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Evaluating Civil Engineering Student Perceptions of Competency-Based Education: A Pilot Study

Dr. Susan Lisa Hotle, Virginia Polytechnic Institute and State University

Dr. Susan Hotle is an Associate Professor in Virginia Tech's Department of Civil and Environmental Engineering. Her research focuses on aviation, transportation operations research, and travel behavior modeling, with an emphasis on data-driven approaches to understanding and improving system performance. She leads operations research projects across aviation enroute and surface transportation. Dr. Hotle is dedicated to innovative, evidence-based teaching methods, with previous research on student success in flipped classrooms.

Dr. Larry A Cox II, Virginia Polytechnic Institute and State University
Douglas Asante, Virginia Polytechnic Institute and State University

Engineering Student Perceptions of Competency-Based Education

Abstract

Competency-Based Education (CBE) is a learning environment where students progress through a defined set of competencies, advancing only after demonstrating mastery of the current competency. Unlike the traditional classroom, CBE provides a flexible learning schedule that includes multiple-attempt assessments paired with targeted feedback to support learning. While CBE is well-established in fields such as medicine and business, its application in engineering education remains limited. This pilot study examines civil engineering student perceptions of CBE. In Spring 2023, Introduction to Transportation was taught during a 16-week semester in a traditional format but taught in CBE during weeks 3–5. Overall trends showed that students preferred the CBE format over traditional, regardless of test anxiety level. Those reporting medium to high homework anxiety favored CBE, while students with low homework anxiety preferred the traditional classroom. Students generally found the CBE structure easier to navigate, though opinions were mixed regarding which environment best supported learning. Students viewed the traditional classroom as community-oriented, with stronger peer connections. They also described its rigid structure as stressful. Students appreciated CBE's flexibility, immediate feedback, and opportunities to learn from repeated attempts. However, some noted that the additional time required for retakes and individualized pacing occasionally led to feelings of isolation, as collaboration was limited to preserve assessment integrity. This exploratory pilot study's findings suggest changes to the CBE environment implementation to improve its future implementation in a civil engineering setting.

Introduction

Competency-based education (CBE) is a classroom where students complete material at their own individual pace through a list of defined core competencies (i.e. concepts). In this setting, students only continue to the next competency after "mastering" the current competency, where mastering is a minimum level of knowledge and understanding said to meet the necessary requirements (Cuyacot, Cuyacot 2022). This is in contrast to the traditional classroom and flipped classroom formats where students are expected to complete assignments and tests by specific dates and students move to the next topic after the homework or test regardless if the material was sufficiently understood. Also, unlike the traditional classroom, CBE provides a flexible learning schedule that includes multiple-attempt assessments paired with targeted feedback to support learning. CBE literature focuses on implementation in high-liability fields such as medicine, called Competency-Based Medical Education (CBME) (Fan, Wang, Chao et al, 2015) and business (Dragoo, Barrows 2016). Despite its application in other fields, there are currently limited empirical findings in literature on implementing CBE in a higher education engineering course.

To begin filling this knowledge gap, the purpose of this exploratory study is to evaluate student perceptions of the CBE classroom in an engineering course. In particular, this study explores how civil engineering students perceive the influence of the CBE environment on their learning processes, engagement, and sense of mastery. The CBE classroom was piloted in Introduction to Transportation, a junior-level course in the Department of Civil and Environmental Engineering

(CEE) at Virginia Tech. After defining the core competencies using civil engineering governing bodies guidelines, a study was conducted where one instructor taught part of the semester using the traditional classroom environment and the remaining part using CBE. Student perceptions were measured using an end of course survey. The main motivation for this study stems from the importance of engineers to have a deep understanding of the material and "why things are done the way they are." However, the single-attempt assessments in traditional classrooms can lead to a high-pressure environment when learning the content, resulting in students focusing on what is needed to attain a good grade instead of a deep understanding of the course material.

Literature Review

Engineering courses typically follow a traditional classroom or flipped classroom model with grade-based measurements to gauge student success throughout the duration of the course. These classrooms are dependent on single-attempt, scheduled assessment activities and coursework, which result in an A-F final grade ranking. However, given the grading scales and pre-determined course schedule, these classrooms can frustrate students if they move at a slower or faster pace than the rest of the class. Literature shows that A-F grade-based systems cause stress to students that leads to negative effects on their education. For example, switching an A-F course with pass/fail grading was found to "reduce stress, foster positive mood, and enhance a sense of group cohesion" across the students (Rohe et al., 2006). Similarly, another higher education study found that "grades did not enhance academic motivation. Instead, grades enhanced anxiety and avoidance of challenging courses" (Chamberlin et al., 2023).

