Exploring perspectives and experiences of diverse learners' acceptance of online educational engineering games as learning tools in the classroom

Kimberly Cook-Chennault
Mechanical & Aerospace Department., Educational Psychology Department., Biomedical Engineering Department.
Rutgers, the State University of New Jersey
Piscataway, NJ, USA
cookchen@soe.rutgers.edu

Idalis Villanueva
Department of Engineering Education.
University of Florida
Gainesville, FL, USA
i.villanueva@ufl.edu

Abstract**—** This Research Full paper focuses on perceptions and experiences of freshman and sophomore engineering students when playing an online serious engineering game that was designed to improve engineering intuition and knowledge of statics. Use of serious educational engineering games has increased in engineering education to help students increase technical competencies in engineering disciplines. However, few have investigated how these engineering games are experienced by the students; how games influence students' perceptions of learning, or how these factors may lead to inequitable perspectives among diverse populations of students.

Purpose/Hypothesis: The purpose of this study was to explore the perceptions, appeal, and opinions about the efficacy of educational online games among a diverse population of students in an engineering mechanics statics course. It was hypothesized that compared to majority groups (e.g., men, White), women of color who are engineering students would experience less connections to the online educational game in terms of ease of use and level of frustration while playing. It is believed that these discordant views may negatively influence the game's appeal and efficacy towards learning engineering in this population of students.

Design/Method: The Technology Acceptance Model (TAM) is expanded in this study, where the perspectives of women of colour (Latinx, Asian and African American) engineering students are explored. The research approach employed in this study is a mixed-method sequential exploratory design, where students first played the online engineering educational game, then completed a questionnaire, followed by participation in a focus group. Responses were initially analyzed through open and magnitude coding approaches to understand whether students thought these educational games reflected their personal culture.

Results: Preliminary results indicate that though the majority of the students were receptive to using the online engineering software for their engineering education, merely a few intimated that they would use this software for engineering exam or technical job interview preparation. A level-one categorical analysis identified a few themes that comprised unintended preservation of inequality in favor of students who enjoyed contest-based education and game technology. Competition-based valuation of presumed mastery of course content fostered anxiety and intimidation among students, which caused some to "game the game" instead of studying the material, to meet grade goals. Some students indicated that they spent more time (than necessary) to learn the goals of the game than engineering content itself, suggesting a need to better integrate course material while minimizing cognitive effort in learning to navigate the game.

Conclusions: Preliminary results indicate that engineering software's design and *the way is* coupled with course grading and assessment of learning outcomes, affect student perceptions of the technology's acceptance, usefulness, and ease of use as a "learning tool." Students were found to have different expectations of serious games juxtaposed software/apps designed for entertainment. Conclusions also indicate that acceptance of inquiry-based educational games in a classroom among diverse populations of students should clearly articulate and connect the game goals/objectives with class curriculum content. Findings also indicate that a multifaceted schema of tools, such as feedback on game challenges, and explanations for predictions of the game should be included in game/app designs.

Keywords**—***Engineering Education, Online Games, Technology Acceptance Model*

I. Introduction

Over the last two decades, digital serious games and online learning software/apps have become ubiquitous in US classrooms. For example, educational video games used to enhance the engagement and subject mastery of undergraduate students (UGs) in several fields such as: physics [1], spatial learning [2], general engineering [3], computer science [4], mechanical engineering (ME)[5-7], software and electrical engineering [8], aerospace engineering [9], and computer aided design [10]. However, scarce studies have examined how the *way these games/apps are infused* into courses, affects student motivation to learn and accept video game technology as learning tools in their engineering classes. And, even fewer of these studies have examined the *appeal* and *efficacy* of these online educational games' (in an undergraduate classroom environment) taking into account gender differences. Joiner et al. [11], used "Race Academy", (an engineering learning game) in a mechanical

XXX-X-XXXX-XXXX-X/XX/$XX.00 ©20XX IEEE

engineering class comprising 138 UGs (11% women) and concluded that there was no significant difference between men and women students in "motivation towards engineering" (4.2 ± 0.5, pre- and post-survey results for women) or in "perceived engineering competence" (3.4 ± 0.7, pre-survey to 3.3 ± 0.4, post-survey for women). There are very little *undergraduate studies that have examined the impact of engineering games/apps as a function of engineering subgroup population, e.g. race/ethnicity, sexuality, student age, gender, or intersectional subgroups comprising students who fall into multiple subgroup populations*. This paper represents a first step in this direction.

