



Thermodynamics in the Arts

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Abstract

Thermodynamics is a difficult course for many undergraduate students due in part to the complex nature of the concepts learned. Pedagogical literature has suggested that students learn difficult concepts better when they are presented in different formats that address different learning styles (verbal, visual, etc). During the last two years a new student project called “thermodynamics in the arts” has challenged students in an introductory thermodynamics course to represent one thermodynamic concept in an art project. Each team of students selected a thermodynamic concept and a different art medium including poetry, sculpture, music, painting, drawing, photography, and creative essays. Concepts the students visualized included entropy, enthalpy, irreversibility, exergy, phase change, Carnot cycle, Brayton cycle, internal energy, work, radiation, convection, and conduction.

Assessment of the artwork used a rubric that included artistic merit, but also the accuracy of the thermodynamic concept explored. A survey of the participating students was conducted to determine if the intersection of art and thermodynamics helped the students construct more concrete understanding of the concepts chosen. This paper explores the student perceptions of the project, presents examples of the student art projects, and provides an overview of the pedagogical merits of the project. Student survey results strongly support keeping the project for future classes. Student art examples demonstrate the success of the project and a nuanced depth of conceptual understanding of the material.

Introduction

The idea of integrating science and art has existed for hundreds of years, and in fact a division between humanities and science has only emerged in modern times. Great historical scientists like Leonardo DaVinci were also known for artistic skill. The project *Thermodynamics in the Arts* was developed as a classroom exercise to allow undergraduate students to explore thermodynamic topics intellectually and creatively.

The importance of creativity in the engineering education seems clear as current students will join an engineering work-force that demands innovation. Prior studies indicate that engineering students are creative,^{1,2} and that creativity can play a role in improving engineering outcomes on challenging problems.^{3,4} Field demonstrated a stronger correlation between performance on design

projects with visualization and intuition skills than mathematics skills.⁵ Charyton and Merrill developed an assessment tool to quantify creativity in engineering students.⁶

Other authors argue that the engineering curriculum should be evolving to allow more creative and open-ended elements.^{2,3,6-8} Eisner and Powell put this well in the conclusion of a study that found many successful scientists use visualization, creative cognition, and musical themes as they pursued research.

*One way schools might change is to provide activities and experiences that allow for the use of imagination, somatic knowledge, and empathic knowledge. Such activities would be open-ended. Students would be allowed to explore and experiment with possibilities, draw on personal information and experience, and use a variety of media with which to explore ideas. In this view of teaching, curriculum, and assessment, multiple truths are possible, and multiple ways of knowing are encouraged.*⁷

Orhun and Orhun further make the case for incorporating creative elements into the engineering education process to enhance problem solving skills in students.⁹

The idea of incorporating the creative process explicitly in an undergraduate thermodynamics class was formulated with several objectives:

- Encourage students to reflect on thermodynamic concepts and link them to more concrete applications.
- Enable students to communicate thermodynamic concepts using media or methods they felt comfortable with.
- Connect more directly with students in a large lecture environment.
- Foster a collaborative learning environment in the classrooms as students engaged with other student projects.

The specific project described was also intended to address needed pedagogical elements in the class. Felder et al. has identified several types of learning styles including visual, verbal, sensing, intuitive, global, sequential, and more.¹⁰ Felder recommends that engineering instructors focus not on specific learning style needs, but organize classroom methods and materials to include all types of learners. Ogot and Okundun provide insights about the way creative problem solving processes may improve results for different learning styles.¹¹

The thermodynamics project discussed in this paper was intended to address each type of learning style by allowing each student to express concepts in different mediums. For example, a verbal learner might choose to explore a concept using music or poem. When presented to the class as a group, this music or poem may convey meaning effectively to other verbal learners in the class.

