Using Project- and Theme-Based Learning to Encourage Creativity in Science

By Mika Munakata and Ashwin Vaidya

In this article, we describe a project that was developed for an introductory-level physics course. The aim of the project was to encourage the creative process in science, as science is seldom mentioned in discussions about creativity. We sought to engage students in the creative process by posing a collective challenge to the class. The challenge involved designing a sustainable means by which to produce short films on the theme of sustainability. Through the project, students experienced project-based learning, open-ended questions, and independent research. The overall project went beyond the physics classroom, however; it linked physics to visual arts, music, theater, and English. In this article, we present the physics project and provide the context of the overarching project. We describe the motivation for the project and the implementation and outcomes of the project, report on impact on students, and suggest ways in which creativity can be encouraged in all science classes.

As STEM educators, one of our goals is to prepare students to explore new ideas in science and to be creative in their approach to these new ideas. Traditional definitions of creativity, however, often associate it with artistic endeavors. In our search through dictionaries (*Oxford Dictionaries,* www.oxforddictionaries.com; *Mirriam-Webster Dictionary*; www.mirriam-webster.com), we found phrases such as "artistic creativity," "creative writing," and "creative team of designers." Nowhere in our search of official definitions did we see creativity being linked to scientific activities. Furthermore, even among science and mathematics students, arts-related disciplines are deemed to be more creative than the sciences (Munakata & Vaidya, 2013).

In their authoritative work on creativity, Sternberg and Lubart (1999) considered creativity to include the ability to connect ideas, see similarities and differences, have flexibility, have aesthetic taste, be unorthodox, be motivated, be inquisitive, and question norms. These traits are often embodied by scientists and are thus ones that we'd like to encourage in students. Unfortunately, however, creativity and imagination are seldom emphasized in STEM learning (Donovan & Bransford, 2005) with blanket practices often leading to students dropping out of science, technology, engineering, and mathematics (STEM) fields (Goldberg, 2008). In many cases, students, especially in introductory courses, are taught by lecture, and their laboratory experiments are usually predetermined, leaving little room for open-ended exploration.

Many institutions have made deliberate attempts to revamp their undergraduate curricula by replacing traditional lecture-style-only teaching with inquiry-based teaching, encouraging students to fully engage in the scientific process. Some have proposed refocusing introductory science courses to reflect two aims: to promote conceptual understanding and showcase the process of scientific inquiry (Meinwald & Hildebrand, 2010). These aims can be achieved by making courses student-centered and encouraging exploration and dialogue (see DeHaan, 2005*)*. We propose that one way to encourage exploration and dialogue is through open-ended tasks that encourage creativity in the sciences.

In this article, we describe a project that linked sustainability, arts, and science in an effort to engage students in the creative process in science. The project was motivated by a need for a course in science that highlights creativity and challenges students' perceptions that creativity and science are not compatible.

Challenges and constraints

Supported by funding from the American Physical Society, we developed a project for students in beginning level Physics 1 and Classical Mechanics courses. The goals for the course include the conceptual, mathematical, and applied understanding of Newton's laws. The project described here was undertaken during the lab component of the course. It not only helped to illuminate theoretical concepts that were being discussed in the lecture portion of the course, but also engaged students in activities that merged creativity in the arts with creativity in the sciences around the theme of sustainability.

We started with some hypotheses about the kind of environment that would both stimulate creativity and best exemplify the kind of work scientists do. Our project was centered around a unifying goal but was open-ended in its possible approaches. There were no instructions to follow, providing complete freedom to explore. Neither the students nor the instructor (AV) knew the "answers," and together we sought solutions as the questions became apparent. Another assumption was that the existence of constraints would encourage creativity. In other words, obstacles created by constraints (whether intended or not) are opportunities for students to think creatively and to problem solve. One constraint that was embedded within the project was the theme of sustainability. In all activities, students and the instructor considered ways to leave as little impact as possible on the environment. When feasible, material was scavenged. Everyday objects, such as a spatula, took the place of fancier, store-bought items like a crank handle. This forced students to consider the alternative functions of various objects. Another constraint was that of timing. The course was only a semester long and met for just 3 hours each week. Both the instructor and the students were forced to be creative as they determined how to finish the project on schedule.

Description of the project

The project brought undergraduate physics and arts students together in the development of a hand-crank camera and in the subsequent production of sustainability-themed short movies. It began as a challenge from an artist colleague concerned about the environmental impact of producing movies. The amount of energy spent on both the production and consumption of media nowadays is enormous. Cinema itself, however, was born of modest mechanical means. Just over a century ago, hand-cranked cameras and bioscopes harnessed human energy to present the visual illusions that still hold our attention today. The challenge for us was to come up with appropriate tools for making a film on environmental sustainability using sustainable means and to facilitate an interaction between science and art students.

