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Assessing Learning and Self-Efficacy in Online Modules on Systems Thinking and Systems Engineering

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Assessing Learning and Self-Efficacy in Online Modules on Systems Thinking and Systems Engineering

As today's products increasingly merge elements of mechanics, electronics, and computation, engineers from conventional disciplines must increasingly use elements of systems thinking / systems engineering (ST/SE) to analyze these complex systems[1,2]. There is a corresponding push among engineering educators to inject ST / SE concepts throughout undergraduate curricula[3–6]. Various approaches have been reported in the literature, from single dedicated classes[1,7–14] to modifications to existing classes[7,12,14–24]. These efforts have also extended into high school[25] and technology[26] curricula. In parallel with this curriculum work is a growing body of work on ST / SE skills assessment[27–32]. Together, these streams promise to educate innovative, "flexible thinkers" capable of designing tomorrow's complex products[6,33,34].

Curriculum-wide efforts to infuse ST / SE concepts are difficult. One challenge is that many engineering faculty do not have a strong background in ST / SE fundamentals. These instructors may feel uncomfortable developing, delivering, and assessing ST / SE content in their courses. A second difficulty is that, similar to design and ethics education, multiple coordinated interventions across the curriculum provide better learning than a single standalone experience. Such curriculum-wide coordination requires the approval of a broad swath of faculty and administrators. This paper discusses the use of online learning modules to introduce ST / SE concepts, thus allowing content developed by ST / SE specialists to be delivered in classes taught by non-experts. These modules can also be deployed in multiple classes throughout the curriculum to create a cohesive learning environment. As a final benefit, to the extent that the online modules replace material currently covered in-class, they create a flipped classroom environment that facilitates active learning activities[24,35].

The online learning modules discussed in this paper were developed in the Open Learning Intiative (OLI) platform developed at Carnegie Mellon University[36]. The OLI environment was chosen due to its compatibility with a wide variety of learning management systems and its ability to seamlessly manage embedded assessments[37–40]. Figure 1 shows an example image from one of the OLI modules discussed in this paper.

This paper assesses the effectiveness of teaching ST / SE concepts in a first-year mechanical engineering course via OLI modules[23]. Data are presented from three partner institutions, including a small private institution (Carnegie Mellon University), a small public technical university (South Dakota School of Mines and Technology), and a large public university (Texas State University). The paper is organized as follows. Firstly, the introductory mechanical engineering courses at the three collaborating institutions are described, followed by a discussion

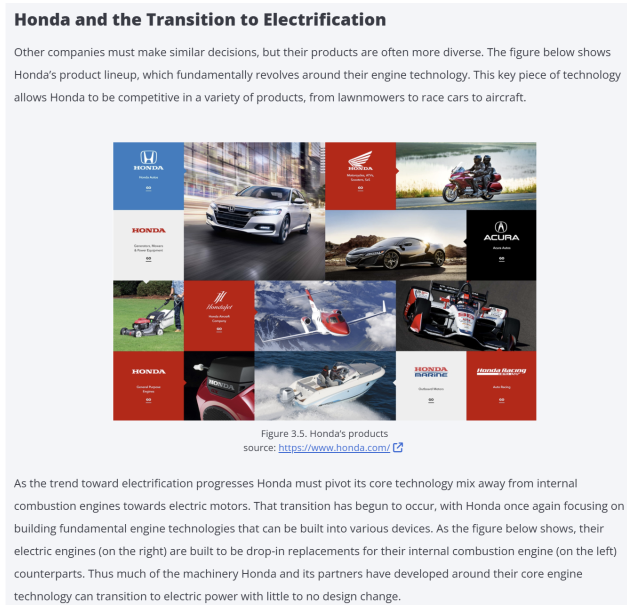

Figure 1: Snapshot of OLI content. OLI content can include a mixture of text, images, audio, and video.

of the OLI module structure and learning outcomes. The various data sources used to assess student self-efficacy, ST / SE knowledge, and module satisfaction are then considered. After discussing the assessment instruments, the key findings are presented. Finally, conclusions are summarized and avenues for future work are suggested.