The teaching community also notes the need for reflection elements in engineering courses. Chachra articulates the cycle of the learning process for a student.¹²

*The learning cycle consists of four way points: concrete experience (feeling), reflective observation (watching), abstract conceptualization (thinking), active experimentation (doing), and then back to concrete experience and continuing around.*¹²

The process of developing an artistic expression directly addresses the third part of the learning cycle, the abstract conceptualization. The act of building or developing the art project may also assist the student with the active experimentation.

Methods

The students in an undergraduate thermodynamics course were assigned the project after approximately eight weeks of instruction (mid-point of the semester). The project was introduced in class and examples of art and science were provided for several mediums including poetry, music, photography, video, sculpture, and collage. For music, the recent Muse album titled “The Second Law” was referenced. For video, examples from the NPR Science Friday website were provided. The students were also informed that other projects were possible, but they might want to check scope with the instructor. In the second year of the project examples from the first class were displayed. A few other rules were in place, including a requirement for the equivalent of 5 stanzas for poetry to prevent a submission of only one brief Haiku.

The project instruction sheet outlined the goal and learning objectives for the students.

Project Goal: Using the creative medium of your choice explore a concept from thermodynamics. Suggested concepts include entropy, enthalpy, exergy, energy, heat, work, phase change, vapor dome, ideal gas law, polytropic, irreversibilities, internal energy, turbine, compressor, power cycle, refrigeration cycle, power, others ...

Project Objectives: Explore one thermodynamic idea in a new context; Explain thermodynamics in a way that a high school student could understand; Engage the general public about the ideas of thermodynamics.

The project instruction sheet included a requirement for one paragraph explaining how the art project explores a thermodynamic concept. This was often helpful when the instructor graded the art to provide context for the more abstract artifacts. The grade breakdown had only a small component associated with artistic merit (10%). The remainder of the points were associated with thermodynamic accuracy, level of effort, creativity, and communication of the concept. This was intentional to make the students more comfortable, and to make the project possible to grade. This also addressed some of the maxims for creativity in education identified by Kazerounian and Foley including rewarding creativity and encouraging risk.²

After the art projects were completed, an informal class presentation time was provided. Students willing to share projects were allowed to do so in class. A short, optional survey was distributed to the students with the following questions near the end of the semester.

1. Did you find the thermodynamics course interesting? Rank 1-5.
2. Did you find the art project increased your interest in thermodynamics? Rank 1-5.
3. Did your understanding of the thermo concept you worked on change or improve as you brainstormed for the art project? Rank 1-5.

4. Did your comfort with thermodynamics concepts increase when you looked at other student's art projects? Rank 1-5.
5. Would you recommend this project for future thermodynamics students? Rank 1-5.
6. What was the most helpful aspect of the art project? (open format)
7. What improvements would you suggest for the project in the future? (open format)

Student Project Results

Most of the students enrolled in the thermodynamics class embraced the project enthusiastically. Projects created included poems, videos, collages, songs, sculptures, devices, and photographs. Although many of the creative projects are difficult to include in paper form, the following examples highlight some of the projects.

Entropy

A team of students used a photo collage to convey the idea of entropy (Figure 1). The burned match represents a highly irreversible process (combustion) and the equation for the entropy balance used in the textbook is shown on the hand.



Figure 1: Student art example: Entropy by Kyle Zada and Becca Baldwin.

Irreversibility

A student picked “irreversibility” to represent graphically as shown in Figure 2. This is clear as the word “thermodynamics” passes through a throttling device and produces entropy and the word missing several letters. This art is simple compared to other projects, but clearly and cleverly expresses the idea of irreversibility to the viewer.

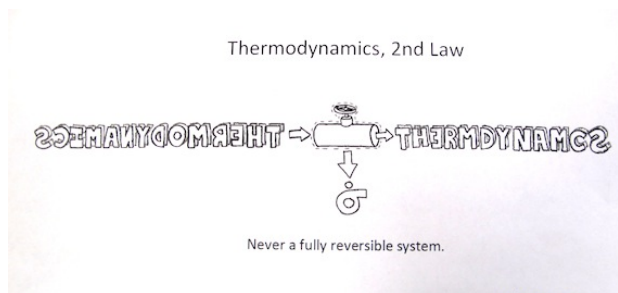


Figure 2: Student art example: Irreversibility by Stephen Christensen.