The project turned out to be an elaborate collaborative effort between various disciplines, bringing together students, faculty, and visiting artists, and aimed at bringing the playful side of science to the forefront of student consciousness. The project was conducted in three distinct phases. The first phase involved discussions about various approaches to energy generation, conversion of mechanical to electrical energy, and sustainable energy practices. In the laboratory, we took apart hand-crank units and worked on putting together one of our own (see Figures 1 and 2). Several pieces were constructed, and the effects of magnet size, number of windings of the wire, and other related issues on the voltage and current produced were explored.

The second phase involved the development of a bicycle-powered generator (Figure 3). Power generated by operating appropriately rigged bicycles was stored in generators. The semester project for the students was to write a joint (whole class) paper on the experience and to develop a user's manual for the generator. More photographs of activities at various stages can be found on our website (Hand Spun Tales, 2015).

In the final phase, students from the art department, with the assistance of a visiting artist, began to create a series of short videos that explored issues of ecology and sustainability. The human-powered generators and hand-crank systems were

FIGURE 1

Students in the Classical Mechanics course at Montclair State University explore a simple model of the hand-crank generator.

FIGURE 2

A power-drill as a hand crank. The drill uses electricity to perform mechanical work. In the classroom, students at Montclair State University attempted to invert the device in order to produce electricity.

used to charge all electronic devices used in the production and post-production processes. Recycled or live music was used for background sound, which also brought music students into the project. Costumes were designed by students in the theater department, and the script for the productions was written with the help of students from the English Department. Periodically, participation of various undergraduate students from other science and nonscience departments (such as gender studies and physics club students) was solicited. All in all, the project was a collaborative performance on a scale not previously imagined.

The final product was a series of short films (Hand Spun Video-1, https://vimeo.com/65612254; Hand Spun Video-2, https://vimeo.com/65382000; and Hand Spun Video-3, https://vimeo.com/65358333), which were shot with a camera powered using the bike-generated power. These films feature mythological interpretations of the theme of sustainability and ties into the students' creation of the human-powered energy source. The films feature a guest appearance by a character similar to Miss Piggy, who explains the inspiration for the project and films. The films have been presented at several conferences to audiences ranging from humanities faculty to physicists.

Additionally, a blog (Hand Spun Tales, 2015) was set up to discuss the various themes of the project and encourage audiences outside the university community to offer their commentaries. Another significant product of the course was a student-developed magazine, *The Art of Making Science*, which can also be found on the blog. The magazine describes the project from the students' perspective and offers suggestions for the replication of the project in middle and high school settings. It also features photographs taken by university and middle school students that capture science in everyday settings; poetry about molecular biology; and interviews with a photographer and scientist, conducted by a science student, on their perspectives related to the intersection of the arts and sciences.

FIGURE 3

The bicycle-powered generator produced by students in physics courses at Montclair State University. This setup was ultimately used in generating the power needed for the Art and Science project.

Impact on students

We collected data to assess the impact of students' participation in the project on their perceptions of science content and science learning. We were limited to qualitative analyses because of the small number of students ($n < 25$) in the course and the smaller number who filled out surveys ($n = 11$). In addition to the final joint paper, which was written collectively by the students, impact of the course was measured through surveys (Appendix 1) given during the last week of the semester and a focus group interview. The survey asked students about their perceptions of the benefits and challenges of this approach to learning. After viewing the responses, four students who had the most to say (positive or negative) were identified and asked to participate in a focus-group interview (Appendix 2). During the interview, the students were asked questions about the content and approach of the course, as well as the impact of the course on their understanding of physics. The interview transcripts and surveys were read for emergent themes (Glaser & Strauss, 1967). The themes, along with five sample responses categorized under each theme, are presented in Table 1. In identifying these themes, we determined that although terms such as *project-based learning, inquiry, hands-on,* and *open-ended* are often used interchangeably, they can be taken to be mutually exclusive as well. For example, it is quite possible to engage students in project-based learning without teamwork, much as it is possible to have hands-on experiences without inquiry. Our data revealed that these themes represented the various elements of the course from the students' perspectives.

TABLE 1

Comments from written surveys and focus-group interviews. The comments made during the focus group interviews are indicated by an (FG), otherwise they were written on the surveys.

