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WIP: Implementing Mini-Projects to Build Community and Improve Student Engagement

Leon Liebenberg (Teaching Associate Professor)

Leon is a Teaching Associate Professor in mechanical science and engineering at the University of Illinois at Urbana-Champaign. He is also a Fellow of the UIUC's Center for Innovation in Teaching and Learning. In the Grainger College of Engineering, Leon leads the ENGagement In eNgineering Education (ENGINE) instructional innovation team, where he and his multidisciplinary colleagues are investigating ways to promote deep learning. Before coming to UIUC, he was a professor of mechanical engineering at two South African universities and a higher education consultant in Switzerland. For the past 25 years, Leon has approached teaching as a craft with his conscious desire for self-expression and by crafting experiences to excite learning. He holds doctoral, master's and bachelor's degrees from the University of Johannesburg, a master's degree from Imperial College London, and a diploma in advanced mechanical engineering from the University of London.

Taylor Tucker (Research Assistant)

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Abstract

At the core of successful teaching and learning lies a change in student attitude. A great learning experience should elicit enthusiasm and help students become more motivated and self-directed. As students often report low motivation due to a lack of self-regulation skills or insufficient engagement with their peers, it follows that social and emotional engagement are necessary complements to cognitive engagement.

This study explored a whole-student pedagogical strategy that melds cognitive and emotional learning in a mandatory, sophomore-level, face-to-face thermodynamics class. Our whole-student approach uses a series of four self-directed mini-projects (i.e., complex design modules divided into smaller segments) to better engage students in creatively solving real-world problems. Based on their learning preference questionnaires, students were placed in diverse teams of three to four with the intention of generating a sense of community and promoting creative thinking. Each mini-project was comprised of both open-ended and well-defined non-trivial analytical questions that addressed contemporary energy-related challenges. Teams were also expected to reflect on energy options for the future and interpret the United Nations Sustainable Development Goals. To promote accountability and critical evaluation, teams peer-reviewed one another's mini-projects.

This study uses data from participant questionnaires (n = 77) to analyze the efficacy of using mini-projects in a face-to-face learning environment. The questionnaires, which targeted cognitive and emotional engagement constructs pertaining to the mini-projects, were evaluated using descriptive statistics and factor analysis. The results suggest that mini-projects can help foster self-directed learning and enhance self-awareness by providing students with valuable insight toward their own learning styles. Students' development of self-awareness during this process can in turn help them regulate and improve their learning behavior as well as develop critical thinking skills by conceptualizing and articulating their thinking in a disciplinary context. Findings from this work may contribute to the development of teaching strategies that can enhance and facilitate improved student engagement. Implementing a series of self-directed mini-projects can also improve self-regulation skills and help generate a sense of community.

Introduction

As they are forced to adjust to today's online or hybrid learning environments, undergraduate students are experiencing significant challenges such as a sense of emotional disconnect. These challenges imply the increased importance of fostering effective learning communities. In turn, belonging to a community implies that students will act as creators and co-owners, which should promote a deeper sense of emotional ownership in both their community and the university as a whole. With regard to emotional engagement, the importance of effective teamwork (or collaboration) cannot be overemphasized [1], [2], [3].

The competitive, autonomous nature of contemporary higher education further challenges students to take responsibility for the success of their learning [1]. Added stress from learning online has increased the need for students to develop self-regulation skills that enable their learning and management of various learning facets such as motivation, organization, and time management [1], [2]. The development and enhancement of self-directed learning skills are not only crucial for self-regulation, but also help strengthen students' ability to navigate online learning. This is especially pertinent in light of the tendency of online learning environments to rely on students' autonomy by requiring them to initiate the bulk of their learning activities themselves (e.g., viewing asynchronous lecture videos, participating in online discussions, and managing group work remotely) [3].

For most students, self-directed learning skills are not inherent but instead must be fostered through (a) the development of agency (i.e., awareness of one's own competence), and (b) effective coaching in productivity and teamwork. Developing such a skillset requires that students master the ability to make emotional connections among theoretical concepts [4], which means that engineering educators need to engage students at cognitive and emotional levels in authentic, meaningful, and immersive learning experiences. This study, which uses mixed methods to analyze data taken from one semester of face-to-face instruction in a sophomore-level thermodynamics course, seeks to address this need by investigating the following broad research question: How might engineering educators leverage pedagogies of cognitive and emotional engagement to support the development of students' self-directed learning skills?

Background

Self-directed learning

Self-directed learning is broadly conceived as a learning process in which learners take the initiative, with or without help, to diagnose their learning needs, revisit their motives, formulate learning goals, identify human and material resources for learning, choose and implement appropriate learning strategies, evaluate learning outcomes, and reflect on learning [5], [6], [7], [8]. However, self-regulation is strongly influenced by external factors such as the learning environment, instructor and instruction, modeling, and peer interaction [9].

Effective self-regulation requires not only the provision of clear instruction and explicit modeling of possible solutions and problem-solving strategies, but also designing a learning environment conducive to such learning [10]. The level of self-regulation depends on the extent of the learner's knowledge within the subject domain [9].

A key facet of self-regulation is self-efficacy, which requires the knowledge and use of specific learning strategies and performance self-monitoring [11]. Thus, self-efficacy indicates learners' belief in their innate ability to achieve goals. Learners with high self-efficacy tend to implement more effective learning strategies as well as better self-monitoring of their learning outcomes as compared to students with low self-efficacy [12]. Self-regulation also implies that learners will take responsibility for reflecting on their learning [13], [7], [14], meaning that learners should possess the requisite skills to evaluate their strengths and weaknesses and reflect on meeting their learning objectives [15]. Reflection allows for introspection, which helps learners identify the positive aspects of, and areas of improvement for, each learning experience [8].

A major question facing university educators is how to support the development of self-regulated learning with the requisite components of self-efficacy, reflection, and critical thinking. Effective support must also address the challenge of balancing theoretical understanding and relevant, authentic practical application.