Combustion

A team of students worked to create time lapse images with a thermodynamics theme using sparklers as shown in Figure 3. The students included a discussion about the thermodynamics of a combustion process, the heat produced, and the way the pictures were created.



Figure 3: Student art example: Fireworks by Caroline Pisani and Audre Ramey.

Entropy Comic

A student illustrated a comic story about the evil entropy and the sustainable world. Figure 4 shows one pane from the illustrated story. In the end the hero manages to minimize the entropy production in the system.

This comic was one example of an illustrated story. Many students wrote short stories or children's stories. Another student project explored the idea of why a refrigerator requires two thermal reservoirs using ice cream and two children.

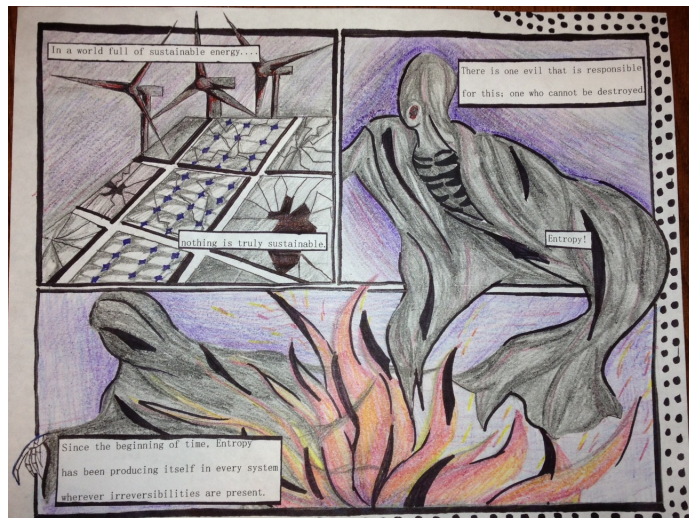


Figure 4: Student art example: Entropy comic by Alex Varvel.

Carnot's Cube

This team of students repainted a puzzle cube. Each side of the cube represents a different process in a Carnot cycle. The top and bottom of the cube represent the hot and cold reservoir for the cycle. The students were inspired by the perfect square shape representing the Carnot cycle on a Temperature-Entropy phase diagram.

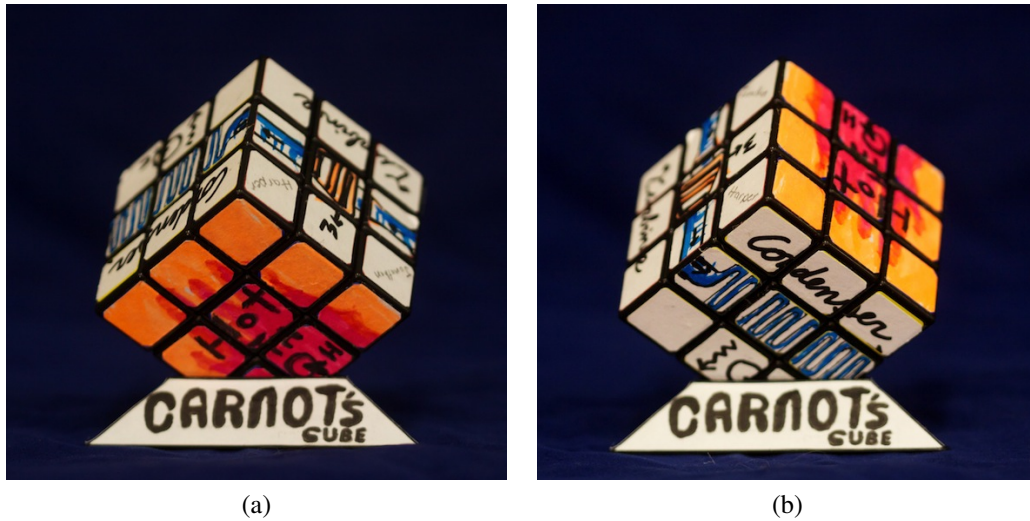


Figure 5: Student art example: Carnot's Cube by Jonathan Harper and Alvaro Garay.

