ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #37688

Enhancing effectiveness and inclusivity of introductory ME courses: A cognitive psychology approach

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Abstract

Introductory mechanical design courses can either be invigorating and inspiring experiences, or alienating and intimidating depending on students' prior experience with design, as well as their socio-economic, and demographic backgrounds. This work-in-progress study explores cognitive psychology-based methods to teach mechanical engineering design courses effectively and inclusively for a diverse body of students regardless of their backgrounds. The theoretical foundation for this course design are two seminal theories of cognitive psychology: deliberate practice (DP) [1], and preparation for future learning (PFL) [2]. Deliberate practice theory, as described by Ericsson is used for development of competency in many different fields (e.g. sport, musics, physics, etc.). PFL has shown how a prior learning activity that prepares the learner can enhance learning from future instructor-led sessions. Based on deliberate practice theory: 1) we designed targeted learning activities for each of the weekly course learning goals, 2) students would receive ***timely, and specific*** feedback on their performance in these activities, and 3) they would be given opportunities to incorporate the feedback for improving their performance.

PFL learning activities are given to students as small group activities in the coaching sessions led by course assistants (CA) in advance of corresponding instructor-led sessions on the topic. The PFL learning activities are designed to engage the students in trying to solve an interesting problem that will be unlike what they may have seen in previous courses or projects. This helps put all students on equal footing. During these activities, the CA engages students to share ideas, reflect on progress, and explore the problem and solution space further, by providing timely feedback. By the end of the small group activity students are asked to summarize their learning from the activity. The instructor-led sessions are then split into three parts, the first two are didactic lectures, and the third is an active learning activity which takes place in small groups.

The impact of this course design will be studied with pre-, post-surveys and assessments, interviews, and students' performance in the course to evaluate their sense of belonging in the field of engineering [3] and their development of mechanical design competency.

Introduction

In 2015, the Undergraduate Curriculum Committee and other faculty in the Mechanical Engineering Department at Stanford University redesigned the Bachelors of Science in Mechanical Engineering (BSME) dividing the curriculum into a set of core classes and four concentrations [4]. The core classes aim to achieve the ABET learning goals [5] with special attention being given to "identify, formulate, and solve complex engineering problems" and "apply engineering design to produce solutions that meet specified needs." This development led to the creation of a new course, ME 102 Foundations of Product Realization, an introductory course to the relevant fields. ME 102 introduces students to new spaces (a prototyping lab and woodshop), new machines and software (3D printers, laser cutters, woodworking tools, CAD, etc.), as well as formally introducing the design process.

It is known that a large factor for students leaving STEM is success or failure in introductory courses [6]. Success in introductory STEM courses is mainly determined by students' levels of preparedness. The preparedness and disparity in it depends on the high school students attended and their prior experience [7]–[11]. Unfortunately, there are demographic patterns in students' access to quality high school and STEM preparation. Hence, demographics play a large role in the way students experience their first foray into engineering [12]. Many high schools have introduced makerspaces to attract more students to STEM, but this impact remains fairly marginal on the general student population [13]. These converging phenomena threaten to make ME102, as a course, an amplifier of such disparities.

As illustrated in figure 1, this work-in-progress study aims to redesign the course over the AY 21-22 by: (1) redefining and categorizing the course learning goals (Summer '21), (2) developing and piloting measuring tools to assess the effectiveness of the changes proposed (Summer '21, Fall '21, Winter '22), (3) using cognitive psychology-based teaching methods, namely deliberate practice (DP) and preparation for future learning (PFL) [14]–[16], to develop more effective and inclusive course activities (Fall '21, Winter '22), (4) implementing the changes (Summer '22) and (5) analyzing the difference in the pre- and post-intervention measures (Spring '22, Summer '22, Fall '22).

Furthermore, the course redesign builds on problem-solving teaching methods by leveraging prior work that have identified building blocks of competency in STEM problem-solving [17], [18], and reflection and experimentation practices which improve problem-solving in STEM [19]. As illustrated on figure 2, this redesign first mapped these STEM reflection and experimentation practices onto mechanical design practices. Further developing the model, these practices were mapped onto decisions experts make when solving ambiguous problems.

Concurrently, assessable and measurable learning goals [20] were derived from the prior version of the course. The learning goals were then mapped onto the set of practices and decisions that must be mastered for problem-solving. Then, deliberate practice activities were created based on the specific practice, and entailing decisions in the targeted learning goal. These activities take place in small CA-led coaching groups with ample opportunities for feedback and reflection, all in preparation for future learning via active learning activities in instructor-led sessions [21].

