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Engineering as an Educational Tool: Restructuring Conceptual Physics

Dr. Franz J Rueckert, Wentworth Institute of Technology

Dr. Rueckert is an experimental physicist specializing in condensed matter. His research interests include magnetic and electronic properties of perovskite materials and, more recently, novel approaches to physics education.

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Abstract

A strong basis in physics is required for the success of any engineering student. As such, the development of novel systems and methodologies in physics which improve engineering education have generated much interest. Likewise, diverse populations of students can benefit by inverting this paradigm; using engineering practices and techniques to better communicate physics.

While primarily an engineering college, our institute also offers strong programs in interior and industrial design. Though not focused on advanced computation, an understanding of physics concepts is vital to any good design. The goal of our Conceptual Physics course is thus to develop the ability of students to evaluate the form and function of their work through an understanding of general physical principles.

In the past, student engagement has suffered as students struggled to relate class topics to the design fields. Borrowing from successful aspects of engineering education, I have recently redesigned this course to better complement the practical and applied nature of these disciplines. Rather than traditional problem solving and calculations, students learn through analysis of complex systems. In lieu of homework and exams, the focus of the class has been shifted to group projects and case studies which demonstrate the application of important topics. As a centerpiece of the course, students are tasked with the construction and presentation of Rube Goldberg chain-reaction machines. This provides a structure by which students can test and refine their understanding of physics topics while highlighting their creativity and ingenuity. In this talk, I will outline the new structure of the course and discuss the improvements in student engagement.

Introduction

Modern pedagogy in physics education has shown the many advantages of a hands-on approach to the learning and retention of various student populations [1]. Novel approaches in physics for engineers, such as *active learning, flipped classrooms,* and *just-in-time teaching* have demonstrated marked improvements over the traditional lecture system [2]. At Wentworth Institute of Technology (WIT), interactive methodologies have been fully embraced, and the institute as a whole is undergoing a conscious shift toward collaborative, project-based learning at all levels [3]. Included those efforts are joint projects by our Sciences and Design departments [4].

WIT hosts strong programs in both Industrial and Interior Design. On the job, the goal of a designer can best be summarized as the realization of an idea. Toward that end, Design majors are well trained in composition, visualization, and modeling and therefor spend extensive time in studio. While clearly focused on the creative aspects of production, in a professional setting these specialists will work closely with engineers, architects, and builders. A familiarity with scientific vocabulary and the processes they describe is necessary both for good composition and to facilitate communication. Recognizing the importance of an understanding of materials and their properties, Conceptual Physics is a required portion of the Design curriculum. One difficulty with previous iterations of this course has been in matching the aim of physics instruction with the needs of the design fields. Previously, students failed to associate class ideas with their specialization, and engagement in the course suffered. As a new member of the Sciences faculty, I was asked to develop a fresh interpretation of Conceptual Physics in closer coordination with design objectives. I found this to be an intriguing challenge, and reasoned that the best basis from which to draw was my experience instructing Engineering Physics.

In an effort to improve the student experience and increase the perceived usefulness of the course, I redesigned Conceptual Physics by drawing inspiration from engineering perspectives. Through a comprehensive understanding of scientific principles and their interactions, the successful engineer is able to design and create any number of complicated systems. As a novel approach to the conceptual course, we transpose this process, using the design of a complex system to develop and reinforce an understanding of physics topics. Over the course of the semester, students work in groups to design, construct, and present Rube Goldberg chain-reaction machines (RGM) which demonstrate their understanding of physics. Additionally, the structure of the class has been shifted to more closely align with the learning style of this unique group of students.

Course Design

Integral to the design of an effective class in a careful understanding of the students it seeks to serve. Earlier versions of the course instructed through the process of problem solving and calculation. While certainly an effective approach for mathematically trained students, the audience for this course does not have the appropriate background to gain insight in this manner. Instead, I chose to mirror the design process as much as possible throughout the course. To create a successful product, design students repeat cycles of research, ideation, prototype, and refinement. In many ways, this is similar to the scientific method used by scientists and engineers, wherein a hypothesis is tested and improved to generate a successful model. Thus, physics topics can be presented to this group in a style not only familiar to the students, but which will be recalled as they progress through their careers as designers.