Gender and race are not mutually exclusive. Instead, engineering subgroup populations can intersect in a myriad of ways that influence the *intersectional* experiences of women in multiple settings according to Crenshaw [12, 13]. The role that gender *and* race play in students' responses to online educational tools/software that engineering educators use in their courses and the role they play in forming engineering perceptions about the field are both understudied areas in engineering education.

This study elucidates how freshman and sophomore engineering students accept this serious engineering game/software as a tool in learning engineering mechanics (statics) content. Statics is one of (if not the first) the engineering courses <u>all</u> engineering majors encounter in their journey towards a bachelor's degree in engineering.

A. Technology Acceptance Model

The Technology Acceptance Model, developed by Davis [16], states that individuals' adoption of information technological systems is linked to and is a function of two primary variables: users' *perceived usefulness* and the *perceived ease of use* of the technological system. In other words, people will use or not use an application/tool to the extent that they believe that the tool will enable them do their jobs better[14]. However, according to the TAM, if people deem the level of effort needed to use the tool is *too hard*, they will abandon use of the technology, if they believe the benefits of use do not outweigh the effort.

B. TAM in Educational Games and Engineering Education

The extension of the TAM model to include the intersectionality of race and gender in engineering is an area only studied by the authors [15, 16] to date, though several have been expanded this model to account for gender or race in general education of middle and high school students and undergraduate computing education. For example, Bourgonjon et al., [17] used a modified TAM model to examine 858 Flemish secondary school students' (ages 12 – 20) preference for video game usage (results averaged across broad subject/disciplines) as educational tools *in general* and found that students' perceptions of usefulness and ease of use were directly related to students' perception of the games' opportunities for learning within the games, where responses varied according to student gender. This group also noted that differences in gender were *mediated by experience with and ease of use of the game*[17]. Porter et al., [18] extended the TAM model to explain differences in internet acceptance between younger/older, less/well educated, White/minority and lower/high income Americans learners, and concluded that while barriers to access was an important effect in the model, the ease of use and usefulness had stronger effects in terms of game acceptance. Hwang et al., [19] applied an extended TAM model to explore 6th grade Taiwanese children's acceptance of a game to explain differences in boys/girls' cognitive load and competition anxiety when playing synchronous and sequential forms of the game. Differences in load and anxiety were found between gender. The study concluded by stating that game designers should consider reducing competition anxiety and cognitive load by extending time-frames for sequential competition to enhance the efficacy of the games for female students [19]. Rajan et al., [20] examined the impact of the video game, "Engineering Heights – The Design Process in Action" on a group of high school seniors and found that on average, majority of the students' perceived usefulness (3.31), perceived subject matter learning (3.75) and ease of use (3.60) were good.

II. Research Questions and Design Method

The engineering game/app examined was designed to improve student's intuition and understanding of engineering mechanics and statics concepts by having students design truss structures in the game. First, students played the engineering game, then completed a questionnaire with questions designed to garner their prior experiences with the educational and entertainment online games/apps. Subsequently, students participated in focus groups. The focus group was designed to obtain students' perceptions about the game software used within a engineering course environment. The subjects participating in the study represented a diverse population of engineering undergraduate students. This diverse population of students allowed for the analysis of their perceptions in terms of gender and race/ethnicity.

A. Research Study Questions

The project goals of this study included exploration of the perceived ease of use and usefulness of an online engineering educational game/app from the perspective of a diverse population of freshman and sophomore engineering students through the lens of the TAM [16]. <u>Specifically, this work focused on determining if students' perceptions of the tool differed according to participant gender and race; and whether this students expected/wished aspects of their ethnicity or culture to be included in the app.</u> The research method used for the study was a Mixed-Method Sequential Exploratory Research Design Approach that was approved by a cross-institutional Institutional Review Board that was approved for both authors in this study. The study took place at a Tier-1 Research-Intensive institution in the Northeastern region of the United States. The data described herein is still in the initial phases of a multi-year study, where all of the participants were UG engineering students from the School of Engineering. Students provided demographic information such as gender, age range, race/ethnicity, engineering discipline and prior experience with online learning tools/apps. The research questions were the following:

1. In what ways was the online engineering educational game perceived as valuable to students' learning of engineering courses concepts?
2. In what ways did engineering students, particularly intersectional women, communicate how the online educational game supported their context (e.g., culture, race, ethnicity, etc.)?

