Developing KSAs in Engineering Capstone Students (WIP)

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This work-in-progress research analyzes undergraduate outcomes after participation in an engineering design capstone course. In this context, knowledge, skills, and abilities (KSAs) are integrated within a competency-based educational (CBE) [1] model with an emphasis on formative assessment and feedback throughout the semester. Mirroring work in industry, the course also incorporates elements of new-product design (e.g., pre-work, definition, iterations) [2]. The course provides authentic learning through community and industry partnerships for teams of mixed-major engineering students (e.g., electrical, mechanical), exemplifying integrated learning experiences [3] in pursuit of real-world engineering competencies.

Competency-based education (CBE) is an instructional approach that focuses on actionable outcomes rather than traditional knowledge-based outcomes. Competencies are necessary to effectively perform specific functions and solve contextually-specific problems [4], [5], [6]. Competencies can be described as applying general and occupation-related KSAs to complete a task [7]. Specifically, knowledge is the domain-specific knowledge, skills include higher-order thinking to apply knowledge, and abilities, sometimes conceptualized as dispositions, relate to the attitudes and values of the learner [1].

Additionally, CBE course learning objectives are framed around professional practices and problem-solving [7]. For engineering education, CBE provides a transition from university to industry. Many parallels exist between CBE and industry practices, in particular those surrounding design-based concepts. In industry, new-product development (NPD) requires attention to detail at the individual project, business, and systems level to create a successful product launch [2], whereas university engineering design courses tend to focus on the individual project level. Cooper's [2] NPD success drivers often reflect the type of skills that are a focus in CBE. For individual new-product projects, overlapping concepts include voice-of-the-customer,

pre-work, definition, and iterations. Building in the voice-of-the-customer may involve market research for businesses, whereas students in CBE may work with an actual client. Pre-work tasks can look similar in the two contexts, just at different levels. For example, both could analyze feasibility, risks, and proof of concept, but only the business is looking at the implications for scaling up. Defining the scope, benefits, and specifications of individual products could easily apply in both contexts during NPD. Iterative, spiraling development approaches are key to both industry and course-based projects. The build-test-feedback-revise cycle [2] guides customer interactions surrounding a product. Through showing the customer a physical or virtual model (build), interacting with it (test), gauging the customer's reaction (feedback), and making changes based on benefits, values, and feedback (revise), successful products can be created in both industry and CBE contexts.

Interacting with customers or clients requires engineering students to apply the knowledge learned in previous coursework as they implement the skills portion of KSAs (i.e., from the CBE model). In fact, Harishree and colleagues [8] suggest that these skills, also known as 21st century skills (21CS), have surpassed technical skills in importance among industry employers. Several extant empirical studies further point to the demand for 21CS in industry [8], [9], [10]. For this study, the four components of 21CS' Learning and Innovation Skills (see [11] for the full model) will be analyzed: communication, collaboration, critical thinking/problem-solving, and creativity (4Cs). The Partnership for 21st Century Skills [11] defines creativity as the ability to develop, analyze, and communicate new ideas. Critical thinking involves evaluating evidence though forms of reasoning to solve problems. Communication not only includes the ability to clearly articulate thoughts and ideas in diverse environments, but also the ability to listen effectively. Collaboration is the ability to work with others, including sharing

responsibility and willingness to compromise [11]. These four constructs connect to the skills in KSAs and the CBE framework, as depicted in Figure 2.

Current Study

These theories are translated to practice through a sequence of real-world tasks in the context of a capstone course, in the final year of the undergraduate engineering program. As seen in Figure 2, early engineering coursework is meant to help students develop KSAs, and this capstone course allows students to apply their KSAs through the CBE process. Design teams work through team formation, client briefings, and a series of budget and design reviews with their professors and clients before presenting a prototype and closing out their projects. This project-based course incorporates elements of NPD, which requires critical thinking, creativity, and problem solving to iterate through the design cycle. Through keeping the same group and clients throughout the semester, students are also challenged to collaborate well and communicate effectively with multiple audiences. From the community-facing view, 21CS were evident, thus, this is the context that framed our decision to focus on the 4Cs of 21CS. Through a mixed-methods design, our intent is to understand if students perceive that their skills change over the semester, and to which course elements they attribute these changes.