Fundamentals Classes and OLI Structure

Curriculum design for first year students has a strong impact on students' experiences[41], and there are several models for first-year engineering courses in common use. These range from unified engineering design courses for all incoming engineering students to discipline-specific courses[42]. The introductory engineering courses covered in this paper use the latter model, specifically in the field of mechanical engineering. All three courses cover a broad overview of the main subject areas covered in the remainder of the mechanical engineering curriculum (e.g., solid mechanics, hydrostatics) and provide an introduction to the engineering design process[23]. The OLI modules described in this work were developed to replace the in-class discussion of the design process. This replacement frees up roughly 3 50-minute class sessions to use for hands-on design activities[24].

The OLI content is arranged into two main units, each consisting of several smaller modules as shown in Figure 2[23]. The first unit is dedicated to describing the conventional product development process as described in Ulrich and Eppinger[43], whereas the second unit is used to introduce fundamental ST / SE concepts. Most modules include formative assessment questions to improve student learning, and each unit concludes with a summative assessment. An example formative assessment question is shown in Figure 3. The product development unit consists of nine modules, while the ST / SE unit features six modules. In total, it is expected that students

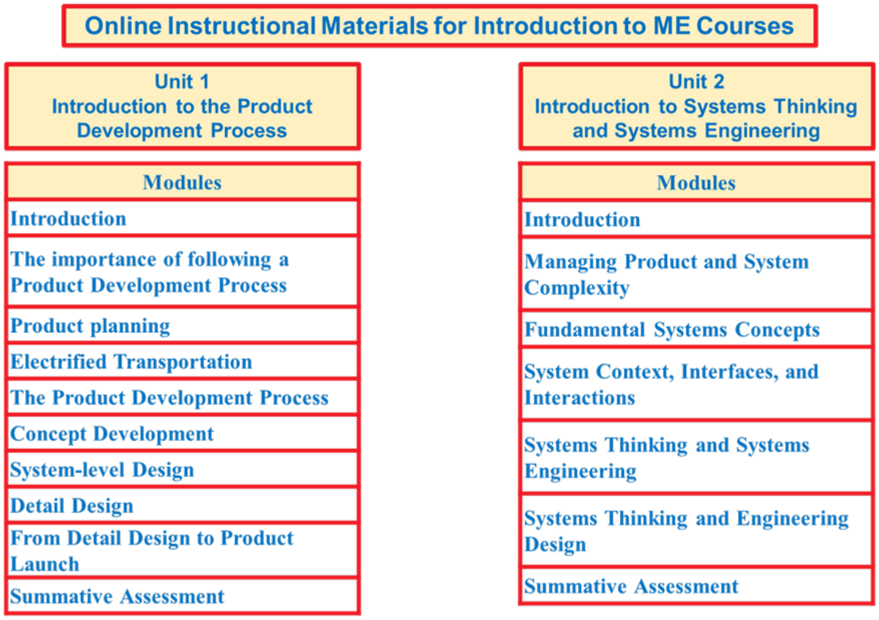

Figure 2: Structure of OLI modules. The first unit focuses on a conventional development of the product development process, while the second unit emphasizes ST / SE concepts.

will spend 3 - 6 hours on their own to complete all OLI content.

At all three universities students completed the OLI modules as part of their homework. At Carnegie Mellon University (CMU) and South Dakota School of Mines and Technology (SDM), the OLI modules *replaced* the in-class coverage of the engineering design process, whereas at Texas State University (TSU) the OLI modules *augmented* the traditional in-class presentations. The OLI modules were delivered in October 2024 at SDM and TSU and in November 2024 at CMU. In the Fall 2024 semester 147 students at CMU, 166 students at SDM, and 94 students at TSU completed the OLI modules, for a total of 407 students.

Assessment Approaches

The effectiveness of the OLI modules is assessed using two data sources. The first source is a survey administered at the beginning and end of the course. This survey[44] measures both students' self-efficacy in ST / SE concepts[15] and students' sense of belonging as engineers[45]. When responding to the self-efficacy items, students select their perception of their ability to apply each learning outcome (5-point Likert scale). For the belongingness scale, students used a 7-point Likert scale to indicate the degree to which the items resonated with their experience. For this survey, control data from the conventional content delivery are available from the Fall 2023 semester. These data are used below to determine whether the move from in-person to online coverage of design and ST / SE concepts had a significant effect on students' senses of self-efficacy and belonging.