B. Demographics of Study Subjects

One hundred and thirty-two undergraduate engineering students that were freshman and sophomores participated in an on-campus study that introduced the online engineering educational game, *Build-Truss**. A pseudonym is used here for the game to protect both the students and instructor's identities. The demographics for the study are provided in TABLE 1 where the students selected their identity as women, men, non-binary and *other*. The percentage of women, men, non-binary and *other* students in the total population studied were 44%, 52%, 2% and 2%, respectively. In addition, the demographics of the population in terms of race/ethnicity is provided in TABLE 1, where 46% of **all of** the participants were women of color and 59% of the women who participated were women of color. Students were recruited to participate through engineering courses (engineering mechanics statics and dynamics) and engineering organizations. Students who were recruited from classes and were given extra credit for participation in the study.

Demographics				
Male (Count)	Female (Count)	Non-binary (Count)	Other (Count)	Total (Count)
69.00	58.00	2.00	3.00	132.00
% Male	% Female	%Non-binary	%Other	Total (%)
52.27	43.94	1.52	2.27	100.00

TABLE 1. DEMOGRAPHICS OF THE PARTICIPANTS ACCORDING TO RACE

	African American/ Black	Caucasian /White	Latinx	Asian	Mixed-Race	Other
	% of Total Population of Participants					
Men	0	36	6	48	10	0
Women	3	40	7	47	2	2
Non-binary	0	50	0	50	0	0
Other	0	33	33	0	0	33
Total	2	38	7	46	6	1

C. Online Engineering Education Tool

This online educational tool emphasizes the structural stability of truss structures, which is a topic covered in the traditional undergraduate engineering mechanics statics course. The game was selected for this study because it is presently used in an existing engineering statics course at the university. Instructors that opted to use this tool in the classroom believe that it supports student learning of engineering statics and is used to supplement course textbook and in-class lecture materials. The game was also suggested for this study by the instructors of the statics course because of its use in an existing course.

The game was designed to assist students in developing engineering intuition regarding the design of truss structures when subjected to forces. The software is premised in finite strain theory, and is designed to allow users to visualize geometric and material nonlinearities and dynamic movement of structures that have failed or been compromised after the application of force [15]. Users play the game by positioning bars and joints (using a touch screen or mouse) to construct a truss configuration able to support an external mass along with the weight of the truss structure itself. Players are rewarded with nut(s) and points based on the player's ability to create a structure of minimal weight and optimal structural stability. Participants can move the location of the bars and joints and manipulate the mass of the truss by adjusting the thickness of the bars. Participants observe the success or failure of their structure in real-time. If a structure fails and collapses, clanging sounds are made in association with the destruction of the structure. The bars subjected to loading from the weights change color (shades of blue and red) to illustrate compression and tension of the bars.

The game was designed to teach students intuition pertaining to relationship between the structural design of trusses, material selection and geometric nonlinearities that can foster system dynamic success or failure [15]. The game does not provide written clues or a tutorial with game rules in the game interface. However, supplemental resources are available such as instructional documents and videos on the software website and in YouTube videos. No supplemental resources were provided as a part of this study to maintain the intent of the game designers to teach engineering design intuition, which is apprehension or direct knowledge about a subject without instruction pertaining to the science or engineering governing the mechanical structures. Students who described their experiences with this game within a classroom environment (during the focus group discussion) were given one in-class lecture by a teaching assistant on the operation of the game and interpretation of the game results. This instruction was in a class the year previous to their participation in this study.

D. Data Collection Procedure

Initially, participants played the engineering game for 20 minutes. The study subjects then completed a questionnaire (questions provided in TABLE 2) and took part in a focus group discussion for ~1 to 1.5 hours. The questionnaire was designed in a Likert-scaled format with questions relating to to participants' experiences with the game, student demographical facts (race/ethnicity/gender, and prior experiences with video apps/games. The questionnaire incorporated a Likert-scale: (1) Strongly Agree, (2) Agree, (3) Somewhat Agree, (4) Neither Agree nor Disagree, (5) Somewhat Disagree, (6) Disagree and (7) Strongly Disagree. For this scale, "Strongly Agree" and "Strongly Disagree" were rated from 1 to 7, respectively. During the focus group discussions, participants described their perceptions of the game as an engineering educational learning and motivational tool. Selected questionnaire questions were repeated during the focus group along with several additional questions. These questions are provided in TABLE 2. The focus group questions enabled a more in-depth discussion of the topics ascribed to the TAM [16] , such as perceived usefulness and ease-of-use of the game. The students played the game in a quiet computer laboratory with section partitions around each player to limit interaction of participants while playing the game. Students wore noise cancelling headsets attached to their computers that allowed them to hear the sounds of the game. The focus group discussions were conducted in a conference room, which was separate from the computer room..

