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Incorporating Active Learning of Complex Shapes in STEM Courses

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Incorporating Active Learning of Complex Shapes in STEM Courses

Abstract

A major obstacle students encounter in many STEM subjects is visualization of complex three-dimensional shapes, such as the *p-v-T* surface in thermodynamics. Conventional means of content delivery, such as textbooks and projector screens, are passive in nature and are ineffective in many situations. Alternatives such as immersive visualization technology are often costly and require specialized laboratory, creating a disconnect between lecture and spatial learning. An exploratory method is introduced whereby learners can achieve meaningful, long-term understanding of the material by constructing 3-D objects. This method was implemented in a thermodynamics course over two consecutive semesters at University of Illinois at Chicago. Overall, the observations suggest that the proposed method can yield a significant improvement in student learning of the subject.

Introduction

The current mechanical engineering curriculum at University of Illinois at Chicago (UIC) includes introductory and intermediate thermodynamics courses. In the introductory course, instructors primarily use traditional lecturing method, supplemented by an in-class display of a plastic mold of the *p-v-T* surface – the first examples of which were constructed by James Thomson[1] in 1871 and James Maxwell[2] in 1874. Despite the sculpture display, however, a significant number of students who subsequently enrolled in the intermediate thermodynamics course, instructed by the author, struggled to make sense of the *p-v-T* surface and failed to use the data tables for calculations. Many students in the intermediate thermodynamics class often made the mistake of constructing improperly sloped isobars on a *T-v* diagram (or isotherms on a *p-v* diagram). Consequently, using the data tables to identify the state of a substance became challenging, and errors were made as a result. More complex problems involving the first and second laws, as well as cycle analyses, presented an even bigger obstacle, and it all stemmed from the lack of, or incorrect, understanding of the *p-v-T* surface. This paper intends to introduce a method of rectifying the problem and enhancing student success in thermodynamics. The same method may also be applied to other core STEM courses where complex shapes are the fundamentals for understanding the subject matter.

Many STEM subjects are three dimensions in nature. From human anatomy to particle transport, complex geometries are involved. A major obstacle students encounter in these courses is visualizing these three-dimensional shapes, such as the *p-v-T* surface in thermodynamics. Often times, understanding of the subject matter cannot be achieved without a firm and thorough appreciation of the intricacies in the geometry.

Conventional lecturing methods, such as textbooks and projector screens, are passive and two-dimension in nature, and are ineffective in many situations. In recent years, many attempts have been made whereby the conventional methods are challenged. Programs such as NSF's Engage[3] and pedagogies such as classroom flipping[4] are being demonstrated across many institutions. However, these strategies may present an adoption-rate challenge among instructors, particularly seasoned professors and lecturers who may have already developed structured lesson plans that are resistant to modifications. Other alternatives such as immersive visualization technology are often costly and require specialized laboratory and wearable equipment, creating a disconnect between lecture and spatial learning.

The positive impact of active learning, spatial visualization and tactile models in long-term student success has been well documented. Clark and Jorde[5] described a sensory instrument to help science students achieve a deeper understanding of thermal equilibrium. Dewoolkar et al.[6] incorporated inquiry- and team-based learning in geotechnical engineering courses and saw promising results in student outcome. An active learning strategy was proposed and successfully implemented by Hall et al.[7] McGrath and Brown[8] described the importance of visual technique in STEM courses. Bullard and Felder[9,10] documented the many benefits of active learning in young adults and STEM students alike. Prince[11] dissected the effectiveness of active learning and showed its impact in student outcome. Dong[12] documented the importance of spatial learning skills in STEM subjects.

An exploratory method is introduced whereby the teaching of thermodynamics fundamentals is accomplished through student-centered and team-based active learning, spatial visualization and tactile modeling. With this method, learners can achieve meaningful, long-term understanding of the material by *constructing* 3-D objects – a *p-v-T* surface, in this case. This method may also be implemented in many core STEM courses without the need for restructuring, and without incurring additional cost. Learners assume the role of information creator instead of audience. Using existing material or technology – free or open-source software, foodstuffs, etc. – students now build the object from the ground up, by imitation, imagination, or both. The deliverables include a computer model as well as physical product, and the desired outcome is a meaningful appreciation of the 3-D object of interest and, ultimately, the subject matter.