The OLI environment provides the second data source, which itself consists of objective student performance data and subjective student feedback. Student performance data consists of the

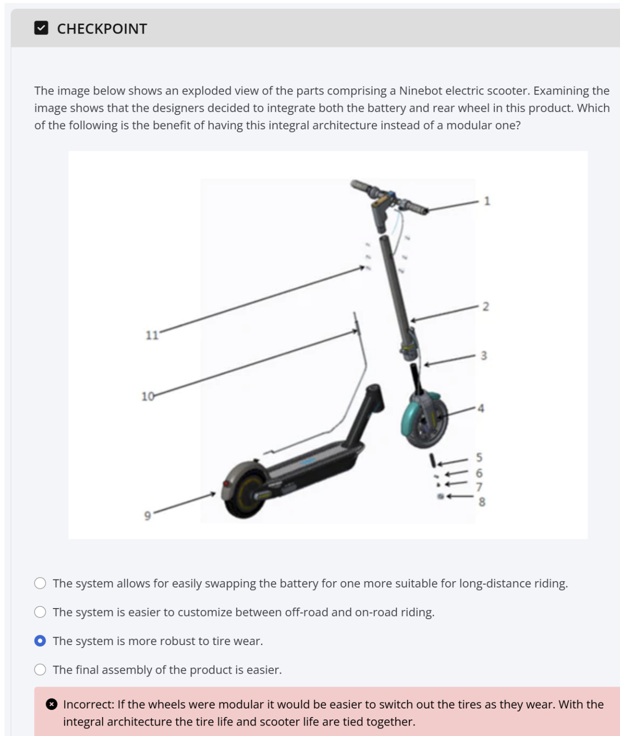

Figure 3: Example OLI formative assessment question. Custom feedback is given to students after each attempt, and students have unlimited attempts to correctly answer.

completion percentage, measured by the percentage of OLI content with which the student interacted, and summative assessment scores for each unit. These performance data are available at the individual student level, and thus can easily be correlated with the pre-post surveys discussed above. Students at SDM and TSU had five attempts to complete the summative assessments, while students at CMU had only a single attempt. Because formative feedback was provided even for the summative assessment questions, the scores for students at SDM and TSU are artificially inflated for summative assessment results. Thus only summative assessments at CMU are used below in analysis.

Student feedback data are collected at both the module and unit levels within the OLI. At the module level students are asked to rate the module clarity and engagement on a 5-point Likert-like scale. At the unit level students are asked to identify the muddiest points in an open-ended question and also asked to rate their self-efficacy on the unit's learning outcomes. While it is possible to extract identifiable information from these student feedback data, in this paper the student feedback is analyzed in the aggregate across all three partner institutions. This paper focuses on the student satisfaction data and muddiest points; unit-level self-efficacy analysis will be a topic for future work.

Results and Discussion

In examining the fall 2024 data from all three institutions, there was a statistically significant increase between students' pre self-efficacy (M = 2.89, SD = 0.85) to post self-efficacy scores of

Table 1: Self efficacy changes in ST / SE skills for first-year courses across institutions. Students shows a significant increase in self-efficacy, with no significant differences between institutions.

	Self-Efficacy Mean (SD)			
	N	**Pre**	**Post**	***p***
CMU	97	2.90 (0.81)	3.83 (0.72)	<0.001
SDM	24	2.97 (0.71)	3.68 (0.52)	<0.001
TSU	116	2.87 (0.91)	3.69 (0.76)	<0.001
Overall	237	2.89 (0.85)	3.75 (0.72)	<0.001

Table 2: Sense of belonging changes for first-year courses across institutions. Students at two of the three institutions show a statistically significant increases in sense of belonging.