Current Timeline

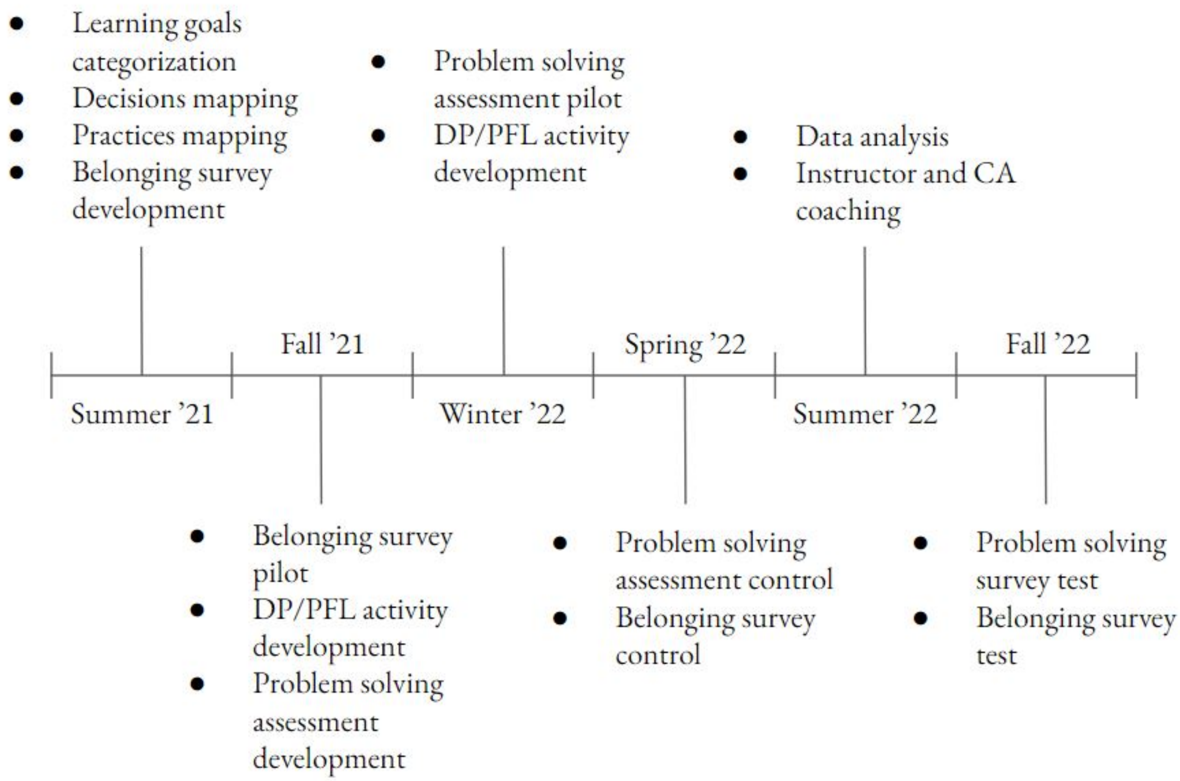


Figure 1: Timeline of the study

Conceptual framework

1. Preparation for future learning (PFL)

Previous works have shown that if learners engage in a properly designed learning activity, even if they cannot complete the activity correctly, the activity would enhance their learning from following instruction. In other words, the activity would prepare them for future learning from instruction. The PFL is in contrast to the tell and practice model common in many STEM courses where one lectures learners on a new topic and then provides them with activities to practice it [2]. PFL is understood to be the ability for individuals to learn new concepts and to organize this knowledge in such a way that they are then able to retrieve and adapt these concepts in new environments thereby inventing new ways of learning and solving problems [22]. PFL is generally used in terms of long-term knowledge organization and transfer but it has been shown to be effectively used in a shorter time frame (e.g. to prepare students for a weekly lecture) [23].