We explore the following research questions:

1. Do participants' critical thinking, collaboration, communication, and creativity/problem solving change from pre- to post-semester in an engineering design capstone course?
2. Do participants' self-ratings and reflections throughout the semester align with any quantitative changes resulting from question 1?
3. How do students perceive their growth in communication, collaboration, critical thinking, and creativity at the conclusion of the capstone course?

Methods

Study Context

Engineering Design II (EDII) is a senior-level engineering design course where groups of mixed-major engineering students develop products in collaboration with local clients (e.g., businesses, organizations, schools, etc.). Each group of 6-8 students is working on a unique project, though they follow the same procedures to present progress to their clients, from an initial design briefing to the final design review and verification. As in many capstone courses, student groups fabricate their design and deliver the prototype to their client at the conclusion of the semester.

Participants are students in EDII ($n \approx 50$) in a private university in a southwestern state. Participants were recruited by the professors in the course and given the option to take the survey digitally with the link shared via email. We did not provide any incentives for this pilot semester. Interview selection will be based on growth from pre- to post-survey, and the 10-15 students who showed the most change will be invited via email for a virtual interview.

Research Design

EDII is a process-based course, so formative assessments are already collected throughout the semester. Existing data includes self- and team member-ratings of KSAs and effective collaboration (CATME; see [12] for full scale information including psychometrics), alongside open-ended personal reflections assessing their own performance on the team and in their roles (i.e., one quantitative and one qualitative component). CATME is used for peer- and self-evaluation at the beginning, middle, and end of the semester, then reflections follow in response to the results. Existing course data will be compiled at the end of the semester, in May 2024. KSAs are measured briefly by CATME (see Appendix), so we would like to expand

measurement of this component with an additional survey. Our proposed direction forward includes a convergent mixed-methods design with an embedded explanatory sequential ending (see Figure 1) [13].

Concurrent with the course's existing instruments, we intend to include a survey adapted for this course from the TRAILS instrument (see [14] for full scale information including psychometrics) that takes place before, midway through, and at the end of the course that measures the 4Cs. At the conclusion of the semester, participants will be selected for a semi-structured interview based on their growth throughout the semester. The growth will be most apparent through mean differences between the pre- and post-surveys (e.g., from dependent samples t-tests) with support from reflective responses. Key areas where participants grew or did not grow (e.g., communication) will be a focus in the semi-structured interviews. The researcher-developed questions in the interview protocol were designed to encourage participants to share examples from the semester, likely involving one or more of the 4Cs, and adding further explanation to their perceptions of growth in skills throughout the semester. The Appendix contains all survey and interview items.

Proposed Analysis

This work-in-progress research expands on reflective feedback that is already incorporated in the course by adding an additional quantitative and qualitative component. To investigate students' perceptions of their growth in the 4Cs, we anticipate a series of analyses for quantitative and qualitative data, as well as combining the data using explanatory sequential mixed-methodology [13]. Quantitative analysis is expected to include regression and paired samples t-tests performed in Mplus version 8.10 [15], and qualitative analysis will include inductive coding, pattern matching, and thematic analysis. The data will also be analyzed

wholistically, combining each participant's quantitative and qualitative data and analyzing each theme (e.g., 4Cs) for agreement, elaboration (e.g., from quantitative to qualitative), and change.

Together, these data points will provide triangulation for trustworthy conclusions about students' growth throughout the course of a capstone project, adding to the body of literature in the field. More directly, the results of this study could provide a deeper understanding of students' perspectives surrounding this specific university's course, which can further inform the innovative instruction taking place in the culminating course of the program.

Preliminary Results and Feedback

We have quantitative results from the pre- and mid-semester surveys at this time, and our sample was smaller than expected (n = 20 pre-, n = 16 mid-semester). Though we do not yet have post-semester data to run our planned quantitative analyses, we noticed in the descriptives (see Table 1) that our sample started out rating themselves so high on the 4Cs that there is not much room for growth. Thus, we need to find a way to capture most/all of the class in order to detect an effect if one exists. Also, these students already receive CATME training to assist them in assigning more realistic ratings to themselves and peers. We would like to adapt this training for our survey next semester and see if the self-reports change, indicating a moderating effect on the known issues with self-reports.

By the time of the conference, we should receive and analyze additional data from the pilot semester of this study (CATME, reflections, post-survey, interviews). We seek feedback from any instructors who have integrated surveys for all students and interviews/focus groups into their design courses, particularly at the end considering we have graduating seniors. We have been offered the opportunity to work with the junior engineering design course, following them into senior design, and welcome ideas for adjusting our mixed-methods procedures.