	Sense of Belonging Mean (SD)			
	N	**Pre**	**Post**	***p***
CMU	97	4.71 (0.72)	5.19 (0.73)	<0.001
SDM	24	4.91 (0.64)	5.10 (0.75)	0.11
TSU	116	4.77 (0.82)	5.01 (0.85)	<0.001
Overall	237	4.76 (0.77)	5.09 (0.80)	<0.001

(M=3.75, SD=0.72) as seen in Table 1. A paired-samples t-test indicated that this difference of 0.85 was statistically significant, 95%CI [-0.97, -0.74], t(236)=-14.39, p<.001, *d*=0.93. As indicated in Table 1, this significant difference was present at each of the institutions. However, there was no significant difference between institutions when it came to this self-efficacy improvement, despite differences in the way that materials were presented in class. CMU and SDM performed hands-on activities in class[24], whereas TSU used class time for conventional coverage of ST / SE concepts.

Similarly, for the sense of belonging measure there was a statistically significant increase from the pre (M = 4.76, SD = 0.77) to post scores (M=5.09, SD=0.80) A paired-samples t-test highlighted that the 0.33 difference was statistically significant, 95%CI [-0.42, -0.24], t(236)=-7.26, p<.001, *d*=0.46. Two of the three institutions also had statistically significant increases in students' reported sense of belonging (Table 2).

Using the fall 2023 scores as a control, a three-way mixed ANOVA was performed. Findings indicate that there was not at statistically significant interaction between time (pre-survey to post-survey), semester, and institution, for either the self-efficacy measure F(2, 337) = 0.17 or sense of belonging measure, F(2, 337) = 0.17. The absence of two-way interactions indicate that while there is a difference from pre-scores to post-scores, that increase does not vary significantly between institution types or across semesters. This implies that the move from in-class to OLI coverage of the ST / SE contents did not have a substantial impact on the students' perceived effectiveness.

There was a large positive correlation between CMU students' OLI progress and their average

Table 3: Student feedback on clarity and engagement of each module on a scale from 0 (lowest) to 4 (highest). The module on Detail Design scored the lowest in both categories; further detail on the Detail Design scoring is shown in Figure 5.

Unit	Module Content	Clarity	Engagement
Product Development Process	Importance of Process	2.74	2.44
	Product Planning	2.63	2.42
	Electrified Transportation	2.76	2.55
	Product Development Process	2.68	2.43
	Concept Development	2.64	2.41
	System-level Design	2.70	2.49
	Detail Design	2.02	2.17
	Product Launch	2.75	2.58
Intro to ST / SE	Managing Complexity	2.68	2.79
	Fundamental Concepts	2.45	2.57
	Context, Interfaces, and Interactions	2.50	2.64
	ST & SE	2.55	2.61
	ST and Design	2.57	2.60
	Average Across Modules	2.59	2.52

OLI assessment scores. $r = 0.64$, $p<0.001$, $N = 95$, 95% CI [.50, .74]. This indicates that students' pre-existing knowledge is insufficient to answer the assessment questions, i.e., that the OLI content is making a measurable difference in student ST / SE knowledge. However, there was no correlation between the students' performance on OLI summative assessment questions and their reported self-efficacy. Note that SDM and TSU are excluded from this analysis because their students had multiple attempts at each assessment question.

The other relevant dimension from a content developer standpoint is student engagement with the OLI content. As described above, students were asked to rate each module on both clarity of content and engagement with the OLI design. Table 3 shows the average student responses on a five-point scale from zero (lowest score) to four. The data show that on average both clarity and engagement scores are above 2.5, with the engagement mean slightly below the clarity mean. One concern that the research team had was a decrease in engagement / clarity scores as students progress through the units due to fatigue, but no such effect is evident in the Table 3 data.

Most modules have a response distribution similar to the example shown in Figure 4, which provides results for the Importance of Process module. While relatively few students "strongly agree" that the module was clear and engaging, fewer students strongly disagree. The one module that does not follow this general trend is the module on Detail Design, with results shown in Figure 5. While "agree" is still the mode for both clarity and engagement, a significant number of students either disagreed or strongly disagreed that the Detail Design module was clear and engaging. This makes the Detail Design module a clear candidate for revision.