Mini-projects

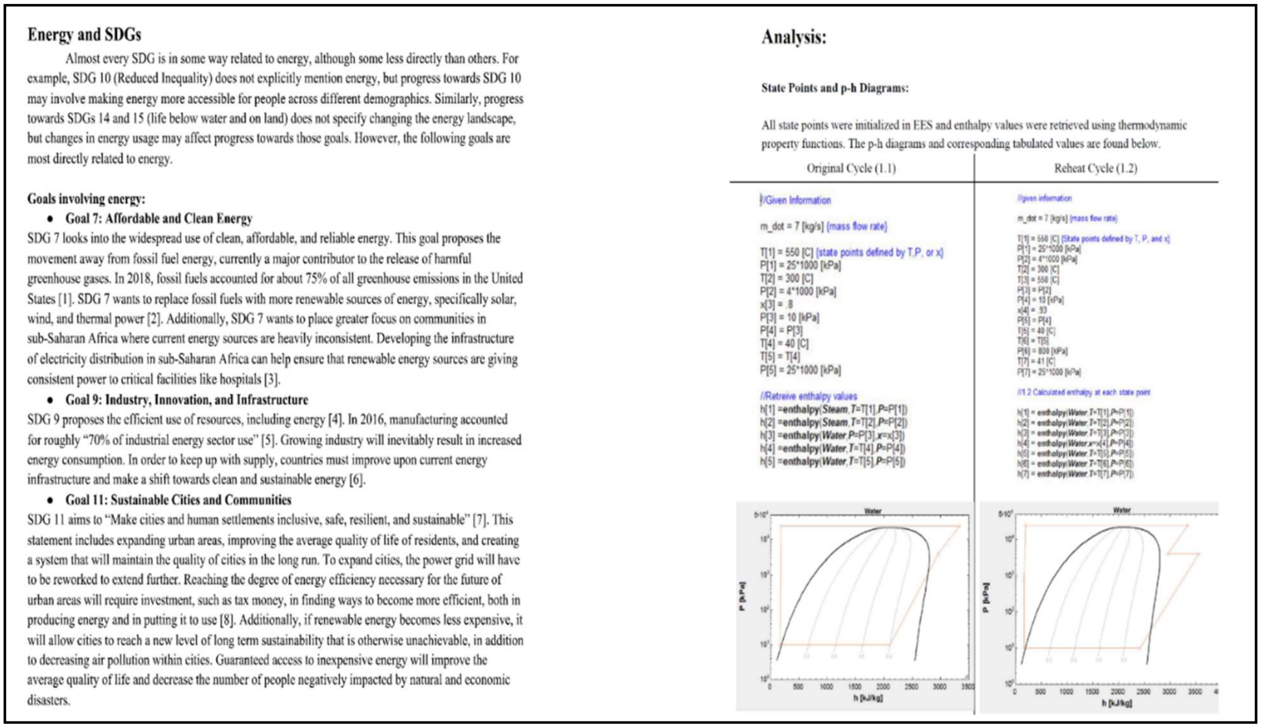
Per mini-project structure, course material is divided into "bite-size" chunks, with each chunk representing a core aspect of the syllabus. These chunks are then crafted into a series of mini-projects, usually between four and eight, that are offered as team-based or solo assignments. It is important to note that a series of mini-projects is not simply a collection of discrete learning units, but rather a scaffolded learning platform that is flexible enough to accommodate the individual needs and desires of students. The use of such a platform aims not to simply cede control of the learning process to the student, but to intentionally add a degree of freedom and flexibility often missing from academic coursework. Allowing students some ability to shape their learning experience enables them to advance their personal skillset and interests in new and constructive ways.

The teaching team focused heavily on making the mini-project topics, which were selected based on students' interests, as engaging and customizable as possible. Furthermore, mini-projects were designed to require roughly four hours of work per week from each student. Appendix A provides the structure of a typical semester, including mini-project deliverable deadlines. These mini-projects made up 40% of the course final grade, thereby shifting the focus from high-stakes exam performance to lower-stakes project performance. The decision to assess student performance using mini-projects was intentional, signaling to students that they would be evaluated on both technical skill development and the acquisition of knowledge necessary to understand, utilize, create, and communicate their ideas. This assessment method has proved adaptable for face-to-face and online course settings [16], making it both a practical pedagogical strategy and one that allows for comparative data collection on student learning experiences in-class and online.

Most thermodynamics topics were covered in lecture prior to mini-project deadlines. However, students were expected to perform independent research on topics pertaining to UN Sustainable Development Goals. The mini-projects in this course addressed the following topics:

> Mini-Project 1 (team-based): *Energy and Sustainability* (sustainable energy; UN Sustainable Development Goals (SDGs); greenhouse effect; net-zero emissions; annual energy consumption and concomitant carbon dioxide emissions of a household; communication of ideas via social media)
>
> Mini-Project 2 (team-based): *Stirling Power- and Heat-Cycles* (Stirling cycle vs. Otto cycle vs. Diesel cycle; operation of Stirling engine regenerator; Stirling-based refrigeration cycle; communication of project using a high-impact fact sheet)
>
> Mini-Project 3 (team-based): *Advanced Fossil-Fired Steam Power Plants* (power plant visit; Rankine cycle; reheat cycles; flue gas desulphurization; carbon emissions from burning coal, oil, or gas; communication of project via an ePortfolio [16])
>
> Mini-Project 4 (individual): *Thermodynamics and Achieving the UN's SDGs* (student-chosen project topic pertaining to novel energy-related technology/ies – with a strong thermodynamics slant – or action/s that can be adopted to significantly reduce US greenhouse gas emissions; communication of project via high-impact fact sheet)

Appendix B provides the structure of a typical thermodynamics mini-project, which includes a series of contextualized analytical, design, and reflection questions. Figure 1 provides extracts from two mini-projects.



Energy and SDGs

Almost every SDG is in some way related to energy, although some less directly than others. For example, SDG 10 (Reduced Inequality) does not explicitly mention energy, but progress towards SDG 10 may involve making energy more accessible for people across different demographics. Similarly, progress towards SDGs 14 and 15 (life below water and on land) does not specify changing the energy landscape, but changes in energy usage may affect progress towards those goals. However, the following goals are most directly related to energy.

Goals involving energy:

- **Goal 7: Affordable and Clean Energy**

SDG 7 looks into the widespread use of clean, affordable, and reliable energy. This goal proposes the movement away from fossil fuel energy, currently a major contributor to the release of harmful greenhouse gases. In 2018, fossil fuels accounted for about 75% of all greenhouse emissions in the United States [1]. SDG 7 wants to replace fossil fuels with more renewable sources of energy, specifically solar, wind, and thermal power [2]. Additionally, SDG 7 wants to place greater focus on communities in sub-Saharan Africa where current energy sources are heavily inconsistent. Developing the infrastructure of electricity distribution in sub-Saharan Africa can help ensure that renewable energy sources are giving consistent power to critical facilities like hospitals [3].

- **Goal 9: Industry, Innovation, and Infrastructure**

SDG 9 proposes the efficient use of resources, including energy [4]. In 2016, manufacturing accounted for roughly "70% of industrial energy sector use" [5]. Growing industry will inevitably result in increased energy consumption. In order to keep up with supply, countries must improve upon current energy infrastructure and make a shift towards clean and sustainable energy [6].

