2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC

Host Sponsor UNC Charlotte

ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #51763

WIP: Using the System Architecture-Function-Outcome framework to facilitate cross-disciplinary collaboration by undergraduate engineering students

Dr. Rea Lavi, Massachusetts Institute of Technology

Rea Lavi received the dual B.Sc. degrees in biology and in psychology as part of the neuroscience track from Tel-Aviv University, Tel Aviv-Jaffa, Israel, in 2009, the M.Ed. in curriculum management (with Hons. and with a thesis) from Bar-Ilan University, Ramat Gan, Israel, in 2013, and the Ph.D. in science and engineering education from the Technion—Israel Institute of Technology, Haifa, Israel, in 2019. Later that same year he joined the New Engineering Education Transformation Program with the School of Engineering, Massachusetts Institute of Technology (MIT), Cambridge, MA, USA, where he is also Lecturer with the Department of Aeronautics and Astronautics. During his time at MIT, he obtained educational project grants from the Alumni Class Fund, the d'Arbeloff Fund for Excellence in Education, and the Jameel World Education Lab. His work has been published in IEEE Transactions on Education, Journal of Science Education and Technology, and Studies in Educational Evaluation, among other peer-reviewed journals. His research interests include problem structuring, systems thinking, and creative ideation, with specific focus on undergraduate STEM education.

Dr. Amitava 'Babi' Mitra, Massachusetts Institute of Technology

Amitava 'Babi' Mitra linkedin.com/in/babimitra|+1-617-324-8131 | babi@mit.edu

Dr. Amitava â€˜Babiâ€™ Mitra is the founding Executive Director of the New Engineering Education Transformation (NEET) program at MIT

WIP: Using The System Architecture-Function-Outcome Framework to Facilitate Cross-Disciplinary Collaboration by Undergraduate Engineering Students

This is a work-in-progress paper.

1. Introduction

1.1. Need and rationale

Today's challenges and technologies straddle across disciplines. Both the National Academy of Engineering [1] and ABET [2] have recognized the importance of training more engineers who can collaborate across disciplines towards mutual goals. They have stated the value in bringing undergraduate students together to work on context-based learning focused on interdisciplinary topics and in collaborating with students from other disciplines.

While active learning methods such as problem- and project-based learning are considered as effective approaches for developing the ability for multi- or interdisciplinary collaboration [3], in practice, these methods are usually implemented in engineering schools at the intra-disciplinary or intra-department course level [4]. Indeed, multi- and interdisciplinary and cross-departmental courses and workshops for engineering students have been reported [6-8] to help promote various such skills: for example, students working in teams to complete a social-space problem solution project for a real-world field task using design thinking have been found to improve their creativity [5]. Students working in teams to design, simulate, and construct pendulums using software, integrating mathematics and engineering concepts through modeling, physical prototyping, reports, and presentations, have been reported to improve teamwork, among other skills [6,7].

Systems thinking is a higher order thinking skill important for addressing complex problems in science, engineering, and society [8,9]. The United States National Research Council [10] presented a framework for 21st century skills in science and engineering education—primary, secondary, and higher, including systems thinking. Additionally, the ABET 2024–2025 criterion 3 (student outcomes) for accrediting engineering programs [2] includes the ability to produce engineering solutions while considering factors that require a systems perspective, namely global, cultural, social, environmental, and economic.

[11] have previously shown that a discipline-agnostic framework for teaching systems thinking, the System Architecture-Function-Outcome framework (SAFO for short) was effective for teaching systems thinking to first-year engineering students and for assessing the systems thinking expressed in their learning artifacts. Based on two other previous studies where SAFO was applied to teach and assess collaborative problem-solving assignments [12,13], we hypothesize that SAFO can be effective in a collaborative problem-solving setting for bridging undergraduate (first to fourth year) disciplines.

1.2. Research objective and questions

The objective of this study is to evaluate the effectiveness of applying the System Architecture-Function-Outcome framework (SAFO) in a collaborative problem-solving setting with undergraduate students from different engineering disciplines.

The research questions (RQs) of this study are as follows when applying SAFO to describe and address real-world challenges in a collaborative problem-solving learning setting with undergraduate students from different engineering majors:

- RQ1: How well do the challenge and proposed solution descriptions adhere to SAFO?
- RQ2: How correct are the challenge descriptions?
- RQ3: How viable are the proposed solutions?

2. Background

2.1. Case-based learning and collaborative problem-solving in undergraduate engineering education

Active learning typically involves learners (a) applying knowledge and higher-order thinking to problems, cases, or scenarios, (b) working in groups, and (c) reflecting on their own learning [14,15]. Studies in undergraduate engineering education have shown that active learning can help students facilitate students' higher-order thinking and collaborative skills [16]. In undergraduate engineering education, collaborative problem-solving is often facilitated through some form of active learning such as problem-, project-, or case-based learning, and, depending on the levels of problem complexity and structuredness (i.e., how well-defined the problem is), may involve several iterations of problem design and analysis [17].

Case-based learning (CBL) is an active learning pedagogical approach that makes use of specific occasions or 'cases' to contextualize the learning of discipline-specific knowledge. This approach can help students develop conceptual understanding and thinking skills as they work through and reflect on the process of solving cases. CBL originated in professional education, more specifically in medicine, business, and law [18] and has since also been applied in engineering education [19]. Implementations of CBL vary by the degree of student autonomy (control) over their learning, from lecture-based (low student autonomy) to problem-based (high) [20].

The findings concerning active learning approaches and their positive impact on the development of higher order thinking and collaborative skills strengthen the consideration for applying these methods to foster students' interdisciplinary collaboration skills. We maintain that CBL, being less resource-intensive than other forms of active learning, is an attractive candidate for piloting new active learning experiences.