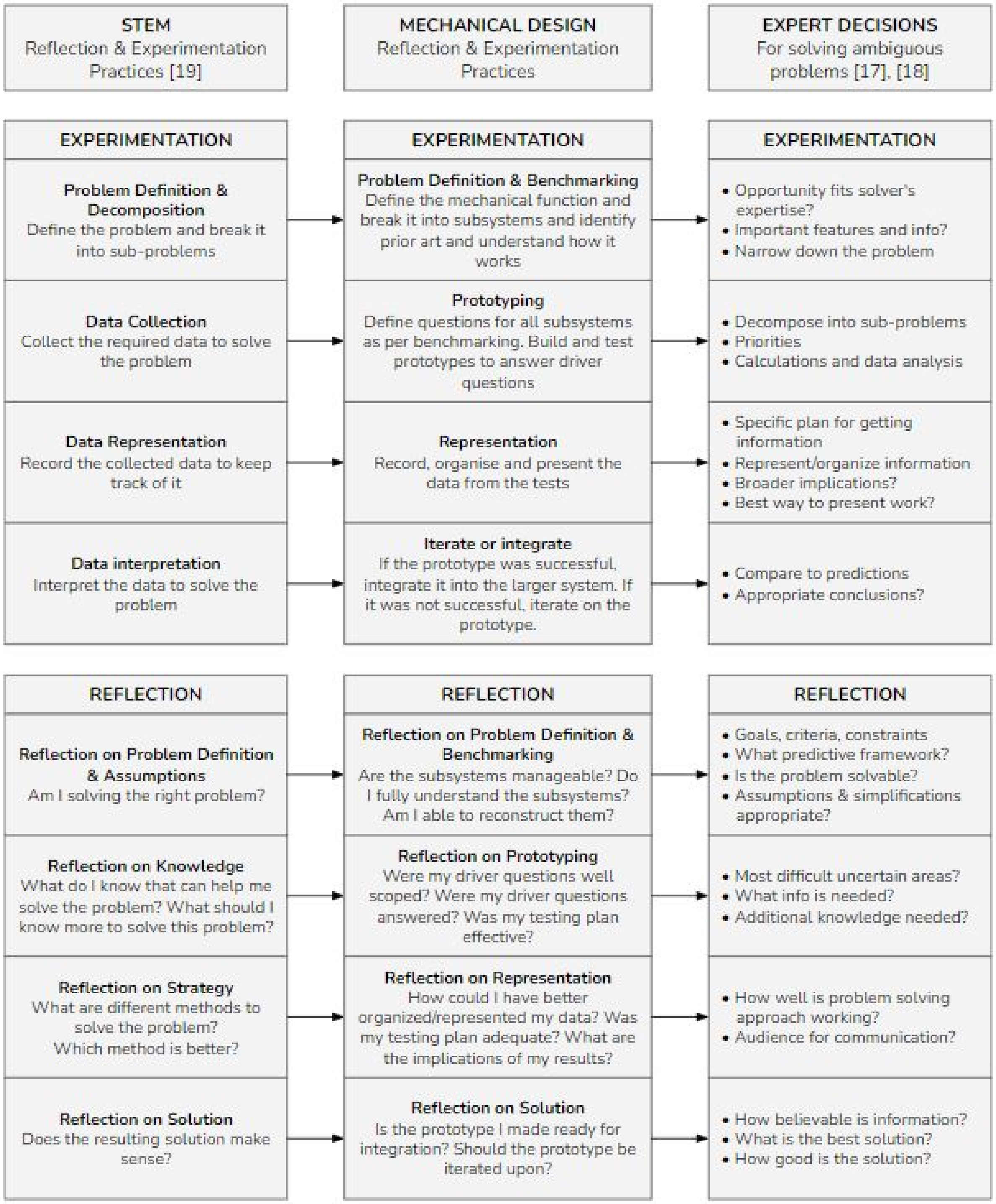


Figure 2: Mapping of practices to decisions

2. Deliberate practice (DP)

The seminal theory of deliberate practice, developed by Ericsson [1], shows that acquiring expertise in a given subject requires: (1) the decomposition of expertise into sub-skills, recognizing that some are dependent on others, (2) creating learning activities which target the sub-skills, (3) engaging students in the learning activities, (4) providing timely and specific feedback, and (5) allowing students to practice the skill repeatedly [24]. The deliberate practice has been shown to be effective in a variety of topic from sport, to chess, to math and physics.

Course redesign

1. Structure of the course as it was

ME 102 met twice a week, one lecture, and one coaching session. Then, the learning goals were vague and non-conductive to measurable assessment (e.g. "Develop an aptitude for mechanical components, systems, and principles through first hand tangible experience"). The class deliverables were split into two categories, weekly homework assignments and two consecutive five-week projects. The coaching session consisted of a group of four to five students led through a set of activities by a graduate TA who had previously taken the course, a "Course Assistant (CA)". The lecture introduced a novel topic, and the activities in the coaching session were designed to reinforce the content covered in lecture with the aim of providing students with an opportunity to test their understanding and ask any clarifying questions to the CA. This coaching session was also an opportunity for students to receive direct feedback regarding their project's progress.

2. Restructuring the course

The course still meets twice a week. An overview of the structural changes of the course is outlined in figure 3. In addition to these changes, the course has been redesigned by: (1) redefining the course's learning goals, (2) changing the pacing of the content delivery to introduce novel topics in coaching using DP and PFL rather than during the instructor-led session and, (3) creating active learning worksheets for students to complete during the instructor-led session. The more significant changes are being implemented in the coaching session, having it now split into three part, the first being an opportunity to clear up any misconceptions highlighted by the last week's homework, the second being a PFL/DP activity which introduces a new concept with an authentic problem [25] and the third, being an opportunity to address the past instructor-led session's one-minute paper (OMP) [26].

