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Integrating Problem-Solving Studio into an Introduction to Engineering Course via a Real-World Project

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Abstract. The objective of this study was to introduce a group of diverse students (Chemical Engineering, Civil Engineering, Mechanical Engineering and Generals Engineering students) to problem-solving (PS) and foster entrepreneurial mindsets (EMs) through a 4-week project. This 4-week project was to design a snowmaking system for a local ski resort. Our hypothesis was that using a real-world project can promote students' curiosity in problem-solving, help students make connections between the knowledge they learned in classroom and the problem, and encourage students to apply this knowledge to create values for our communities, which are the 3Cs of EMs. To test this hypothesis, we organized a field trip and used teaching techniques such as Jigsaw in addition to traditional lecturing. The outcomes were evaluated using surveys, ICAP framework, technical memo, and modeling results using Excel.

1. Introduction.

Integrating effective problem-solving techniques into engineering education is crucial for preparing students to tackle real-world challenges. This study aims to embed a Problem-Solving Studio (PSS) approach within an introductory engineering course, leveraging a real-world project as the central learning module. The PSS, pioneered by Joseph M. Le Doux and Alisha A. Waller at the Georgia Institute of Technology in 2016, represented an innovative educational paradigm designed to enhance analytical problem-solving skills while deepening students' conceptual understanding of engineering principles(*1*). The unique structure of the PSS emphasizes collaborative teamwork, interactive engagement with in-class mentors and instructors, and a dynamic approach to escalating the complexity of problems. This methodology aligns well with contemporary educational theories that advocate for active, student-centered learning environments. My engagement with the PSS workshop at the Georgia Institute of Technology in 2022, led by Joseph M. Le Doux, Carmen Carrion, and Sara Schley, provided valuable insights into its practical implementation(*2*). Since then, I have been working on implementing PSS into Engineering Curriculum, aiming to foster a robust problem-solving mindset among engineering students.

The integration of an entrepreneurial mindset (EM) into engineering education has become increasingly prevalent, reflecting a paradigm shift in how engineering problems are approached and solved. This project, serving as the capstone of an Introduction to Engineering course, was designed to instill EM in a diverse group of engineering students, equipping them to tackle multidisciplinary challenges innovatively. Historically, EM has been a staple in business education but has only recently begun to permeate engineering curricula globally over the past few decades (*3*). The Kern Entrepreneurial Engineering Network (KEEN), established in 2005, has been pivotal in promoting EM within undergraduate engineering programs across the United States(*4*). This initiative underscores a growing recognition of the value of entrepreneurial thinking in engineering, evidenced by enhanced student performance and improved retention rates(*4, 5*). Central to EM are the '3Cs' – Curiosity, Connections, and Creating Value – which collectively foster a mindset oriented towards recognizing and capitalizing on opportunities to make positive societal impacts. The objective of this project is to deepen the impact of EM among engineering students by embedding it into various levels of problem-solving. Such an approach is novel in its application and focuses on assessing how EM can be effectively integrated into engineering problem-solving processes, thereby enriching the educational experience and outcomes for engineering students. This introduction to the engineering course project serves as a testbed for this innovative pedagogical approach, with potential implications for broader adoption in engineering education.

Recognizing the evolving demands of the engineering profession, it is essential to equip future engineers with not only advanced problem-solving skills but also a robust EM, as underscored by the Accreditation Board for Engineering and Technology (ABET)(*6*). The growing emphasis on EM reflects the industry's need for engineers who can effectively communicate and collaborate with professionals from diverse disciplines, such as chemistry and marketing, and who possess a comprehensive understanding of solving real-world problems while creating value in a competitive marketplace(*4*). Hence, it is necessary to incorporate EM into the engineering curriculum. Considering the nature of the EM, it can be incorporated into the engineering curriculum via various approaches at different levels, which is the motivation of this project. Integrating EM into the engineering curriculum, therefore, becomes a strategic necessity, preparing engineers for the rapidly changing global work environment by fostering innovation, adaptability, and cross-disciplinary thinking. This project, motivated by the multifaceted nature of EM, aims to explore, and implement diverse approaches for its incorporation at various educational levels, aligning engineering education with contemporary industry requirements and ABET standards, and thus preparing graduates for the dynamic challenges and opportunities in modern engineering fields.

This project was designed to incorporate PSS and EM into the Engineering Curriculum at the sophomore level through a four-week long real-world project. Project-based learning (PBL) has been known as a student-centered instruction that centers on three principles: context/confinement-specific, active-learning, and involving social interaction and the sharing of knowledge and understanding(*7-9*). PBL has connections with problem-based learning and experiential and collaborative learning. However, it also distinguishes itself from these pedagogical approaches based on the three principles. In this project, the author aims to integrate PSS and EM into PBL to fulfill the evolving demands of the engineering profession.

2. Introduction to Modeling of Engineering System Course Structure

This course is currently offered to multidisciplinary engineers only during the Fall Semester with one or two sessions depending on the number of registered students. In this study, two sessions (Session A&B) were offered this semester. Session A had 15 students (6 Civil Engineering, 1 Mechanical Engineering, 6 General Engineering, and 2 Chemical Engineering) with an average GPA of 3.25. Session B had 9 students (5 Civil Engineering, 3 Chemical Engineering, and 1 General Engineering) with an average GPA of 3.13. Each session was facilitated by different instructors, employing varied teaching methodologies. Session A incorporated systematic training in PSS and EM, while Session B followed a more traditional approach, focusing on conventional lecturing and homework assignments. Notably, both sessions converged on a common real-world project assigned as the final task. This bifurcated approach was designed to evaluate the efficacy of PSS and EM training in better preparing engineering students for practical, real-world project execution, compared to traditional teaching methods.