2.2. Systems and systems thinking

The definition of 'system' is subject to rich and ongoing academic discourse [21]. Based on previous work in undergraduate engineering education research by the first author [11], our working definition of a technological system is as follows: a technological system is an entity composed of interacting parts, delivering a predetermined function through its architecture, the latter being a combination of its structure and behavior. The system's function is delivered through interactions between parts of the system, both internally and with the system's environment. All these interactions are cause-and-effect relationships. Some whole-system properties are different to those of the system's individual parts. The system's purpose is to provide a predetermined benefit to group(s), which are the system's beneficiaries. This purpose is delivered by its function. Examples of technological systems included under this definition are a bicycle, a coal-fired power plant, or an e-reader, among numerous others.

In the context of technological, engineered systems, systems thinking can be considered as a holistic understanding of the system's function, structure, and behavior, and how a system's structure and behavior deliver its function. Systems thinking in engineering can be thought of as a higher-order thinking skill, or set of skills, enabling one to identify, understand, predict, and suggest improvements for every aspect of a technological system, and for the way these aspects inter-relate within the system [11].

2.3. The System Architecture-Function-Outcome framework

Teaching systems thinking in first-year engineering education, and especially as early as the first semester, is different to teaching it in later years, because first-year students are not yet specialized in any sub-discipline of engineering and would usually have at best a rudimentary understanding of technological systems, as engineers [22]. This presents a particular challenge for teaching systems thinking to first-year and even more so to first-semester students.

More generally for undergraduate engineering education, as [12] shows, there is a lack of pedagogical frameworks for both fostering and assessing systems thinking. Frameworks lacking in one or the other application prevent either flexibility in assignment design or rigor in assessment design.

SAFO is a discipline-agnostic pedagogical framework for systems thinking in undergraduate engineering education. It allows for both fostering and assessing of students' systems thinking, individually or in teams, artifact- or student-based. The framework was developed to teach first-year engineering students about (mostly) technological systems in a discipline-agnostic way [12] and draws in part on previous work on an assessment method which made use of conceptual models of systems created by students to assess their systems thinking [23]. In this way, SAFO's purpose is to help instructors both foster and assess undergraduate engineering students' systems thinking. The framework allows for the inclusion and distinction between technical and contextual aspects of a system and is simple enough to be implemented without prior expertise and can be applied effectively with pen and paper or on any interactive screen device.

2.4. Overview of the New Engineering Education Transformation program at the Massachusetts Institute of Technology

New Engineering Education Transformation (NEET) was launched as a pilot program in 2017, as an answer to efforts by Massachusetts Institute of Technology (MIT) to reimagine undergraduate engineering education. An extra-curricular, cross-departmental endeavor with a focus on integrative, project-centric learning, the program's mission is to prepare undergraduate students to collaborate across disciplines through immersive and applied learning to engineer a better tomorrow.

Unlike most undergraduate non-degree academic programs at MIT, NEET is both multi-year and cross-departmental, allowing students to collaborate on interdisciplinary projects of increasing complexity. These two features of NEET help students acquire the required skills in their chosen track.

NEET students join one of four interdisciplinary tracks ("threads") in their sophomore year: Autonomous Machines, Climate and Sustainability Systems, Digital Cities, or Living Machines.

The program is voluntary and is not a degree program or major or minor as offered by MIT; students joining the program graduate with their degree and simultaneously get a NEET certificate, in the usual four years.

As of Spring 2026, the program has over 200 registered students across sophomore, junior, and senior years at MIT. More information on the program and its history can be found in [24-30].

3. Methods and materials

The study received exempt review approval from MIT's institutional review board, E-7500.

3.1. Methodology

We opted for a case study approach [32], given the clearly defined scope (one day in one room with the same people) and the multiple sources of data being collected.

3.2. Research setting

Data collection took place during a competition for MIT's undergraduate students, under NEET's banner. The title of the competition was 'Applying systems thinking to challenges in the MIT campus food system.' Each participant received $20 in TechCASH (MIT's campus-based stored-value payment system) for full participation and there were also awards for first to third place teams, worth $350, $200, and $100 in TechCASH, respectively.

3.3. Participants

We recruited 10 undergraduate engineering students: a mix of engineering majors from MIT, including aerospace, biological, chemical, civil, electrical, mechanical, and nuclear engineering (Table 1). We made sure to recruit students from at least four different engineering majors.

Participants (students) were recruited using convenience sampling. Internal e-mail lists and physical flyers were distributed to prospective participants (undergraduate students), encouraging them to sign up for the competition.

Table 1. Study participants.

Team	N	Majors	Academic Year	Genders
1	2	Aeronautics and Astronautics; Nuclear Science and Engineering	All 1st	All men
2	3	Materials Science and Engineering; Mechanical Engineering; Nuclear Science and Engineering	All 1st	One man, two women
3	3	Electrical Engineering and Computer Science; Mechanical Engineering	All 3rd	All women
4	2	Biological Engineering; Electrical Engineering and Computer Science	All 1st	All women

3.4. Data collection

The competition started with one-hour information sessions (remote, synchronous) on March 17 and 18, 2026. Participants had to sign up for the competition beforehand and attend one of the sessions to participate in the competition. During these sessions, we obtained informed consent from participants to participate in the research study. One student who chose not to provide their consent to participate in the study was still allowed to participate in the competition.

This was followed with an overview of the competition and of SAFO, which included examples of system diagrams and system outcome descriptions for artificial systems that are different from the one in the competition.

We then presented to the students the competition challenges, all three related to the MIT campus food system. We formulated these challenges together with representatives from MIT's Office of Sustainability (MITOS) and Department of Facilities.

Students were asked to organize into teams of two to four members each. One student could not find a team and so we placed them on one of the existing teams, with that team's approval. Each team selected one to work through for the rest of the competition.