	Previously	Redesign	Theory
Instructor-led sessions (meets once per week)	. New topic covered weekly . In-class activity . No deliverable	**. 1st part of the session:** Formal introduction to subgoal introduced in coaching **. 2nd part of the session**: Expansion into the rest of the subgoals **. 3rd part of the session:** Active learning incorporating all sub goals into overarching goal . One-minute paper	DP, JIT, PFL, AL, OMP
Coaching (meets once per week)	. Design coaching . Graded HW clarifications	. Current HW worked example by CA . Last week OMP clarifications . PFL activity introducing next week's topic	DP, PFL, JIT, R
Lab (meets week 2 and 3 only)	. Introduction to processes (laser cutting, 3D printing, etc.) . No deliverables	. Introduction to processes (laser cutting, 3D printing, etc.) . Deliverables tied to the current project	DP, JIT
Projects	. Two 5-week projects . Process documentation . Presentation	. Two 2-week projects, each targeting specific practices . One final 5-week project . Process documentation . Presentation	DP, JIT, R
DP: Deliberate practice, **JIT**: Just in time telling, **PFL**: Preparation for future learning, **R**: Reflection, **AL**: Active learning, **OMP**: One-minute paper			

Figure 3: Restructure of the course

Original Learning Goal:
Communicate design and engineering intent through process documentation, hand drawings, and digital models of 2D and 3D geometry.

Redesigned Learning Goal:		
Communicate design intent through concept sketches		
Content:	To do this you will need to know and be able to explain these terms:	Isometric, Oblique, Perspective views , Concept sketch
		Orthographic projection
		Orthographic projection line types and views
Application:	To do this, you will need to be able to:	Select and justify the front view of a part
		Given a front view, identify the top and right views
		List the primary rules of orthographic projections
		Represent a concept without ambiguity using orthographic projections and additional views

Figure 4: Before and after learning goals

(a) Redefining the learning goals

Prior to the redesign, the course's learning goals were broad, and difficult to assess and understand, e.g. *"Communicate design and engineering intent through process documentation, hand drawings, and digital models of 2D and 3D geometry."*. To make these learning goals clearer to students and the teaching team, the first task in redesigning the course was to go through the slides shown during lecture for all three offerings of the course in the AY 20-21 and extract the intended learning goals. Eighty seven specific learning goals were identified. They were then categorized into four genres: Primary (35), Content (21), Skill (23) and Not Valuable (8).

This categorization was shared with and approved by the original course designers and current instructors. Next, the learning goals were organized in a hierarchical manner such that each week had an overarching learning goal which entailed mastery of a set of *content* learning goals and *application* learning goals. The "Not Valuable" learning goals were discarded. Figure 4 shows the contrast between the learning goals as they were and as they are. Note that the original learning goal is covered in multiple weeks throughout the quarter, but the new learning goal is covered in a single week. The week's topic is "Visual Communication". The overarching learning goal is "Communicate design intent through concept sketches". Sub-goals, content and skill, are listed below it. The targeted learning goal for PFL/DP, covered in coaching, is highlighted.

(b) Coaching sessions

Each week, a sub-skill was identified for a DP exercise in a coaching session [27]. The criteria for selection was: feasibility, complexity and the decisions and practices it involved. From that learning goal, a problem-solving activity was created. The activity takes place during the coaching session. The activity engages students in a way which they may encounter in "the real world" of mechanical design.

The deliverable for this DP exercise is low-stakes, and graded only for completeness. The students are offered a problem and guided by the CA through the activity. In pairs and then with the full coaching group, they share possible solutions. The deliverable for this activity is a set of rules to be followed when engaging with the week's problem. An example DP exercise is shown in the next section of this paper.

In order to facilitate the discussion and keep the activity on pace with the schedule of the coaching session, the CA is given a timed script which scaffolds the whole of the coaching session. During the DP activity, the coach uses a timer to have students explore the problem, share and reflect with their partner and ultimately with the larger group. At any time in the process of reflecting and sharing the coach is encouraged to provide just-in-time feedback to guardrail against the evolution of misconceptions. Outside of that narrow scope, the coach is encouraged to use a Socratic approach when prompting students in the discovery phase.

One goal of these exercises is to increase the motivation of students when facing a difficult problem. When they see their knowledge and skill as applicable in a realistic scenario, they are more likely to fully engage with the problem in a meaningful way [22].

(c) Instructor-led sessions

During the instructor-led session session, the hierarchical learning goals are made explicit at the beginning and periodically through the period. The first part of the session (20 minutes) is a formal introduction of the sub-goal introduced in coaching: student examples and sets of rules (deliverables from coaching) are shown and discussed. Lessons are drawn from the students' experience with the PFL activity and the set of rules is formally revisited. The second part of the session expands on the rest of the sub-goals highlighting how they relate to one another, the decisions and practices implied by them, and how this set of learning goals fits into the bigger picture of the design process.

