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Work in Progress: Improving Students' Achievement on Summative Exams in Large Undergraduate Engineering Classes: Taking Advantage of Online Formative Assessments

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Improving Students' Achievement on Summative Exams in Large Undergraduate Engineering Classes: Taking Advantage of Online Formative Assessments

Abstract

Testing has been found to help students retain studied information as well as potentiate new learning. Anxiety associated with high-stake testing however hinders students' learning. Formative assessments are characterized by testing for the purpose of identifying and correcting misconceptions. These tests are completely optional and have no bearing on students' final grades, and hence address the concern of test anxiety. These characteristics make formative assessments as the most favorable intervention to help students' learning retention and hence achievement on summative exams. However, large class sizes, particularly in fundamental engineering courses, make it difficult for instructors to frequently administer formative assessments and provide personalized feedback to students. Recent advances in in educational technologies and learning management systems facilitate instructors to administer frequent formative assessments, evaluate students' learning and provide timely feedback.

This research investigates the students' participation in completely optional, online formative assessments and its relationship with their achievement on summative exams in a large undergraduate Fundamentals of Electronics course. Sample includes of 820 students enrolled in the course over 7 semesters (spring 2018 – spring 2021). Data includes participation of students in 12 formative assessment quizzes with automatic conceptual feedback, and their scores on three midterm and one final (summative) exams.

Preliminary findings suggest that female students had higher formative assessment participation (FAP) compared to male students. The analysis also showed significant positive correlations between students' FAP and their achievement on summative exams. Both FAP as well as its relationship with students' exam scores favored female students, however some of the relationships were not statistically significant. The lack of significance might be attributed to smaller group sizes of female participants. Future work includes a qualitative investigation to explore and understand reasons and motivations for differential FAP and its relationship with students' summative achievement. This study has implications for students' self-regulated and self-directed life-long learning.

Keywords: Formative Assessment, Summative Assessment, Achievement, Engineering Education, Self-Directed Learning

1. Introduction

Research literature shows promising effects of testing in helping students retain studied information [1 – 5] as well as potentiate learning of new concepts [6 – 9]. Literature shows that *additional exposure*, *retrieval effort*, *transfer-appropriate processing of information*, and *intrinsic and extrinsic motivation* associated with testing provide possible explanations for these testing effects [10]. Testing has traditionally been used to assess students' learning to assign grades and make decisions on their progression to the next level [1]. High stakes associated with

testing in the form of extra rewards and weightages in the final grading have found to induce test anxiety [11 – 12]. The detrimental effects of test anxiety on students' learning calls for no-stake testing to capitalize on its positive effects while avoiding test anxiety. This makes formative assessment as the most favorable intervention to help students' learning.

Formative assessment is distinguished from summative assessment both in terms of purpose and timing [13]. *Summative assessment* is the *"assessment of learning"*, usually terminal to a module, topic, chapter, or semester, and is used to assign grades and make decisions on students' progression to the next level. *Formative assessment* on the other hand is the "*assessment for learning"* and occurs during the process of learning a module or topic to receive timely feedback. This feedback is then used by instructors to adjust and improve their instruction and by the students to reflect on their own learning, correct their misconceptions, and revise their learning strategies at an early stage. Providing students with the opportunity to self-assess their learning, receive feedback, identify, and correct misconceptions, and revise and refine their learning strategies has implications for promoting self-directed, self-regulated life-long learning.

Large class sizes (particularly in fundamental engineering courses make it difficult for instructors to frequently administer formative assessments for practice purposes and provide personalized feedback to students. Fortunately, recent developments in educational technologies have made it possible to facilitate instructors to automatically administer frequent assessments, evaluate students' performance, and provide feedback to students.

Purpose of the Study

The purpose of this study is to investigate students' participation in completely optional, online formative assessments and its relationship with their achievement on summative exams in a large undergraduate Fundamentals of Electronics course. This work in progress is guided by the following two research questions:

RQ#1: What are the trends in undergraduate engineering students' participation in completely optional online formative assessments in a fundamental engineering course?

RQ#2: What is the relationship between students' formative assessment participation in completely optional, online formative assessments and their achievement on summative exams in a fundamental engineering course?