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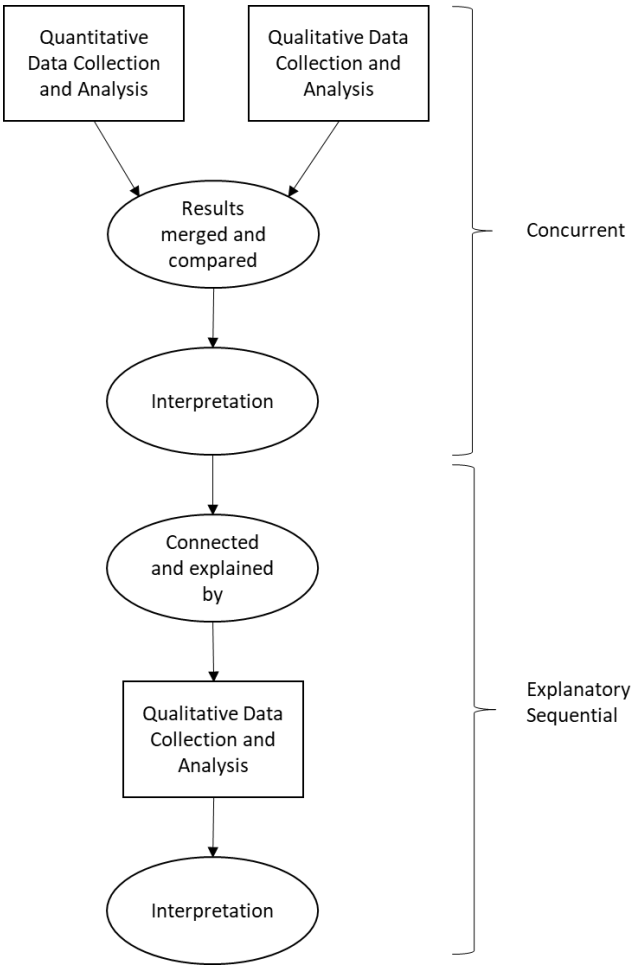

Fig. 1. Mixed methods design diagram.