The last part of the session has students congregate in small groups (4 to 6 students) working in pairs and then sharing within the small groups to work through a worksheet following the active learning model. The teaching team walks around the room to answer questions or help guide the discussion. This worksheet specifically targets the overarching learning goal for the week.

In the last five minutes of the session, students answer two short reflective questions. The first asks what remains unclear after the day's session, and the second probes the students' understanding of the learning goal by asking them to define a set of rules related to it. (e.g. list a set of rules to follow when making a concept sketch.)

(d) Lab sessions

Lab sessions happen outside of class time, with larger groups (10 to 15 students). One of these sessions is in the prototyping lab, and the other is in the woodshop. The first part of the session has students, under the guidance of CAs, learn how to safely operate machines and use tools and processes. For the second half of the session, they are tasked with following up on the work they did in coaching by putting their prototyping plan into action. The deliverable for these sessions is incorporated into the two small project deliverables.

Example

Build and test a physical prototype to advance a design		
Content:	To do this you will need to know and be able to explain these terms:	Ideation, Iteration, Prototyping, Documentation, Reflection
		Works-like prototype & looks-like prototype
		Serial prototyping & parallel prototyping
Application:	To do this, you will need to be able to:	Safely use prototyping tools like a hot glue gun and a utility knife
		Break a system down into sub-systems to enable prototyping
		Create a plan to test and define the measure of success of the prototype
		Use the appropriate level of prototype refinement for the current stage of design
		Incorporate found or purchased components to accelerate the prototyping process

Figure 5: Week two hierarchical learning goals

Week two's topic is Prototyping. The overarching learning goal is ***"Build and test a physical prototype to advance a design"***. The learning goals' hierarchical structure is illustrated in figure 5, with the targeted learning goal for PFL/DP highlighted. That week, the DP/PFL activity in coaching session centers around the following prompt:

"You are part of the design department of a company that makes products and accessories focused on personal mobility. The marketing department has conducted research that shows that consumers want a way to mount their phones to bicycles and other personal means of transportation, to improve their ability to use navigation apps while on the go. You have been tasked with ideation and early-stage prototyping for the project. You need to formulate a plan of action for this early-stage prototyping."

When analyzing this prompt, it should be noted that the prior week's overarching learning goal was to ***"Communicate design intent through concept sketches"***. Therefore this activity builds on the past week's learning goal and offers students an opportunity to: (1) practice making concept sketches and communicating their ideas, and (2) experience how other students make concept sketches and communicate their ideas.

The coaching session is set up such that 20 minutes are spent on this activity: the first five minutes are spent discussing with a partner the potential solutions to this prompt, analyzing existing solutions and potentially ranking them in order of feasibility and reliability. The next five minutes are spent sketching. Then, the group comes together for another five minutes to talk about the different solutions proposed. For the last five minutes, the CA engages students to think about a set of rules they may want to adhere to when creating a plan for early stage prototyping. Over the next few days, the students are given access to a lab and materials to prototype their concepts following their plan and rules.

In the following week's instructor-led session, the prototyping process is covered, including all of the learning goals in listed in figure 4. At this stage, a majority of students will have engaged in prototyping, but no significant and applicable lessons will have been extracted and no measure of success for the prototype will have been established. This in turn is made even more clear during the instructor-led session. In a second round of prototyping and plan making, students now are much more systematic in their approach defining metrics for success and testing criteria to categorize the effectiveness of their solution.

Methods

Various methods are used to evaluate the effectiveness of the course's redesign: (1) A set of pre- and post-course problem-solving assessments using a disguised ladder model and faulty design approach [28] to analyze the change in mechanical design expertise, (2) a belonging survey to measure self-assessment levels and help-seeking behavior, (3) coaching observations to analyze participation of under-represented minorities and overall group information sharing and learning, (4) inter- and post-course reflective interviews, and (5) evaluation of homework and project deliverables.

1. Problem-solving assessment

This assessment tool is currently being piloted. It uses an authentic prompt, which places the participant as an engineering college student responsible for coaching a high school student through a design challenge, see figure 6. Given an original prompt, the student returns a faulty design, and the participant is asked to give feedback to the student. The assessment is designed such that the first opportunity for feedback provides no scaffold to the participant (e.g. "What feedback would you give the intern?). Then, as the participant advances through the assessment's prompts, they are asked to give feedback on more specific aspects of the student's work. More expert participants will need no prompting in recognizing a fuller set of the missing or incorrect aspects of the design, while more novice participants will require a certain level of scaffolding.

The faulty designs have been developed to create a composite of student designs, extracting the most common mistakes generated by students over the AY20-21, into one design (see example on figure 6). As a first pilot procedure, the assessment uses Product Realization Lab (PRL) CAs as participants. The second pilot procedure use students of ME102. The piloting phase aims to ensure clarity and common understanding of the questions and prompts for both novices and more expert participants.