2. Brief Literature Review

Extensive prior research has shown auspicious effects of formative assessment to improve students' learning and achievement on summative exam scores [14] [15], [16] across a variety of disciplines and at all levels of education [10]. Pick and Cole [14] found significant improvement in students' learning outcomes, engagement, and satisfaction levels in a large class of undergraduate aerospace, mechanical and product design engineering students, studying first-year fluids and thermodynamics course. They concluded that formative assessment and feedback informed students' learning strategies to engage effectively in the online course. Similarly, Cummings (2020) found significant positive correlations between students' formative

assessment participation and their achievement on summative exams in undergraduate mechanical engineering classes studying thermodynamics and heat transfer courses [15]. O'Connell [16] administered formative assessments in part of electric circuits' theory course. Results indicated a significant improvement in students' summative exam scores on part of the course which was formatively assessed. These findings establish that formative assessment can be positively associated with students' achievement on summative assessments.

3. Methods

Design of the study

This study is based on quantitative analysis of students' formative assessment participation and their achievement (scores) on summative exams. Students were offered formative assessments in the form of extra practice quizzes. Since these quizzes had no bearing on students' final grades, students were not obligated to participate in these quizzes. The voluntary nature of participation helped eliminate bias and capture students' natural quiz-taking behavior in data collection, referred to as natural design [17]. All data for this IRB approved study is secondary in nature and were received from Academic and Instructional Services (AIS) department of the educational institution in de-identified form. The data are free of self-report bias.

Context and participants of the study

Fundamentals of Electronics for Engineers is a mandatory fundamental course offered to all undergraduate engineering students every semester. The course is enrolled by 100 to 200 students every fall and spring semester. Participants of this study include 820 students (656 males and 164 females) who enrolled and completed this course between spring 2018 and spring 2021. Students who studied the course in summers were excluded from the study due to differences in structure and duration of the course in summer semesters. The course was taught by the same instructor, presenting the same materials, with all the students having equal access to the same online resources.

The course facilitator (co-author) developed 12 practice quizzes each comprising 10 multiple-choice questions, each with only one correct answer. Each question presented 3 distractors in addition to the correct answer. Answer choices were carefully chosen so that students cannot eliminate the wrong answers easily and apply problem-solving strategies to find the correct answer.

Information about the practice quizzes was equally disseminated to all students through canvas announcements, syllabus, and orientation class. Students were explicitly informed that there is no limit on frequency or duration of attempts. Students were also informed that these quizzes will have no bearing on their final grades. Each quiz offered minimal feedback showing correct answer, and single line description of the concept/law/theory required to solve the problem correctly. The feedback was always displayed even in case of getting the question right to reinforce the concepts. Figure 1 below shows an example of feedback after submission of the quiz:

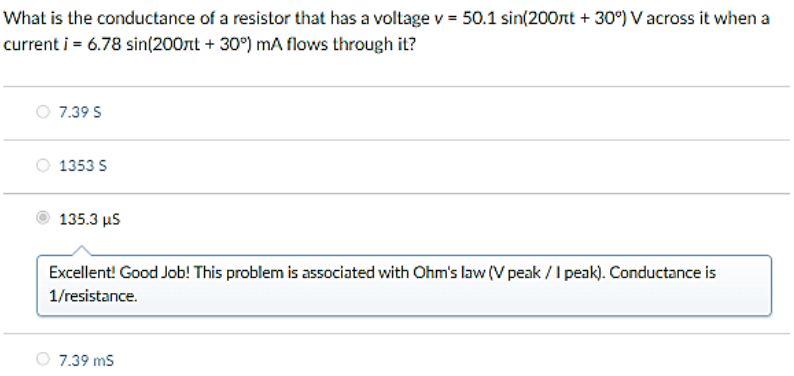

Figure 1: Example of Minimal Automatic Feedback to Students

Summative assessments in this course comprised 11 weekly homework, 7 lab tasks, 3 midterm exams and 1 comprehensive final exam. Summative exams offered similar level of difficulty and contents to be comparable to practice quizzes. Participants had 60 minutes for each midterm exam and 120 minutes for the comprehensive final examination to complete.

Data collection

Formative assessment participation data for each student include total number of quizzes attempted, number of attempts on each quiz, and average score on each quiz. *Achievement on summative exams* included each students' percentage scores on three (03) midterm and one comprehensive final exam, and their overall grades in the course. Course grades were calculated based on their performance on all summative components (including exams, lab tasks, and homework).