Methodology and Goals

The primary learning goals are for students to achieve a long-term understanding of the *p-v-T* surface, and how to use data tables in practical calculations. The secondary goals include an appreciation of complex geometry, acquiring new software skills, and collaborating effectively with peers to produce results. The goals for administration (i.e., faculty, department or institution) are to incur minimal cost, and be able to implement the method in existing courses with relative ease and without having to overhaul the curriculum.

The approach presented herein consists of two parts: tactile and software. In part one, students are tasked with sculpting a *p-v-T* surface using any foodstuffs and bringing the completed sculpture to the following class. In part two, a CAD model is to be created and subsequently imported into a freely-available scientific visualization tool, with the best submitted model selected for 3-D printing.

Figure 1 below illustrates the process. It begins with adjusting the grading scale to accommodate the projects. For this project-based approach to succeed, the course syllabus must be modified by the instructor such that the project weighs substantially in determining the student's overall grade. An example of the old and new grade scale is shown in Table 1.

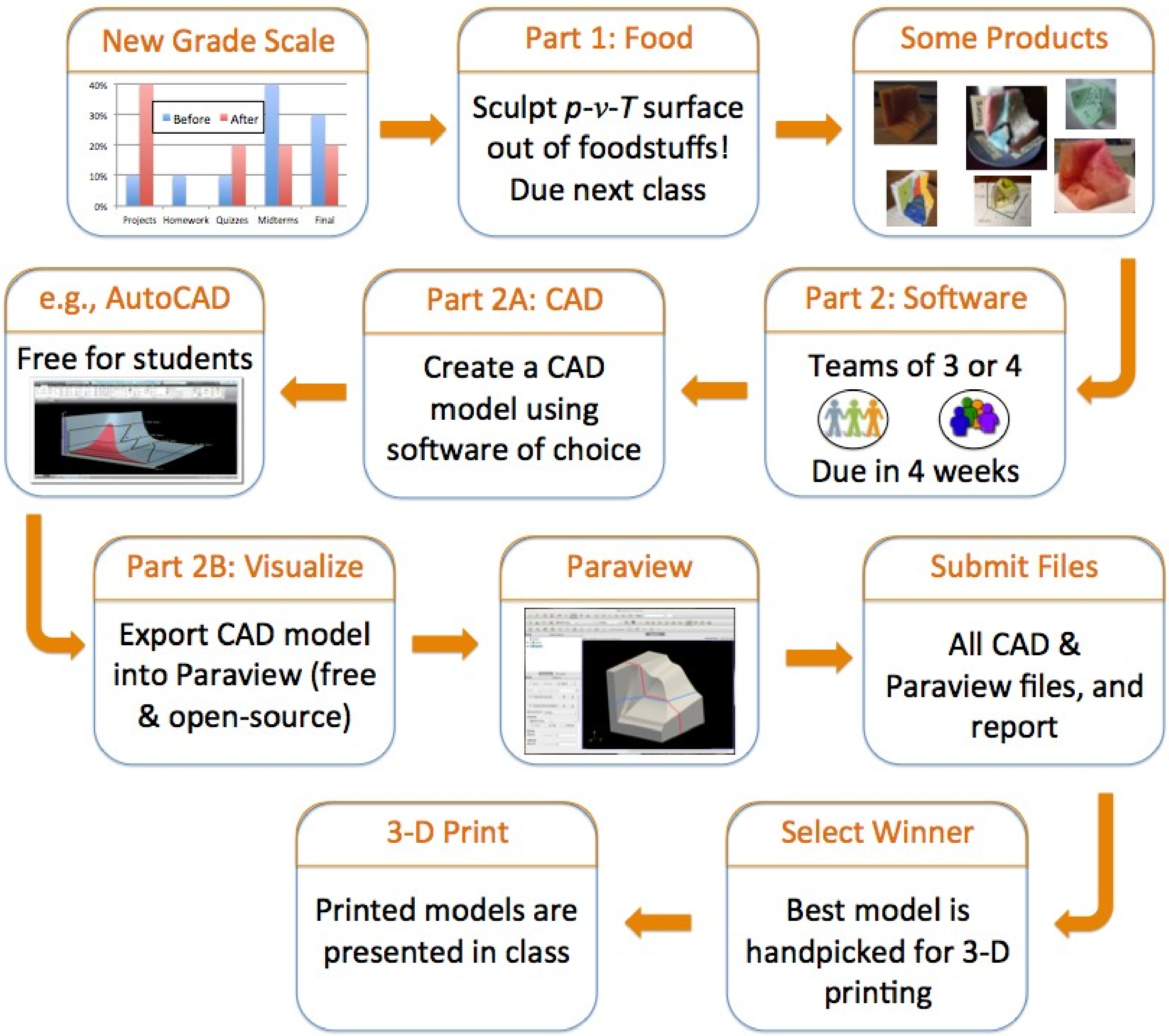

Figure 1. The process.

Table 1. Revised grading scale.

	Old Grading Scale (%)	New Grading Scale (%)
Projects	10	40
Homework	10	0
Quizzes	10	20
Midterm Exam	40	20
Final Exam	30	20

Part One: Sculpting with Foodstuffs

This portion of the project may be considered a "pre-project." It is designed to incite a sense of fun, encourage participation, and engage in initial learning. For this project, due the next class, each student individually is tasked to create a tangible *p-v-T* surface by sculpting foodstuffs. To minimize waste and cost, students are encouraged to use their planned meals. Once completed, students must either bring the food sculpture to the next class, or present photographic evidence by the same deadline.

Part Two: CAD and Paraview Project

Part two is the focus of the approach, and it is a team-based project due in four to six weeks. Teams of three to four students are formed by random assignment. Each team member's agreed-upon task(s) must be clearly defined and well documented in a group report that accompanies the final deliverables.

Each team must create a 3-D CAD model of the *p-v-T* surface in any CAD software package that is royalty-free for the public, open source, or commercially available with free student license. Packages from AutoDesk, for example, have been made available for all students without cost, while TurboCAD offers free trial period, and Google SketchUp is freely available to the public. Specialized commercial software such as SolidWorks and Creo are also allowed if it has already been installed on campus computers, so that no additional licensing cost will be incurred.