This introductory engineering course is a foundational element of our spiral curriculum, strategically positioned to build upon students' prior knowledge in Excel modeling, Methods of Engineering Analysis, Mathematics (including Calculus I & II and Differential Equations), Physics I, and General Chemistry I. Its primary goal is to familiarize students with modeling techniques based on system accounting principles and equations, thereby preparing them for advanced disciplinary-specific courses. The course specifically focuses on the system accounting principles and equations related to four key quantities: mass, charge, energy, and momentum. In addition to introducing these fundamental concepts, a significant objective of this course is to systematically develop students’ problem-solving skills, an essential component for the ABET accreditation of our Engineering College. This course represents the initial step in the engineering curriculum where problem-solving skills are formally integrated and assessed. One of the course's challenges is the dual requirement for students to grasp the principles of common engineering fundamentals, as detailed in Table 1, while also achieving the student outcomes listed in Table 2. In meeting this demanding objective, the PSS and EM approaches were employed in this study as ideal methodologies.

Table 1. Common engineering fundamental areas

Time (week)		Fundamental Area	Conservation Laws	Diagram	Constitutive Laws/Empirical Relationships	1st Order Transient Example
3		Mass Balance	Total Mass, components, and atoms	Process Flow Diagram	Ideal Gas, Flow Relationships	Level in a Tank
4						
5						
6						
7		Charge Balances & Electrical Circuits	Kirchhoff's Laws: KVL & KCL	Circuit Schematic	Ohm's Law, Power Equation	Flash charge & discharge
8						
9		Energy Balance	Total, Thermal, Mechanical	Process Flow	Heat Capacity	Total Energy of System
10						
11	Final/Real-world Project					
12						
13		Fluids	Linear and Angular Momentum	Free Body Diagram	Drag Force	
14		Statics			Newton's 2nd Law	Reaching Terminal Velocity

Table 2. Student learning outcomes of this course.

	Student Outcomes:
1.	Applying the balance principle in the solution of simple engineering problems.
2.	Developing models by applying the balance principle and selecting the appropriate empirical relationships.
3.	Given a set of problems from different areas, explaining the similarities and differences in solution methods and underlying concepts.
4.	Applying the modeling process in the solution of engineering problems.
5.	Modelling engineering systems using fundamental principles listed in Table 1.

In Session A, the instructor integrated the PSS and EM methodologies from the outset of the course, aligning them with the real-world project. Students were exposed to various levels of PSS and EM through illustrative examples and encouraged to apply these concepts in a structured manner during in-class activities (Table 3). Given the course's content, covering numerous principles and areas, a key focus was on teaching students to effectively connect these principles and apply them strategically in problem-solving scenarios. This approach was consistently reinforced across all course components, including interactive in-class activities, homework, quizzes, the final exam, and the culminating real-world project in Session A.

Table 3. Comparison of teaching activities between Session A & B that are designed to prepare students for the real-world project.

Session A	Session B	Notes
Lecturing (PPT, handwriting on PPT, textbook, other resources such as online videos or websites)	**Lecturing** (PPT, handwriting on whiteboard, textbook, other resources such as online videos or websites)	The same set of PPT slides were shared among the instructors of both sessions. However, they used the PPTs in a different manner and order. Session A started with general accounting equations and then moved on to mass, charge, energy, and finally momentum balance. The instructor of session A followed this sequence because mass balance was fundamental to all the rest of balance. This rationale was also designed to prepare students' knowledge for the final project.
Homework (Modeling using Excel)	**Homework** (Modeling using Excel)	The number, type, and format of HW submissions were different between the two sessions.
Quiz (5 quizzes were assigned)	**Quiz** (5 quizzes were assigned)	The number and format of quizzes were similar between the two sessions, but the questions were different. Amont the five quizzes, Quiz 0 was designed to evaluate students' knowledge background from prerequisites. Quiz 1-4 evaluated students' learning outcomes of general accounting equation, mass balance, charge balance, and energy balance.
Final Exam (Two parts and accumulative to evaluate students' overall learning outcomes)	**Final Exam** (Two parts and accumulative to evaluate students' overall learning outcomes)	The format of the final exam was similar between the two sessions, but the questions were different. The format of Part I is like that of Quiz 0&1, but Part II is like that of Quiz 2-4 as mentioned above.
Final Project (Real-world project)	**Final Project** (Real-world project)	All the materials are shared among both sessions. Both sessions were offered with the field trip. However, how the instructors facilitated the students during the project was different. For example, Session A followed the timeline

