to success included a lack in learning the applications of certain math skills and the gap in time between completing the math sequence and thermodynamics courses. The understanding gained from this study will be used to guide the design of exercises that improve students' ability to transfer knowledge.

Introduction

In the majority of classes in any discipline and at any level, students are expected to use knowledge from prior courses to solve problems in the current course. Typical examples in the engineering field include the transfer of knowledge from the first-year curriculum into discipline-specific classes that come later in the course of students' studies, such as using integration skills to solve differential equations in heat transfer or fluid mechanics. These first-year courses are often delivered by faculty from outside the major of the student. It is common at many institutions, for example, for faculty from the math and physics departments to deliver foundational courses to engineering students from multiple disciplines. Problems then arise when the links between these core, foundational courses and later discipline-specific classes are not clear to the students. In such cases, students are often unable to use their prior knowledge learned in these classes in new situations and some form of remediation is required.

While problems with student ability to transfer knowledge can be found across the engineering curriculum, of particular interest to this study is student ability to use knowledge of integration from their mathematics curriculum and to apply these concepts in their engineering courses. Several studies have been completed in this area, particularly in the mathematics and physics communities, while work from within the engineering field is scarcer. Orton [1] presents a summary of these problems from the mathematics perspective and also suggests the usefulness in revisiting fundamental mathematical concepts and reinforcing them throughout a student's education.

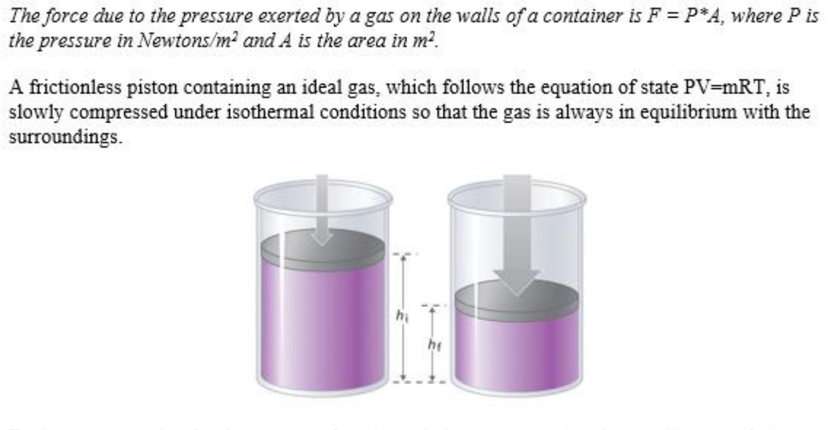
Rebello et al. [2] observed that while students might possess the requisite mathematical knowledge, the problems they have in applying this knowledge are likely related to students' inability to see how this work properly applies in a given context, including which assumptions and approximations they are required to make. Rebello et al. also suggest that student knowledge structures are not adequately prepared and do not sufficiently link mathematics with the physical examples that students might later encounter. It is suggested that specifically showing students examples and how to recognize similarities between problems helps students develop these structures [3].

Within the physics community, Christensen and Thompson [4] examined student understanding of mathematical concepts and how students apply these ideas in their higher-level physics and thermal-physics courses. By asking students questions about the area under curves in both a math (x, y) and thermodynamics (P, V) framework, they found that students often lacked the prerequisite mathematical knowledge or the ability to apply it correctly. Several other studies have also noted student problems with applying mathematical knowledge to thermodynamic principles such as work done, along with other state and process functions [5,6]. Pollock et al. [7] also examined student application of mathematical concepts to $P - V$ diagrams and found similar results. Their students often failed to see the relationship between mathematical concepts and thermal physics. Of particular note is that the authors suggested the use of “resource activation” (prior knowledge activation) as a potentially helpful tool in remedying these issues. They did not study this concept specifically, however.

While work has been completed in the engineering field related to knowledge transfer and deeper conceptual learning [8,9], there is still a need to develop tools to help students in furthering their understanding and their ability to transfer skills between courses. Through this study, we aim to assess whether students truly understand material delivered in first-year mathematics courses and are able to apply this knowledge in new or unfamiliar situations. Based on this pilot study, techniques for developing these cross-course connections and for promoting prior knowledge activation and transfer will be developed.

Implementation

In the initial pilot implementation of this work, student ability to transfer knowledge from mathematics (a first-year course) to thermodynamics (a second-year course) was tested using an in-class activity in which students were presented a problem from thermodynamics that required knowledge of integral calculus to solve. Data from two second-year thermodynamics classes (N=114) are presented. The in-class activity proceeded in three steps; (1) solving the thermodynamics problem without guidance, (2) provision of a prompt to activate prior knowledge, (3) a second attempt at solving the thermodynamics problem after prior knowledge activation.



The force due to the pressure exerted by a gas on the walls of a container is $F = P*A$, where P is the pressure in Newtons/m^2 and A is the area in m^2.