The challenges student teams had to choose from were as follows:

(A) Waste contamination in circulation spaces: Large amounts of food waste are discarded in non-organic waste bins in circulation spaces across campus (corridors, hallways, etc.) and vice versa.

(B) Waste contamination during outdoor events: Large amounts of food waste are discarded in non-organic waste bins during outdoor events on campus.

(C) Food waste in dorms: Large amounts of food ordered to dorms end up being discarded instead of being consumed or recovered.

We provided students with a digital document of resources (summaries and hyperlinks to Web pages) relevant to all three challenges and from which they could conduct desk-based research.

Participants were told they could contact the first author in case they have any questions or any issues arise. No team took advantage of this opportunity, possibly due to the Spring break which began shortly after the March 18, 2026, information session and ended shortly before the March 31, 2026, presentations session.

The competition ended with another session (remote, synchronous) on March 31, 2026, in which each team presented system diagrams of their challenge and solution, ending with individual reflection and feedback.

On April 6, 2026, following evaluation of their learning artifacts by judges (the first author and the two experts from the MIT Office of Sustainability), students were notified of the winning teams via email.

Table 2 outlines the sequence of activities during data collection as well as their associated dates, modalities, configurations, artifacts, and RQs.

Table 2. Competition participant activities and learning artifacts and related research questions.

#	Student activity	March 2026 dates	Modality	Configuration	Learning artifact	Research questions
1	Attending information session about competition and SAFO	17-18	Remote, synchronous	Class	None	-
2	Filling out and submitting informed consent form	17-18	Remote, synchronous	Individual	Output spreadsheet (responses)	-
3	Forming teams and selecting a challenge	17-19	Remote, synchronous	Team	Table of teams, participant names, and challenges	-
4	Modeling selected challenge	19-30	Asynchronous	Team	SAFO diagram of challenge[1]	RQ1; RQ2
5	Modeling proposed solution	19-30	Asynchronous	Team	SAFO diagram of solution[1]	RQ1; RQ3
6	Presenting challenge and solution models	31	Remote, synchronous	Team	Oral presentation with SAFO diagrams	-
7	Conclusion	31	Remote, synchronous	C	None	-
8	Reflection and feedback	31	Remote, synchronous	I	Responses to digital form (survey)[1]	RQ1

[1] Collected learning artifact data were analyzed for the current study.

3.5. Data analysis

Students' learning artifacts were evaluated for adherence, correctness, and viability.

3.5.1. RQ1: How well do the challenge and proposed solution descriptions adhere to SAFO?

Adherence, evaluated by the first author, pertains to how well students follow the rules of the framework, as shown by their system diagrams and system outcome descriptions. Additionally, in the reflection and feedback survey, participants were asked to rate their own understanding of how to apply SAFO.

3.5.2. RQ2: How correct are the challenge descriptions?

Correctness, evaluated by MITOS and Department of Facilities staff, pertains to the validity of teams' challenges based on their respective system diagrams and system outcome descriptions.

3.5.3. RQ3: How viable are the proposed solutions?

Viability, evaluated by MITOS and Department of Facilities staff, pertains to the applicability of teams' solutions based on their respective system diagrams and system outcome descriptions.

3.5.4. Control items in survey

Relevant items were added to the survey to ensure that results were not potentially skewed by varied levels of understanding of the competition rules, challenges with teamwork, or lack of belief in the usefulness of the SAFO framework for the task at hand.

Table 3 outlines the data collection analysis of the study across both qualitative and quantitative methods.

Table 3. Data analysis.

Collected learning artifact from each team	Learning artifact data format/s	Evaluation and analysis
System diagrams for challenge	Boxes-and-arrows diagram	Adherence: SAFO diagram rules Correctness: expert rating (up to expert and based on challenge)
System outcome description for challenge	Text	Adherence: SAFO diagram rules Correctness: expert rating (up to expert and based on challenge)
System diagram for solution	Boxes-and-arrows diagram Text	Adherence: SAFO diagram rules Viability: expert rating (up to expert and based on challenge)
System outcome description for solution	Text	Adherence: SAFO diagram rules Viability: expert rating (up to expert and based on challenge)
Additional information on challenge and solution (digital documents/slides)	Digital files	No direct analysis; provides additional context to system diagrams and system outcome descriptions
Presentation of system diagrams and system outcome descriptions by team (video recording)	Video recording	No direct analysis; provides additional context to system diagrams and system outcome descriptions
Responses to survey	Self-rating of understanding how to apply SAFO	Descriptive (no analysis)

3.5.4. Example of evaluating adherence

Team 3, which ended up winning second place in the competition, selected the following challenge:

(C) Food waste in dorms: Large amounts of food ordered to dorms end up being discarded instead of being consumed or recovered.

As Figures 1-4 show, team 3 created system diagrams and system outcome descriptions for their selected challenge and for their proposed solution.