- **Goal 11: Sustainable Cities and Communities**

SDG 11 aims to "Make cities and human settlements inclusive, safe, resilient, and sustainable" [7]. This statement includes expanding urban areas, improving the average quality of life of residents, and creating a system that will maintain the quality of cities in the long run. To expand cities, the power grid will have to be reworked to extend further. Reaching the degree of energy efficiency necessary for the future of urban areas will require investment, such as tax money, in finding ways to become more efficient, both in producing energy and in putting it to use [8]. Additionally, if renewable energy becomes less expensive, it will allow cities to reach a new level of long term sustainability that is otherwise unachievable, in addition to decreasing air pollution within cities. Guaranteed access to inexpensive energy will improve the average quality of life and decrease the number of people negatively impacted by natural and economic disasters.

Analysis:

State Points and p-h Diagrams:

All state points were initialized in EES and enthalpy values were retrieved using thermodynamic property functions. The p-h diagrams and corresponding tabulated values are found below.

Original Cycle (1.1)

```
//Given Information

m_dot = 7 [kg/s] {mass flow rate}

T[1] = 550 [C] {state points defined by T,P, or x}
P[1] = 25*1000 [kPa]
T[2] = 300 [C]
P[2] = 4*1000 [kPa]
x[3] = .8
P[3] = 10 [kPa]
P[4] = P[3]
T[4] = 40 [C]
T[5] = T[4]
P[5] = 25*1000 [kPa]

//Retreive enthalpy values
h[1] =enthalpy(Steam,T=T[1],P=P[1])
h[2] =enthalpy(Steam,T=T[2],P=P[2])
h[3] =enthalpy(Water,P=P[3],x=x[3])
h[4] =enthalpy(Water,T=T[4],P=P[4])
h[5] =enthalpy(Water,T=T[5],P=P[5])
```

Reheat Cycle (1.2)

```
//given information

m_dot = 7 [kg/s] {mass flow rate}

T[1] = 550 [C] {State points defined by T, P, and x}
P[1] = 25*1000 [kPa]
P[2] = 4*1000 [kPa]
T[2] = 300 [C]
T[3] = 550 [C]
P[3] = P[2]
P[4] = 10 [kPa]
x[4] = .93
P[5] = P[4]
T[5] = 40 [C]
T[6] = T[5]
P[6] = 800 [kPa]
T[7] = 41 [C]
P[7] = 25*1000 [kPa]

//1.2 Calculated enthalpy at each state point

h[1] = enthalpy(Water,T=T[1],P=P[1])
h[2] = enthalpy(Water,T=T[2],P=P[2])
h[3] = enthalpy(Water,T=T[3],P=P[3])
h[4] = enthalpy(Water,x=x[4],P=P[4])
h[5] = enthalpy(Water,T=T[5],P=P[5])
h[6] = enthalpy(Water,T=T[6],P=P[6])
h[7] = enthalpy(Water,T=T[7],P=P[7])
```


Figure 1: Extracts from the assignments for Mini-Projects 1 (left) and 3.

Pedagogically, the mini-projects aim to move students from a simple to complex level of understanding; for example, moving beyond simply grasping how a tool is employed to understanding its purpose, the need(s) it addresses, and the expectations surrounding its use. In short, students learn how to investigate tools and operations that are viable, feasible, and desirable. Adding opportunities for pursuing some of their own interests can further challenge students to look beyond tools employed in engineering and recognize the fundamental relationships between acquiring foundational knowledge and developing personal expertise.

Supporting self-direction through mini-projects

As students progress through the mini-project sequence, their tasks require more independent research by becoming more complex and ill-defined [17]. Allowing students to engage with an ill-defined problem space, especially before they have obtained much of the knowledge necessary for analysis and design, can lead them into a state of productive struggle that fosters the capacity to identify, and take responsibility for, their own knowledge needs [18]. Students learn to become more self-sufficient and resourceful in locating and implementing necessary knowledge [19], [20]. Self-directed learning also fosters personal autonomy and agency, which can positively influence students' ability to form individual academic identities. In this manner, learning becomes more about the individual and less about the course.

Mini-project scaffolding

The first few mini-projects in a series are typically team-based and meant to build confidence in foundational concepts. Each subsequent project builds on the previous, culminating in students completing individual mini-projects. The removal of scaffolds over time relies on the assumption that students are adapting to, and developing strategies for, these tasks, meaning that as they develop as problem solvers, they become capable of better exploring and planning within an open-ended space. Indeed, students seem to derive a sense of personal accomplishment from doing this work, which may motivate and contribute to the maturation of their insight and work [16]. Figure 2 shows depicts a mini-project's typical phases.

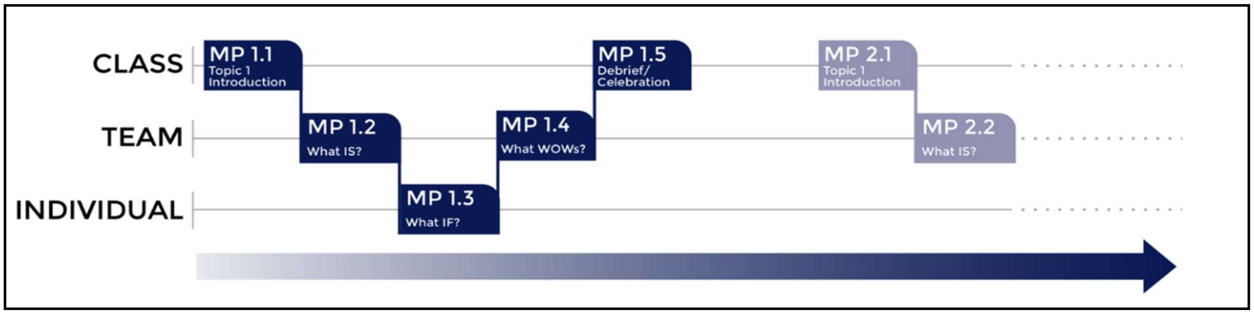


Figure 2: Mini-projects are typically comprised of introductory, exploratory (what is?), ideation (what if?), consolidation (what wows?), and class presentation/debrief phases. Each team-based mini-project builds the previous, culminating in an individual project.

Mini-project design, analysis, and reflection

In each mini-project, students are tasked with solving both well-defined analytical problems and open-ended design problems that require guided self-directed learning. While some questions contain background theory and hints, the tasks intentionally require students to perform rigorous research to identify theory-backed solution techniques. Students are also asked to contextualize their analyses and reflect on their learning. Through the reflection process, students combine "how to" and "why" questions to form individualized value judgments (e.g., Fig. 3). Reflection exercises also activate emotional awareness, which can lead to students "knowing that they know something" [21]. Reflection helps students to identify patterns and trends in the ways they work and learn, thereby composing a repertoire of strategies they might use for making future choices in coursework and professional work [22].