CBE is an instructional design approach that centers on clearly-defined competencies, meaning the knowledge, skills, and abilities learning requirements, rather than on the amount of time spent in class (Strategy Labs, 2017). This model acknowledges that learning does not occur uniformly for all students and developing expertise may require multiple attempts. Within this framework, setbacks are treated as part of the learning process. Assessments are structured around demonstrated mastery, allowing students to move through course material at varying speeds according to their individual progress and learning needs.

In a CBE course, instructors first determine the essential competencies students must achieve and then design evaluations that assess student mastery of those competencies. Competencies extend beyond factual knowledge to include the skills, dispositions, values, and observable behaviors necessary to carry out specific tasks effectively in practical settings (Brophy and Kiely 2002; Morris et al., 2013). Once students demonstrate mastery of a competency, they advance to more complex competencies that rely on previously mastered competencies (Strategy Labs 2017). Advancement is therefore determined by verified learning rather than by the academic calendar. In contrast to many traditional or online courses that maintain a fixed semester structure, CBE models grant credit when students show that they have achieved the required learning outcomes (McClarty and Gaertner, 2015).

Methodology and Data

Introduction to Transportation (CEE 3604) covers 8 modules spanning topics of highway system design, including horizontal/vertical curves road design, signal timing, traffic flow theory and queueing theory. This study implemented CBE for Module 3 which contains the topics:

designing highway vertical curves, designing highway horizontal curves and checking for sight distance issues in the design of highways. Designing horizontal and vertical curves involve calculating the roadway alignment so vehicles can travel safely at the intended design speeds. Horizontal curves represent changes in roadway direction and are designed by selecting the appropriate radii and roadway superelevation while maintaining adequate sight distance for drivers. Vertical curves provide transitions between changes in roadway grade. They are designed to ensure sufficient sight distance for crest curves and sag curves, consistent with safety guidelines that relate curve length to grade differences.

Module 3 spanned across weeks 3-5 in the 16-week semester. All other modules were taught in the traditional format. Therefore, the study started and ended as a traditional course, with 3 weeks of CBE in the middle. Students could retake the Module 3 competencies as the course proceeded through Module 4, giving a longer flexible timeline to the CBE competency completion while meeting the fixed semester timeline of the university.

The requirements from general engineering and civil engineering governing bodies were used to define the competencies. This includes the ABET Criteria for Accrediting Engineering Programs (ABET, 2022), ASCE's Civil Engineering Body of Knowledge (ASCE, 2019) and National Council of Examiners for Engineering and Surveying's (NCEES) Fundamentals of Engineering (FE) Exam Specifications (NCEES, 2022) and formula book. The applicable competencies were:

1. Ability to identify, formulate, and solve engineering problems
2. Ability to design a system, component, or process to meet desired needs within realistic constraints
3. Critical Thinking

As shown in Table 1, there was a many-to-many relationship between the competencies and assessment questions. For example, the competency of "Formulate & Solve" within the topic of vertical curves could span several problems and assessments. The CBE classroom included 2 homework and 1 quiz assessments. The typical CBE set up was revised to fit the limitations of Canvas, the course's Learning Management System (LMS), and the instructor's limited ability to enforce the honor code in the CBE environment (students should not work with together on the quiz, but could work together on the homework assessments). For example, the LMS gave students infinite chances at the assessments and immediate results. They were informed of how many questions they got correct, but the incorrect problems were not identified. Feedback was provided on problems if their answer indicated a common sub-calculation error (e.g. "Something is off about your K value"). The assessments were static where the problems did not change. If a student retried the assessment, they would have to answer all problems again as the LMS could not remove the problems that had already been successfully solved. The highest score ever attained was the final outcome noted for the student.

In summary, the CBE version of the course differed from the traditional in two main aspects as defined in literature. First, CBE aligned the assessments with the core competencies defined by the civil engineering education governing bodies ABET, ASCE and NCEES while covering the topics of the course. In Table 1, the topics of the course are on the first row (e.g. Vertical

Curves) and the required competencies from ABET, ASCE and NCEES are on the second row (e.g. Formulate & Solve). There were a total of six competencies, as shown in Table 1. The CBE classroom included 2 assessments and 1 quiz. Table 1 illustrates an example of how the assessments problems had a many-to-many link with the competencies. Second, CBE increased the flexibility with the competency assessment timeline, allowing for reattempts and failure as part of the learning process.