Proficiency in using CAD software is essential for STEM students. In a typical engineering curriculum, students usually acquire CAD skills during the first two or three semesters. Therefore, most students enrolled in *core* STEM courses are expected to possess at least rudimentary level of CAD proficiency. For those without any or much experience in CAD, however, this portion of the project can serve as a peer-learning opportunity.

In constructing the 3-D model, students are in complete control of every detail of the surface and the degree of accuracy. Once created, the CAD model is then visualized by importing it into Paraview. Paraview is a powerful, open-source software for visualizing multidimensional scientific data. It is widely used in the scientific and engineering research community as well as commercially. In Paraview, students can manipulate the model by slicing it in multiple axes, whereby isobars (in *T-v* orientation) and isotherms (in *p-v* orientation) are created and superimposed on the 3-D surface.

Alternatives to Paraview include K3DSurf, Misfit Model 3D, Houdini, among others. Paraview is chosen as the visualization software of choice because it has been identified by the author as the most popular across industries, and it has a strong online support community.

All submitted models are subsequently judged by the instructor. A score, up to 100%, is assigned to each team based on the quality of the 3-D model and the report. The submitted model that best resembles a *p-v-T* surface is handpicked for 3-D printing, and the printed parts are in turn presented to the entire class.

Implementation

Data were collected from the third-year intermediate thermodynamics course during three consecutive semesters, all of which were taught solely by the author. The Fall 2013 semester serves as the baseline term where no projects were assigned. During the following two semesters, Spring 2014 ("Term 1") and Fall 2014 ("Term 2"), the project was integrated into the course in an identical manner. Terms 1 and 2 are collectively dubbed "project semesters."

Enrollment was 23 in the baseline term, 62 in Term 1 and 61 in Term 2. This disparity must be noted especially when comparing assessment data. A larger class is inherently more challenging to manage, and student success in such a class may suffer when all things are held equal. Any apparent improvement in the project terms may therefore be somewhat conservative.

Outcomes were measured in terms of student success rate, i.e., test score average, as well as anecdotal evidence collected at the end of the current semester. Test scores were collected, assessed, and compared among the baseline and project semesters. Average examination scores were also compared within the project semesters before and after the project had been completed. Specifically, Exam 1 was administered mid-project, and Final Exam post-project.