Variables and Measures

Measure of student's participation in each quiz was adopted from Forster, Weiser and Maur [17]. They considered a quiz to be actively processed by the student if the student had correctly answered at least 10% of the quiz questions. In our research we used a hurdle of 50% achievement on a practice quiz to be considered as actively processed. The researchers assumed that 50% achievement on a quiz possibly eliminate any attempts to blindly guess the answers for the quiz.

Since the course included 3 midterm exams in three different sets of modules and one comprehensive final exam covering all 12 modules, students' formative assessment participation (FAP) was measured at four different stages indicated by four different variables. Each variable below indicates number of actively processed quizzes corresponding to each summative exam in percentage terms as shown below:

FAP1: No. of actively processed quizzes before Exam1 (corresponding to module 1 – 4)
FAP2: No. of actively processed quizzes before Exam2 (corresponding to module 5 – 8)
FAP3: No. of actively processed quizzes before Exam3 (corresponding to module 9 – 11)
TFAP: No. of actively processed quizzes (corresponding to module 1 – 12)

4. Data analysis and preliminary findings

The data were predominantly continuous in nature and participant could be grouped based on gender and FAP participations. Therefore, *t-tests and correlational* analysis were carried out to find any significant mean differences (based on gender and FAP), and relationships between variables of interest to answer the two research questions. This work in progress (WIP) reports the preliminary findings about students' FAP trends and its relationship with their achievement on summative exams. Gender differences in FAP and its relationship with summative achievement are also reported.

Formative assessment participation and gender differences

Descriptive analysis shows that sample included 20% females which is representative of national average of female enrollment in engineering disciplines. Approximately the same ratio of female participants appears in all semesters except for spring 2020 (11% females). A total of 75% male and 82% female students actively processed at least one quiz. However, smaller group size of non-participant females might not produce significant results. Distribution of participants based on gender and 5 different levels of FAP participation as shown in Table 1, revealed that cumulatively more males (56.7%) fall into no participation, low participation and medium participation categories compared to females (47%). On the other hand, cumulatively more females (53%) fall in moderate to high participation groups compared to males (43.3%).

Table 1: Gender Difference in Formative Assessment Participation

	Students' Participation Rank (Percentage of Actively Processed* Quizzes)				
Gender	No Participation (0%)	Low Participation 1% – 25%	Medium Participation 26% - 50%	Moderate Participation 51% - 75%	High Participation 76% - 100%
Male (*N = 656)*	27.3% (179)	16.6% (109)	12.8% (84)	14.5% (95)	28.8% (189)
Female (*N = 164)*	22% (36)	12.8% (21)	12.2% (20)	13.4% (22)	39.6% (65)

**Actively processed refers to an achievement of at least 50% of maximum achievable points*

Independent sample t-tests showed statistically significant mean differences in overall formative assessment participation (TFAP) between male and female participants. On the average, FAP of female participants 7.18% higher than males (Cohen's *d* effect size of 0.23). However, there were no statistically significant mean differences in FAP based gender before individual exams.

Formative assessment participation and learning achievement

Correlational analysis shows that participants' FAP corresponding to each exam was positively correlated with their performance on that exam (see table 2). For example, FAP1 (i.e., formative assessment participation in all modules corresponding to exam1) is positively correlated with students' achievement on exam1. All the correlations were statistically significant at $p < .01$. Similarly overall participation (i.e., TFAP) was significantly positively correlated with students' achievement on final exam ($p < .01$).

Table 2: Correlations between formative assessment participation (FAP) and summative exam scores

	Exam1	Exam2	Exam3	Final Exam	TFAP	FAP1	FAP2	FAP3
Exam 1	1							
Exam 2	.498**	1						
Exam 3	.429**	.550**	1					
Final Exam	.492**	.574**	.569**	1				
TFAP	**.195****	**.320****	**.341****	**.274****	1			
FAP1	**.221****	**.246****	**.241****	**.242****	**.657****	1		
FAP2	**.163****	**.243****	**.300****	**.253****	**.725****	**.216****	1	
FAP3	**.121****	**.246****	**.255****	**.307****	**.627****	**.290****	**.329****	1

**Correlations are significant at $p < 0.01$ level (2-tailed)

Independent Sample t-tests showed that students who participated in at least half of the formative assessments corresponding to a summative exam, achieved higher mean scores on the exam compared to those who participated in less than half of these assessments. All these differences were statistically significant (but low Cohen's *d* effect sizes). Comparison between non-participant group (i.e., TFAP = 0%) and participant group (TFAP > 0%) revealed that participants who actively processed at least one formative assessment quiz, on the average scored higher than those who did not participate in any formative assessment.