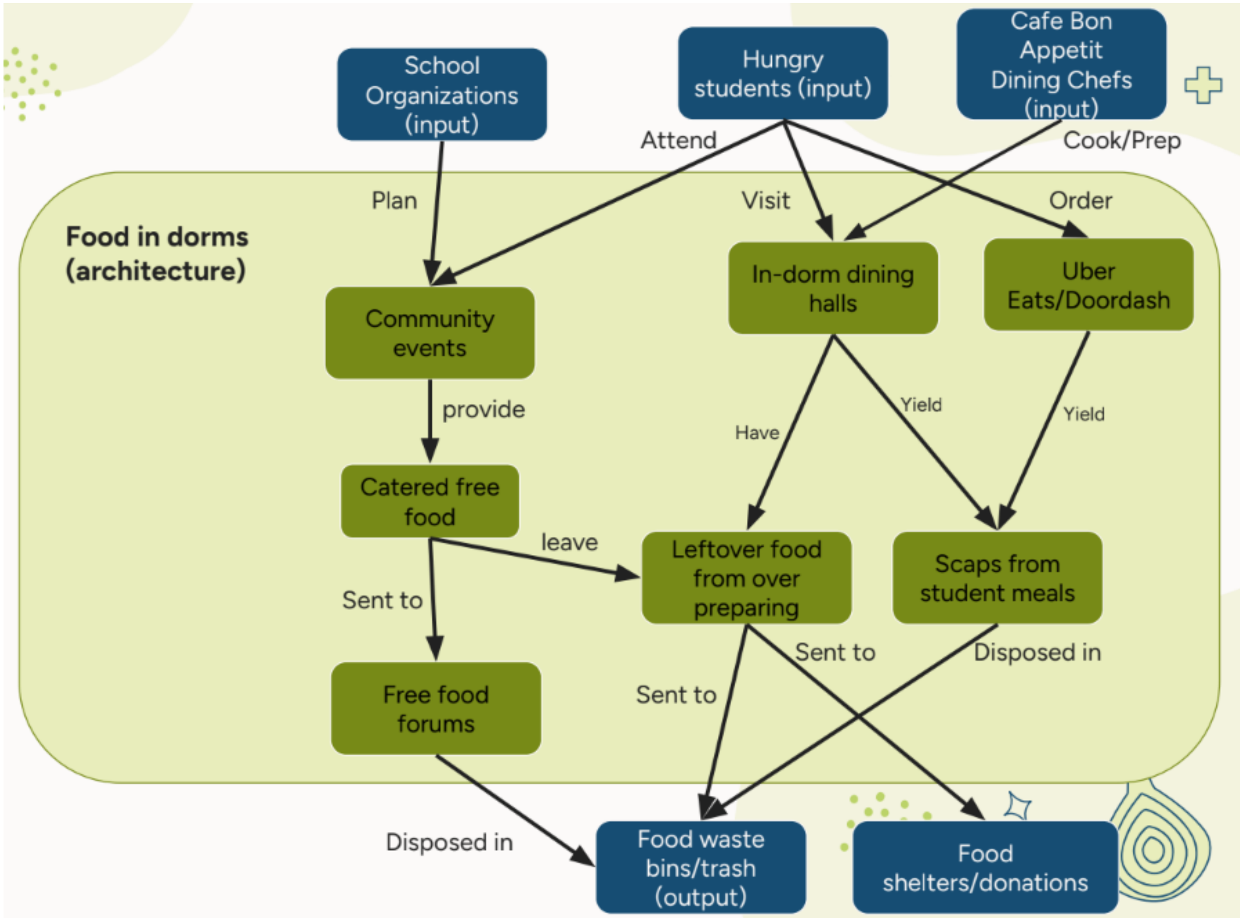

Figure 1. Team 3's system diagram for their selected challenge.

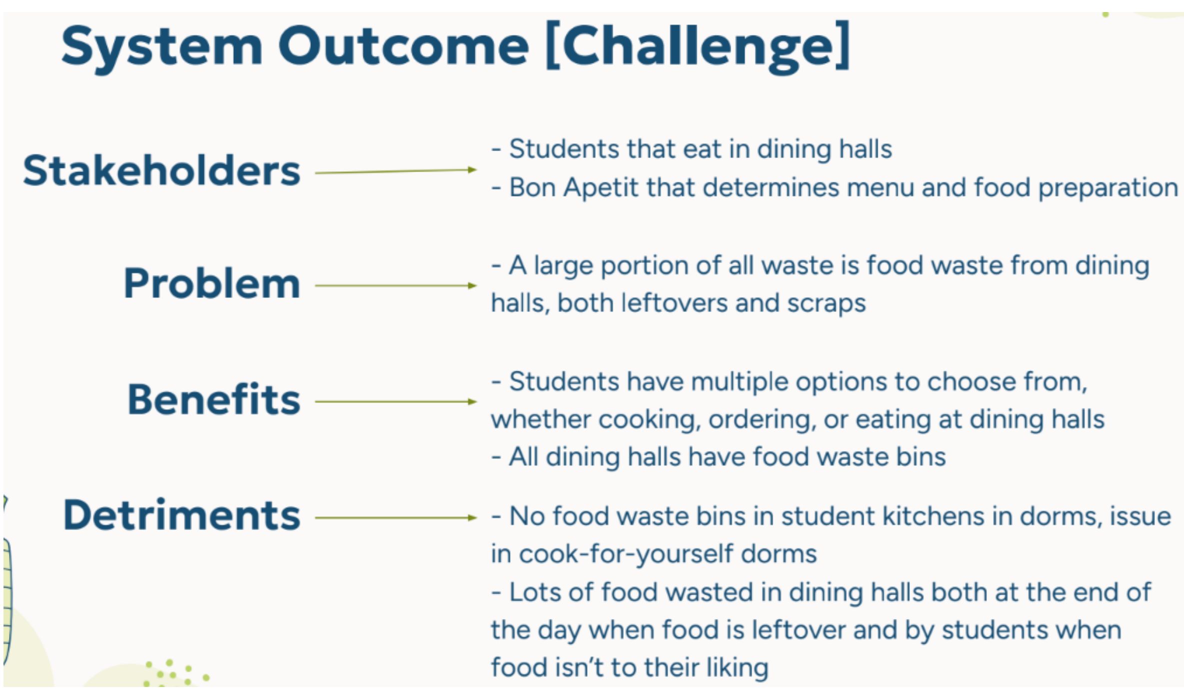

Figure 2. Team 3's system outcome description for their selected challenge.