Peer learning in mini-projects

The mini projects are peer-graded by other teams (and checked by teaching assistants) so that students can learn from one another's work and reflection. Peer-grading supports the evolution of students' problem solving and knowledge-making by helping them to (a) develop confidence in sharing knowledge and learning from others and (b) strengthen and define their own areas of expertise [23]. To facilitate effective peer grading, teams are provided with detailed grading keys and rubrics that require commenting on each question instead of only providing a score. This ensures that an expected level of rigor is maintained while promoting curiosity and the critical evaluation of peer approaches. Students and teaching assistants are further required to provide feedback specifically designed to help their peers improve "thinking" and "feeling" competencies. While students are penalized for being overly difficult or easy with grading, they can also receive bonus credit for performing excellent peer grading (such as providing peers with meticulous feedback). For ease of workflow, peer grading is performed via Google Forms. Individual peer grading is used solely as a method for students to learn from one another and does not impact instructors' final grades.

The SDGs are not achievable by 2030 for numerous reasons. The SDGs were established in 2015 and currently as of 2022, the progress being made isn't promising or on track to be completed in the next 8 years. For instance, one of the 17 goals is to have affordable and clean energy for everyone. This goal is crucial as it affects other goals such as having sustainable life on land and water. While more renewable energy is being used, energy from fossil fuels is still on the rise leading to a larger carbon footprint and global warming. This is shown in figures 2 and 3 below. It's evident from the two graphs that renewable energy use has significantly increased from 2015 to 2019 which is a great step towards achieving more sustainable energy sources. However, it's also visible that fossil fuels usage drastically increased or remained constant in opposition to the goal outlined in the SDGs. In fact, coal, oil, and gas made up 80% of total energy consumption in 2015 before the SDGS were established and continued to be 78.9% in 2019 [45]. This shows that while fossil fuels made up a smaller percentage after the SDGs were set, the change was only 1.1% in 4 years which is very trivial. At this rate, by 2030, fossil fuels consumption will only decrease by approximately 3%, which is nowhere near the progress required to achieve clean energy for everyone and reduce climate change. In addition, many other goals are nowhere near completion. For instance, the goal for restoring and promoting life on land insists on halting biodiversity loss. However, a study done on 30 countries revealed that "only 20% of them mention biodiversity as a national priority in their report of SDG progress" [13]. With less than 10 years left to achieve the 2030 Agenda for Sustainable Development, increased cooperation is essential to expedite the process and have a chance for success especially with the regression caused by larger obstacles such as Covid 19.

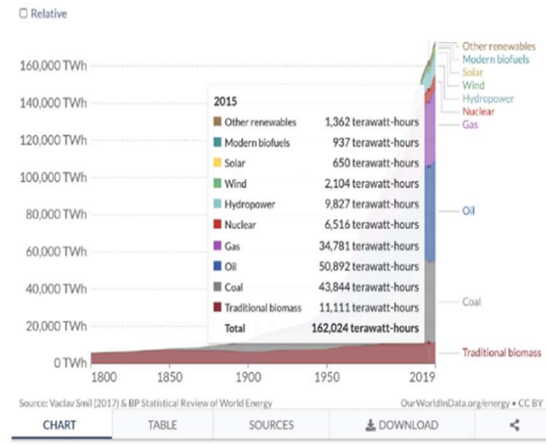


Figure 2

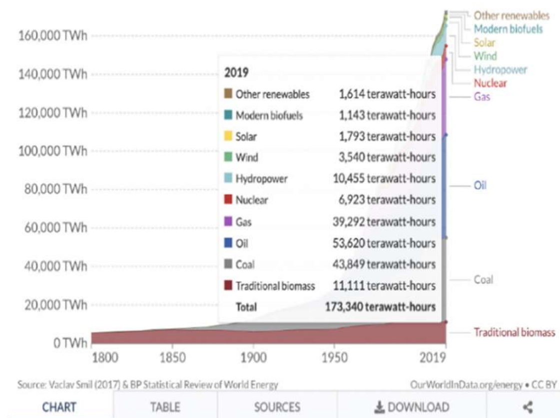


Figure 3

Figure 3: Extract from a team's mini-project, in which they reflect on the attainability of the United Nations' SDGs by 2030. The teams also provide self-reflections on their learning.

Assessment

Team members must complete forms to grade their own and their teammates' contributions to the mini-projects. The average grade that team members receive from one another is used to curve their individual mini-project score (assessed by the instructor). For example, if student A's team receives 90% on mini-project 3, but student A's teammates assess him at an average of 72%, then student A's individual project score is curved to a final grade of $0.72 \times 90\% = 65\%$. In the event of a team member adversely affecting the performance of a team, the defaulting team member may be removed and required to complete the remaining mini-projects alone. This measure has acted as a great motivational factor for students to contribute fairly to every project. Furthermore, at the end of the semester, the five highest-scoring teams are invited to participate in a competition where they can showcase projects to the class. The team that receives the most votes for best project is awarded a 1% increase in final course grades.

Methodology

Design
This study is part of an ongoing exploration of pedagogies of engagement that aims to evaluate the efficacy of several pertinent pedagogies (i.e., mini-projects, guided self-directed learning, peer learning, analysis & design, reflective learning) implemented over time in a sophomore-level thermodynamics course.

Participants
The mandatory, face-to-face, sophomore-level thermodynamics course was comprised of approximately 80% mechanical engineering majors, 10% engineering mechanics majors, and 10% nuclear or industrial and systems engineering majors for the Fall 2021 semester. All enrolled students were sent an optional survey designed to measure their cognitive and emotional engagement during participation in a series of mini-projects. Consenting survey participants were assured that their responses would be fully anonymized. Of the 120 student surveys sent, 77 received responses (64% response rate). Data from anonymous teaching evaluation questionnaires were also collected.

Analysis
Students' cognitive and emotional engagement were measured using a series of questions designed by following the guidelines and factor-groupings in Halverson and Graham's extensive meta-study [24]. All questions were written to align positive values with a desired agreement response. Response options corresponded to the following Likert scale: strongly disagree, disagree, slightly disagree, slightly agree, agree, strongly agree. Questions were preassigned to the following 13 factors: attention, comfort with ambiguity, creativity, curiosity, willingness to embrace risk, empathy, enjoyment, lack of anxiety, lack of boredom, lack of frustration, optimism, teamwork, and (conceptual) understanding. All responses were coded numerically to indicate positive and negative tendencies, where "strongly disagree" corresponded to -3, "disagree" to -2, "strongly agree" to 3, and so on. Factor analysis was used to connect students' responses to task-related experiences. Appendix C lists the survey questions.

Results

Quantitative
Survey prompts were grouped according to the 13 listed factors. Figure 4 summarizes the surveys' salient results (n = 77). A tendency toward the positive X-axis indicates a more positive response to the factor captured by the prompt; in other words, a higher value means that students on average tended to more strongly agree/identify with the prompt. A negative value indicates that students on average tended to disagree, or did not identify, with the prompt.