Results and Discussion

The overall observation is overwhelmingly positive. Not only did students perform better in subsequent tests following the project, the average grade also improved over the baseline semester.

Part One: Sculpting with Foodstuffs

This pre-project yielded some interesting results. Figure 2 shows some of the submitted entries. Cheese, fruit, cake, or ice cream were used, and the results were more than impressive. Some students utilized non-food materials such as used foam, which was acceptable as long as no additional waste was generated.

The assessment of Part One was pass/fail only, and since most students opted to submit results online as photographic evidence, no further analysis was conducted.

Part Two: CAD and Paraview Project

Several interesting observations have been made. Firstly, most students were unfamiliar with Paraview, so learning to download, install, and use the software was a rewarding experience on its own. In particular, through researching the required file structures and formats, students are introduced to the world of scientific computation - an area involving highly valuable careers and life-long skills.

Secondly, most teams were consistently productive throughout the entire course of the project. This is further proof that collaboration is necessary in technical problem solving.

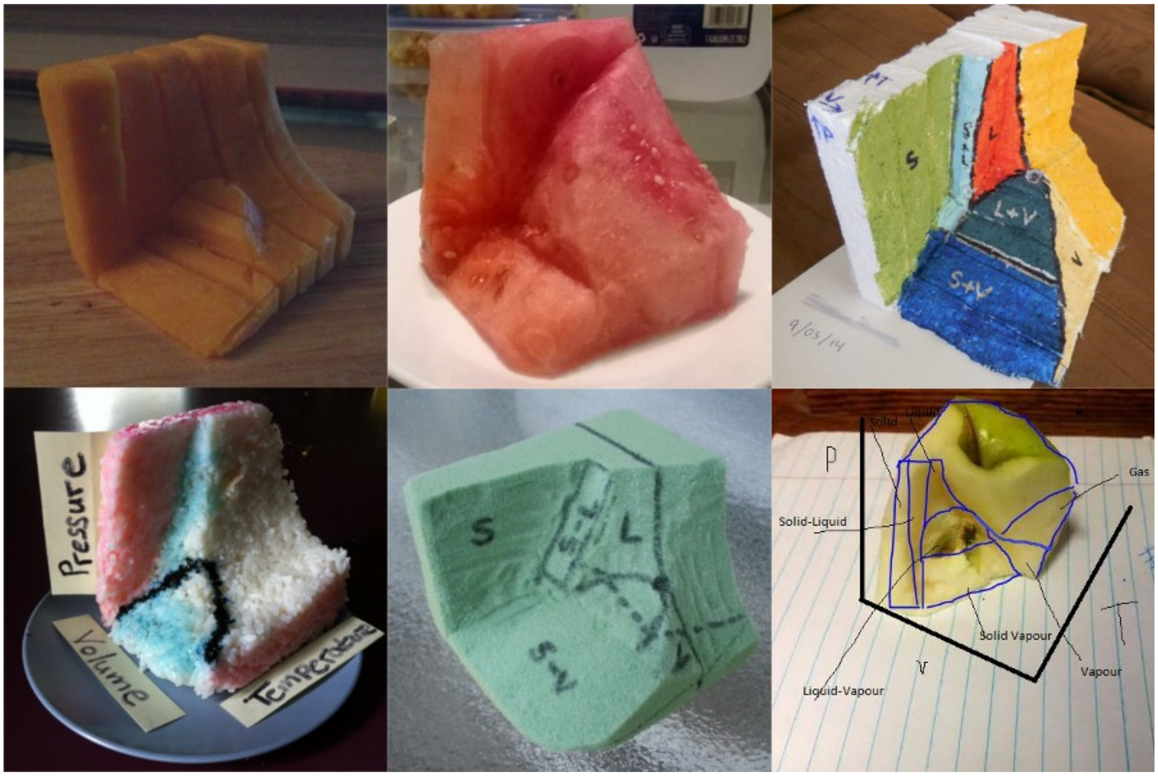

Figure 2. Submitted sculptures of *p-v-T* surface. Clockwise from top-left:
Cheese, watermelon, cake with food coloring, apple, foam, rice with food coloring.

Lastly, due to unfamiliarity with the software and 3-D visualization in general, some students were initially struggling. However, through instructor's guidance and students' own efforts, problems were eventually solved. It must be noted that the instructor's support during the project is crucial to the success of this method.