		below closely and after the mechanical energy balance was introduced during lecture. Session A has systematically introduced students to PSS and EM before the final project.
Examples (PSS & EM)	**Examples**	Session A demonstrated PSS and EM while walking students through some well-defined examples.
In-class activities (PSS & EM)	**Extra Homework**	In session A, for each quantity such as general accounting equation, mass balance, charge balance, energy balance, and momentum balance, the instructor prepared two PSS in-class activities. Each activity will last 45-60 minutes, during which students worked in groups or individually to solve a problem with EM. The team members were fixed throughout the semester. To encourage participation, the instructor offered up to 5 extra points toward their upcoming quiz to students. Each student instead of a group needs to show the instructor their modeling, solutions, evaluation, and analysis to claim their extra points. The instructor adjusted the challenge level by controlling how much information was provided at when. Students were encouraged to discuss the strategy of problem solving as a group and ask the instructor questions or suggestions. Students' ideas were also criticized by the instructor and in-class mentor.
Concept map (Connections between principles, variables, and areas)	**Equation Sheets**	In session A, to help students make connections between the quantities, concepts, and variables, the instructor taught the students how to prepare a concept map. To encourage participation, up to 5 extra points were awarded. Students needed to develop their own version of concept map. They were asked to apply the concept map during the final project and exam.
Zoom recordings	None	The instructor of session A recorded each lecture and an introduction to the final project to accommodate students who missed the lectures due to athletic competitions, work, or health issues and students' needs on reviewing the lecture contents afterwards. These recordings can also allow the instructor to flip the classroom in the future.

3. Real-world project as the final project.

3.1 Design of the real-world project.

The real-world project, spanning the last four weeks before the final exam (Table 4), served as a practical culmination of the course. Prior to this project, Session A systematically introduced students to PSS and EM, providing a solid foundation in these methodologies (Table 3). In addition, key concepts such as mass, charge, and energy balance, crucial for the project's execution, were covered before the introduction of the final project (Table 1). The project's primary objective was to enable students to apply PSS in identifying, formulating, and solving complex engineering problems by utilizing engineering, science, and mathematics principles. Furthermore, it aimed to facilitate the application of engineering design to generate solutions that meet specific needs while considering economic factors, aligning with student outcomes 1 and 2 as defined by ABET accreditation. The specific objectives of PSS for this project are outlined in Table 5, highlighting the project's alignment with the course's educational goals and ABET criteria.

Table 4. Timeline of the real-world project.

Time	Activity	PSS	EM
Week -4	Contacting local ski resort for a field trip.		Curiosity
Week -3	1. Introducing the final project to the Session A students. 2. Sending out the survey to students to find the common time for the field trip. 3. Sending out the survey to assess students' curiosity level to the project.		
Week -2	Scheduling the transportation for the field trip and discuss with students about what questions to ask.	Introducing the not-well defined question	Connections between knowledge and real-world problem
Week -1	Conducting the field trip.	Promoting students to actively identify/request parameters	
Week 0*	Project introduction (objective, student deliverables/submissions, rubrics, and reflections) and group assignment. (Supplementary Material 1)	Adjusting the level of challenge by asking questions and controlling when and how to provide information	Connections between knowledge
Week 1*	Brainstorm the parameters that needed to be defined and equations for modeling. (Supplementary Material 2)	Group discussion, instructor, and in-class mentor	
Week 2*	Modeling in Excel.		
Week 3*	Modeling in Excel.		Creating values for the Mount Southington Ski Area

*: Instructor of Session A dedicated the first 15-20 minutes of each lecture to the final project.

Table 5. Summary of PSS and EM objectives of this project.

PSS objectives	EM objectives	Assessment
Students should be able to: 1. Identify problems/opportunities.	Students should be able to: 1. Demonstrate curiosity to the	1. Student submission: • Modeling in Excel (Sessions A&B)

2. Identify the key parameters for problem solving. 3. Develop the assumptions for problem solving. 4. Develop the materials and energy balance equations for directing the optimization process in Excel. 5. Evaluate calculation results. 6. Identify the profitable pipe and pump size. 7. Demonstrate efficient written communication.	opportunities and impacts they can make by proposing a profitable snowmaking system. 2. Make connections between the knowledge they learned in classroom and real-world problems. 3. Create value for the Mount Southington Ski Area.	a. Determining the pipe diameter and pump size that could satisfy the requirement of xxx ski area with the least cost. b. Determining the impact of water reservoir's elevation and operation hours on total cost using sensitivity test. • Technical memo (Sessions A&B) a. Summarizing, analyzing, and evaluating the results. b. Recommending the design to the Mount Southington Ski Area. • Concept map (Session A) 2. Instructor's observation (Session A) 3. Survey using google forms or one-minute paper (Session A)

As for EM, because EM focuses on the 3Cs (curiosity, connections, and creating values) for identifying opportunities and making larger impact to our society, this final project aimed to achieve the following:

3.1.1 Curiosity.

The instructor of Session A chose the design of a snowmaking system as the final project to allow students to practically apply the knowledge and skills acquired throughout the course. This project choice evolved from the previous instructor's water transportation project, which had been successfully implemented in 2022. Proving to be a multidisciplinary endeavor, it effectively integrated various course concepts (Table 1) and facilitated students' advancement through Bloom's Taxonomy by applying their knowledge in modeling, analyzing information, and evaluating results to innovate a new water transportation system (*10, 11*). However, in its initial iteration, the project lacked specific elements of PSS and Entrepreneurial Mindset EM, which were subsequently incorporated to enhance its educational impact.