More questions were added to the questionnaire questions during the focus groups to foster the consideration of student's opinions related their previous encounters with video games and enjoyment playing the game. These questions also focused on whether students' ethnicity or culture should be included in the design of the educational learning games. Focus group participants were dispersed into groups based on their *self-described* gender, race, ethnicity and schedule availability in terms of date and time. Each group consisted of 4 – 6 participants. All of 132 students participated in the focus group discussions, where they were in groups of 4 – 6 participants. The data was collected from during three semesters, Spring 2018, Fall 2019 and Spring 2019.

E. Data Analysis and Interpretation

Research question 1, which incorporated and extended the TAM was addressed via the incorporation of questions Q1 – Q2 and Q5 – Q9. Research question 2, which focused on aspects of the game pertaining to culture and identity, were addressed with Q3 and Q4. All questions in questionnaire were examined in terms of gender and race/ethnicity with the goal of illuminating the differences in student perceptions as a function of these groups. A one-way ANOVA analysis was performed to ascertain the relationships between the mean responses to the questions as a function of race and gender. An open coding approach [21] was used to classify similar comments, sentiments and experiences discussed during the focus group.

III. FINDINGS AND DISCUSSION OF RESULTS

A summary of the mean responses to the questions posed on the questionnaire are provided in TABLE 2. One-way ANOVA results for responses as a function of gender and race are presented in Table 3 and TABLE 4, respectively. Mean responses as a function of gender and race/ethnicity are provided in TABLE 5 and TABLE 6, respectively. There were a total of 132 responses to every question, incomplete questionnaires were removed from the data set.

A. Comparison of Aggregate Population Means

A comparison of the general means for the population studied is provided in Table 2. The results indicate that majority of the students agree that online engineering learning games/apps could be used to help them better understand engineering topics and that games/apps like these should be incorporated into classrooms in the future (Q8 and Q9), (means = 2.17 $\pm$ 0.95 and 2.67 $\pm$ 1.47, respectively). In addition, the majority of the engineering students either agreed or somewhat agreed that the game was easy to play (Q2) (mean = 2.83 $\pm$ 1.36) and enjoyed playing the game (Q7) (mean = 2.48 $\pm$ 1.12). These responses partially support the TAM, which states that students are more likely to incorporate a new technology if they find it to be easy to learn.

Two questionnaire questions were posed to answer the second research questions (Q4 and Q5). Majority of the participants did not think the game reflected aspects of their culture or identity (Q4) and did not think that the games *should* reflect aspects of their culture or identity (Q5) (means = 5.26 $\pm$ 1.55 and 4.94 $\pm$ 1.51, respectively). Only twenty students stated that inclusion of culture and ethnicity *should* be embedded in the games in focus group discussions. Focus group discussions elucidated key aspects of the participant's interpretation of the terms culture and identity, and whether these factors are beneficial in their learning condition. Although the game used in this study did not include avatars or storylines, students described avatar usage and story line themes when answering focus group questions about culture and identity. For example, in one focus group, respondents made statements such as, "*Naming a game avatar 'Ravi' or 'Patel' would not enhance my learning of engineering concepts (Ali, Southeast Asian male, Spring 2018)* Second, students indicated that inclusion of stories lines (this game did not include story lines) that illustrate the engineering aspects of design, real-world challenges and images, story lines and realistic looking structures would have enhanced the appeal of the game and their perception of the tool's useful in development of engineering skills. The real-world examples articulated by the students in the focus group discussions differed according to gender. For example, men gave examples of space flight structures and automobiles creating loads as they traveled over bridges. On the other hand, women gave examples that incorporated bridges that were constructed to transport food and supplies to impoverished people. A more thorough examination to ascertain whether these variances in story themes along gender and/or cultural/racial lines is critical. There were no sufficient examples provided for ethnic or racial considerations of the game.