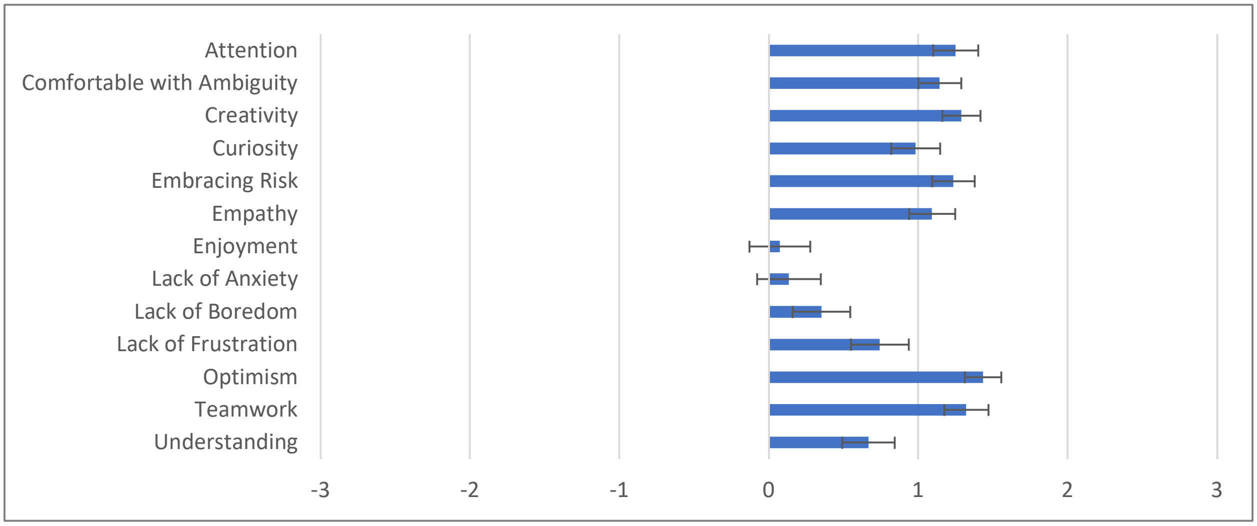


Figure 4. Salient results of student evaluation surveys (n = 77).

Table 1 presents statistical data of the 48 questions grouped into 13 factors. Table 1 and Figure 1 show that participants responded positively (averaging responses of at least "Slightly Agree" on a six-point Likert scale ranging from "Strongly Disagree" to "Strongly Agree," $\bar{X} > 1.000$) for factors pertaining to attention, comfort with ambiguity, creativity, embracing risk, empathy, optimism, and teamwork, with optimism and teamwork receiving the highest correlated responses respectively.

Table 1. Statistical Results of Questionnaires

Factor	**Mean, $\bar{X}$**	**Standard Deviation**	**Standard Error**
Attention	1.250	1.322	0.151
Comfortable with Ambiguity	1.144	1.260	0.144
Creativity	1.288	1.112	0.127
Curiosity	0.983	1.436	0.164
Embracing Risk	1.235	1.250	0.142
Empathy	1.092	1.355	0.154
Enjoyment	0.074	1.789	0.204
Lack of Anxiety	0.135	1.868	0.213
Lack of Boredom	0.352	1.692	0.193
Lack of Frustration	0.743	1.703	0.194
Optimism	1.434	1.068	0.122
Teamwork	1.321	1.302	0.148
(Conceptual) Understanding	0.667	1.540	0.175

Qualitative

Students also had the opportunity to provide open-ended, anonymous feedback in end-of-semester teaching evaluation questionnaires. Although most students provided wonderfully positive feedback, some were not enthused by the open-ended nature of many of the questions posed in the mini-projects. Even so, no student reported that the mini-projects were too time-consuming or difficult. A sample of responses, which demonstrate overarching participant sentiments, is provided below:

> "The setup of the course was excellent, the mini projects were a good way to learn more about the material well, and it let us focus more on our learning!"
>
> "It may be an 8 AM lecture, but the way he teaches makes thermodynamics interesting and engaging. He does not teach in the standard way of lecturing and then giving homework/quizzes. Rather, there are mini-projects that make you think more about what we are really learning."
>
> "The mini-projects were very applied to the real world, so it was very helpful to understand how thermodynamics worked in our world."
>
> "The projects need to be less vague in rubrics and requirements."
>
> "Grading was done fairly, and for the projects the students were tasked with grading other groups projects, and this helped me understand how to grade objectively, and then the TAs would make sure the grades were fair for the work that was done."
>
> "It was hard at first to discern what a good mini-project looks like."

Discussion

Quantitative

For this class, no factors averaged in the negative, meaning that students tended to identify positively. This was the first semester in our ongoing study for which no factor received a negative average response [1], [16], indicating the efficacy of using surveys to iterate task design over time. Of the 13 factors measured, enjoyment and lack of anxiety were deemed to be of lesser importance ($0.0 < \bar{X} > 0.3$). However, the non-negative tendency for lack of anxiety ($\bar{X} = 0.135$) can still indicate desirable attributes of the task. Pekrun noted that on simple tasks anxiety does not affect, or may even enhance, performance; however, learning may become impaired on complex or difficult tasks that demand cognitive resources [25]. Thus, the slight tendency toward lack of anxiety is desirable for supporting emotional and cognitive energy reserves in complex learning contexts.

The factor of attention received a positive reaction ($\bar{X} = 1.250$). This cognitive engagement factor is seen by many as the gatekeeper for information processing [26] and is therefore one of the basic indicators that students are engaging mental effort in the learning process. Participants' responses averaged a slight tendency toward the positive (i.e., an average score between "neutral" and "slightly agree") for seven factors (roughly half), including conceptual understanding ($\bar{X} = 0.667$). Despite capturing participants' attention, the mini-projects may not have encouraged students to become as deeply asborbed in subject contents as would ideally be desired. As students have busy schedules and cannot afford to become too immersed (or spend too much time) on any one course or topic, this trend is not surprising. A "flow" state, or one of deep immersion, is described by Csikzentmihalyi as "a state in which people are so involved in an activity that nothing else seems to matter" [27]. Analysis from previous semesters revealed a deeper immersion in subject contents, indicating a change in students' experiences [1], [16]. The source of this change is ambiguous, as environmental and other factors that were not measured during the study may have had an impact.

Previous analysis also revealed that students' potential engagement with subject content was further supported by a similarly positive response for curiosity [1], [16]. In this dataset, curiosity also received an average score below "slightly agree" ($\bar{X} = 0.983$), which supports the idea that students' responses to curiosity, attention, and understanding may be inherently related and thus similarly impacted through the entry (or lack of entry) into a flow state. It should be the on-going goal of the task to help students collaboratively enter a state of deep engagement, which may in turn support their learning outcomes.