Male participants with more than 50% FAP, on the average achieved significantly higher scores on all summative exams compared to males with less than 50% FAP. On the other hand, females with more than 50% FAP achieved statistically significantly higher scores only on final exam compared to those with less than 50% FAP. Differences in achievement on midterm exams were not statistically significant. As mentioned earlier, this lack of statistical significance might be attributed to smaller group size of female participants.

Analysis of students' overall grades in relation to FAP shows an interesting trend. Figure 2 below shows for each letter grade the split between high FAP (blue bars) and low FAP (orange bars) students. It is encouraging to see high percentage of high FAP students (blue bars) in higher grades. This indicates higher FAP correlated with better achievement scores (grades). However, it can also be seen that there are some percentages of students with low FAP (orange bars) achieving A and B grades. Similarly, there are high FAP students (blue bars) in C and D grade groups. The most interesting of all is B grade cohort which is an equal mix of high FAP and low FAP students. These trends call for an in-depth, quantitative and qualitative investigation to understand the reasons and motivations behind why some students participate in formative assessments while other do not. Moreover, how do these reasons and motivations explain the differential relationships between FAP and achievement on summative exams as emerging in figure 2 below?

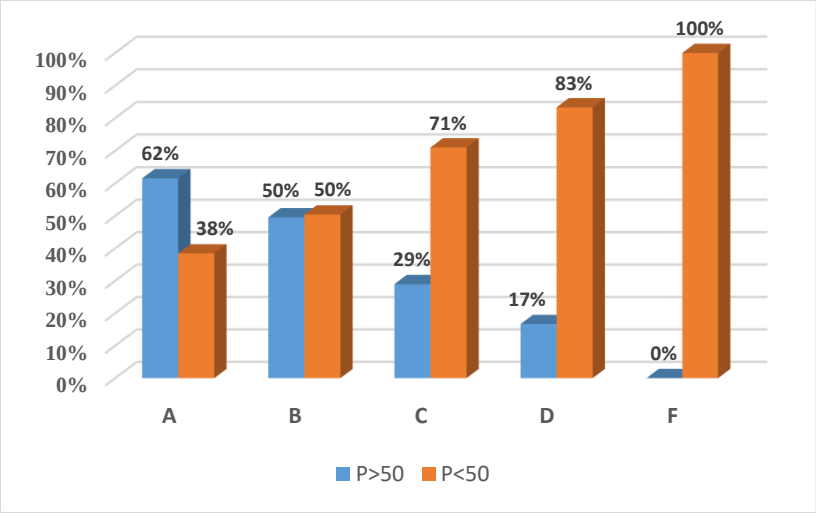

Figure 2: Formative Assessment Participation vs. Learning Achievement (Final Grades)

5. Discussion and Conclusions

The preliminary findings are very encouraging as majority students participated in formative assessments. Gender-based mean differences in overall formative assessment participation partially verify existing research findings [17], that female students rely on extra learning resources (e.g., formative assessments), more than male students. Significant positive correlations between participants' FAP and their achievement on summative exams in combination with significant mean differences in achievement based on FAP strongly support findings in the existing literature. However, unique trends as revealed in figure 2, need further qualitative and quantitative investigation.

Current study is limited by several factors. For example, students' achievement on summative assessments and even their formative assessment participation might be attributed to their personalized study habits. This research also did not control for students' use of other learning resources (e.g., homework, textbook, video lectures, and lab tasks etc.). To establish causality, future studies must control for confounding variables which might provide alternative explanation for these relationships.

6. Future work

Future work includes a qualitative investigation into the reasons and motivations behind students' differential FAP and its relationship with their achievement on summative exams. The qualitative investigation will also try to explore ways to improve these formative assessments and enhance students' motivation to participate in these assessments.

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