Several of the women respondents indicated that they "did not expect inclusion" (8 statements) of their culture or identity in an engineering educational game/app, while they thought "it might be nice" or "more interesting" if the apps did. On the other hand, men's responses were divided into two categories. Either they did not verbally respond to the question at all or verbally indicated that they were opposed to inclusion of culture or ethnicity into engineering games/apps. For example, some White men students stated (with group agreement) in one focus group of all men that inclusion of culture or ethnic elements into engineering games would render a "reverse effect" that would lead to "turning off students" who were already engaged in engineering (3 respondents shock their heads in agreement). Other men commented that insertion of culture and identity components into engineering games would not necessarily make learning the technical content easier or more engaging (2 respondents).

When the data is examined in aggregate, participants were ambivalent, i.e. did not agree or disagree with Q1 (clarity of the game goals), Q5 (frustration when playing the game) and

Q6 (ability to reach advanced levels in the game based on engineering skills). These results do not sufficiently support the idea that the software will be readily or easily adapted into a classroom setting according to the TAM. According to this model, users' frustration in using technology should be minimized (playing the game should be perceived to be easy), while gains (additional engineering skills) should be optimized from the technology usage. Ambivalence towards Q1, Q5 and Q6 seem to contradict these aspects of the model. Also, though in aggregate, the majority of the students indicated that the game would be a meaningful addition to classroom tools, most students stipulated that they would only advise use of the game if additional resources and lecture discussions could be supplemented in the game. And, less than 10% of the population studied indicated that they would use the game to prepare for a job interview or an exam in the engineering statics course. Since the game used in this study did not include numerical calculations or directly depict real life structures, it does not appear to be a tool that could be used for evaluation of professional competencies according to student responses during focus group discussions.

TABLE 2. SUMMARY OF MEANS AND STANDARD DEVIATIONS

Question	Mean	Std. Dev.
Q1. The learning lessons or goals of each challenge are defined in enough detail to play the game.	3.79	1.61
Q2. This game is easy to play.	2.83	1.36
Q3. This game reflected aspects of my culture and/or identity.	5.26	1.55
Q4. I think engineering learning tools *should* reflect aspects of my culture and/or identity.	4.94	1.51
Q5. I got frustrated playing this game.	3.53	1.69
Q6. I was able to advance to the higher levels of the game using my engineering skills.	3.43	1.65
Q7. Did you enjoy playing this game?	2.48	1.12
Q8. Do you think engineering video games may help you to better learn engineering topics?	2.17	0.95
Q9. I would recommend that this game be used in classrooms in the future.	2.67	1.47
Focus Group Questions		
F1. If you played the game in a previous class, what was your experience with the game? How was the game incorporated into the course?		
F2. Do you play video games on your computer? If you do, what games do you play and why? If not, why not?		

B. One-Way ANOVA as a Function of Gender and Race

Questions that demonstrated significant variance based on gender or race were examined via one-way ANOVA analyses, those with p-values equal to or less than 0.05 are highlighted in gray in Table 3, TABLE 4, TABLE 5, and TABLE 6. The one-way ANOVA analysis of the participant responses indicated that there was variability in responses for four of the nine questions when analyzed in terms of gender: Q1 (p-value = 0.008), Q2 (p-value = 0.009), Q7 (p-value = 0.001) and Q9 (p-value = 0.022). These results indicate that there were differences in perceptions/beliefs between the genders. For example, though the aggregate mean data suggests that participants did not have strong feelings of agreement or disagreement regarding the clarity of the goals of the game (Q1, aggregate mean = 3.79 ± 1.61), women, non-binary and those classified as *other* students felt that the goals of the challenges were not defined in enough detail, with means of 4.22 ± 1.7, 4.50 ± 0.7 and 5.00 ± 0.0, respectively. This sentiment was supported by the differences in challenge level achieved between genders (p-value=0.053), where male students reached higher challenge levels on average than women counterparts.