Table 1: Example competency mastery assessment matrix

	Vertical Curves			**Horizontal Curves**		
	Formulate & Solve	Design to Meet Desired Needs	Critical Thinking	Formulate & Solve	Design to Meet Desired Needs	Critical Thinking
Assessment 1						
Problem 1	X					
Problem 2	X	X				
Problem 3		X	X			
Assessment 2						
Problem 1				X	X	
Problem 2					X	X
Problem 3	X	X		X	X	

For spring 2023, there were 42 students enrolled with 29 students completing the study's end of semester survey. Table 2 presents summary statistics for the survey respondents, providing an overview of the study participants' demographic and academic characteristics. All but one of the study participants were between 18 and 23 years old. The study participants consisted mostly of third year and fourth year college students. The majority of respondents identified as male, and most did not identify as Hispanic, African American, Pacific Islander, or Native American. Nearly all participants reported English as their first language. With respect to academic major, most students were enrolled in Civil and Environmental Engineering, followed by Industrial Engineering. Finally, while a majority of participants indicated they were not employed in addition to being students, a subset reported holding a job during their studies. For each of the demographic questions, many of the categorical answers had a small sample size. This prevented statistically significant comparisons across cross-sections of the sample based on a characteristic. Therefore, the study results only discuss the findings for the entire sample.

Table 2: Summary statistics of survey respondents

Question	Group	Count
What is your age in years?		
	18-20	15
	21-23	13
	24-26	1
	27 or older	0
	Prefer not to say	0
How many years have you been in college/post-secondary education?		
	This is my Second year	4
	This is my Third year	17
	This is my Fourth year	7
	This is my Fifth year	0
	More than Five years	1
	Prefer not to say	0
What is your sex?		
	Female	8
	Male	21
	Prefer not to say	0
Are you Hispanic, African American, Pacific Islander or Native American?		
	No	26
	Yes	3
	Prefer not to say	0
Is English your first language?		
	No	2
	Yes	27
	Prefer not to say	0
What is your major?		
	Construction Engineering and Management	1
	Civil & Environmental Engineering	24
	Industrial Engineering	4
	Prefer not to say	0
Do you have a job in addition to being a student (are you employed)?		
	No	21
	Yes	6
	Prefer not to say	2

Results

Table 3 outlines student self-reported anxiety levels and their views on the traditional vs CBE classroom. Statistical significance could not be measured due to low sample sizes. Students preferred CBE over traditional, regardless of test anxiety level. Students with medium to very high homework anxiety preferred CBE, but students with low to very low homework anxiety preferred the traditional classroom. These findings suggest that perceived structure and flexibility in CBE environments may help mitigate anxiety for certain student groups. The difference in preferences among students with lower homework anxiety may indicate that traditional formats provide sufficient clarity for those learners in a less flexible environment.

In Table 4, students found CBE to be an easier learning environment to navigate, but were divided on which environment best supported their learning. It seems students each preferred one of the classrooms over the other, where no student responded with the classrooms supported their learning about the same. This means there are two distinct groups of learners in this study.

Future work should explore these trends with larger samples to better assess statistical significance and underlying factors correlated with preference between the two classrooms.

Table 3: Student anxiety levels vs classroom type

	Traditional					CBE					
	I hate it	**I don't like it most of the time (I dislike it more than I like it)**	**I like it most of the time (I like it more than I don't like it)**	**I love it**	**Prefer not to say**	**I hate it**	**I don't like it most of the time (I dislike it more than I like it)**	**I like it most of the time (I like it more than I don't like it)**	**I love it**	**Prefer not to say**	**Total**
What in your level of anxiety regarding test taking?											
Very High	1	1	2	1				1	3	1	**5**
High		4	6	1		1	2	5	3		**11**
Medium	1		11	1		1	1	6	4	1	**13**
Low											**0**
Very Low											**0**
What in your level of anxiety regarding homework?											
Very High	1		1						1	1	**2**
High		2	2	1				3	2		**5**
Medium	1	2	6	2			1	3	6	1	**11**
Low			9			2	2	5			**9**
Very Low		1	1					1	1		**2**
TOTAL	**2**	**5**	**19**	**3**	**0**	**2**	**3**	**12**	**10**	**2**	**29**

Table 4: Course design preference

	Competency-Based	**They were the same**	**Traditional**	**Prefer not to say**	**Total**
Which was easier to navigate?	12	11	5	1	**29**
Which supported your learning better?	16	0	12	1	**29**

Students were then asked to provide the pros and cons of each classroom in a free response format, with the most common responses summarized in Table 5. Students found the traditional classroom to be more engaging and they felt they learned the information better. Students felt more connected to others in the classroom and, therefore, felt they had more community and support in the learning process. However, the traditional classroom was more rigid in structure, causing students to feel stressed.