To incorporate PSS and EM into the final project, the instructor of Session A modified the final project as part of the snowmaking system. This modification aimed to spark students' curiosity through a real-world, multidisciplinary approach. The instructor reached out to local ski areas and after several emails and phone calls, two ski areas expressed openness to a field trip. However, only one, the Mount Southington Ski Area, had an existing snowmaking system. Coincidentally, in November 2023, xxx ski area was in the process of replacing 2000 ft of their water transportation pipes in preparation for the upcoming snow season. This timely development made the Mount Southington Ski Area an ideal choice for a practical field trip, offering students a valuable opportunity to engage with a real-world engineering challenge. To gauge the impact of this field trip on students' engagement with the final project, a survey was conducted to assess their curiosity levels both with and without the field trip experience. Students were informed that participation in the field trip was optional and would not impact their grades, ensuring their decision was uninfluenced by academic considerations. Additionally, comprehensive information about the field trip was provided to help them make an informed choice.

3.1.2 Connections

In this course, students from various engineering disciplines, including Civil, Chemical, and General Engineering, faced the challenge of addressing ill-defined real-world problems. Many initially struggled with understanding where to begin, the necessity of learning specific principles, identifying relevant variables for equation formulation, applying these principles for problem-solving and modeling, and recognizing the assumptions and constraints needed for simplification. This course represents their first systematic introduction to these essential problem-solving skills. A critical focus of the course was to help students comprehend how principles underpin the connections between variables, aiding them in defining problems and developing equations for modeling and problem-solving. These skills are fundamental to achieving the course's objectives and successfully completing the final project. When preparing for the field trip in Session A, students' active engagement in linking classroom knowledge with the real-world project was evident. Questions about the parameters needed for the field trip highlighted their evolving ability to make these connections. The assessment of their understanding and application of these connections was carried out through their modeling in Excel, the creation of concept maps, and the composition of technical memos.

3.1.3 Creating values

The real-world project, particularly enhanced by the field trip experience, served as a significant motivator for students to create value for the community, addressing a pressing sustainability challenge faced by local ski areas due to the increasingly limited snowmaking season. Direct interactions with the staff and on-site visits enabled students to form personal connections, thereby increasing their motivation to devise valuable solutions for the Mount Southington Ski Area's survival. Beyond motivation, the project also aimed to guide students in considering economic aspects of designing a snowmaking system, identifying opportunities for value creation, and assessing the potential impact of their proposals. Students were expected to take into account factors such as budget constraints, parts availability, and the ski area’s financial resources, integrating this information into their decision-making process to develop viable and impactful solutions.

3.2 Results

3.2.1 Curiosity

An assessment was conducted to evaluate whether the field trip enhanced students' curiosity towards the final project in Session A. A survey was administered to the 15 students in Session A three weeks before introducing the final project, with a participation rate of 93% (14/15 students). Of those who responded, 12 students (80%) expressed interest in the field trip, with 8 indicating strong interest. The survey results showed that 9 students believed the field trip significantly boosted their curiosity about the final project, 3 felt it somewhat increased their curiosity, and 1 did not perceive any impact. The data, as detailed in Table 6, suggested a positive correlation between the students' interest in the field trip and its effectiveness in enhancing their curiosity about the project. However, coordinating the field trip proved challenging, potentially affecting student interest, as it was difficult to schedule a common time suitable for students from both Session A and Session B, which were conducted at different times. The field trip, lasting a minimum of 4 hours, eventually included 8 students from both sessions (6 from Session A and 2 from Session B).

Table 6. Comparison between students' interests in the field trip and level of curiosity due to the field trip.

Q1: If there will be a field trip, will you attend? Please be aware that no points will be subtracted if you do not attend. (Answers: Yes/No/Maybe/No input)		**Q2:** To which level do you think adding a field trip will promote your curiosity to our Pitch Project (Designing a Snow Generation System for a Ski Resort)? (Answers: A lot/A little/Not at all/No input)	
Yes	57%	A lot	64%
No	7%	A little	22%
Maybe	29%	Not at all	7%
No input	7%	No input	7%

3.2.2 Connections

Connections were evaluated from the following two aspects.

Aspect 1. Connections between knowledge.

In Session A, the evaluation of how students connected classroom knowledge with their final project was conducted using concept maps and the equations they employed in the project. All 15 students were encouraged to create a concept map for extra credit, and they submitted their decision trees by the end of the reading days. The instructor of Session A showcased a decision tree example in Week 6 (Table 1) and shared the instructor's version in the final lecture of Week 15 (Supplementary Material 3). The assessment of students' concept maps focused on three criteria: level of connection between classroom knowledge and project application (0-100%), authenticity of their work (0-100%), and performance in the final exam (0-100%), as summarized in Fig. 1a. The results, illustrated in Fig. 1a, indicate that students who established stronger connections between variables, principles, and fundamental areas generally performed better in the cumulative final exam. However, Fig. 1a also reveals that these connections were not the sole determinants of final exam performance, as evidenced by outliers. For instance, student #4, despite making substantial connections, demonstrated less proficiency in applying this knowledge to problem-solving compared to students #1-3. Students #12 and #15 exhibited similar patterns to student #4, suggesting that the depth of knowledge connection varied across individuals.