Table of Tables

A student group used copies of the thermodynamics steam tables to construct a small table. This sculpture was titled *Table of Tables* and was a clear favorite with the other students in the class. This project was a good example of another theme in the art projects, the use of irony or humor. The piece is ironic because the thermodynamics class requires extensive property look-ups using the appendix of the textbook, often called the “steam tables”. By constructing a table from the steam tables the students captured a humorous reference.



Figure 6: Student art example: Table of tables by Andrew Stacey and Bruce Julian.

Sculpture and mixed media pieces were common student submissions. Other student projects included welding, engine part fabrication, a dinosaur made of soldered resistors, and an airplane mobile featuring a Brayton cycle theme.

Ideal Gas Law

A student wrote a short poem describing the ideal gas law. This poem is characteristic of many of the student poems submitted, it is accurate and illustrates the thermodynamics concept well. In this case the student alludes the importance of the universal gas constant and compressibility.

When it comes to common gases I am just the law to know,
I make things work quite nicely,
but my standards are not low

My equation has two sides and their balance is the key,
pressure, volume,
temperature, and moles are things that I must see

My conditions are inaccurate without a common tie,
Each gas I treat is special,
The constant 'R' can tell me why

To picture how I work, you can just think of a balloon,
Once heated up,
my right-side increases so my left increases too

Constant pressure expands the volume,
the balloon gets very round,
That way my equation: $PV=nRT$, is balanced and I'm sound

Conversely, if volume goes back down because the balloon is squeezed,
Either pressure or temperature must go up,
In order to keep me pleased

I like to make math easier but I don't always make things real,
Gas assumptions are important,
Some might say... that I'm Ideal.

- by Chika Eke

Poems were one of the most popular submissions for the project. Other student poems tackled topics like steady state versus transient systems, conservation of energy, temperature measurement, and refrigeration cycles.

The student project examples demonstrate excellent creativity and knowledge about the thermodynamics concepts. The projects overall reflected nuance about the topics explored in class, often with depth that was surprising for students who had only been exposed to the concepts a few weeks earlier.

Student Survey Results

In the Fall of 2013, 118 students were enrolled in the undergraduate thermodynamics course. Of the students enrolled, 105 filled out the survey on the art project.

The first question, "Did you find the thermodynamics course interesting?" was used to group the subsequent survey results. Most students indicated they did find the course interesting, with most

of the students responding “Agree” or “Strongly Agree” as shown in Figure 7. The average for all the responses was 4.133 with a standard deviation of 0.81.

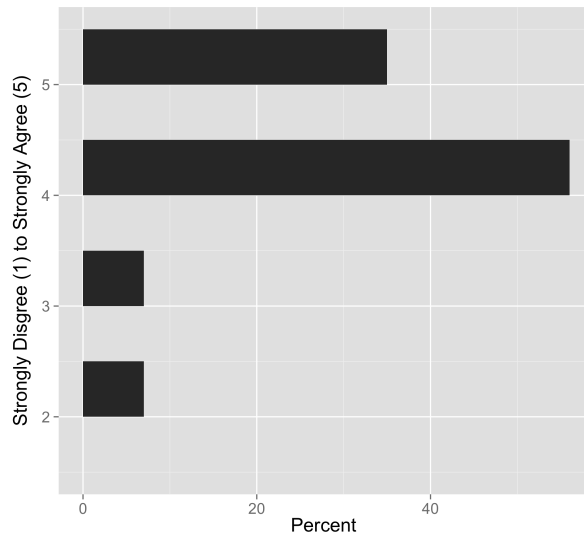


Figure 7: Student responses to the question, “Did you find the thermodynamics course interesting?”.