Project-based learning	• Seeing firsthand applications of theory learned through lecture helped deepen my understanding of the material. • I was able to learn over multiple lab periods about different concepts relating to one model as opposed to multiple unrelated models based on different physical concepts. • I could see how applying knowledge works in practical application. • I do not feel that I benefitted from this model compared to a more traditional one. It is difficult for me personally to immediately integrate concepts from lecture into the lab. • Doing a mathematical model is one thing. Getting the project based on that model to work is an entirely new challenge.
Connection to a real problem	• I stopped looking at problems like they could be from the blackboard, now I try to see how it would look in real life, and how to apply them in daily life. • I found that all science you do has application. While things that you work on at certain points may seem detached from the material world that is never truly the case. • I was already aware of the complexities of real life physics problems but this was the first course that showed it. • Real world doesn't come with a set of instructions . . . but it wasn't as if there was absolutely no guidance. (FG) • It's like a problem, not having direction. You know a lot of real world situations…you got to figure out if you don't know what the problem is you need to figure out what it is. That's part of how you do anything. (FG)
Hands-on learning	• This gives more hands-on learning rather than abstract topics. (There was) connection to a "real" problem. • It helped me get a hands-on experience; for someone that learns through hands-on activities, I benefited greatly. • The benefit comes from the personal hands-on experience in the classroom that you are able to connect with the final paper. • I always wanted a hands-on physics course and this was perfect. There was enough lecture and lab. It was well complemented. • The physical application of concepts was a much more effective means of learning as opposed to a purely theoretical one.
Scientific inquiry	• I found this model to be beneficial because it supported a feeling of independent scientific creativity. Each individual within the class was forced to think and problem-solve. I believe this helped promote dedication to a project and inquiry. • This model was beneficial to the extent that it allowed for the creative application of concepts learned in class without overbearing constraints. • This course made me remember why it is that I feel in love with physics in the first place . . . this course made me see that it is upper level art. • It allowed me to focus on the aspects of physics I enjoy and branch into new areas I found interesting. • This project made everything much more interesting at every turn. I was looking for outside sources because I wanted to not because I needed to.
Open-endedness	• There were some periods of time where we were delving into an area that was really beyond the knowledge of the professor or anyone in the class and it required us to learn new material. Some things that couldn't be found in books or online, we just had to experiment until we found something that worked. (FG) • That was something relatively new for me with the research . . . I am also stumped a lot. I have to go exploring for answers, but (in) a lot of the other classes . . . the lab is handed to you and there's one solution. (FG) • There wasn't a defined objective or an absolute target, if you will or how to go about the project. It was more at certain points he would ask us how we want to proceed and then people would have ideas and then that's how we proceed, because at certain points he also didn't know how to. So I mean it was kind of the learning curve with everyone. (FG)
Teamwork	• Worked in groups with people who looked at problems (from) different angle. • Working as a group talking to each other; helping each other out; and partially even bonding outside of class. We had to mutually understand concepts together. • Some people came up with solutions I didn't consider before. I was working at it with (a) much wider view. • I was proud to contribute to a larger team project, as compared to a small project on my own.
Challenges	• Some components required extensive outside learning to comprehend the issue at hand. Also (not) having a defined plan and schedule was challenging. • It was fairly difficult to go from lecture to lab if the lecture didn't directly relate to what we needed to do in the lab. Situations arose which could not be addressed during lecture time. • Attempting to approach the project while expanding the lecture material was distracting and led to some confusion. • A challenge . . . comes from different skill levels within the group. At certain points individuals with more hands on/engineering experience were able to do more than others who had done less in those areas. • As when you have too many people trying to do anything ever, it's always get ridiculous cause you have everybody throwing all these suggestions and stuff, you don't want to shoot them down . . . it just creates a weird environment. (FG)

The themes that emerged from the survey and interviews indicate that students recognized that other than the physics concepts covered in the course, the structure of the laboratory portion of the course was different from the typical science laboratory exercises. Our goal for the project was to have students simulate, as much as possible, the work of scientists. By basing the project on an open problem and one with applications, we tried

Appendix 1

Survey of Physics Students

This semester, you were involved in a different model of instruction in your Physics 210 course. Because this was a new format for this course, we would appreciate it if you could take a few minutes to complete the survey below. Your response will help us report on successful components of the course and determine next steps for this course.

1. How did you benefit from this model of instruction?
2. Do you think your perceptions about science changed through your participation in this course? Please describe briefly.
3. What were some of the challenges of being involved in project-based learning?
4. How did you benefit from writing a piece of the final paper? How was this experience different from writing a paper on your own?
5. Please write any other comments below.