Research has established that emotions cannot be separated from thinking in cognitive processes such as memory retrieval, decision-making, problem solving, and creativity [28]. As positive emotions assist learning, it is heartening to see that the participants the series of mini-projects mostly enjoyable ($\bar{X} = 1.092$). Although enjoyment (i.e., situational interest) is deemed to be a short-lived affective state [29], it nevertheless focuses attention, enhances cognitive performance and learning, and improves integration [30]. If mini-projects indeed help to spark students' interest, it follows that they become better engaged. In this respect, although enjoyment is considered a short-lived factor, it may be associated with increased creativity and cognitive performance [31].

The factor of optimism received the highest positive response ($\bar{X} = 1.434$), which is an improvement over its ranking in previous semesters [1], [16]. Optimism, which can be considered like a sense of a confidence, may precede and facilitate engagement, as students are more likely to exert effort in tasks when they believe in their capacity to succeed [32]. Likewise, this attitude can also indicate engagement, as it depends on events that occur during problem solving and not on students' incoming beliefs [33]. The persistence of optimism throughout multiple semesters of mini-projects is indicative of the projects' positive impact on students' engagement with, and perception of, course material.

Overall, the quantitative results suggest that the mini-projects increased participants' cognitive engagement (e.g., attention, creativity, optimism) and emotional engagement (e.g. embracing risk, empathy, teamwork) in an interconnected manner. Data accrued through the ongoing study indicates that the iteration and continued implementation of mini-projects in lower-level engineering classes can be worthwhile in supporting students' engagement, making the practice a useful pedagogy of engagement for engineering educators.

Qualitative

From reviewing students' course evaluation comments, findings indicate that students not only enjoyed a meaningful and deep learning experience but also had fun in the process. Students reported that assessing their peers' mini projects led to them taking more responsibility in their own (future) mini-projects as well as enhanced their self-learning management. Results also suggest that students' awareness of peer assessment improved their activation more than the quality of the feedback itself. Peer grading further helped students to understand what elements are appreciated in an answer and to identify common mistakes. This insight provided a meta-perspective on students' own understanding and learning; other research substantiates this finding [34]. As students gave and received feedback from their peers, they enjoyed the benefits of incorporating other perspectives into their progress to help identify, strengthen, and consolidate their learning experiences. However, it is important to note that some students were not in favor of the peer-grading technique employed with assessment of the mini-projects. Those students also tended not to support the open-ended format, and corresponding subjective assessment, of certain questions.

Conclusion

A mandatory sophomore-level thermodynamics course was transformed using a series of four self-directed mini-projects for which students worked first in teams and then alone. Working this way provided a scaffolded course that incorporated authentic projects focused on real-world problems, self- and peer-assessment, competency showcasing, and reflective practice, all underpinned by peer grading to enhance conventional evaluation. Of importance to this investigation was the emphasis placed on the intertwined connections of cognitive and emotional engagement.

Results suggest that mini-projects help foster self-directed learning, as well as enhance self-awareness, by providing students with valuable insight toward their own learning styles. By prompting students to conceptualize and articulate their thinking in a disciplinary context, the awareness gained from this process helps students to develop critical thinking skills as well as regulate, change, and improve learning behavior. Prompted by the mini-projects, students acquired most of their course-related knowledge and skills independently and with minimal guidance. They also effectively reflected on their learning experiences, further evidencing meaningful and self-directed learning.

The strength of mini-projects lies in their capacity to build reflective ability. When used in formative assessment, feedback from peers, instructors, and teaching assistants helps students to identify strengths and stimulates the development of future learning goals and strategies. Successful mini-projects require unambiguous and detailed grading rubrics, which provide students with well-defined objectives and explicit assessment criteria. The use of comprehensive grading rubrics also supports faculty and teaching assistants in providing feedback to support student learning and progression.

Our study demonstrates an innovative method for cultivating self-directed and autonomous problem solvers using mini-projects and teamwork. Our investigation has revealed that mini-projects support and streamline student assessment in ways that enrich their learning experience. Mini-projects have the potential to facilitate deeper understanding of course content, make the curriculum more relevant for students, and help build connections between classroom and professional learning competencies. To ensure quality of learning, mini-project-based teaching and learning activities must be aligned with, and supported by, authentic assessment activities. The successful integration of project-based learning with traditional course aspects (e.g., quizzes) enables a course to be transformed into a series of engaging learning experiences.

Future Work

Future investigation will evaluate how mini-projects affect the development of student expertise over time. Furthermore, this study does not include rigorous analyses to quantify statistical significance of data. This will be done in follow-up work. Over the next few years, mini-projects will be evaluated in several other courses in the mechanical engineering program. This pedagogy will be repeated (with no change) in future installments of the thermodynamics course.

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Appendix A: Typical course syllabus, showing project deliverable deadlines