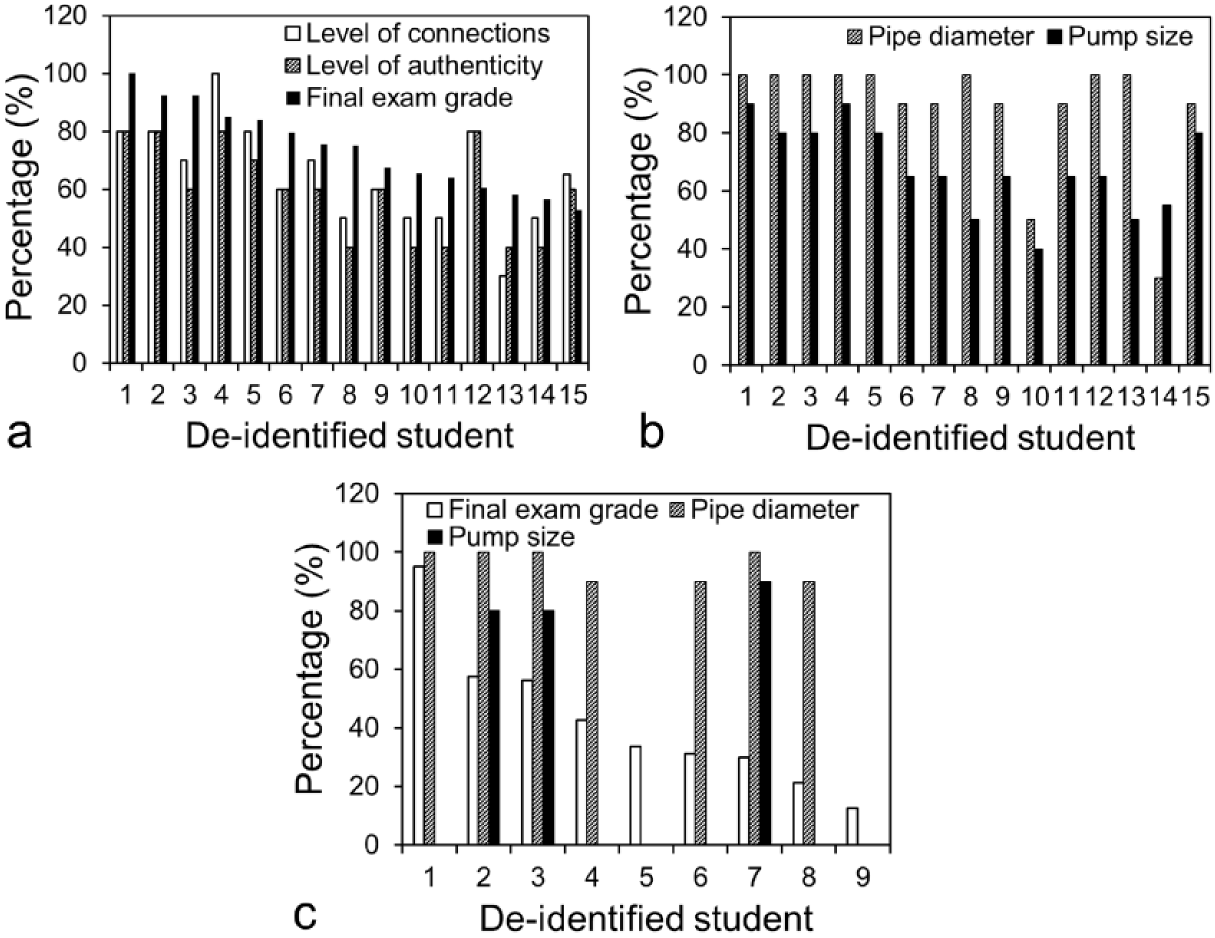

Figure 1. Connections between knowledge and the real-world project. (a) Comparison between students' level of connection (0-100%) and authenticity (0-100%) and instructor's concept map (Supplementary Material 3) and their performance (0-100%) in the final exam. (b) Students' percentage of connections during the modeling for identifying the pipe diameter and pump size that can yield the lowest cost. Students in Fig 1a&b are from Session A and numbered in the same order. (c) Students' percentage of connections during the modeling for identifying the pipe diameter and pump size that can yield the lowest cost. Students in Fig. 1c are from Session B.

Aspect 2. Connections between knowledge and the real-world project.

During the modeling in Excel, 87% of Session A (13 out of 15 students) and 78% of Session B (7 out of 9 students) achieved a high level of connection (80% or higher) between variables, principles, and equations, as shown in Fig. 1b&c. These percentages were determined based on the variables they defined, assumptions they made, and equations they used for calculation in Excel. This success is likely attributable to the clear information provided in Week 0, which helped students draw more apparent connections for identifying the pipe diameter (Supplementary

Materials 1&2). However, the task of selecting the most economical pump size, considering both the pump and energy costs, proved more challenging, with fewer students making strong connections (Fig. 1b&c). In Session A, only 6 out of 15 students managed to establish over 80% of these connections. This lower level of connection might stem from the less obvious nature of the material related to pump size selection. A higher proportion of Session A students (73% or 11 out of 15) made better connections regarding pump size compared to Session B (33% or 3 out of 9 students achieving over 60% connection), suggesting the potential impact of the PSS approach employed by the Session A's instructor.

3.2.3 Creating values

Students' activities in creating values were assessed from the following three aspects in their technical memo.

Aspect 1. Analyzing the modeling results and identifying the pipe diameter and pump size that can satisfy the needs of the Mount Southington Ski Area and minimize the cost.

Most of the students in Session A (14/15 or 93%) analyzed and evaluated the design of pipe diameter and pump size that can yield the lowest cost (with percentage of 80% or higher). The only student in Session A that reached 60% of the activities also discussed the lowest cost but failed to include the numerical results and analysis. Some students (4/9 or 44%) in Session B evaluated and analyzed their modeling results for achieving the lowest cost via designing the pipe diameter and pump size. The rest students either failed to evaluate or analyze the design of pump size or discuss the design of pipe diameter and pump size for achieving the lowest cost for the Mount Southington Ski Area at all in their technical memo (Fig. 2).