Once piloted, the assessment will be given to a different set of CAs to create a grading scheme. The grading will be based on PRL CAs responses for various reasons: (1) the application process to become a PRL CA is rigorous and optimizes for mechanical design competency, communication skills, and mentorship experience (e.g. sports, design, residential associates, etc.), (2) every PRL CA is involved and has experience in providing feedback to students regarding their mechanical design process development, and (3) the PRL is responsible for ME 102. As such, the PRL CAs are an easily accessible resource for this research. Responses from the CAs will be aggregated to create an ”expert response” to the assessment. The expert response will be the measure by which individual students will be assessed.

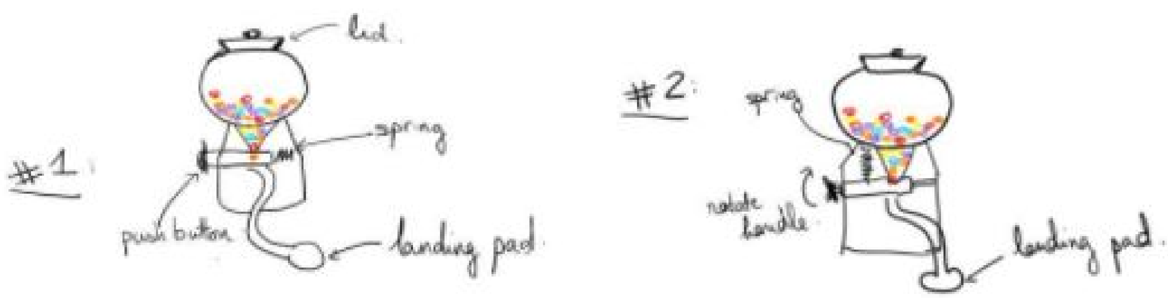
Imagine you have been tasked with coaching a high school student through a design challenge: to create a desktop M&M dispenser using their high school's prototyping space (3D printer, laser cutter, etc.).
In your first interaction with the student, they've conveyed to you that the design requirements for the dispenser are to: (1) hold a bag of M&Ms, and (2) be ""fun"", and for the mechanism to (3) use rotary motion to release a single M&M, and (4) incorporate a spring."
You advise them to explore different mechanisms before they start building or prototyping anything. You ask them to send you some mechanism ideas, their preferred solution, and next steps. "

Desktop M&M Dispenser

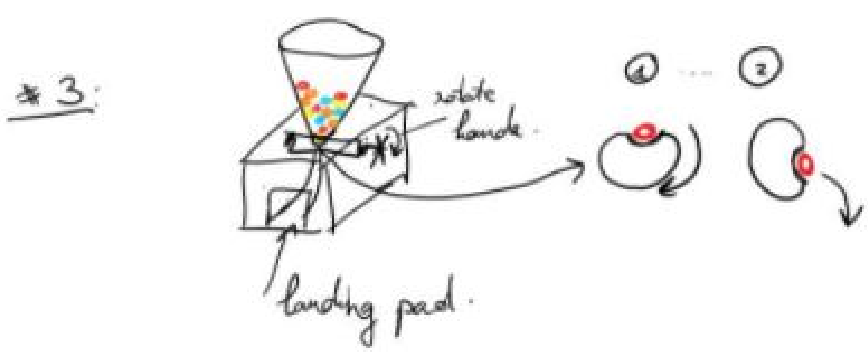
Requirements:

1. Fun
2. Hold a bag of M&Ms
3. Rotary motion
4. Release one M&M
5. Spring loaded

Exploration:



Favored solution:



While the first two devices look interesting, I think that since this device should fit on a desk, it makes more sense as a box. The mechanism is explained to the right, where the M&M nestles into a slot in the rod and, upon rotation, is released down to the landing pad.

My next steps would be to physically prototype the device using real M&Ms.

Figure 6: Assessment prompt and faulty design example

2. Belonging survey

The survey will ask students to self-assess their aptitude on a set of decisions inherent in the mechanical design process. The decisions are modeled on the design methodology practices and reflections illustrated in figure 2 on page 4. The self-assessment will use a Likert scale. The belonging survey will also seek to understand students' help-seeking behavior before, during and after the course. Participants will be asked to share their comfort level when seeking help from various resources (e.g. instructors, CAs, classmates, etc.), and on various types of problems (e.g. problems they feel they should know the answer to, problems which are out of the scope of the course, etc.). Finally, the survey seeks to understand students' engineering identity [29], [30] by assessing students' comfort level in the physical spaces where learning takes place (e.g. asking for help when using a machine, asking questions in class, etc.).

A subset of students will be interviewed every two weeks to gauge their engagement with the course and their experience as it relates to their experience in other classes. The coaching sessions will be observed to examine patterns in students engagement and group dynamics. Last but not least, students' produced artifacts will be analyzed to evaluate their development of mechanical engineering design competency.