	For the class on …	… you should first study the following at home	… which is in the following Lecture Notes	During class, you will do the following (all times are "U.S. Central Time") / Submission deadlines
1.	Mon. 23 Aug	Introduction		Thinking-style questionnaire
	Wed. 25 Aug.	Definitions, units, systems, properties, states, processes, cycles	1	Introduction to teammates
	Fri. 27 Aug.	Temperature, pressure; Continuum; Problem-solving	1, 2, 3	Team-based problem-solving
2.	Mon. 30 Aug.	Energy, heat, work; sign conventions	4	Quiz 1 due by 10 p.m.
	Wed. 1 Sept.	Energy balance, First Law	4, 5	
	Fri. 3 Sept.	Energy and Energy Balance	1 - 5	Team-based problem-solving
3.	Mon. 6 Sept.	Labor Day (no class)		
	Wed. 8 Sept.	Properties of a pure substance. Phase change.	6	Quiz 2 due by 10 p.m.
	Fri. 10 Sept.	Pure substances, phase-change; property tables and diagrams	6	Team-based problem-solving
4.	Mon. 13 Sept.	p-v-T relations; Pure substances, phase-change; property tables and diagrams	7	**Mini-Project 1 due by 10 p.m.** Quiz 3 due by 10 p.m.
	Wed. 15 Sept.	Ideal gas equation of state; C_v and C_p; Ideal gas deviations	7	
	Fri. 17 Sept.	Pure substances	6, 7	Team-based problem-solving
5.	Mon. 20 Sept.	Specific heats.	8	Quiz 4 due by 10 p.m.
	Wed. 22 Sept.	*Closed Systems:* Gas power systems. Air-standard Diesel cycle (disregard entropy, for the time being)	9	
	Fri. 24 Sept.	*Closed Systems:* Gas power systems. Specific heats. Air-standard Diesel cycle (disregard entropy, for the time being)	8, 9	Team-based problem-solving
6.	Mon. 27 Sept.	*Closed Systems:* Air-standard Otto cycle (disregard entropy, for the time being)	10	Quiz 5 due by 10 p.m.
	Wed. 29 Sept.	*Closed Systems:* Air-standard Otto cycle (disregard entropy, for the time being)	10	
	Fri. 1 Oct.	*Closed Systems:* Otto and Diesel cycles	8 - 10	Team-based problem-solving
7.	Mon. 4 Oct.	*Open Systems:* The First Law for open systems (control volumes): conservation of mass, mass flow rate, mass rate balance	11, 12	**Mini-Project 2 due by 10 p.m.**
	Wed. 6 Oct.	**Mid-term exam 1**		
	Fri. 8 Oct.	*Open Systems:* Turbines; compressors and pumps; p-h diagrams; Nozzles, diffusers; p-h diagrams; Heat exchangers; p-h diagrams	13	Team-based problem-solving
8.	Mon. 11 Oct.	*Open Systems:* The Rankine cycle ("steam power plants")	14	Quiz 6 due by 10 p.m.
	Wed. 13 Oct.	*Open Systems:* The Rankine cycle	14	
	Fri. 15 Oct.	*Open Systems:* The Rankine cycle	14	Team-based problem-solving
9.	Mon. 18 Oct.	*Open Systems:* The Rankine cycle	14	Quiz 7 due by 10 p.m.
	Wed. 20 Oct.	*Open Systems:* Refrigeration cycle	16	
	Fri. 22 Oct.	*Open Systems:* Brayton cycle ("gas turbine power plants")	15	Team-based problem-solving
10.	Mon. 25 Oct.	The Second Law of Thermodynamics: Kelvin-Planck and Clausius statements	18	**Mini-Project 3 due by 10 p.m.**
	Wed. 27 Oct.	Entropy: Increase-of-entropy principle; Entropy of closed systems	18	Quiz 8 due by 10 p.m.
	Fri. 29 Oct.	Entropy of open systems	18	Team-based problem-solving
11.	Mon. 1 Nov.	Entropy of pure substances	19	Quiz 9 due by 10 p.m.
	Wed. 3 Nov.	T-dS equations; entropy changes of liquids; entropy change of gases	20	
	Fri. 5 Nov.	T-dS equations; entropy changes of liquids; entropy change of gases	20	Team-based problem-solving
12.	Mon. 8 Nov.	Isentropic efficiencies	21	Quiz 10 due by 10 p.m.
	Wed. 10 Nov.	Exergy of a closed system	22	
	Fri. 12 Nov.	Exergy of an open system	22	Team-based problem-solving
13.	Mon. 15 Nov.	Improving performance of Rankine cycle: superheat, reheat, and supercritical	23	
	Wed. 17 Nov.	**Mid-term exam 2**		
	Fri. 19 Nov.	Actual steam power cycles	24	**Mini-Project 4 due by 10 p.m.** Team-based problem-solving
14.	20 – 28 Nov.	Fall Break (no class)		
15.	Mo. 29 Nov.	Combined gas-vapor power cycles	25	
	Wed. 1 Dec.	Combined gas-vapor power cycles	24, 25	
	Fri. 3 Dec.	Review of salient aspects	Handout	Team-based problem-solving
16.	Mon. 6 Dec.	Discussion	All	Quiz 11 due by 10 p.m.
	Wed. 8 Dec.	**Project Winner's Day**		

Appendix B: Typical Mini-Project Assignment

Mini-Project 4

Topic: Thermodynamics and achieving the UN's Sustainable Development Goals (SDGs)

This mini-project challenges you to move between the focused world of engineering thinking and a "big picture" contextual perspective. Learning to move between these frames is essential in forming sound engineering judgment. This mini-project also challenges you to move both between theory and action and between your life as a student and your life as a citizen of the planet. Integrating theory and action is the essence of engineering. Let us abandon the misleading distinctions we sometimes make between "College" and "The Real World," and between an academic subject like "thermodynamics" and what we more generally refer to as our "life."

When answering the questions below, remember to cite clearly all your sources (e.g. authors, article titles, journal title, year of publication, volume number, page number, URL).

Also, first read all questions, especially Question (d) *before* you begin answering the first question.

1. *Explore.* Identify a set of novel energy-related technology/ies or action/s that can be adopted to *significantly* reduce US greenhouse gas emissions. Your chosen technology must however have a thermodynamics slant. For instance, you may select as your project one of the following:

    i. The recovery of waste heat using an "Organic Rankine Cycle" to produce electricity (e.g. Climeon 150 kW power module)

    ii. An internal combustion engine that runs on propane or methane (e.g. Generac Guardian)

    iii. An advanced air-conditioning/heat pump system (such as the Build Equinox CERV-2, made in Urbana).

    iv. You could choose a topic that deviates from the aforementioned i - iii, as long as your novel solution has a strong thermodynamic focus.

    Summarize the salient operating conditions of your novel technology or action. Also provide drawings (or photos, clear sketches, etc.) that clearly explain how your novel concept/s would work or be enacted.

    In doing so, make it clear how you aim to mainly target SDG #7 (Clean Energy) and SDG #13 (Climate Action) with these actions. Explain how your proposed technology / action has the potential to *significantly* reduce greenhouse gas emissions compared to the use of traditional technologies or actions. (20)

2. *Analyze.* Justify your choice of energy-related technology and/or actions by explaining what impact you expect your chosen technology and/or actions to have and put them in perspective. You must do this quantitatively (using thermodynamics calculations, among others) and qualitatively.

    Quantitatively, also estimate the total *CO_2-equivalent* reductions the actions you have identified would bring about on an annual basis (do your own research to find a definition of

CO_2-equivalents, like by searching the EPA database: https://www.epa.gov/sites/production/files/signpost/cc.html). (40)

3. *Reflect*

   As for an ethical or moral argument, briefly state why you consider your proposed action or technology to be morally justified. (You might investigate some ethical frameworks - e.g., utilitarian, deontological, social justice, morally deep world, etc. Do your own research in this regard). (5)

4. *Discuss* how your action or proposed technology/ies will have social-, technological-, economic-, environmental-, and governance ramifications and interactions. You could also discuss interactions among SDGs when implementing your project. Use diagrams (if possible) to help explain your thinking. (5)

5. *Communicate.* Produce a high-impact "**fact sheet**" to document your findings. This "fact sheet" could comprise of several pages, but should provide a powerful summary of your salient findings from Questions (1), (2), (3) and (4). (30)

What is a Fact Sheet?

A fact sheet is a short, typewritten document that contains the most relevant information about a particular subject in the least amount of space. The goal is to provide facts and key points about a topic in a clear, concise, and easy-to-understand way. In developing a fact sheet, you must decide what is most important, organize it, and communicate it in your own words. All three of these practices relate to how people learn and are linked to increased retention of information.

Fact sheets are often summaries of a longer document or an alternative to writing a detailed essay about a topic. Fact sheets have been extensively used to communicate health information. Most engineers and business people agree that fact sheets are excellent ways way to learn about research and use it in practice; these professionals reported using fact sheets in their personal and professional lives.