While numerical scores are useful for gauging overall student satisfaction and looking for

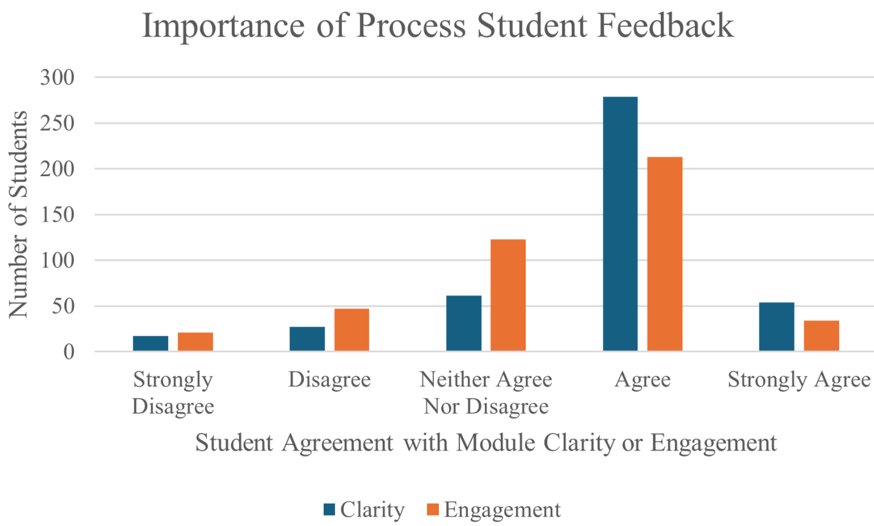

Figure 4: Distribution of student feedback for the Importance of Process module. Students generally found the module both clear and engaging.

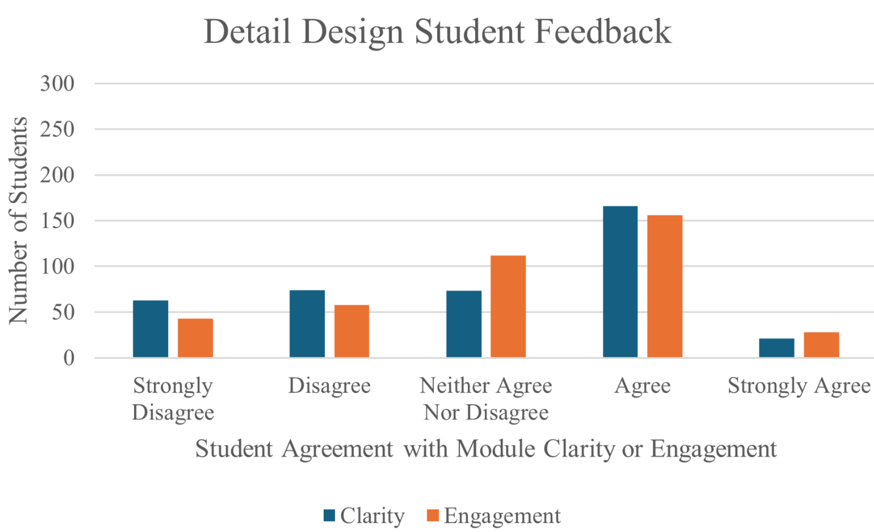

Figure 5: Distribution of student feedback for the Detail Design module. A significant number of students did not find this module to be clear and engaging, and thus this module is a prime target for revision.

Table 4: Summary of student written feedback on muddiest points. Students are interested in real-world applications of the OLI content.

Unit	Muddiest Points
Product Development Process	Confusion on specific elements, e.g., detail design How the entire process works for a real-world system PDP effects on team composition and management Durations of each portion of the PDP Role of analysis in the PDP Variations to the PDP (e.g., Agile)
Intro to ST / SE	Subsystem decomposition and prioritization Systems thinking applications in engineering and life Team dynamics and corporate management Stakeholder management Lifecyle and end of life decisions

modules most in need of improvement (e.g., Detail Design), student's responses to open ended muddiest points prompts are useful to determine specific directions for improvement. Raw student feedback responses were passed into Google's Gemini AI for summarization[46], with the results validated by the authors to eliminate potential hallucinations. The feedback are summarized in Table 4, which shows that students are generally interested in making more connections between the OLI content and their real-world experiences as engineers. The thoughtfulness of the questions both gives the research team clear areas for improvement and shows that students are interested in engaging with ST / SE material.