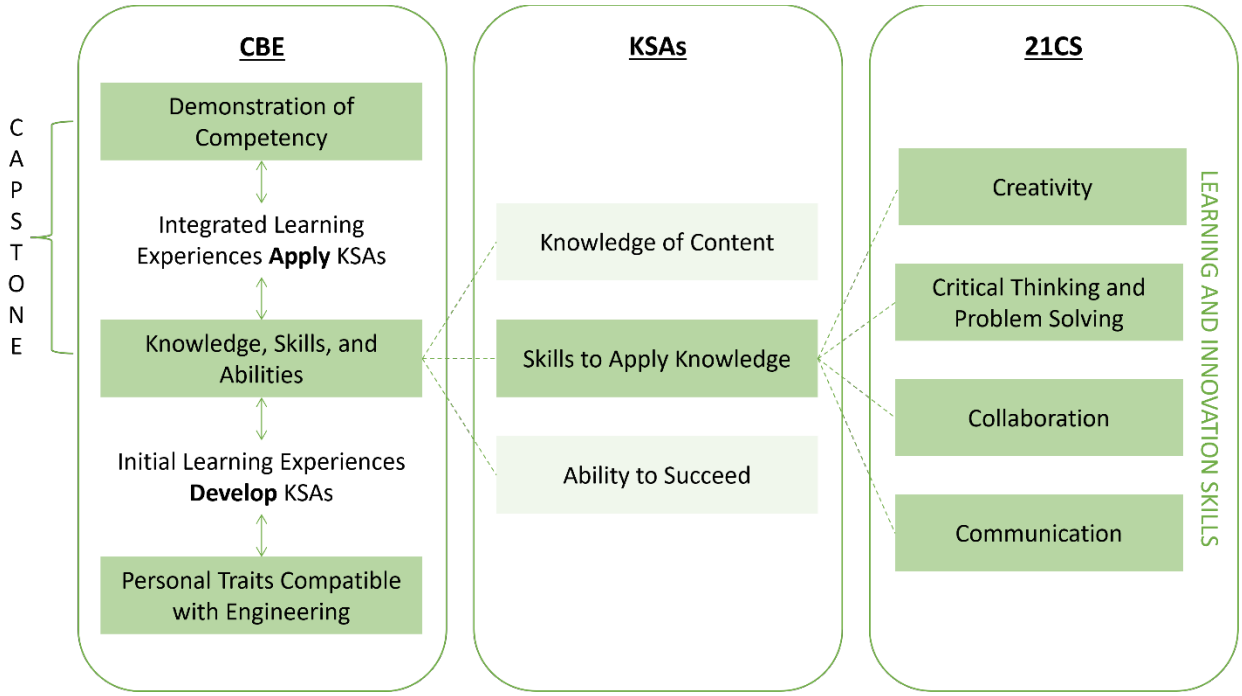

Fig. 2. Conceptual framework adapted from [1], [11]. Note that the overall progression from beginning to competent engineering students is displayed in Box 1, with an emphasis on applying KSAs to demonstrate competency. That application is further narrowed through Boxes 2-3, by citing specific skills that allow students to integrate and apply knowledge in later coursework such as the capstone design course in our study.

TABLE I

DESCRIPTIVE STATISTICS

		Mean	Standard Deviation	Minimum	Maximum
Pre	Critical Thinking	4.24	.385	3.64	5.00
	Collaboration	4.46	.350	3.44	4.89
	Communication	4.47	.380	3.60	5.00
	Creativity	4.31	.556	3.00	5.00
Mid	Critical Thinking	4.35	.435	3.73	5.00
	Collaboration	4.49	.415	3.78	5.00
	Communication	4.30	.495	3.40	5.00
	Creativity	4.39	.481	3.60	5.00

Pre-survey (n = 20) and Mid-survey (n = 16) descriptive statistics. Likert scale ranged from *Strongly Disagree (1)* to *Strongly Agree (5).* Group means show *Agree/SA* for both pre- and mid-survey on all four skills. Minimums show that no participants rated themselves negatively (*Disagree/SD)* on any of the four skills.

Appendix

TRAILS Survey Items

Adapted from T. R. Kelley, J. G. Knowles, J. Han, and E. Sung, "Creating a 21st century skills survey instrument for high school students," *American Journal of Educational Research*, vol. 7, no. 8, pp. 583–590, 2019.

Survey responses are on a five-point Likert scale from *strongly disagree* to *strongly agree*.

I am confident in my ability to:

1. revise drafts and justify revisions with evidence
2. develop follow-up questions that focus or broaden inquiry
3. create new, unique, surprising products
4. identify in detail what needs to be known to answer a science or engineering inquiry question
5. evaluate reasoning and evidence that support an argument
6. create ideas geared to the intended client or user
7. develop follow-up questions to gain understanding of the wants and needs of client or product users
8. combine different elements into a complete product
9. understand questions that lead to critical thinking
10. justify choices of evaluation criteria
11. gather relevant and sufficient information from different sources
12. be polite and kind to teammates
13. acknowledge and respect other perspectives
14. follow rules for team meetings
15. make sure all team members' ideas are equally valued
16. offer assistance to others in their work when needed
17. improve my own work when given feedback
18. use appropriate body language when presenting
19. come physically and mentally prepared each day
20. follow rules for team decision-making
21. use time, and run meetings, efficiently
22. organize information well
23. track our team's progress toward goals and deadlines
24. complete tasks without having to be reminded
25. present all information clearly, concisely, and logically
26. understand how knowledge or insights might transfer to other situations or contexts
27. find sources of information and inspiration when others do not
28. help the team solve problems and manage conflicts
29. adapt a communication style appropriate for the purpose, task, or audience
30. elaborate and improve on ideas

CATME Survey Items

From M. L. Loughry, M. W. Ohland, and D. J. Woehr, "Assessing teamwork skills for assurance of learning using CATME team tools," *Journal of Marketing Education*, vol. 36, no. 1, pp. 5–19, Apr. 2014. Publicly available and downloaded from: https://info.catme.org/instructor/teacher-materials/printable-surveys/)