3. Coaching observation

Two coaching sessions will be observed by the writer. The observations will follow the "classroom observation protocol for undergraduate STEM" as described in [31]. One session will be attended per week, alternating between the two. The observer's aim will be to note participation and in-group dynamics. This data will be used for the purpose of this study and to provide feedback to coaches and the teaching team.

4. Interviews

One on one interviews will be held and after the offering of the course to gather information from students regarding their experience with the format of the course and how it compares to their other and prior experience in other engineering courses. This data will be used for the purpose of this study and to provide feedback to coaches and the teaching team.

5. Deliverables analysis

The deliverables turned in by students (in-class activities, home works, and projects) will be compared to the deliverables from Spring 2022. The two sets of materials will be analyzed with special attention given to "identify, formulate, and solve complex engineering problems" and "apply engineering design to produce solutions that meet specified needs."—the two ABET learning goals which the course is meant to address. This analysis will be aimed at finding contrasting cases in overall and individual students' problem-solving and design methodology approach between the two sets of materials. If found, these contrasting cases may be used to illustrate the effectiveness of the redesign of the course.

Future work

AY22-23 will provide the opportunity to build and iterate on this course redesign. Anecdotally, the changes which have been piloted in flipping the order of introduction of content and active learning activities during instructor-led class sessions have thus far been very well received. The work is being embraced and enthusiastically incorporated into the AY22-23's version of the course. As shown in figure 1 the control portion of the study will run during the Spring '22 term. The impact of the redesign will be measured when comparing these results to those gathered during AY22-23 across the five above-mentioned methods. The findings will be analyzed and included into a larger body of work focusing on the importance of teaching decision making in problem-solving in STEM courses.

The hope for this study is that it helps provide a roadmap for curriculum developers and instructors in designing activities and group sessions which are more conducive to timely and specific feedback, engaging for all students, and thereby provide a more effective and inclusive method of teaching project-based engineering courses.

Acknowledgements

We would like to thank HHMI for their continued support of students from underrepresented backgrounds through our science education programs.

References

[1] K. A. Ericsson, R. T. Krampe, and C. Tesch-Römer, "The role of deliberate practice in the acquisition of expert performance.," *Psychological review*, vol. 100, p. 363, 1993.

[2] J. D. Bransford and D. L. Schwartz, "Chapter 3: Rethinking transfer: A simple proposal with multiple implications," *Review of research in education*, vol. 24, pp. 61–100, 1999.

[3] S. Salehi, N. Holmes, and C. Wieman, "Exploring bias in mechanical engineering students' perceptions of classmates," *PloS one*, vol. 14, e0212477, 2019.

[4] S. D. Sheppard, R. L. Anderson, and T. W. Kenny, "Three stanford faculty write about change & engineering education.," *Advances in Engineering Education*, 2021.

[5] R. Bachnak and A. B. Shafaye, "A Look at ABET Accreditation – Understanding the Basics," Apr. 2017. [Online]. Available: `https://peer.asee.org/a-look-at-abet-accreditation-understanding-the-basics` (visited on 02/14/2022).

[6] E. Seymour, A.-B. Hunter, R. Harper, and D. Holland, "Talking about leaving revisited," *Talking About Leaving Revisited: Persistence, Relocation, and Loss in Undergraduate STEM Education*, 2019.

[7] L. Darling-Hammond, "New standards and old inequalities: School reform and the education of african american students," in *Black Education*, Routledge, 2006, pp. 227–254.

[8] M. Syed, M. Azmitia, and C. R. Cooper, "Identity and Academic Success among Underrepresented Ethnic Minorities: An Interdisciplinary Review and Integration: Identity and Academic Success," en, *Journal of Social Issues*, vol. 67, pp. 442–468, Sep. 2011, ISSN: 00224537. DOI: `10.1111/j.1540-4560.2011.01709.x`. [Online]. Available: `https://onlinelibrary.wiley.com/doi/10.1111/j.1540-4560.2011.01709.x` (visited on 02/09/2022).

[9] H. Lowe and A. Cook, "Mind the gap: Are students prepared for higher education?" *Journal of further and higher education*, vol. 27, no. 1, pp. 53–76, 2003.

[10] E. W. Burkholder, G. Murillo-Gonzalez, and C. Wieman, "Importance of math prerequisites for performance in introductory physics," *Physical Review Physics Education Research*, vol. 17, no. 1, p. 010 108, 2021.

[11] M. J. Khan and C. A. Aji, "Tolerance of Ambiguity (Work in Progress)," en, in *2019 ASEE Annual Conference & Exposition Proceedings*, Tampa, Florida: ASEE Conferences, Jun. 2019, p. 33 443. DOI: `10.18260/1-2--33443`. [Online]. Available: `http://peer.asee.org/33443` (visited on 02/09/2022).