Conclusions and Future Work

This paper has described the effectiveness of replacing in-class coverage of the product development and ST / SE fundamentals with online learning modules in introductory mechanical engineering courses. This partial flipping of course content relieves the need for instructors to have expertise in ST / SE concepts and opens up class time for active learning activities. Module effectiveness was gauged through students' perceptions of self-efficacy, belonging, and module quality along with quantitative results from summative assessments.

Assessment results show no effects on student self-efficacy in ST / SE concepts when moving learning materials from in-class to the OLI environment. In both cases, students show significant improvements in ST / SE self-efficacy and sense of belonging as engineers after taking the first-year mechanical engineering courses. Student satisfaction data show that most students find the modules to be clear and engaging.

Future work will correlate results from OLI performance with in-class activity data and end-of-unit self-efficacy data. More broadly, it will extend the approach to further courses in the mechanical engineering curriculum, starting with capstone design classes. Ultimately, the goal is to develop learning materials and activities appropriate for design classes for each year of the undergraduate curriculum.

Acknowledgements

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References

[1] C. Rehmann, D. Rover, M. Laingen, S. Mickelson, and T. Brumm, "Introducing systems thinking to the engineer of 2020," in *ASEE Annual Conference and Exposition*, 2011.

[2] J. E. Kasser, P. John, K. Tipping, and L. W. Yeoh, "Systems engineering a 21st century introductory course on systems engineering: the seraswati project," in *Asia Pacific Conference on Systems Engineering*, 2008.

[3] J. Monat, T. Gannon, and M. Amissah, "The case for systems thinking in undergraduate engineering education," *International Journal of Engineering Pedagogy (iJEP)*, vol. 12, no. 3, pp. 50–88, 2022.

[4] R. Khan, C. Whitcomb, and C. White, "Self-efficacy analysis of student learning in systems engineering," in *ASME International Mechanical Engineering Congress and Exposition*, vol. 50571. American Society of Mechanical Engineers, 2016, p. V005T06A043.

[5] R. E. Thomassie, "Systems engineering competencies essential for mechanical engineering graduates," Ph.D. dissertation, 2019.

[6] A. Azemi, "Benefits of teaching systems thinking as part of an engineering curriculum," in *2019 IEEE Frontiers in Education Conference (FIE)*. IEEE, 2019, pp. 1–6.

[7] C. Cattano, T. Nikou, and L. Klotz, "Teaching systems thinking and biomimicry to civil engineering students," *Journal of Professional Issues in Engineering Education & Practice*, vol. 137, no. 4, pp. 176–182, 2011.

[8] I. G. Guardiola, C. Dagli, and S. Corns, "Using university-funded research projects to teach system design processes and tools," *IEEE Transactions on Education*, vol. 56, no. 4, pp. 377–384, 2013.

[9] R. Jain, K. Sheppard, E. McGrath, and B. Gallois, "Promoting systems thinking in engineering and preengineering students," in *2009 Annual Conference & Exposition*, 2009, pp. 14–994.

[10] R. Lesh, "Modeling students modeling abilities: The teaching and learning of complex systems in education," *The Journal of the Learning Sciences*, vol. 15, no. 1, pp. 45–52, 2006.

[11] J. P. Monat and T. F. Gannon, "Applying systems thinking to engineering and design," *Systems*, vol. 6, no. 3, p. 34, 2018.

[12] M. Simoni, E. Andrijcic, B. Kline, and A. Bernal, "Helping undergraduate students of any engineering discipline develop a systems perspective," in *INCOSE International Symposium*, vol. 26, no. 1. Wiley Online Library, 2016, pp. 495–511.

[13] M. Valenti, "Teaching tomorrow's engineers," *Mechanical Engineering*, vol. 118, no. 7, p. 64, 1996.

[14] M. K. Yurtseven, “Teaching systems thinking to industrial engineering students.” in *ICSTM*, 2000.