Sample fact sheets: https://reimagine.web.illinois.edu/2021-competition-winners/

GRADING RUBRIC WHICH WILL BE USED TO EVALUATE YOUR MINI-PROJECT 4

	"EXCEEDS EXPECTATIONS" (80 – 100%)	"MEETS EXPECTATIONS" (40 – 75%)	"DOES NOT MEET EXPECTATIONS" (10 – 35%)	"UNACCEPTABLE" (0 %)	COMMENTS
1. Explore Thermodynamics and the SDGs ________ / 20	Novel actions that will significantly reduce GHG and CO_2 emissions. Actions have strong thermodynamic focus. Excellent description or discussion, with evidence of rigorous research (including clear statement of citations and references) SDGs 7 and 13 correctly interpreted.	Acceptable actions that will significantly reduce GHG and CO_2 emissions. Actions have strong thermodynamic focus. Adequate description or discussion, with evidence of some research (including clear statement of citations and references). SDGs 7 and 13 correctly interpreted, but more should have been said.	Unacceptable or impractical actions that will not significantly reduce GHG and CO_2 emissions. Actions do not have a strong thermodynamic focus. Poor description or discussion, with little (or no) evidence of research (and without clear statement of citations and references) SDGs 7 and 13 correctly interpreted but much has been omitted.	Little or no evidence of addressing questions	
2. Analyze thermodynamics and the SDGs ________ / 40	Excellent quantitative analysis of environmental impact based on detailed thermo-dynamic calculations and interpretations. Correct order of magnitude for CO_2 approximation, with reference to uncertainty in values. Excellent explanation about feasibility of proposal	Appropriate quantitative analysis (with minor errors) of environmental impact based on adequate thermodynamic calculations and interpretations. Correct order of magnitude for CO_2 approximation, with acceptable reference to uncertainty in values. Adequate explanation about feasibility of proposal	Poor quantitative analysis (or mainly incorrect) analysis of environmental impact based on poor or incorrect thermodynamic calculations and interpretations. Wrong order of magnitude for CO_2 approximation, with unacceptable (or no) reference to uncertainty in values. Little or no explanation about feasibility of proposal	Little or no evidence of addressing questions	
3. Reflect ________ / 5	Excellent insight into moral justification for proposed technology / actions.	Acceptable insight into moral justification for proposed technology / actions.	Little or no insight into into moral justification for proposed technology / actions.	Little or no evidence of addressing questions	
4. Discuss ________ / 5	Excellent discussion of social, technological, economic, environment-tal, and governance ra-mifications and interac-tions	Acceptable discussion of social, technological, economic, environment-tal, and governance ramifications and interactions	Poor discussion of social, technological, economic, environmenttal, and governance ramifications and interactions		
5. Communicate ________ / 30	High-impact fact sheet, written with clarity, is visually engaging, and is easy to follow. The fact sheet has a powerful and compelling narrative.	Medium-impact fact sheet, written with clarity, is visually engaging, and is easy to follow. The fact sheet has a powerful and compelling narrative.	Low-impact fact sheet, written with clarity, is visually engaging, and is easy to follow. The fact sheet has a powerful and compelling narrative.	Little or no evidence of addressing questions	
Total: | ________ / 100	**COMMENTS:**				

Appendix C: Questionnaires

Participants were provided an online questionnaire with questions that could later be ordered in terms of (a) cognitive engagement and (b) emotional engagement. These questions and their ordering into factors are based on the extensive meta-study reported in [26]. All questions were answered on a 6-point Likert scale.

To evaluate Cognitive Engagement:

Understanding

Doing the mini projects increased my understanding of thermodynamics.
The required reflections helped me to better understand what I learned in the mini projects.
The mini projects helped me understand concepts better as compared to a traditional class format.

Attention

The mini projects focused my attention on specific topics.
The variety of analytical and reflection challenges and research work in the mini projects kept my attention.
When I worked on the mini projects, I devoted my full attention to my work.

Effort and Persistence

The mini projects pushed me to the limits of my skills.
The self-directed nature of the mini projects required significant effort to discover things by myself.
The open-ended nature of most of the mini-project questions required me to productively struggle with concepts.

Time on Task

I spent significantly more time on the mini projects than on traditional non-self-directed assignments.
The mini projects helped me to better plan and organize my analytical work.
The mini projects showed me how to better manage my time and resources.

Cognitive or Metacognitive strategies

In my mini-project reflections, I was able to connect what I learned in this course to knowledge from other courses.
In my mini-project reflections, I was able to connect what I learned in this course to possible future applications.
My evaluation of my peers' mini projects helped promote my insight into a given topic.

Creativity

The mini projects helped me to "think outside the box".
The mini projects encouraged me to be creative.
In the mini projects, I could often see how to improve an idea.

Curiosity

When doing the mini projects, I felt curious about what I was learning.

Evaluating my peers' mini projects made me feel curious about how they solve problems.
The mini projects made me feel like I was discovering new things.

To evaluate Emotional Engagement:

Enjoyment
I enjoyed doing the mini projects.
I would rather work on the mini projects than do work for other classes.
I found most of what I learned in the mini projects very interesting.

Confidence
I have a sense of achievement from the self-directed learning offered by the mini projects.
I feel happy with how well I learned when engaged in mini projects.
I can explain how the law of conservation energy applies to the topics addressed in the mini projects.

Embracing Risk
When working on mini projects, I liked exploring unfamiliar ideas. The mini projects prompted me to try new approaches to solve problems.
When working on mini projects, I shared my ideas with my teammates even when I was not sure if they were correct.

Motivation
My experience working on the mini projects showed me that I can overcome difficult challenges.
Participating in the mini projects seemed like fun to me.
The mini project topics were appealing to me.

Being comfortable with ambiguity and uncertainty
I enjoyed the fact that a solution to a mini project problem could result from an unexpected direction.
I felt comfortable working on problems that could have more than one right answer.

Empathy
The mini projects helped me to empathize with the concerns of other people.
The mini project topics helped me realize that I desire to have an impact on people around me.

Lack of Anxiety
Working on the mini projects reduced my anxiety about the course learning material.
Working with teammates made me less fearful of the course learning material.

Lack of Frustration
I was satisfied with the open-endedness of some of the mini project tasks.
The real-world scenarios in the mini projects provided a sense of meaning.

Lack of Boredom

I felt energized and interested when doing the mini projects.
I found it easy to get excited about my work on the mini projects.
While working on the mini projects, I felt like I was learning things in new ways.

Teamwork

Working in a team on the mini projects was a pleasurable experience.
I felt comfortable learning new things with my mini project teammates.
I felt comfortable working with people who have different perspectives and abilities from mine.
The mini projects helped me to connect and build relationships with fellow team members.

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