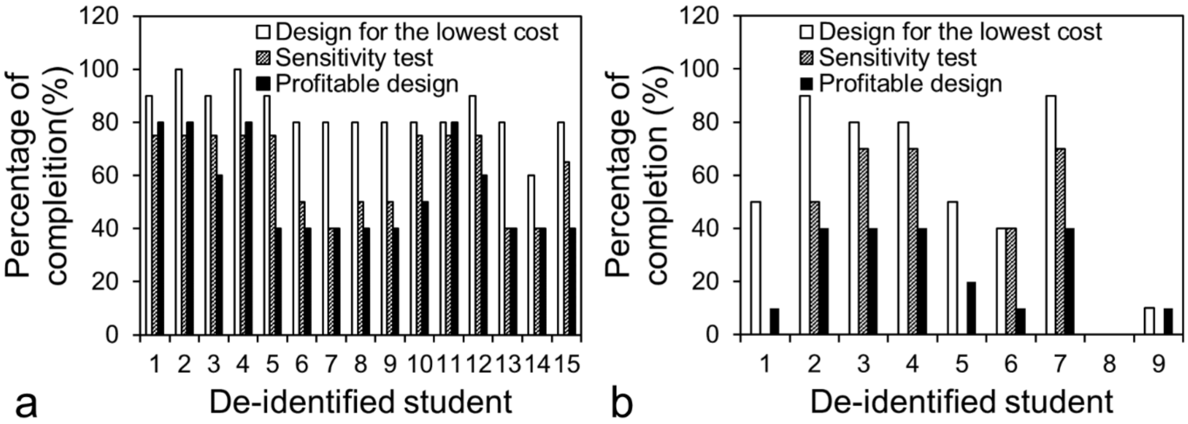

Figure 2. Summary of students' reflections in the technical memos submitted by students from Session A (a) and Session B (b) on how to create values by analyzing and evaluating modeling results. Students in Figures 1 and 2 were numbered in the same order. The percentage of completion was calculated based on the requirements listed in the Project Description (Supplementary Material 1).

Aspect 2. Evaluating the impacts of elevation of water reservoir and operation hours on the design of the snowmaking system.

In this real-world project for the Mount Southington Ski Area, students were tasked with a preliminary analysis to assess how the elevation of a new water reservoir might impact the costs of the snowmaking system. Additionally, they were asked to explore the economic feasibility of extending the ski season by one or two weeks in light of shrinking windows due to global warming, considering both energy costs and potential income. These tasks presented ideal opportunities for students to apply their modeling skills to create value for the ski area. Students in both Sessions A and B conducted sensitivity tests using Excel models to evaluate the effects of the reservoir's elevation and operation hours on costs. All students in Session A (15 out of 15) performed these tests, with their technical memos discussing the economic implications of the reservoir's elevation. However, only 7 out of 15 from Session A addressed the impact of extended operation hours on costs, and none of these analyses included considerations of how such changes might affect the ski area's income. The remaining 8 students in Session A only reported sensitivity test results without discussing their economic implications. In Session B, 6 out of 9 students conducted the sensitivity tests, but just 3 analyzed and evaluated the results in their technical memos, also omitting discussions on the economic impact of operational hour changes on the ski area's income (Fig. 2).

Aspect 3. Analyzing if the design of the snowmaking system could be profitable to the Mount Southington Ski Area considering its capital.

In assessing whether the snowmaking system design would create value for the Mount Southington Ski Area, students were tasked with determining if the most cost-effective design would also be profitable. This required comparing the design costs with the ski area's capital. In Session A, a minority of students (4 out of 15, or 27%) took the initiative to estimate the ski area's capital. Notably, two of these students had attended the field trip, while the other two actively engaged with the instructor during lectures. The remaining students in Session A either deferred the capital identification as future work or did not address the profitability aspect of their design. In contrast, none of the students in Session B included the ski area's capital in their evaluation, thereby missing a critical component in assessing the economic feasibility of their designs.

3.2.4 PSS

In this real-world project, students encountered a mix of well-defined tasks, such as modeling the pipe diameter, and less well-defined challenges, like determining the profitability of the design. Figures 1b&c and 2 illustrate that while students generally excelled in resolving well-defined questions, they required more guidance with the not well-defined ones. Students in Session A showed a relatively better aptitude for tackling these ambiguous questions, likely attributable to the PSS sessions and training they received. For instance, during the modeling for pump size selection, a less defined problem, 8 students from Session A proactively sought the instructor's help to establish connections. Among the 6 students who achieved a high degree of connection (80% or higher), 5 actively collaborated with the instructor during lectures and office hours, while the sixth student worked closely with two of these peers. Additionally, in addressing the complex question of profitability, four students in Session A specifically inquired about the ski area's capital either from the instructor or the field tour guide, demonstrating engagement in PSS activities.