Figure 3 shows a screenshot captured in Paraview of a submitted *p-v-T* model. It was created in SolidWorks and exported to Paraview for visualizing the isobar and isotherm.

It is at this stage of the project – the visualization and manipulation of the 3-D surface – that students gain an appreciation of the *p-v-T* relationship. As mentioned in the introduction section, many students during the baseline semester tended to make the mistake of constructing improperly sloped isobars on a *T-v* diagram (or isotherms on a *p-v* diagram). In problem solving, since using data tables requires a thorough understanding of the shapes of the isobars and isotherms, this final stage of the project is the most crucial phase in enhancing a student's appreciation of the complex 3-D surface.

Test scores have been compiled and presented in Figures 4 and 5. Exam 1 was administered when the project was still ongoing, and final exam was given post-completion of the project. All exam problems were designed to test students' true understanding of the *p-v-T* relationship, as well as their ability to apply first and second laws to solve real-life problems. For each of the tests, different questions were asked from semester to semester due to transparency of the exam solutions, made available by the instructor post-test. However, the essence of each question remain consistent from term to term.

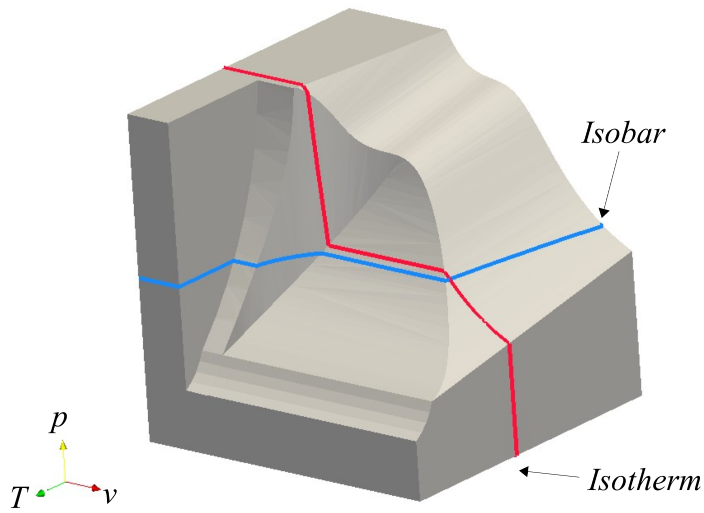

Figure 3. Paraview screenshot of a *p*-*v*-*T* surface.

In Figure 4, Exam 1 and Final Exam scores are compared among all three semesters: The baseline term, Term 1 and Term 2. In Term 1, a 9% improvement is observed from Exam 1 to Final Exam. In Term 2, a 23% improvement was achieved. The baseline semester data is included in Figure 4 as a reference, since no projects were assigned during that term. During baseline term, a 4% improvement was made between Exam 1 and Final.

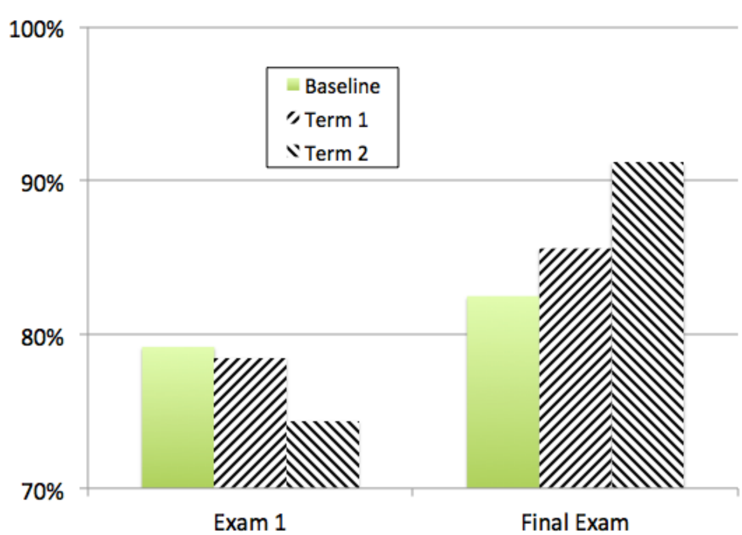

Figure 4. Average examination scores in baseline and project semesters.
Exam 1: Before project completion; Final Exam: After completion.