To aid in that endeavor, I met with the chairs of both design departments to identify those topics most useful to students in the field. Topics were chosen to include motion, forces, simple machines, structure, stress and strain, waves, sound, light, heat, and energy. The course is divided into weekly modules addressing each area. These students spend a significant portion of their training in studio, critiquing each other’s work and collaborating on projects. To follow suit, lectures in Conceptual Physics often break into group discussion of the concepts at hand, encouraging students to offer insight or debate a posed question.

Before beginning a new project, designers conduct thorough background research. In that vein, homework is used to introduce new modules rather than as a review. A variety of formats, including websites, online video, and print articles are used to present interesting case studies of particular physics themes. For example, before discussing the descriptions of motion, students watch NASA video capture of the launch of the space shuttle *Endeavour*. Using the mission clock and telemetry shown, students plot graphs of the shuttle speed, altitude, and range. This primes students for an analysis of motion and the interpretation of plots and slope. Questions students ask as follow up to these assignments often initiate further discourse in lecture and raise student interest.

A key aspect of the design process is prototype and refinement. This is an excellent analogue to the testing of a hypothesis. In-class activities are used to provide a similar experience, where students can suggest a solution and immediately try an idea. For instance, during our module on structures and stability, I employ the Marshmallow Design Challenge popularized by Peter Skillman and Tom Wujec [5]. Students have a limited time to build the highest tower possible using only spaghetti, tape, and string. While still a useful tool for good design practices, the challenge also underscores lessons on materials and equilibrium in an engaging, hands-on exercise. Similar investigations of bottle acoustics or eggshell architecture recast physics lectures as design evaluations in a lively fashion, promoting student enthusiasm and interaction.

The course also includes a weekly laboratory section. Akin to time spent in studio, this is used as an opportunity to refine techniques and understanding through extended exploration. Here, students have the time to attempt different strategies or investigate a model more thoroughly. As a case in point, shortly after the Marshmallow Challenge in class, the lab asks students to construct a structurally sound pasta bridge spanning a set gap. Students can attempt a number of strategies and benefit from the innovation of their group and others. Creativity, an area at which these students already excel, is used as a fundamental learning tool.

Rube Goldberg Machine

Student ingenuity is put to full use by the course project. While frequent, short quizzes are used to gauge student progress, the midterm and final are replaced by the RGM project. Students are asked to imagine their group has been hired by the Museum of Science to design a RGM installation that illustrates basic physics for the public. Throughout the semester, students compose and build a chain-reaction machine with a set number of stages that eventually raises a WIT flag. Each stage acts as a showcase for a particular topic. At the midpoint of the semester, the groups present the RGMs to the class. Their presentations must explain how each stage operates and the chosen physics principle it demonstrates. The group is graded on the physics content of their presentation, their adherence to criteria, and an individual schematic write-up. A portion of the grade is reserved for an undefined “wow factor.” The details of the latter are left purposely ambiguous. Designers flourish mastering the interplay between aesthetics and utility, and rise to an open ended challenge.