Students found the CBE classroom to be more flexible and easier to learn the content. Also, they liked the ability to get immediate results from their assessments and the ability to retake the assessments as many times as they wanted. This allowed them to learn from mistakes. However, there were aspects of this flexibility that students disliked. Retaking the assessments took more time than the “one and done” traditional classroom assessments. Students felt they did not learn the material as well compared to the traditional course in terms of long-term memory. Also, since students were going at different paces and unable to help each other (prevent from copying answers), this caused some to feel isolated from their peers in the learning process. This reduced interaction appeared to weaken students’ sense of community within the classroom. These findings suggest that while CBE supports individualized learning, additional strategies may be needed to foster peer connection and engagement.

Student comments on the negative aspects of CBE provided how to improve future iterations of CBE. First, students stated that CBE made them feel isolated and unable to ask questions. The class had regularly scheduled office hours outside of class, two in-class session per week and the instructor’s and Teaching Assistant’s (TA) emails if they had questions. However, it seems having each student going at their own pace, focusing on different material at any point in time caused them to feel like they could not ask questions to the instructor or TA. Second, one student commented that CBE caused them to rely on others more than themselves. For both the CBE module and traditional classroom modules, students were asked not to work together on the quizzes, however could work together on the homework assessments. This means the CBE course is dependent on honor code policies that are nearly impossible to enforce. To make dynamic questions in CBE (multiple questions fulfilling the exact same topics and competencies) would require significant course planning and LMS design flexibility. Third, students brought up that sometimes the incorrect answer was in the LMS system or the margin of error accepted on an answer was too small. The workload for planning assessment problems, working out the problems correctly for the key and incorrectly to give immediate system feedback with comments on the most-common errors requires a lot of bandwidth from the instructor. Overall, while students ranked the CBE classroom higher than the traditional classroom, the workload to create a CBE course is substantially more time-consuming for the instructor in order to do it well.

Table 5: Pros and cons by classroom

	Pros	Cons
Traditional Classroom	- Discussing with students and teacher, socializing with peers - Studied more, knew information better - Students have to push harder - Able to get help more - Meeting others - In-person guidance - Set time to ask questions - Takes less time, one and done - Partial credit	- Boring, not as engaging - Stressful exams, stressful in general - Performing under pressure - Not flexible - Time constraints - Inability to do multiple attempts - Not self-paced - One chance, even if it is a day you are not performing well - Grading is unforgiving
CBE Classroom	- Easier, less stressful - Can make mistakes, multiple chances, trial-and-error learning - Less studying - Immediate results/grades - Flexibility/easier to learn content - Had to learn from mistakes - Change pace, quicker/slower	- Did not study as much, therefore did not learn the material as well. Less prepared for assessments - Easy to rely on others and not learn material for yourself - Only final answers mattered, no partial credit - Not seeing which questions were right/wrong - Procrastination - Incorrect answers in the learning system - Need more feedback on what did right/wrong in the system for answer - Answer margin of error - Less interaction in the learning process and in-class - Less thought-provoking

Conclusions and Future Research Recommendations

Findings from this exploratory pilot study show CBE could be a promising learning environment for engineering courses and programs. They show the CBE classroom requires careful planning as there are several pitfalls that can occur when trying to modify university LMSs and course curriculum logistics to a CBE design. Therefore, this type of classroom in the engineering setting should only be attempted with significant upfront planning and instructor workload bandwidth. Future research should consider conducting similar studies with a larger sample size to provide statistically significant findings. Future studies should also consider longer study durations, preferably the entire semester instead of a few weeks within the semester. Also, performing CBE studies on courses with more diverse student demographics would be beneficial in detecting if there are demographics that prefer each of the classroom types. This study did not have the sample size and diversity of participants to complete statistical testing between groups listed in Table 2 to see if the CBE vs traditional classroom varied by demographic.

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