[12] S. Salehi, E. Burkholder, G. P. Lepage, S. Pollock, and C. Wieman, "Demographic gaps or preparation gaps?: The large impact of incoming preparation on performance of students in introductory physics," en, *Physical Review Physics Education Research*, vol. 15, p. 020 114, Jul. 2019, ISSN: 2469-9896. DOI: `10.1103/PhysRevPhysEducRes.15.020114`. [Online]. Available: `https://link.aps.org/doi/10.1103/PhysRevPhysEducRes.15.020114` (visited on 02/09/2022).

[13] J. Helbling and L. Traub, "Impact Of Rapid Prototyping Facilities On Engineering Student Outcomes," ISSN: 2153-5965, Jun. 2008, pp. 13.693.1–13.693.11. [Online]. Available: `https://peer.asee.org/impact-of-rapid-prototyping-facilities-on-engineering-student-outcomes` (visited on 02/09/2022).

[14] W. F. Helsen, J. L. Starkes, and N. J. Hodges, "Team sports and the theory of deliberate practice," *Journal of Sport and Exercise psychology*, vol. 20, no. 1, pp. 12–34, 1998.

[15] K. Anders Ericsson, "Deliberate practice and acquisition of expert performance: A general overview," *Academic emergency medicine*, vol. 15, no. 11, pp. 988–994, 2008.

[16] E. Burkholder, S. Salehi, S. Sackeyfio, N. Mohamed-Hinds, and C. Wieman, "An equitable and effective approach to introductory mechanics," *arXiv preprint arXiv:2111.12504*, 2021.

[17] E. Burkholder, L. Hwang, and C. Wieman, "Evaluating the problem-solving skills of graduating chemical engineering students," *Education for Chemical Engineers*, vol. 34, pp. 68–77, 2021.

[18] A. M. Price, C. J. Kim, E. W. Burkholder, A. V. Fritz, and C. E. Wieman, "A detailed characterization of the expert problem-solving process in science and engineering: Guidance for teaching and assessment," *CBE—Life Sciences Education*, vol. 20, no. 3, ar43, 2021.

[19] S. Salehi, *Improving problem-solving through reflection*. Stanford University, 2018.

[20] S. Chasteen, K. Perkins, P. Beale, S. Pollock, and C. Wieman, "A thoughtful approach to instruction: Course transformation for the rest of us," 2011.

[21] C. J. Ballen, C. Wieman, S. Salehi, J. B. Searle, and K. R. Zamudio, "Enhancing diversity in undergraduate science: Self-efficacy drives performance gains with active learning," *CBE—Life Sciences Education*, vol. 16, no. 4, ar56, 2017.

[22] D. L. Schwartz, J. M. Tsang, and K. P. Blair, *The ABCs of how we learn: 26 scientifically proven approaches, how they work, and when to use them*. WW Norton & Company, 2016.

[23] D. M. Belenky and T. J. Nokes-Malach, "Motivation and transfer: The role of mastery-approach goals in preparation for future learning," *Journal of the Learning Sciences*, vol. 21, no. 3, pp. 399–432, 2012.

[24] S. Salehi, C. J. Ballen, G. Trujillo, and C. Wieman, "Inclusive Instructional Practices: Course Design, Implementation, and Discourse," *Frontiers in Education*, vol. 6, 2021, ISSN: 2504-284X. [Online]. Available: `https://www.frontiersin.org/article/10.3389/feduc.2021.602639` (visited on 02/10/2022).

[25] L. Zech, N. J. Vye, J. D. Bransford, *et al.*, "An introduction to geometry through anchored instruction," *Designing learning environments for developing understanding of geometry and space*, pp. 439–463, 1998.

[26] D. R. Stead, "A review of the one-minute paper," *Active learning in higher education*, vol. 6, no. 2, pp. 118–131, 2005.

[27] K. Miller, K. Callaghan, L. S. McCarty, and L. Deslauriers, "Increasing the effectiveness of active learning using deliberate practice: A homework transformation," *Physical Review Physics Education Research*, vol. 17, p. 010 129, 2021.

[28] M. P. Flynn, *Assessing Expertise in Mechanical Engineering Design*. Stanford University, 2020.

[29] A. Johri and B. M. Olds, *Cambridge handbook of engineering education research*. Cambridge University Press, 2014.

[30] J. Morelock, "A systematic literature review of engineering identity: Definitions, factors, and interventions affecting development, and means of measurement," *European Journal of Engineering Education*, vol. 42, pp. 1–23, Feb. 2017. DOI: `10.1080/03043797.2017.1287664`.

[31] M. K. Smith, F. H. Jones, S. L. Gilbert, and C. E. Wieman, "The classroom observation protocol for undergraduate stem (copus): A new instrument to characterize university stem classroom practices," *CBE—Life Sciences Education*, vol. 12, no. 4, pp. 618–627, 2013.