Appendix 2

Focus-Group Interview Protocol

This was a semistructured interview, so the interviewer adjusted questions according to the responses given. This protocol merely served as a general guide.

To be read at the beginning of the focus group session:

The purpose of this study is to see how this physics course has affected your ideas about science and mathematics. I am going to ask you a series of questions. Please try to answer each question as honestly and thoroughly as possible. I may ask you to provide examples to illustrate some of your points. I will be taking notes and our conversation will be audiotaped. Before we start: (1) Do you wish to continue the interview? It's ok if you don't want to, we can stop here. (2) Are you ok with being audiotaped? I am only videotaping so that I can tell who said what. I will not show the videotape to anyone. But, it's ok if you do not want the video camera on—we don't have to turn it on. (3) Also, you don't have to answer all of the questions. Just let me know that you want to skip any question you'd rather not answer. Although everyone here will know what you say, your answers will remain anonymous outside of this room and no names will be used in our reporting of the results.

Because this is a group interview, I am going to ask that you just chime in whenever you'd like. You do not have to contribute an answer to any of the questions, if you do not want to. Before we begin, I'd also like to assign each of you a number. Let's go around the room and count-off. So you'd be one, you'd be two, … (etc.) When you speak, please start with, "I'm number one, and I'd like to say" or "I'm number seven, and I think . . ." Does everyone understand and feel comfortable with this process?

1. The first set of questions have to do with the course.
    a. Was this course different from other physics courses you've taken? In what ways?
    b. Was the content different? (If "yes") In what ways?
    c. Was the delivery different? In what ways?
2. In what ways has this course affected you?
    a. Did it change how you think about science? In what ways?
    b. Did it change how you think about physics? In what ways?
    c. Did this change how you perceive education in general? In what ways?
    d. Did the course change how you will approach learning in other classes? In what ways?
    e. Did the course change how you will think about your career? In what ways?
3. If you could change anything about the course, what would it be?
4. What else would you like to share?

to engage students in teamwork and problem solving, while reinforcing the notion that "doing" science entails uncertainty and flexibility, and *creativity*. Though for some, it was difficult to connect the physics theories to the project, several students appreciated the application of theory and the connections made between lecture and the project.

Students also enjoyed the teamwork aspect of the project. They learned how to work on their own piece of the project while keeping the big picture of the group project in mind. Teamwork allowed them to combine their knowledge and to share ideas. For example, some in the group were "better with their hands," whereas others had "deeper theoretical knowledge." Although some alluded to different starting points within the group, groups were able to find their rhythm and learn to communicate efficiently and effectively.

Conclusions

Much like teams of scientists, the collective goal for the course created a collaborative atmosphere where students depended on teamwork. In its open-endedness, the project encouraged problem solving and discouraged students from seeing the instructor as a dispenser of answers. Instead, the instructor worked with the students, trying to facilitate learning in a role simulating that of a coach rather than of a typical lecturer. The fact that the task was also new to the instructor—that he didn't necessarily know the answers (or even the right questions)—enabled him to engage in the scientific explorations with the students.

As with any experiment, this teaching experiment also met its challenges. In trying to simulate an engineering task, the students had a deadline (the end of the semester), but it was arbitrary to the task (as it was dictated by the academic schedule and not tied to the complexity of the problem). Because the end date could not be adjusted, we found the need to adjust the task to fit the time allotment. This, however, can also be viewed as encouraging creativity. The ability to determine how to be more efficient and how to simplify tasks are consistent with the creative person's ability to be flexible and unorthodox (Sternberg & Lubart, 1999).

A new question that arose through this project was that of the carbon footprint involved with the human-powered system. Was it in fact a more environmentally friendly alternative to using traditional batteries or tapping into the grid? What energy costs of transportation and production would become apparent through a life-cycle assessment? These questions were posed by our ecology colleague, who is currently working with us to determine a possible solution. This extension of the project would add a new dimension (and a new discipline) to future offerings of the course.

Despite the fact that students believe that creativity is relegated to the arts (Munakata & Vaidya, 2013), opportunities abound for science faculty to encourage creative thinking in their students. From slight revisions of test questions to complete revamping of courses, it is possible to create situations where students are engaging in the creative process. Though the project described in this article was funded and quite extensive in nature, it is possible to incorporate elements of it into existing science courses. We believe that three elements from our experiences encouraged creativity in our science students: (a) the open-endedness of the project, (b) the project-based learning environment, and (c) the collaboration between physics and arts students. Most important, the course was both challenging and rewarding for all. As Albert Einstein said "creativity is intelligence having fun." ■

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