	Your name					**Peer Evaluation** **Section Number _____** **Team Number _____** ← Write the names of the people on your team including your own name. This self and peer evaluation asks about how you and each of your teammates contributed to the team during the time period you are evaluating. For each way of contributing, please read the behaviors that rating. Then confidentially rate yourself and your teammates by placing a mark in the relevant box.
Contributing to the Team's Work						• Does more or higher-quality work than expected. • Makes important contributions that improve the team's work. • Helps to complete the work of teammates who are having difficulty.
						Demonstrates behaviors described in the row just above and just below.
						• Completes a fair share of the team's work with acceptable quality. • Keeps commitments and completes assignments on time. • Fills in for teammates when it is easy or important
						Demonstrates behaviors described in the row just above and just below.
						• Does not do a fair share of the team's work. Delivers sloppy or incomplete work. • Misses deadlines. Is late, unprepared, or absent for team meetings. • Does not assist teammates. Quits if the work becomes difficult.
Interacting with Teammates						• Asks for and shows an interest in teammates' ideas and contributions. • Improves communication among teammates. Provides encouragement or enthusiasm to the team. • Asks teammates for feedback and uses their suggestions to improve.
						Demonstrates behaviors described in the row just above and just below.
						• Listens to teammates and respects their contributions. • Communicates clearly. Shares information with teammates. Participates fully in team activities. • Respects and responds to feedback from teammates.
						Demonstrates behaviors described in the row just above and just below.
						• Interrupts, ignores, bosses, or makes fun of teammates. • Takes actions that affect teammates without their input. Does not share information. • Complains, makes excuses, or does not interact with teammates. Accepts no help or advice.
Keeping the Team on Track						• Watches conditions affecting the team and monitors the team's progress. • Makes sure that teammates are making appropriate progress. • Gives teammates specific, timely, and constructive feedback.
						Demonstrates behaviors described in the row just above and just below.
						• Notices changes that influence the team's success. • Knows what everyone on the team should be doing and notices problems. • Alerts teammates or suggests solutions when the team's success is threatened.
						Demonstrates behaviors described in the row just above and just below.
						• Is unaware of whether the team is meeting its goals. • Does not pay attention to teammates' progress. • Avoids discussing team problems, even when they are obvious.
Expecting Quality						• Motivates the team to do excellent work. • Cares that the team does outstanding work, even if there is no additional reward. • Believes that the team can do excellent work.
						Demonstrates behaviors described in the row just above and just below.
						• Encourages the team to do good work that meets all requirements. • Wants the team to perform well enough to earn all available rewards. • Believes that the team can fully meet its responsibilities.
						Demonstrates behaviors described in the row just above and just below.
						• Satisfied even if the team does not meet assigned standards. • Wants the team to avoid work, even if it hurts the team. • Doubts that the team can meet its requirements.
Having Relevant Knowledge, Skills, and Abilities						• Demonstrates the knowledge, skills, and abilities to do excellent work. • Acquires new knowledge or skills to improve the team's performance. • Able to perform the role of any team member if necessary.
						Demonstrates behaviors described in the row just above and just below.
						• Has sufficient knowledge, skills, and abilities to contribute to the team's work. • Acquires knowledge or skills needed to meet requirements. • Able to perform some of the tasks normally done by other team members.
						Demonstrates behaviors described in the row just above and just below.
						• Missing basic qualifications needed to be a member of the team. • Unable or unwilling to develop knowledge or skills to contribute to the team. • Unable to perform any of the duties of other team members.

Semi-Structured Interview Protocol

Interviewer Script:

Hello. My name is *(Researcher Name)*, and I will be asking you, *(Participant Name)*, questions about your experience in Engineering Design II. Do you consent having this interview recorded? Please state yes or no.

Undergraduate participant will state yes or no.

If they state yes, the interview will continue following the described protocol

If they state no, the interview will end

1. Why did you decide to enroll in EGR 4390?

2. Tell me about your design/capstone project. (If they signed an NDA for their project, encourage participant to speak generally and focus on general skills and scenarios.)

    a. Topic? General idea? Skills you used? Design process? Iteration?

3. Describe your best experience from this semester.

4. What was your brainstorming process like?

5. Were there any problems that needed to be addressed? Can you give an example and explain how you/your team tried to solve it?

6. Describe how your team worked together. Was there a clear leader or multiple? Were all ideas heard and valued?

7. What was your contribution to the team process and final product? How do you feel you did performing your role?

8. How was the communication with your clients? Was there anything that surprised you or that you learned in the process of client briefing, PDR, and CDR? (Preliminary design review, critical design review.)

9. How did you/your team determine the needs of the client and determine if you met those needs with the final product?

10. What skills do you think you developed over the semester?

    a. Your surveys noted that you did/did not grow in _____ (creativity/critical thinking/collaboration/communication).

b. Describe any experiences in this course that facilitated your development of _____.
c. Were any other courses or experiences in college impactful for you in developing _____?

11. Has this course had any effect on your future life, goals, or career?

12. What was your main takeaway from this course/experience?