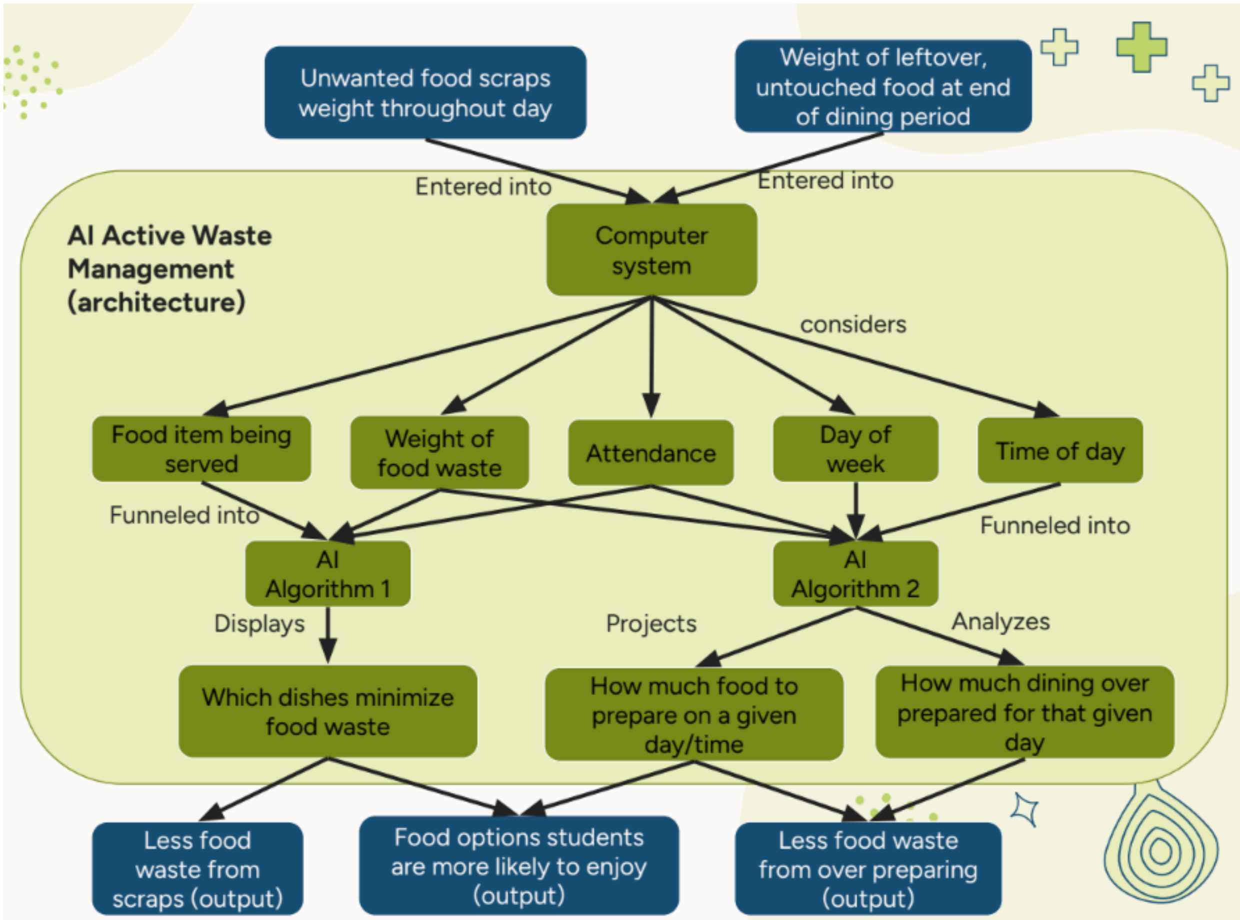

Figure 3. Team 3's system diagram for their selected challenge.

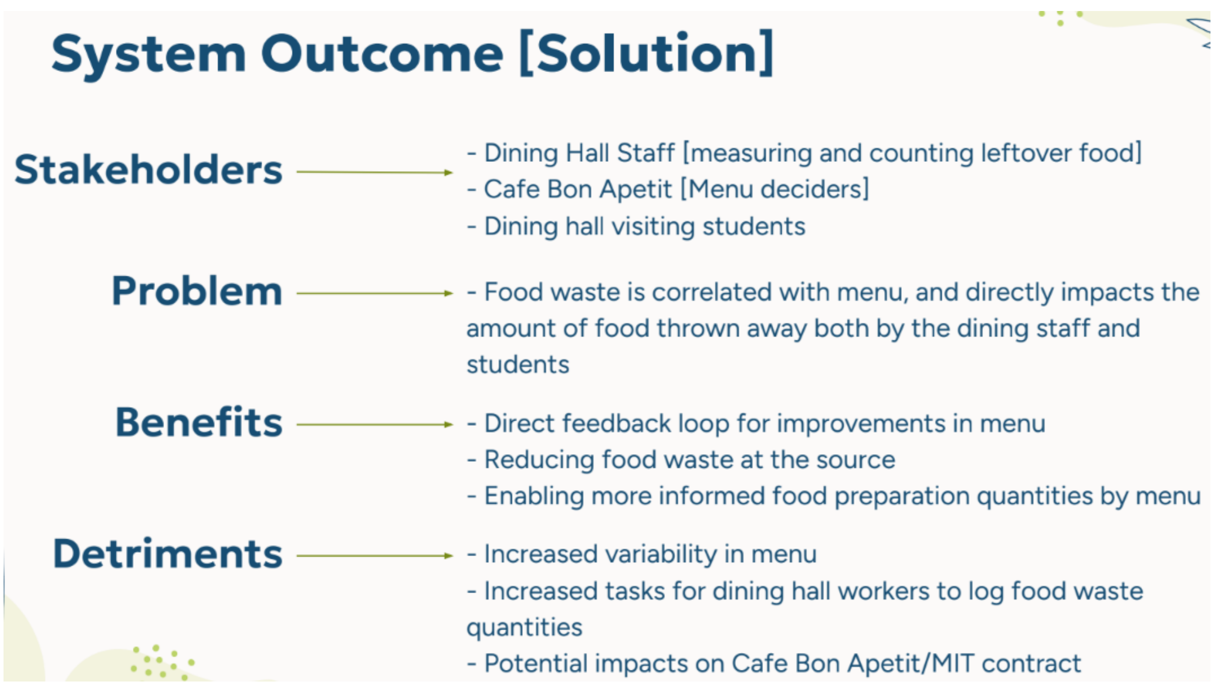

Figure 4. Team 3's system outcome description for their proposed solution.