3.3 Discussion and conclusions

The real-world project aimed to teach diverse engineering students Problem-Solving Studio (PSS) with an Entrepreneurial Mindset (EM). This project fulfilled the characteristics of projects for PBL, including centrality, driving question, constructive investigations, autonomy, and realism(*7*). Students from both A&B constructed end products (e.g., excel spreadsheet and a technical memo), which is unique of PBL(*7*). They also achieved the outcomes of PBL, including practicing self-regulated learning, acquiring and applying conceptual knowledge within a systematic process of documenting, reflecting on learning, developing self-reliant, developing collaboration skills, and exercising decision making (*7-9*). In addition, in Session A, the instructor systematically employed PSS and EM to enhance students' problem-solving skills through examples and in-class activities. When compared to Session B, which was the control group, it was evident that PSS combined with EM could better engage students' curiosity in tackling real-world or less well-defined problems, as shown in Table 6. This approach not only encouraged students to actively seek information and establish connections for solving complex questions, such as determining the most cost-effective pump size (Fig. 1b&c and Fig. 2), but also motivated them to analyze and evaluate their results, aiming to design a system that adds value to the Mount Southington Ski Area (Fig. 2). Notably, after the field trip, students in Session A identified an additional opportunity to add value to the ski area - analyzing the impact of water temperature on the efficiency of the nucleation reaction for snow generation. With guidance from the instructor, all students in Session A performed this analysis in Excel, and 5 out of 15 included an evaluation of their results in their technical memos, discussing potential value creation for the ski area. In contrast, in Session B, only one student conducted this analysis, and none included it in their technical memo. This extra credit activity further underscored the positive impact of PSS and EM in fostering problem-solving skills among engineering students.

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References:

1. J. M. L. DOUX, A. A. WALLER, The Problem Solving Studio: An ApprenticeshipEnvironment for Aspiring Engineers. *Advances in Engineering Education*, 27 (2016).
2. C. A. Carrion, J. M. LeDoux, paper presented at the 2019 ASEE Annual Conference & Exposition, Tempa, Florida, 2019.
3. B. H. Sababha, A. Abualbasal, E. Al-Qaralleh, N. Al-Daher, Entrepreneurial mindset in engineering education. *Journal of Entrepreneurship Education* **23**, 23 (2020).
4. J. Blessing, K. Mekemson, D. Pistrui, paper presented at the *The Kern Entrepreneurship Education Network* Paper presented at 2008 Annual Conference & Exposition, Pittsburgh, Pennsylvania, 2008.
5. M. W. Ohland, S. A. Frillman, Z. G., B. C.E., T. K. Miller, The Effect of an Entrepreneurship Program on GPA and Retention *Journal of Engineering Education* **October**, 293-301 (2004).
6. ABET. (2021), vol. 2023.
7. V. M. Dimitra Kokotsaki dimitra.kokotsaki@durham.ac.uk , and Andy Wiggins, Project-based learning: A review of the literature. *Improving Schools* **19**, 267-277 (2016).
8. J. Uziak, A project-based learning approach in an engineering curriculum. *Global Journal of Engineering Education* **18**, 119-123 (2016).
9. R. Savage, Chen, K. & Vanasupa, L., Integrating Project-based Learning throughout the Undergraduate Engineering Curriculum. *Journal of STEM Education* **8**, (2008).
10. N. E. Adams, Bloom’s taxonomy of cognitive learning objectives. *J Med Libr Assoc.* **103**, 152–153. (2015).
11. M. T. Chandio, S. M. Pandhiani, R. Iqbal, Bloom’s Taxonomy: Improving Assessment and Teaching-Learning Process. *Journal of Education and Educational Development* **3**, 203-221 (2016).

Supplementary-Materials: Integrating Problem-Solving Studio into an Introduction to Engineering Course via a Real-World Project

1. Supplementary Material 1: Project Description.
2. Supplementary Material 2: Important Equations.
3. Supplementary Material 3: Instructor's Concept Map Example

UNIVERSITY OF NEW HAVEN
TAGLIATELA COLLEGE OF ENGINEERING
EASC2211 Introduction to Modeling of Engineering Systems Fall 2023

TO: **EASC2211 Students**
FROM: **Huan Gu, EASC Instructor**
CC: **Mr. Jay Dougherty, President/General Manager at Mount Southington Ski Area**
RE: **Designing a Snowmaking System for the Mount Southington Ski Area**
Date: **December 07, 2023**

Mount Southington Ski Area is replacing their water pipes to prepare for their upcoming snow season from December 22, 2023, to March 22, 2024. The basis for design is presented in this memo. Your preliminary design must minimize the total system cost as discussed below. The work should be summarized in a technical memo, due Thursday, December 7th. It should be submitted on Canvas via TurnItIn, with the spreadsheet submitted on Canvas as a separate item.

A schematic of the desired system is presented in Figure 1. The specific dimensions and relative positions are presented in Table 1 along with some additional system specifications.

Map

Snowmaking system

14 trails

Figure 1. Schematic: Spatial Orientation of Design Basis.

Using data for the assigned design case from Table 1 you are to determine the pipe diameter for the lowest cost pumping system. The criteria to be used for determining lowest cost is the installation cost plus five years of operation. Technical data needed for calculation of cost is available in the memo “Equations for Design of Pumping Systems”. The pump power requirements are calculated using energy accounting principles. In determining the optimum pipe diameter and pump power refer to Table 2 for available pipe diameters and available motor power.

Once the optimum system parameters (pipe size and pump power) have been determined a sensitivity analysis is to be performed. For the sensitivity analysis the pipe size is to be held constant at the optimum diameter with water flowrate at design value. The pump power and total cost is to then be determined for the following two variables each of which includes two cases:

1)Inlet (staining steel cage/settlement tank) level fluctuation (Point 1): increase level be 50 m, reduce by 50 m.

2)Operating hour variation: increase operating hours by 500 hrs, reduce by 500 hrs.