A frictionless piston containing an ideal gas, which follows the equation of state PV=mRT, is slowly compressed under isothermal conditions so that the gas is always in equilibrium with the surroundings.

Derive an expression for the amount of work needed to compress the piston a distance of Δh.

Figure 1: Thermodynamics (boundary work) problem statement

The thermodynamics problem chosen for the students to solve was that of boundary (pressure-volume) work done by an ideal gas expanding within a piston-cylinder device under isothermal conditions. The problem statement is shown in Fig.1 and requires students to compute the integral $\int_{V_1}^{V_2} PdV$ (eq.1) by expressing the pressure P from the ideal gas law (eq.2) in order to find the work done in this process (eq.3).

$$W = \int_{V_1}^{V_2} PdV \tag{1}$$

$$PV = mRT = k\ (constant\ under\ isothermal\ conditions) \tag{2}$$

$$W = \int_{V_1}^{V_2} \frac{k}{V} dV = k \cdot \ln\frac{V_2}{V_1} \tag{3}$$

Following the presentation of this problem as the first stage of this activity, students were presented with a problem covered in the integral calculus course (required for all engineering students) that would remind them of the need to both substitute and integrate in order to solve the thermodynamics problem. In this case the mathematics problem chosen concerned the work done in pushing a block of wax 100 *m* across a surface while leaving a trail of wax behind, i.e. the block loses mass as it is pushed. Hence, both substitution and integration are required to solve this problem (eq.4 & 5) and it can be used to activate the knowledge students need to solve the initial boundary work problem.

$$W = \int_0^{100} F\,(x)dx,\ \text{where}\ F(x) = \mu \cdot m(x)\ \text{and}\ m(x) = 50 - 0.5x \tag{4}$$

$$W = \int_0^{100} \mu \cdot (50 - 0.5x)dx = 5000\ [a.u.] \tag{5}$$

Again, students were asked to solve this mathematics problem and were not given the solution. Finally, they were then asked to solve the initial thermodynamics problem again to test the hypothesis that their prior knowledge would be activated by the mathematics problem. Following completion of the problem set, students were shown the solution to both the mathematics and thermodynamics problems.

Student solutions to each problem were graded and a point was awarded for each of the following: recognizing that $W = F \cdot x$, recognizing the need to integrate, and, finally, achieving the correct solution. A total of 3 points would then be awarded if the student completed the problem correctly. Students were also asked to rate their confidence in their own solution on a scale of 1-10 and, following the activity, students completed a short survey asking them the following questions:

1. Did solving the math problem help you to solve the thermodynamics problem? If yes, please explain in what way. If no, why not?
2. Do you agree or disagree that you had sufficient knowledge/skills to solve the problem without instructor guidance? Why or why not?
3. When did you study integral calculus?

4. Approximately how many times have you used these skills (integration & substitution) between this class and when you took your calculus class?

Results & Discussion

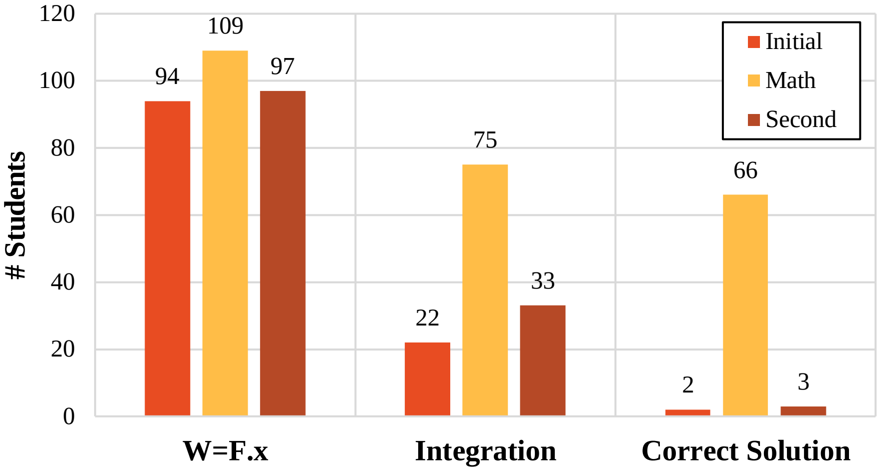


Figure 2: Student performance on the initial and second attempts at the thermodynamics problem as well as the math intervention as measured by their ability to recognize (a) W=F·x (b) the need to integrate to solve the problem and (c) to achieve the correct solution to each problem (N = 114).

Student performance in the sequence of problems that formed this study was mixed as shown in Fig.2. In each of the problems students were presented with, almost 90% of the class recognized the need to apply the "work = force x distance" ($W = F \cdot x$) relationship to solve the problem. Initially however only 22 students (19% of the class) realized the need to integrate, a realization that 75 (66% of) students came to in the math problem. More troubling is that even with the math problem available as a guide, only 11 additional students applied integration to solve the thermodynamics problem on the second attempt. While 66 students (58% of the class) were able to correctly solve the math problem, only two students correctly solved the thermodynamics problem at the first attempt, rising to 3 students out of the class of 114 at the second attempt.