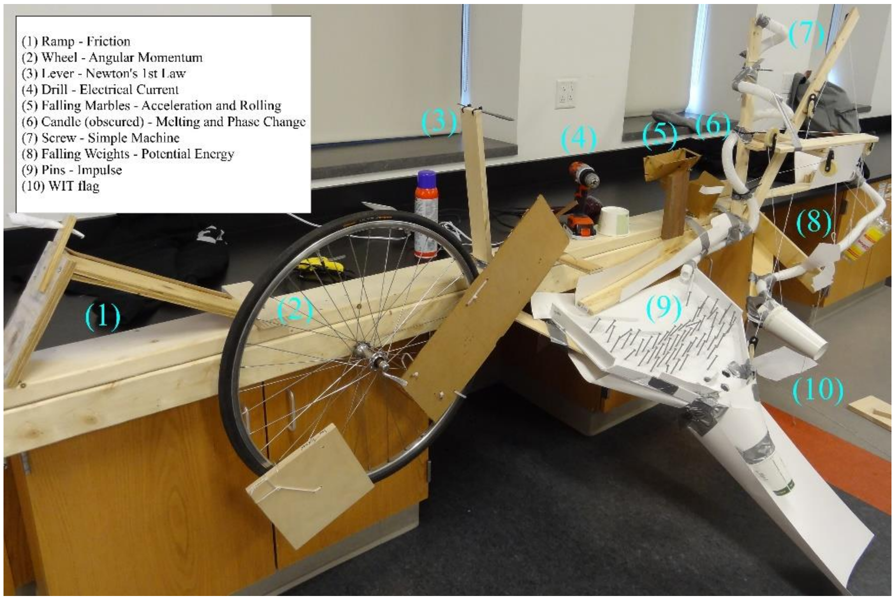

Figure 1 An example of an original Rube Goldberg machine. In lieu of exams, student groups designed and created complex machines which demonstrated a number of topics from the conceptual class. Groups were graded on the creativity of their designs and their ability to discuss and explain the topics at hand. The focus of each stage is noted in the legend.

In doing so, students have designed machines with creative themes, and often explore areas beyond those covered in class. One group laser-cut interlocking gears, generating an investigation into the friction caused by various tooth shapes. Another created a torsion catapult and had to evaluate the strengths and weaknesses of several designs. Since the RGMs must be tested and presented twice in class, reliability of materials and tolerance factors become necessary considerations. The groups receive feedback from both the instructor and their peers, and are able to expand and refine their machines for the final presentation.

More than simply an opportunity to exemplify their understanding, the complex RGM system offers a striking analogy to the process of scientific comprehension. Just as each stage of the machine is relatively simple, each physics concept can be understood in a straightforward manner. However, as the topics interact, complexity can arise in fascinating and thought-provoking ways. As with any good theory, the RGMs are only useful if the can be repeated in various conditions. Much like their machines, the intricacy of physics can be appreciated as much for its artistry as its mechanics.

Results

Qualitatively, the course was a notable success in a number of ways. Primarily, student enthusiasm for the project in particular and the class in general was a marked improvement from what was previously observed. Beyond the students, project presentation days are a minor campus event, drawing spectators from the staff and faculty up to the Dean and Provost. Student responses were generally quite favorable. Evaluations were rated highly, including comments such as; “I feel [the RGM project] brought the class together as a group and got people involved in the physics topics we discussed” and “Having to move the RGM to Lab helped me understand my machine and how everything worked together… I think this project makes Physics less scary!"

Quantitative measurement of the impacts of this method are more challenging. This is partly due to the fact that I was not part of the faculty when the class was taught in the more traditional manner. Having informally interviewed past students, I have been told several times that the previous course was not considered advantageous to their current work. It was due to this reputation that the Design departments first requested a different approach. Since deploying the new RGM version, the chairs have expressed their agreement with the strategy and relayed the improved opinion of students. Perhaps most promising for the new method is the fact that several of previous students of the new course have contacted me for input on their current design projects. This demonstrates an acknowledgement that physics concepts are practical tools offering an advantage to the design process and their future careers. To generate more quantifiable metrics over time, I plan to compile surveys on student satisfaction and perceived utility of the course as they continue through their Design studies.

Conclusion

Conceptual Physics at WIT has undergone a novel transformation toward a project-based approach. The course uses the engineering of a complex RGM system as a learning tool and attempts to align the curricula with the learning style of design students. These changes were largely successful in improving both student engagement and opinion of the course. It must also be pointed out that the success of the new method benefited greatly from the resources of the design program. Design majors have the access and knowledge to use a variety of manufacturing tools and techniques. They also have ample access to many types of building materials and designated studio space in which to work on long term projects. While the major audience for the class is design majors, approximately 25% of the students (throughout all sections) have been from management, information systems, or other programs. An important aspect of the course is to ensure each group represents as diverse a cross section as possible of the majors attending.

My current section of the course inverts this trend, with design students in the minority. Future work will focus on the suitability of this class for non-design majors and mixed groups. This course is certainly a work in progress, now offered for its third semester. As WIT continues to work toward interdisciplinary, project-based curricula, Conceptual Physics will undergo its own process of testing and refinement to better meet the needs of our students.

References

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