Table 3 shows how Team 3's challenge system diagram and system outcome description were evaluated.

Table 3. Adherence evaluation for Team 3's challenge system diagram and system outcome description.

System aspect	System element	Guidelines	In team's diagram/description	Discrepancy from rules
Architecture (⅓ of overall score)	Structure	7-9 parts	7	None
	Behavior	Every part must be represented at least once; all parts must be interconnected directly or indirectly through another part	Yes	None
Function (⅓ of overall score)	Input	2-3 entities/systems interaction with specific part/s in Structure	3 entities, interacting according to guidelines	None
	Output	2-3 entities/systems interaction with specific part/s in Structure	2 entities, interacting according to guidelines	None
Outcome (⅓ of overall score)	Stakeholders	1 group of stakeholders (3-10 words)	2 groups (3-10 words each)	Two groups of stakeholders mentioned instead of one
	Problem	1 problem (3-10 words)	1 problem (3-10 words)	None
	Benefit	1-3 benefits for each output entity (3-10 words)	1-3 benefits for each output entity (3-10 words)	None
	Detriment	1-3 detriments for each output entity (3-10 words)	1-3 detriments for each output entity (3-10 words)	None

Table 4 shows how Team 3's solution system diagram and system outcome description were evaluated.

Table 4. Adherence evaluation for Team 3's solution system diagram and system outcome description.

System aspect	System element	Guidelines	In team's diagram/description	Discrepancy
Architecture (⅓ of overall score)	Structure	7-9 parts	11	11 instead of 7-9 parts
	Behavior	Every part must be represented at least once; all parts must be interconnected directly or indirectly through another part	Yes	None
Function (⅓ of overall score)	Input	2-3 entities/systems interaction with specific part/s in Structure	2 entities, interacting according to guidelines	None
	Output	2-3 entities/systems interaction with specific part/s in Structure	3 entities, interactions not specified (no text labels on arrows)	Output interactions not specified
Outcome (⅓ of overall score)	Stakeholders	1 group of stakeholders (3-10 words)	2 groups (3-10 words each)	Two groups of stakeholders mentioned instead of one
	Problem	1 problem (3-10 words)	1 problem (3-10 words)	None
	Benefit	1-3 benefits for each output entity (3-10 words)	1-3 benefits for each output entity (3-10 words)	None
	Detriment	1-3 detriments for each output entity (3-10 words)	1-3 detriments for each output entity (3-10 words)	None

4. Results

Related to RQs 1-3, Table 5 shows the total scores for each team's SAFO diagrams, for adherence, correctness, and viability.

Table 5. Team scores.

Team	**Challenge**	**Score**			
		Challenge		*Solution*	
		Adherence	Correctness[1]	Adherence	Viability[1]
1	A	2.00	3.50	4.00	3.50
2	B	5.00	3.25	5.00	3.00
3	C	5.00	3.25	3.00	3.75
4	C	5.00	3.00	4.00	3.25

[1] Mean average of two scores, from MITOS and Department of Facilities representatives. Score: 1 = lowest, 5 = highest.

Related to RQ1, table 6 shows aggregated self-rating scores for each team concerning their understanding of SAFO (item 2). The table also shows aggregate scores for the control items in the survey.

Table 6. Aggregated team responses to survey items.

Team	**Survey item aggregated team score** 1: I very much disagree; 5: I very much agree				
	1. The instructions for the competition were clear to me and my team.	*2. It was clear to me and my team how to apply the SAFO framework to describe and work through our selected challenge.*	*3. As a team, we worked well together.*	*4. I think the SAFO framework can be helpful for describing/analyzing/understanding real-world challenges.*	*5. I think the SAFO framework can be helpful for designing/prescribing solutions to real-world challenges.*
1	4, 5	All 5s	All 5s	All 5s	All 5s
2	All 5s	All 5s	3, 4, 5	All 5s	All 5s
3	All 5s	4, 5, 5	All 5s	All 5s	All 5s
4	All 5s	All 5s	All 5s	All 5s	All 5s

The results show that without exception students reported to have understood fully how to apply SAFO, and that almost without exception they all understood the competition rules fully, worked well as a team, and believed SAFO was generally useful for doing the kind of task in which they were engaged.

Select quotes for survey item 4:
"*I think the SAFO framework can be helpful for* ***describing/analyzing/understanding*** *real-world challenges."*

#1, Team 1: "100%. I think SAFO is very useful for breaking down system architecture and function to identify weak points."

#5, Team 2: "The SAFO framework takes into account most aspects of a problem which makes it easier to tackle problems. Often the difficult part of solving problems is starting your plan. The SAFO framework simplifies this process in a digestible way."

Select quotes for survey item 5:
" I think the SAFO framework can be helpful for designing/prescribing solutions to real-world challenges."

#7, Team 3: "...it was useful to visually layout those involved in the system and how they interact with the system to weigh the costs and benefits to evaluate the solution."

#10, Team 4: "SAFO also makes solutions feel more realistic since you're building them around real constraints and people's motivations. It helps me think through trade-offs early, so the ideas are actually doable and not just idealistic."

5. Discussion

5.1. Key findings and previous literature

The objective of this study is to evaluate the effectiveness of applying SAFO in a collaborative problem-solving setting with undergraduate students from different engineering disciplines.

Overall, given the results of the study, there is indication that SAFO can be used effectively by cross-disciplinary teams of students, when applied to a real-world problem.