Table 1			
Design Basis: Dimensions and Relative Positions			
Pipe Length	**Point 1 Elevation Inlet (staining steel cage/settlement tank)**	**Point 2 Elevation Outlet (Top of the hill)**	**Base case operation hours**
(ft)	**(ft)**	**(ft)**	**(hours/yr)**
2000	0	425-500	3 months/yr
Water flow rate	**Point 1 pressure**	**Point 2 pressure**	**Pressure leaving the high-pressure pump**
(gallons/min)	**(psig)**	**(psig)**	**(psig)**
3000	60	450	900
	Temperature of Point 1 inlet	**Temperature of Point 2 Outlet**	**K-factor**
	(°F)	**(°F)**	
	55	37	12
Note: 1. This table may not include all the specifics you need for your design. Please specify the specifics you used in your excel spreadsheet for modeling. **2. You don't have to use all the specifics in this table in your modeling.**			

Table 2
Component Availability – Piping Dimensions and Pump Motors
Available pipe diameters (inch) – 2.5, 5.0, 7.5, 10.0, 12.5, 15.0, 17.5, 20.0 Pricing information: https://www.crestwoodtubulars.com
High-pressure pump/motor sizes (hp) – 100, 150, 200, 250, 300, 350, 400, 450, 500 Note: Minimum 4 working simultaneously Always prepare a spare pump/motor in case something goes wrong. Pricing information: http://www.torrentee.com/products/details1b26.html?ContentDetails_id=2628 https://fuelled.com/listings/400-hp-multistage-high-pressure-pump-10601
Note: 1. Please pick one pipe diameter and one pump/motor size to set up the modeling first and then only change the pipe diameter to identify the pipe size that can minimize the cost. **2. Then, use the pipe diameter you identified, and only change the pump/motor size to identify the pump/motor size that can minimize the cost.** **3. In real world, the maximum efficiency of a pump is 55%.**

Report your results to Mr. Jay Dougherty, President/General Manager at Mount Southington Ski Area, in a technical memo, no longer than 3 pages. The memo should include a presentation of your results along with a discussion of how you selected the pipe diameter with summary tables and figures include in the memo to justify your choices.

The report should also summarize the results of your sensitivity analysis to give Mr. Jay Dougherty that the design will fulfill the needs of the community. Do not include all data in your report but select values to show in small tables and figures to make your case. For example, you may show a table with the results of the sensitivity analysis. Students may work in groups to develop the models/strategies, but each student must write and submit her or his own memo. Your work is due Thursday, December 7th. The memo should be submitted via TurnItIn on Canvas and the spreadsheet should be submitted via Canvas.

Bonus/extra point activity:

During the field trip, we identified the opportunity for Mr. Jay Dougherty. The ideal water nucleation process happens when the water temperature in the pipe is 37°F. Mr. Jay Dougherty wants to obtain a curve of water temperature vs. efficiency of water nucleation reaction. This curve can help him to make the decision if he needs to add a cooling process between the high-pressure pump and snow gun.

$$I = 1.78 \times 10^4 * \exp\left[-\frac{1.11\times10^4}{T(\Delta T)^2}\right] \qquad \text{Ref. } (1)$$

T: water temperature (K)

$\Delta T = T_M$-T $\quad$ T_M: melting temperature of water, 32°F or 273.15 K.

Please plot I versus T to get the curve.

References:

1. A. F. Heneghan, P. W. Wilson, A. D. Haymet, Heterogeneous nucleation of supercooled water, and the effect of an added catalyst. *Proc Natl Acad Sci U S A* **99**, 9631-9634 (2002).
2. J. Kónya, N. M. Nagy, in *Nuclear and Radiochemistry*. (2018), chap. 9, pp. 247-286.

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TO: EASC2211 Students
FROM: Huan Gu, EASC Instructor
RE: Designing a SnowMaking System for Mount Southington Ski Area
Date: December 07, 2023

This memo presents equations for calculation of costs associated with pumping systems (piping, pumps, energy cost). These estimation methods are for use with the pumping system design project specified in the memo “Designing a Snowmaking System for the Mount Southington Ski Area, December 07/2023” Cost estimation equations are included for piping, pumps, energy cost, and total cost.

Estimating cost of piping:
Pipe (\$/meter) = $6.4 + 820*D + 9400*D^2$
where D in units of meter

Estimating cost of pump:
Pump (\$) = $2.6 * (14 + 231 * P^{0.6})$
where P is shaft power in units of kW
Note: P is not the motor power

Estimating cost of electricity:
Motor power = shaft power/pump efficiency
Annual electricity use (kWh/year) = Motor power * operating hours
Electricity (\$/year) = \$0.14 * kWh/year
where - motor power in units of kW, operating hours is hours per year (given)

Estimating total cost:
Installed cost = pipe cost (\$/m) * pipe length (m) + pump (\$)
Total cost = installed cost + 5 * electricity (\$/yr)

Other equations:
Energy equation: $\Delta P/\rho + \Delta(V^2)/2g_c + \Delta h*g/g_c + F = W_s/m$
Friction: $F = (0.0015*L/D + K) * V^2$
where - **D** is pipe diameter in meters, **L** is pipe length in meters, **V** is velocity in meters/second,
P is pressure in Pa, **m** is mass flow in kg/s, **K** is floss loss term (pipe fittings),
W_s is pump shaft power in kW

Supplementary Material 3