Figure 5 shows the average overall course grade among the baseline and project semesters. An apparent 5.2% improvement is observed in Term 1 over the baseline, and 8.6% improvement in Term 2 over baseline. It must be reiterated that the enrollment in both project semesters were nearly three times that in the baseline semester (62 and 61 vs. 23). The effective improvement, therefore, may be greater than shown.

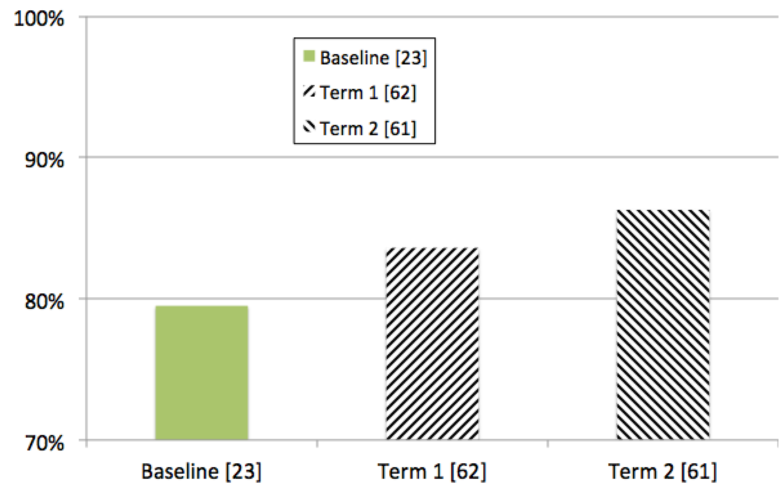

Figure 5. Overall class average among baseline and project semesters.
Square brackets contain the enrollment numbers.

End-of-semester course evaluation data for the baseline and the project semesters have been compiled and are presented in Figure 6 below. It shows that the rating of the course overall quality ("Rate the overall quality of the course") has improved, from baseline's 4.69 to 4.86 in both project terms. The second questions, "Was the instructor's use of technology effective?" scored an even more significant improvement, from baseline's 4.40 to 4.79 in Term 1 and 4.83 in Term 2.

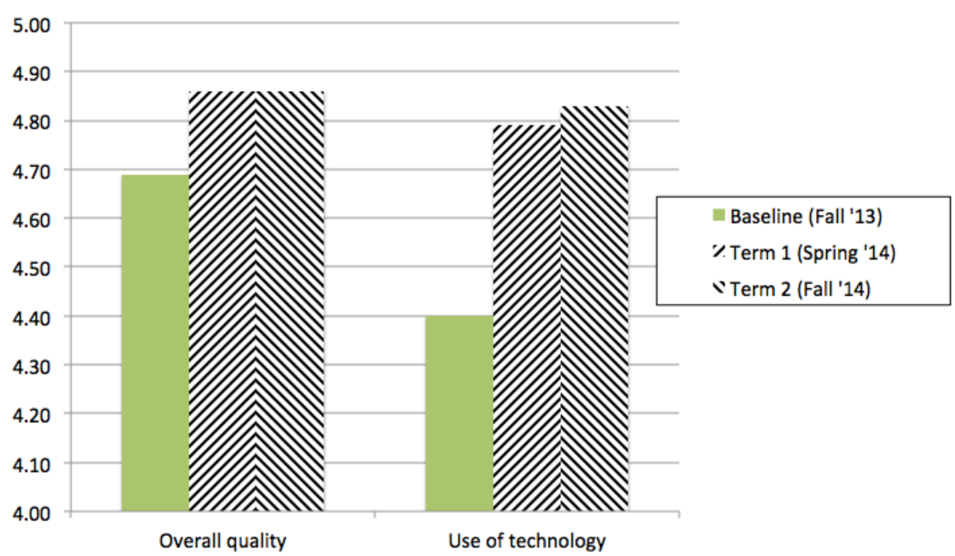

Figure 6. Course evaluation results between semesters; maximum score: 5.0.