The study results relate to each RQ as follows.

5.1.1. RQ1: How well do the challenge and proposed solution descriptions adhere to SAFO?

As Table 5 shows, only one submission by one team received an adherence score which is below moderate, i.e., below 3 out of 5; that was Team 1, for their challenge. Other submissions by any team received mostly 5s, with two 4s and one 3. This result points to an overall high level of adherence with the SAFO framework.

Additionally, nearly all the participants responded with a 5 ("I very much agree") to survey item 2, and only one participant responded with a 4: "It was clear to me and my team how to apply the SAFO framework to describe and work through our selected challenge". This is further indication that participants understood how to apply SAFO to their selected challenges and proposed solutions.

In conclusion, overall, the challenge and proposed solution descriptions adhered to the SAFO framework. Interestingly, the two teams whose submissions showed the strongest adherence, descriptively, both comprised third-year students exclusively and had three members each, whereas the two teams whose submissions showed the weakest adherence both comprised first-year students exclusively and had two members each.

5.1.2. RQ2: How correct are the challenge descriptions?

As Table 5 shows, every submission scored 3.00 to 3.50 (moderate) for correctness. This shows that participants were able to come up with at least somewhat viable solutions, with support from the sources provided for them.

However, this result also shows that, according to the subject matter experts (representatives from MITOS and Department of Facilities representatives, none of the teams came up with a highly viable solution.

5.1.3 RQ3: How viable are the proposed solutions?

As Table 5 shows, every submission scored 3 to 3.75 (moderate) for viability. This shows that participants were able to understand the challenge they had selected, with support from the sources provided for them.

However, this result also shows that, according to the subject matter experts (representatives from MITOS and Department of Facilities representatives, none of the teams had a good understanding of the challenge, only moderate.

5.2. Limitations and future work

The small sample (N = 10) did not allow for inferential statistics. Future studies will expand the sample to 30 participants or more so that inferential statistical testing can be conducted for inter-team differences in adherence, correctness, and viability. We would like to evaluate whether year of study, major, or number of students on a team can affect these criteria.

To further strengthen adherence of challenge and solution descriptions to the SAFO framework, individual participants could receive a short assignment where they apply SAFO to a simple, existing system, with a given source of information such as a Wikipedia article. An example for such an assignment is presented in [23].

The first author is currently developing a GPT (a dedicated chatbot inside ChatGPT) to automate feedback for SAFO adherence. This chatbot can be evaluated in future with a similar scenario to that of the current study and would allow participants and instructors to focus on correctness and viability.

Correctness of challenge descriptions and viability of solution descriptions could potentially be improved by providing participants with feedback throughout the process. Future studies could include a mandatory check-in session with each team, halfway through the work period.

Both adherence and correctness could have been assessed with more rigor, based on existing rubrics for both [11]. However, given that formative assessment (mid-work feedback) was not an option, and submissions were only assessed at the end, these detailed rubrics were not used. Also, the correctness raters would not have been available to apply these rubrics as the process is quite time-consuming. Future studies could include a formal feedback step halfway through the work, where teams would receive formative assessments for adherence to their challenge and solution descriptions, and of the correctness of their challenge descriptions.

The assessment of correctness and viability were done by the representatives from the MITOS and Department of Facilities representatives. In future, the evaluation of correctness and viability could be refined further.

As has been shown in literature [5-8], future studies could also evaluate whether the kind of cross-disciplinary activity described in the present paper could improve undergraduate engineering students' cross-domain skills such as creativity or teamwork, as well as of course their systems thinking.

5.3. Study contributions

The present study makes practical contributions to the field of inquiry. First, it provides SAFO, a workable model for applying a pedagogical framework for teaching introductory systems thinking to real-world challenges and to a cross-disciplinary learning setting in undergraduate engineering education. The study presents a way of engaging students with real-world challenges concerning their own familiar environment while also teaching them systems thinking and allowing for assessment of adherence to the SAFO framework, the correctness of their challenge descriptions, and the viability of their proposed solutions, all using the same framework, which allows for easy comparisons between submissions.

6. Conclusion

Today's workforce and society at large require systems thinkers and engineers who can collaborate across disciplines. However, approaches for giving undergraduate engineering students opportunities to practice these skills are often not cost-effective, or too complex, or not planned for. The SAFO framework and the approach detailed in the present paper show a way for instructors to help students acquire these skills without an enormous investment of time or money in system modeling software. Using systems thinking and engaging in cross-disciplinary work should not and does not have to wait for after one's undergraduate studies are completed; as shown in the present study, it can start in the first year of studies itself.