There was also variability in participants' feelings that the game was easy to play, Q2, where majority of the men agreed with the statement that the game was easy (mean = 2.46 ± 1.26), while the majority of the female and non-binary respondents only somewhat agreed or neither agreed or nor disagreed with means equal to 3.28 ±1.41 and 3.00 ± 0.0, respectively. Most students indicated in the focus group that while the game was "easy" to play, advancing to levels beyond the 4th challenge was extremely difficult, with some students admitting that they struggled and at times became frustrated within the 20 minutes of playing time. Most students indicated that playing the game was "easy", but "winning the game", i.e. designing structures that did not fail beyond Challenge Level 4 was "hard". They expressed frustration at not knowing or understanding why their structures failed and not knowing any details about the design conditions that they typically used in making calculations in the class. For example, students indicated that they were not given quantitative information like, mass, dimensions, etc., which were all elements they typically used in analyzing structures in their classrooms. So, while the game was "easy" to engage in, where they understood how to use the interface to the build structures; it was not apparent to them why some structures failed, while others were stable.

Similar to Q1 and Q2, students did not agree or disagree with the statement (Q6) that they were able to advance to the higher levels of the game using their engineering skills. The ANOVA results indicated that there was variability in terms of race/ethnicity (p-value = 0.025), where White students mostly agreed with this statement (mean = 2.98 + 1.33), while African American women (mean = 5.50 ± 2.12) and the racial category as *Other (*mean = 5.50 ± 2.12) did not. In addition, Asian and non-binary women did not agree with and/or somewhat disagreed with this statement (combined mean = 4.28).

There was also variance (p-value = 0.001) in responses as a function of gender for Q7, where the strongest enjoyment was noted for non-binary students (mean = 1.0 + 0.0) and the most nonchalant responses were observed for students indicated "other" (mean = 4.00 + 1.73) as their gender. Similarly, there was variance for Q9 (p-value = 0.022), where majority of the students stated that they would recommend that the software be used in classes in the future, except for non-binary students, who in general, somewhat disagreed with this statement.

Table 3. ANOVA TABLE (FACTOR = GENDER)

		Sum of Squares	df	Mean Sqr	F	Sig.
Q1	Between Groups	29.822	3	9.941	4.101	0.008

	Within Groups	310.238	128	2.424		
	Total	340.061	131			
Q2	Between Groups	20.921	3	6.974	4.032	0.009
	Within Groups	221.412	128	1.730		
	Total	242.333	131			
Q3	Between Groups	9.434	3	3.145	1.325	0.269
	Within Groups	303.808	128	2.374		
	Total	313.242	131			
Q4	Between Groups	16.305	3	5.435	2.474	0.065
	Within Groups	281.211	128	2.197		
	Total	297.515	131			
Q5	Between Groups	31.425	3	10.475	3.927	0.010
	Within Groups	341.454	128	2.668		
	Total	372.879	131			
Q6	Between Groups	18.683	3	6.228	2.360	0.075
	Within Groups	337.704	128	2.638		
	Total	356.386	131			
Q7	Between Groups	18.534	3	6.178	5.476	0.001
	Within Groups	144.398	128	1.128		
	Total	162.932	131			
Q8	Between Groups	5.191	3	1.730	1.981	0.120
	Within Groups	111.802	128	0.873		
	Total	116.992	131			
Q9	Between Groups	20.445	3	6.815	3.318	0.022
	Within Groups	262.889	128	2.054		
	Total	283.333	131			

TABLE 4. ANOVA TABLE (FACTOR = RACE)

		Sum of Squares	**df**	**Mean Sqr**	**F**	**Sig.**
Q1	Between Groups	8.02	5	1.603	0.608	0.694
	Within Groups	332.05	126	2.635		
	Total	340.06	131			
Q2	Between Groups	8.59	5	1.719	0.926	0.466
	Within Groups	233.74	126	1.855		
	Total	242.33	131			
Q3	Between Groups	8.06	5	1.612	0.665	0.650
	Within Groups	305.18	126	2.422		
	Total	313.24	131			
Q4	Between Groups	14.17	5	2.835	1.260	0.285
	Within Groups	283.34	126	2.249		
	Total	297.52	131			
Q5	Between Groups	16.13	5	3.226	1.139	0.343
	Within Groups	356.75	126	2.831		
	Total	372.88	131			
Q6	Between Groups	34.21	5	6.843	2.676	0.025
	Within Groups	322.17	126	2.557		
	Total	356.39	131			
Q7	Between Groups	4.80	5	0.961	0.766	0.576
	Within Groups	158.13	126	1.255		
	Total	162.93	131			
Q8	Between Groups	7.43	5	1.486	1.709	0.137
	Within Groups	109.56	126	0.870		
	Total	116.99	131			
Q9	Between Groups	11.91	5	2.382	1.106	0.361
	Within Groups	271.42	126	2.154		
	Total	283.33	131			