For all subsequent questions the student responses were tabulated and filtered based on the reported topic interest in the thermodynamics course. This is shown in the Figures 8 to 9 as shaded bars, with the darkest bars representing the students who indicated a strong interest in the course.

Figure 8 indicates that most students did find the art project helpful for increasing interest in thermodynamics. The reported mean for this question was 3.57 with a standard deviation of 1.13. Students that already reported less interest in the topic found the art project more neutral. This result indicates the art activity may not be helpful for inspiring students who are already less enthusiastic about the topic. There may not be a strong correlation because even some students who reported liking the topic of thermodynamics did not report the art project to be helpful in increasing interest in the topic. These students may not enjoy creative projects, but this result might improve if the link between creativity and engineering was shown to the students as the project was assigned.

The written comments from students on the survey explored some of the more neutral feelings about the project. Many students expressed concern that the grade on the art project would reflect a self-perceived “lack of talent.” This was not the case as stated in the project documentation, only a few points were associated with artistic merit. In future assignments the instructor could take more time to address some of these concerns as the project is introduced. Student survey responses also indicated that showing a wider range of examples from prior year’s projects would be helpful to bound the solution set.

Most students reported the comprehension of the concept they picked increased as part of the project as shown in Figure 8. The average for this question was 3.66 with a standard deviation of

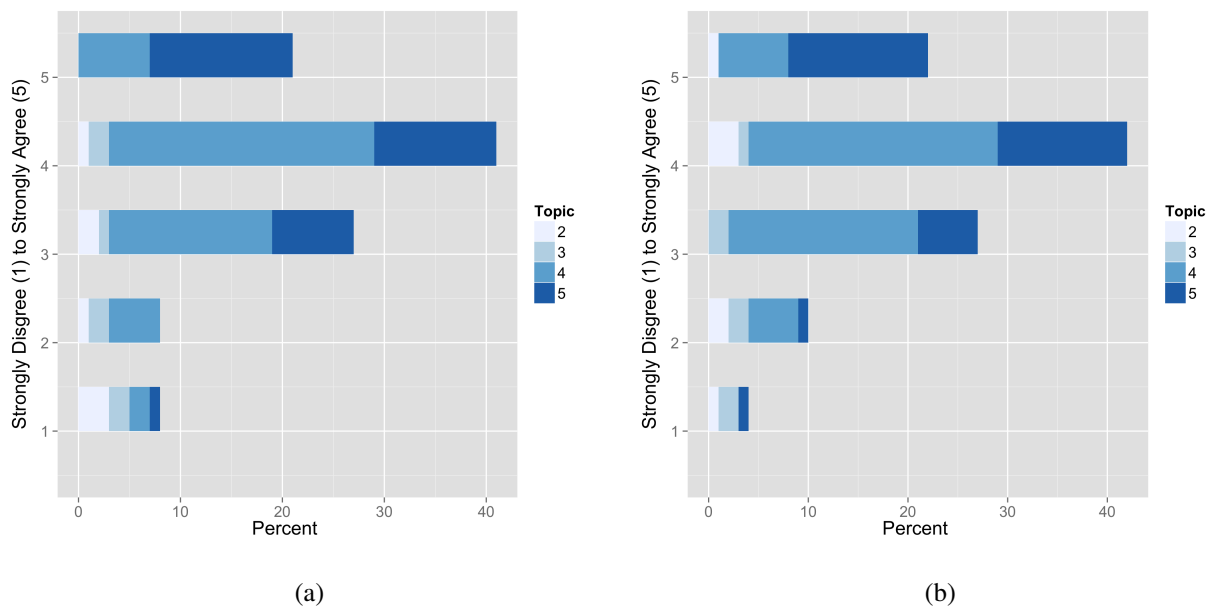


Figure 8: (a) Student responses to the question, “Did you find the art project increased your interest in thermodynamics?”. (b) Student responses to the question, “Did your understanding of the thermo concept you worked on change or improve as you brainstormed for the art project?”.