[15] C. M. Birrenkott, K. H. Muci-Kuchler, M. D. Bedillion, M. Lovett, and L. O. Pottmeyer, “Evaluation of targeted systems thinking and systems engineering assessments in a freshmen-level mechanical engineering course,” in *2021 ASEE Virtual Annual Conference Content Access*, 2021.

[16] K. H. Muci-Kuchler, C. M. Birrenkott, M. D. Bedillion, M. Lovett, and C. Whitcomb, “Incorporating systems thinking and systems engineering concepts in a freshman-level mechanical engineering course,” in *2020 ASEE Virtual Annual Conference Content Access*, 2020.

[17] K. H. Muci-Kuchler, C. M. Degen, M. D. Bedillion, and M. Lovett, “Extending systems thinking skills to an introductory mechanical engineering course,” in *2019 ASEE Annual Conference & Exposition*, 2019.

[18] C. M. Degen, K. H. Muci-Küchler, M. D. Bedillion, S. Huang, and M. Ellingsen, “Measuring the impact of a new mechanical engineering sophomore design course on students’ systems thinking skills,” in *ASME International Mechanical Engineering Congress and Exposition*, vol. 52064. American Society of Mechanical Engineers, 2018, p. V005T07A050.

[19] K. H. Muci-Kuchler, M. D. Bedillion, S. Huang, C. M. Birrenkott, M. D. Ellingsen, W. M. Nikshi, and J. Ziadat, “Incorporating basic systems thinking and systems engineering concepts in a mechanical engineering sophomore design course,” in *2017 ASEE Annual Conference & Exposition*, 2017.

[20] K. H. Muci-Küchler, M. D. Bedillion, C. M. Degen, M. D. Ellingsen, and S. Huang, “Incorporating basic systems thinking and systems engineering concepts in a sophomore-level product design and development course,” in *ASME International Mechanical Engineering Congress and Exposition*, vol. 50571. American Society of Mechanical Engineers, 2016, p. V005T06A040.

[21] J. Ziadat, M. D. Ellingsen, K. H. Muci-Küchler, S. Huang, and C. M. Degen, “Using practical examples to motivate the study of product development and systems engineering topics,” in *ASME International Mechanical Engineering Congress and Exposition*, vol. 50571. American Society of Mechanical Engineers, 2016, p. V005T06A042.

[22] M. D. Bedillion, M. Lovett, K. H. Muci-Kuchler, and C. M. Degen, “Teaching systems thinking in a capstone mechatronic design course,” in *2019 ASEE Annual Conference & Exposition*, 2019.

[23] M. Bedillion, K. H. Muci-Küchler, A. Emami, L. Kojtek, L. Pottmeyer, and C. M. Birrenkott, “Developing online learning modules on systems concepts for first year mechanical engineering students,” in *ASME International Mechanical Engineering Congress and Exposition*. American Society of Mechanical Engineers, 2024.

[24] C. M. Birrenkott, M. Lande, H. Benes, K. H. Muci-Küchler, and M. Bedillion, “Developing hands-on class activities to enhance systems-thinking and systems-engineering course material,” in *ASME International Mechanical Engineering Congress and Exposition*. American Society of Mechanical Engineers, 2024.

[25] A. Shekh-Abed, O. Hazzan, and A. Gero, “Promoting systems thinking and abstract thinking in high-school electronics students: integration of dedicated tasks into project-based learning,” *Int. J. Eng. Educ*, vol. 37, no. 4, pp. 1080–1089, 2021.

[26] A. Gero and I. Shlomo, “Promoting systems thinking in two-year technology students: An interdisciplinary course on medical ultrasound systems,” *International Journal of Engineering Education*, vol. 37, no. 2, pp. 564–572, 2021.

[27] K. E. Dugan, E. A. Mosyjowski, S. R. Daly, and L. R. Lattuca, “Systems thinking assessments: Approaches that examine engagement in systems thinking,” in *2021 ASEE Virtual Annual Conference Content Access*, 2021.

[28] R. Lavi, Y. J. Dori, N. Wengrowicz, and D. Dori, “Model-based systems thinking: Assessing engineering student teams,” *IEEE Transactions on Education*, vol. 63, no. 1, pp. 39–47, 2019.