TABLE 5: MEANS AS A FUNCTION OF GENDER

Gender		**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**
Men (N=69)	Mean	3.35	2.46	5.12	4.72	3.97	3.10	2.25	2.35	2.78
	Std. Dev.	1.464	1.255	1.762	1.571	1.697	1.426	0.946	1.027	1.504
Women (N=58)	Mean	4.22	3.28	5.41	5.17	3.05	3.81	2.72	1.98	2.48
	Std. Dev.	1.697	1.412	1.257	1.403	1.503	1.840	1.167	0.827	1.314
Non-binary (N=2)	Mean	4.50	3.00	4.00	3.50	2.00	4.50	1.00	1.50	1.00
	Std. Dev.	0.707	0.000	0.000	0.707	0.000	2.121	0.000	0.707	0.000
Other (N=3)	Mean	5.00	2.67	6.33	6.33	3.67	3.00	4.00	2.33	4.67
	Std. Dev.	0.000	0.577	1.155	0.577	2.887	1.000	1.732	0.577	2.309
Total (N=132)	Mean	3.79	2.83	5.26	4.94	3.53	3.43	2.48	2.17	2.67
	Std. Dev.	1.611	1.360	1.546	1.507	1.687	1.649	1.115	0.945	1.471

TABLE 6: MEANS AS A FUNCTION OF RACE/ETHNICITY.

Race/Ethnicity		**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**
African Amer/ Black (N=2)	Mean	3.50	3.00	4.50	4.50	3.00	5.50	2.00	1.00	2.50
	Std. Dev.	2.121	0.000	0.707	2.121	0.000	2.121	1.414	0.000	0.707
Caucasian (N=50)	Mean	3.72	2.62	5.32	5.10	3.32	2.98	2.48	2.08	2.74
	Std. Dev.	1.591	1.008	1.491	1.568	1.558	1.332	1.092	0.804	1.509
Latinx (N=9)	Mean	4.22	3.56	4.44	5.78	4.44	3.11	2.33	1.78	2.33
	Std. Dev.	1.922	1.590	1.740	0.833	1.878	1.453	1.225	0.667	1.414
Asian (N=61)	Mean	3.90	2.93	5.31	4.77	3.66	3.74	2.54	2.38	2.74
	Std. Dev.	1.650	1.621	1.608	1.499	1.816	1.760	1.134	1.098	1.482
Mixed-Race. (N=8)	Mean	3.00	2.50	5.50	4.25	3.38	3.25	2.00	2.00	1.75
	Std. Dev.	0.926	0.926	1.309	1.389	1.302	1.832	0.756	0.535	0.707
Other (N=2)	Mean	3.50	3.00	5.50	5.50	2.00	5.50	3.50	2.00	4.00
	Std. Dev.	2.121	0.000	2.121	2.121	0.000	2.121	2.121	0.000	2.828
Total (N=132)	Mean	3.79	2.83	5.26	4.94	3.53	3.43	2.48	2.17	2.67
	Std. Dev.	1.611	1.360	1.546	1.507	1.687	1.649	1.115	0.945	1.471

C. Level–1 Categorical Analysis of Focus Group Discussions

Three categorical themes were highlighted in the first level analysis of focus group discussions. The first theme centered around the TAM's [14] *ease of use of the game,* and was examined via two primary responses*:* 1) the game affirmed coursework at the lowest game challenge levels (40 statements) and 2) engineering intuition from the game broke down at higher challenge levels (20 statements). Although there was a high percentage of participants who indicated that the game was easy to learn to use, majority of the participants indicated that they were not aware of, or did not fully understand key aspects of the game that were important to gaining engineering insight when designing truss structures. Some of these differences in game understanding were observed according to gender and/or race/ethnicity. For example, several students did not realize that the number of nuts awarded when the challenge ended was related to the quality of truss they had designed. These subjects also indicated that they did not realize that optimal designs were those that minimized structure weigh while withstanding additional load from an added weight (~40 respondents). Other students were unable to identify the color coding of the truss bars, which indicated whether bars were in compression or tension. Participants who discovered that they did not understand the game rules during the focus group were also part of the subgroup of the population who played video games the least in their spare time. This group had the least exposure to engineering educational games before entering college. The students who played video games the least in their spare time were women of colour. Specifically, White men (83%) and women (95%) in this study played video/phone games and engineering and physics-based games on their computer more than women of color, i.e. African American (0%), Latina (50%) and Asian (46%). Many of the students who indicated prior experience with games such as these indicated that they played "engineering learning games" in middle and high school STEM classes and/or extracurricular clubs/activities, in addition to their playing games/apps on their computer or phones for fun. Majority of the African American and Latinx women anecdotally indicated during focus group discussions that they either did not play or were not aware of engineering learning games such as these prior to the study and were not exposed to games such as these in middle or high school. These female students of color were among the group of students who did not appear to pick up on subtle game cues, i.e. game scoring, challenge level advancement opportunities, etc. that other students with more gaming experience *intuitively observed* while playing the game. This undoubtedly influenced their ability to navigate through the game and interpret the game structural outcomes, which were important for affirming statics content or learning engineering intuition. It is unclear if these women of color were not introduced to engineering educational and serious games prior to this study due to lack of access (socioeconomic), school district limitations (no pre-engineering classes/clubs) or lack of interest in video games in general.