1.1. Even most students with a lower interest in the topic indicated that researching the thermodynamics question helped them learn.

When students were prompted about how other student projects affected them they primarily responded that they were helpful as shown in Figure 9. The average response was 3.53 with a standard deviation of 1.02. The students who liked the topic overwhelming reported this activity was helpful.

The last survey question simply asked students if they would recommend this project for future students as shown in Figure 9. The response was overwhelmingly positive, with an average of 4.1 and a standard deviation of 1.11. Even students who seemed less interested in the topic of thermodynamics strongly agreed that the project should be continued.

Written comments from the students revealed that many students had become more aware of the presence of thermodynamics in everyday objects and systems. The student comments included the following insights:

- “It [the project] made thermodynamics more exciting.”
- “Brainstorming the project was the most helpful because it gave time to think about thermo creatively and in different ways.”
- “It gave students a chance to study or research in a creative way about a topic in thermo.”
- “It actually took some design work and allowed us to apply concepts we’ve learned, so I felt like an engineer for a bit.”

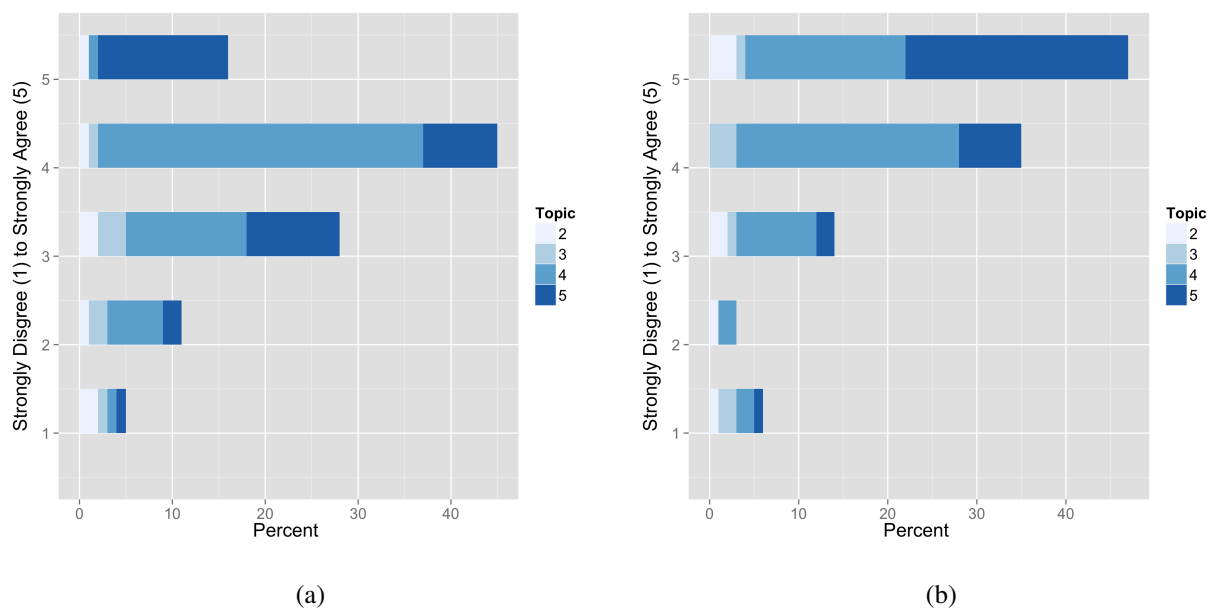


Figure 9: (a) Student responses to the question, “Did your comfort with thermodynamics concepts increase when you looked at other student’s art projects?”. (b) Student responses to the question, “Would you recommend this project for future thermodynamics students?”.