References

[1] National Academy of Engineering. (2004). The engineer of 2020: Visions of engineering in the new century. National Academies Press.
[2] ABET. (2025). Criteria for accrediting engineering programs, 2025–2026. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2025-2026/
[3] Van den Beemt, A., MacLeod, M., Van der Veen, J., Van de Ven, A., Van Baalen, S., Klaassen, R., & Boon, M. (2020). Interdisciplinary engineering education: A review of vision, teaching, and support. Journal of Engineering Education, 109(3), 508–555.
[4] Chen, J., Kolmos, A., & Du, X. (2021). Forms of implementation and challenges of PBL in engineering education: A review of literature. European Journal of Engineering Education, 46(1), 90–115.
[5] Chang, T.-S., Wang, H.-C., MacDonald Haynes, A., Song, M.-M., Lai, S.-Y., & Hsieh, S.-H. (2022). Enhancing student creativity through an interdisciplinary, project-oriented problem-based learning undergraduate curriculum. Thinking Skills and Creativity, 46, 101173.
[6] Costa, A. R., Ferreira, M., Barata, A., Viterbo, C., Salgado Rodrigues, J., & Magalhães, J. (2019). Impact of interdisciplinary learning on the development of engineering students' skills. European Journal of Engineering Education, 44(4), 589–601.
[7] Lattuca, L. R., Knight, D. B., Kyoung Ro, H., & Novoselich, B. J. (2017). Supporting the development of engineers' interdisciplinary competence. Journal of Engineering Education, 106(1), 71–97.
[8] Jacobson, M. J., & Wilensky, U. (2006). Complex systems in education: Scientific and educational importance and implications for the learning sciences. Journal of the Learning Sciences, 15(1), 11–34.
[9] York, S., Lavi, R., Dori, Y. J., & Orgill, M. (2019). Applications of systems thinking in STEM education. Journal of Chemical Education, 96(12), 2742–2751.
[10] National Research Council. (2013). Education for life and work: Developing transferable knowledge and skills in the 21st century. National Academies Press.
[11] Lavi, R., & Bertel, L. B. (2024). The system architecture–function–outcome framework for fostering and assessing systems thinking in first-year STEM education and its potential applications in case-based learning. Education Sciences, 14(7), 720.
[12] Lavi, R., Breslow, L., Salek, M. M., & Crawley, E. F. (2023). Fostering and assessing the systems thinking of first-year engineering students using the system architecture–function–purpose framework. International Journal of Engineering Education, 39(1), 176–188.
[13] Bertel, L. B., Lavi, R., Rathcke, K., Coelho, N. F., & Dyremose, S. C. S. (2025). Towards a framework for assessing systems thinking in collaborative problem-solving in STEM. In Proceedings of the 132nd ASEE Annual Conference. https://peer.asee.org/57702.pdf
[14] Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. In Proceedings of the National Academy of Sciences, 111(23), 8410–8415.
[15] Prince, M. (2004). Does active learning work? A review of the research. Journal of Engineering Education, 93(3), 223–231.

[16] Hernández-de-Menéndez, M., Vallejo Guevara, A., Tudón Martínez, J. C., Hernández Alcántara, D., & Morales-Menendez, R. (2019). Active learning in engineering education: A review of fundamentals, best practices and experiences. International Journal on Interactive Design and Manufacturing, 13(3), 909–922.
[17] Hung, W., Jonassen, D. H., & Liu, R. (2008). Problem-based learning. In J. M. Spector, M. D. Merrill, J. van Merriënboer, & M. P. Driscoll (Eds.), Handbook of research on educational communications and technology (pp. 485–506). Routledge.
[18] Allchin, D. (2013). Problem- and case-based learning in science: An introduction to distinctions, values, and outcomes. CBE—Life Sciences Education, 12(3), 364–372.
[19] Chen, J., Kolmos, A., & Du, X. (2021). Forms of implementation and challenges of PBL in engineering education: A review of literature. European Journal of Engineering Education, 46(1), 90–115.
[20] Kulak, V., & Newton, G. (2014). A guide to using case-based learning in biochemistry education. Biochemistry and Molecular Biology Education, 42(6), 457–473.
[21] Dori, D., Sillitto, H., Griego, R. M., McKinney, D., Arnold, E. P., Godfrey, P., Martin, J., Jackson, S., & Krob, D. (2019). System definition, system worldviews, and systemness characteristics. IEEE Systems Journal, 14(2), 1538–1548.
[22] Luo, Y., Becker, K., Gero, J., Villanueva Alarcon, I., & Lawanto, O. (2021). Systems thinking in engineering design: Differences in expert vs. novice. International Journal of Engineering Education, 37(5), 1398–1413.
[23] Lavi, R., Dori, Y. J., Wengrowicz, N., & Dori, D. (2019). Model-based systems thinking: Assessing engineering student teams. IEEE Transactions on Education, 63(1), 39-47.
[24] Crawley, E. F., Hosoi, A., & Mitra, A. (2018). Redesigning undergraduate engineering education at MIT: The New Engineering Education Transformation (NEET) initiative. In Proceedings of the 125th ASEE Annual Conference. https://peer.asee.org/30923
[25] Crawley, E. F., Hosoi, A., Long, G. L., Kassis, T., Dickson, W., & Mitra, A. (2019). Moving forward with the New Engineering Education Transformation (NEET) program at MIT. In Proceedings of the 126th ASEE Annual Conference. https://peer.asee.org/33124
[26] Lavi, R., Bathe, M., Hosoi, A., Mitra, A., & Crawley, E. F. (2021). The NEET ways of thinking: Implementing them at MIT and assessing their efficacy. Advances in Engineering Education, 9(3), 1–19.
[27] Lavi, R., Lavallee, J., Long, G. L., Melenbrink, N., Salek, M. M., Shepardson, R., & Mitra, A. (2022). Revising the requirements of the cross-departmental project-centric undergraduate engineering NEET program at MIT and launching the new climate & sustainability systems thread. In Proceedings of the 129th ASEE Annual Conference. https://peer.asee.org/41549.pdf
[28] Lavi, R., & Bagiati, K. (2022). The New Engineering Education Transformation program at MIT: The evolving design and implementation of a programmatic evaluation study. In B. Moser, P. Koomsap, & J. Stjepandic (Eds.), Transdisciplinarity and the future of engineering (pp. 658–667). IOS Press.
[29] Mitra, A., & Long, G. L. (2025). How Aurora Flight Sciences and MIT's NEET program are working together to develop and implement industry-oriented projects. In L. Glover (Ed.), Innovation alchemy (pp. 20–27). Wiley.
[30] Lavi, R., Long, G., Salek, M. M., Mitra, A., & McCullough, S. (2025). Analyzing the impact of two co-curricular undergraduate experiential learning programs on STEM students' career readiness. In Proceedings of the 132nd ASEE Annual Conference. https://peer.asee.org/55440

[31] Creswell, J. W., & Creswell, J. D. (2017). Research design: Qualitative, quantitative, and mixed methods approaches. Sage.