In addition to test scores and evaluation ratings, anecdotal evidence may be another important indicator of student outcome. The instructor assigned additional projects, although narrower in scope, for the rest of each project terms. A sample of anonymous student comments collected in the end-of-semester course evaluation of both Terms 1 and 2 include:

"I really like how the professor assigned projects. This really helped me understand thermo more."

"The most helpful part of this course was the projects assigned by the Professor. Projects were interesting and realistic than just doing homework problems to understand the material. Group projects and individual projects taught the student both how to work in a team and how to do assignments on their own."

"For this type of course where book work is tedious and easily copied from a solution manual, the project based approach is more engaging and fair in grading."

"Projects, although very time consuming, forced me to be more resourceful and think outside the box."

Conclusion

The last comment presented above alludes to a major problem in digital-age college education, namely, plagiarism. Solution manuals to homework problems can be easily obtained on file-sharing or dedicated websites, such as Chegg. In courses whose grading policy comprises only homework and examinations, students' dependency on solution manuals can be a serious problem. Copying from a solution manual is not only a case of plagiarism, which could result in disciplinary actions, it also eradicates the very idea of learning.

The learning approach presented herein could provide a solution to the plagiarism problem. Through research and active learning, students can achieve a meaningful appreciation of the subject matter and, upon entering the workforce, apply the acquired knowledge and skills in any real-world and often unexpected situations.

Only three semesters' worth of data were collected and presented here. Certainly, more data are necessary to make a strong argument for the benefits of the proposed projects. On the other hand, it was fortunate that all three semesters in succession were taught by the author, eliminating potential data noises such as different teaching styles. With the limited set of data, however, it can be concluded that active learning of the complex 3-D shape has shown promise to be a useful instrument in thermodynamics.

Future Work

Further refinement of this learning approach may include requiring actual steam data to reconstruct the 3-D surface. More baseline data should also be acquired from past instructors. In addition, tracking of students in the project semesters in later courses (e.g., heat transfer) may provide valuable insight into the effectiveness of the proposed projects. Finally, a survey instrument should be designed specifically to evaluate the success of the projects.

References

[1] Thomson, "Considerations on the Abrupt Change at Boiling or Condensation in Reference to the Continuity of the Fluid State of Matter," Proceedings of the Royal Society of London, 1871.

[2] The Scientific Letters and Papers of James Clerk Maxwell, Vol. III, 1874-1879, Edited by P.M. Harman, Cambridge University Press, 2002.

[3] Metz et al., "Implementing ENGAGE Strategies to Improve Retention: Focus on Spatial Skills Engineering Schools Discuss Successes and Challenges," American Society for Engineering Education Annual Conference, 2011.

[4] Lage et al., "Inverting the Classroom: A gateway to Creating an Inclusive Learning Environment," Journal of Economic Education, 2000.

[5] Clark and Jorde, "Helping Students Revise Disruptive Experientially Supported Ideas About Thermodynamics: Computer Visualizations and Tactile Models," Journal of Research in Science Teaching, Vol. 41, pp. 1–23, 2004.

[6] Dewoolkar et al., "Hands-On Undergraduate Geotechnical Engineering Modules in the Context of Effective Learning Pedagogies, ABET Outcomes, and Our Curricular Reform." Journal of Professional Issues in Engineering Education and Practice, Vol. 135(4), pp. 161–175, 2009.

[7] Hall et al., "Adoption of Active Learning in a Lecture-Based Engineering Class," 32nd ASEE/IEEE Frontiers in Education Conference, 2009.

[8] McGrath and Brown, "Visual Learning for Science and Engineering," IEEE Computer Graphics and Applications, Vol. 25 No. 5, pp. 56-63, 2005.

[9] Bullard and Felder, "A Student-Centered Approach to Teaching Material and Energy Balances. 1. Course Design," Chemical Engineering Education, Vol. 41(2), pp. 93-100, 2007.

[10] Bullard and Felder, "A Student-Centered Approach to Teaching Material and Energy Balances. 2. Course Instruction and Assessment," Chemical Engineering Education, Vol. 41(3), pp. 167-176, 2007.

[11] Prince, "Does Active Learning Work? A Review of the Research," Journal of Engineering Education, Vol. 93(3), pp. 223-231, 2004.

[12] Dong, "Lessons Learned in Engaging Engineering Students by Improving Their Spatial Visualization Skills," American Society for Engineering Education Annual Conference, 2012.