- “Doing my own research and carrying out the project helped to give me a different perspective on my topic and helped me to better understand how the second law works.”
- “It forced us to think about things conceptually instead of just crunching numbers.”

Discussion

The results of the student projects and the student survey both support the merits of this type of project in a thermodynamics course. The project was not universally helpful for inspiring interest in the topic of thermodynamics, but it helped most students learn about the concept or topic they picked to focus on. The art projects developed and the survey results imply the project did provide an important opportunity for reflection as recommended by Chachra.¹² Students strongly supported the idea of continuing the project.

The majority of the goals of the project were successful. The students reflected on concepts and linked them to concrete examples occurring in the world around them. Many students commented on the realization that “thermodynamics is everywhere” at the completion of the art project.

The students were very successful in communicating thermodynamic concepts to a technical audience. The student creativity and the ambiguous nature of the project allowed the instructor and students to connect and discuss interests and hobbies that might never have come up without the art project.

The project also provided important feedback to the course instructor. The ideas and subjects of

the projects were a reflection of discussions in class, homework assignments, quiz questions, and other elements of the course. Each one provided insights about what the students had retained, and concepts that might be unclear or inaccurately represented in students' minds. This opportunity for insight about student understanding is by far the most powerful aspect of this project.

In future years the scope of the project may be expanded to include a more detailed look at how creativity in the students might change using methods pioneered by Charyton and Merrill.⁶ Assessment of the project could be adjusted to include the creativity maxims of Kazerounian and Foley.²

The project "Thermodynamics in the Arts" has been a wonderful method for introducing creative elements into a rigorous engineering course. The project provides pedagogical benefits tied to learning styles, creativity, collaboration, instructor feedback, and the cognitive process. Most importantly the project provides an opportunity to celebrate creativity in the structured world of science.

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References

- ¹ W B Stouffer, Jeffrey S Russell, and Michael G Oliva. Making The Strange Familiar : Creativity and the Future of Engineering Education. In *American Society for Engineering Education Annual Conference & Exposition*, number Torrance 1963, page Session #1615, 2004.
- ² Kazem Kazerounian and Stephany Foley. Barriers to Creativity in Engineering Education: A Study of Instructors and Students Perceptions. *Journal of Mechanical Design*, 129(7):761, July 2007.
- ³ Richard M Felder and Carl R Rogers. Creativity in Engineering Education. 22(3):120–125, 1988.
- ⁴ Aaron S. Blicblau and Joseph M. Steiner. Fostering Creativity Through Engineering Projects. *European Journal of Engineering Education*, 23(1):55–65, March 1998.
- ⁵ Bruce W. Field. Visualization, Intuition, and Mathematics Metrics as Predictors of Undergraduate Engineering Design Performance. *Journal of Mechanical Design*, 129(7):735, July 2007.

- ⁶ Christine Charyton and John A. Merrill. Assessing General Creativity and Creative Engineering Design in First Year Engineering Students. *Journal of Engineering Education*, 98(2):145–156, April 2009.
- ⁷ Elliot Eisner and Kimberly Powell. Art In Science? *Curriculum Inquiry*, 32(2):131–159, January 2002.
- ⁸ David H. Cropley and Arthur J. Cropley. Fostering Creativity in Engineering Undergraduates. *High Ability Studies*, 11(2):207–219, December 2000.
- ⁹ E Orhun and D Orhun. Creativity and Engineering Education. In *SEFI*, number September, pages 16–20, Leuven, Belgium, 2013.
- ¹⁰ Richard M. Felder and When Linda Silverman. Learning and Teaching Styles. *Engineering Education*, 78(June):674–681, 1988.
- ¹¹ Madara Ogot. Systematic Creativity Methods in Engineering Education : A Learning Styles Perspective *. *International Journal of Engineering Education*, 22(3):566–576, 2006.
- ¹² D. Chachra. Interrupt the 'Forced March'. *Prism*, page 23, November 2012.