[29] J. T. Nelson, J. S. Linsey, R. L. Nagel, and M. R. Bohm, “The impact of functional modeling on engineering students’ mental models,” in *2018 ASEE Annual Conference & Exposition*, 2018.

[30] K. E. Dugan, E. A. Mosyjowski, S. R. Daly, and L. R. Lattuca, “Systems thinking assessments in engineering: A systematic literature review,” *Systems research and behavioral science*, vol. 39, no. 4, pp. 840–866, 2022.

[31] M. Lovett, M. D. Bedillion, C. M. Birrenkott, K. H. Muci-Kuchler, and L. O. Pottmeyer, “Building and revising an assessment to measure students’ self-efficacy in systems thinking,” in *2021 ASEE Virtual Annual Conference Content Access*, 2021.

[32] S. Huang, K. H. Muci-Kuchler, M. D. Bedillion, M. D. Ellingsen, and C. M. Degen, “Systems thinking skills of undergraduate engineering students,” in *2015 IEEE Frontiers in education conference (FIE)*. IEEE, 2015, pp. 1–5.

[33] S. Varadarajan, “Measuring the value of systems thinking for design-centric engineering education,” in *Proceedings of the Design Society: DESIGN Conference*, vol. 1. Cambridge University Press, 2020, pp. 1835–1842.

[34] Y. Lin, A. M. Shahhosseini, and M. A. Badar, “Assessing conceptual mapping based active learning for advancing engineering diagnostic skills,” in *2017 ASEE Annual Conference & Exposition*, 2017.

[35] 7 things you should know about flipped classrooms. [Online]. Available: https://library.educause.edu/resources/2012/2/7-things-you-should-know-about-flipped-classrooms.

[36] Open learning initiative. [Online]. Available: https://oli.cmu.edu/.

[37] M. Lovett, O. Meyer, and C. Thille, “Jime-the open learning initiative: Measuring the effectiveness of the oli statistics course in accelerating student learning,” *Journal of Interactive Media in Education*, vol. 2008, no. 1, pp. 13–13, 2008.

[38] S. Gadgil, M. Braun, K. Hovis, M. Harty, and M. Lovett, “Investigating the impact of an online collaboration course on students’ attitudes and learning.” International Society of the Learning Sciences, Inc.[ISLS]., 2018.

[39] K. R. Koedinger, J. Kim, J. Z. Jia, E. A. McLaughlin, and N. L. Bier, “Learning is not a spectator sport: Doing is better than watching for learning from a mooc,” in *Proceedings of the second (2015) ACM conference on learning@ scale*, 2015, pp. 111–120.

[40] Wwc summary of evidence for this intervention: Open learning initiative (oli). [Online]. Available: https://ies.ed.gov/ncee/wwc/Intervention/1426.

[41] C. Bovill, C. J. Bulley, and K. Morss, “Engaging and empowering first-year students through curriculum design: perspectives from the literature,” *Teaching in Higher Education*, vol. 16, no. 2, pp. 197–209, 2011.

[42] B. Boardman and L. Peterson, “Freshman engineering courses: Discipline specific vs. interdisciplinary approaches,” in *2003 GSW*, 2021.

[43] S. Eppinger and K. Ulrich, *Product Design and Development*. McGraw-Hill Higher Education, 2015. [Online]. Available: https://books.google.com/books?id=S7FZCgAAQBAJ

[44] K. H. Muci-Küchler, L. Pottmeyer, M. Bedillion, C. M. Birrenkott, and M. Melville, “Assessment of sense of belonging and systems thinking skills in introduction to mechanical engineering courses at three academic institutions,” in *ASME International Mechanical Engineering Congress and Exposition*. American Society of Mechanical Engineers, 2024.

[45] G. M. Walton and G. L. Cohen, “A question of belonging: race, social fit, and achievement.” *Journal of personality and social psychology*, vol. 92, no. 1, p. 82, 2007.

[46] Google, “Gemini,” 2023, generative AI model from Google, accessed [1/9/2025].