These results are consistent with the findings of other researchers who have examined how students apply prior knowledge to new topics [4-9]. Having said this, however, a potential factor in this study is the way in which the thermodynamics problem was asked. Students were shown a diagram of a piston cylinder device and given the ideal gas law before being asked to find the work required to compress the gas a distance of Δh. It is possible that the use of volume in ideal gas law and 'h' in the problem statement confused the students, or that there were too many steps involved. It should be said however that one of the students who solved this problem correctly did so in terms of 'h' rather than using volume. Further work needs to be completed to assess whether the way in which the problem is stated affects student ability to solve it.

In their responses to the post-activity survey questions, students did cite the math problem as being useful in indicating the method required to solve the thermodynamics problem (question 1 of the post-activity survey). In particular, it was observed (Fig.2) that several students realized the need to integrate to solve the thermodynamics problem only after solving the math problem, a fact that was also noted by the students in their survey responses.

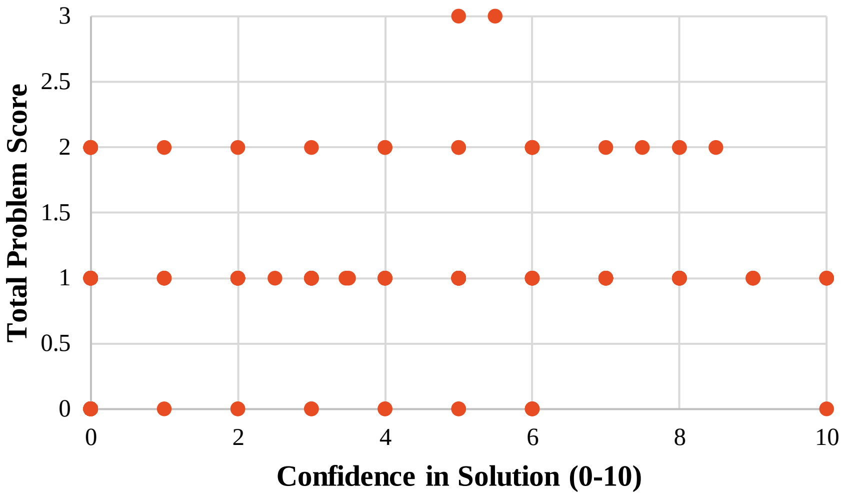


Figure 3: Student confidence in their solution to the presented problems against their overall score on the final problem.

Interestingly, although students were not able to solve the thermodynamics problem, students overwhelmingly believed that they had the skills required to do so – 82% (94/114) of students answered question 2 of the post-activity survey positively. This result did not correlate with the students own ratings of their confidence in their solutions as shown in Fig.3 however, where student confidence ratings were highly distributed and showed no correlation with performance on the problem.

Parsing the survey responses, the most common reply as to why students were not able to solve the problem given that they believed they had the skills to do so was that they either were not given sufficient practical applications of the concepts involved in the math curriculum, or that they had not needed to use these skills in the time period between taking mathematics and thermodynamics (typically one year or more for the majority of students). There was some disagreement between students regarding the number of times they had used these skills that warrants further work to examine whether these responses are major or course specific i.e. are these skills used in certain courses and majors but not others?

Conclusions

A proposed solution for aiding students in transferring knowledge from mathematics to thermodynamics was investigated. Without guidance, students attempted a boundary work problem requiring integration to solve before being given a related mathematics problem as a relevant reminder of the skills needed to solve the problem. Students then attempted the initial thermodynamics problem again. The math prompt did help students realize the need to integrate to solve the thermodynamics problem and while the majority of students (58%) were successful in solving the mathematics integral problem, only 3/114 students correctly solved the thermodynamics problem at the end of the activity. Furthermore, students' rating of their own confidence in their problem-solving ability and solution were in no way correlated with their score on the thermodynamics problem.

A post-activity survey of student perceptions and thoughts about the problems revealed that although students overwhelmingly (82%) felt they had the tools required to solve the problem, they did not initially see how integration as a tool could be applied in this situation. Survey results also indicated a large variation in how often students had been required to use these skills in the time between taking their math courses and the thermodynamics class.

Future Work

Future work will expand this study to include a greater number of students and by developing new exercises to aid knowledge transfer. Student ability will be tested pre- and post-course using concept inventories. Work will also be completed in order to correlate student performance with other indicators of ability such as grades in the math sequence, overall GPA, and to examine any links that might exist between different student populations i.e. major, gender, URM status. A key goal will be to develop effective tools and activities that better enable students to make links between their courses and transfer knowledge and skills effectively.

Acknowledgements

This work was conducted under IRB 2019-018(N) and grew out of work started under the NSF Foundations Project, Award #1524656, at Stevens Institute of Technology.

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