The second theme focused on the TAM's *perceived usefulness of the game*, where students were asked Q6 and how the game related to materials in their class. Most students indicated that while the first four challenge levels could be solved using rudimentary skills gleaned in Statics pertaining to two-dimensional simple truss structures, higher levels ceased to be intuitive at all, and did not directly relate this work to their course work in a meaningful way, which diminished the *perceived usefulness of the game.* For example, students created structures that were successful through trial and error (met game requirements), but were not based on engineering skills learned in class (20 statements). The trial and error strategy diminished student's ability to meaningfully correlate engineering concepts from the class or textbook to *Build-Truss**. Hence, student's perception of the tool as being *useful* within the classroom environment was compromised as a result. Also, many of the subjects were doubtful that the game taught them content covered the statics course. For example, some students attributed their success in the game to "gaming the game" versus their acquisition of engineering skills (in cases where students reached high challenge levels). In addition, some subjects stressed that people without an engineering background could achieve some level of success in the game by trial and error (16 participants). As a results, students did not perceive the app to be a useful learning tool for validating engineering concepts beyond the games' first three challenge levels. Another student stated, "*…towards the end of the high-level challenges, the solutions… they seemed to make less sense…sometimes I got more nuts and bolts where I felt like my [design] was unrealistic." (Lin, Asian, female, sophomore, 2018)* Female students of color voiced the most concern over highly ranked structures that were not realistic in terms of real world application during focus group discussions in comparison to their male and Caucasian counterparts.

The third theme focused on TAM's assertion that people will use a technology if they believe the benefit of use outweighs the effort in learning how to use it. Though majority of the participants recommended that a game like *The game* be included in classes in the future (Q9), ~79 respondents provided stipulations regarding how the game would be incorporated into the class and/or how they would improve the game in preparation for its used in a class. For example, since the game did not provide feedback (oral or text) on failed structures other than loud clanging sounds after structures broke, students linked the lack of interface instruction/feedback as a source of frustration (over 12% and 48% of men and women, respectively either strongly agreed or agreed that they got frustrated). Since female students indicated higher levels of frustration with the lack of interface/feedback, this might suggest a higher level of cognitive load unnecessarily used for playing the game for female students than their male counterparts. The students who indicated that they got frustrated and/or would recommend the game with stipulations all indicated that they would supplement the game with in-class instructions or supplemental hints in the game interface to explain the interpretation of game outcomes and clearly articulate strategies for linking course theory with game outcomes. For example, one student noted, "*I wish there was like an instruction box or something to tell you what the point of the game was.*" *(Ravi, sophomore, Southeastern Asian, man, 2019)*

Though majority of the students indicated that they would use a textbook to prepare for a job interview in the engineering field as opposed to using this game, it is unclear which *explanation/rational* dominated their decision. For example, students indicated a myriad of explanations for their choice not to use this game as a tool for job interview preparation, such as the textbook related the physics of the systems to engineering equations (which was similar to their other classes), software that does not include explanations for results or relate to engineering equations are deemed less reliable, and software that allows unrealistic designs to be ranked higher than more realistic designs are untrustworthy.

IV. CONCLUSIONS AND FUTURE WORK

In summary, the findings of this study focuses on the experiences of 132 participants and their evaluation of an engineering education app designed to help students in gaining engineering intuition in statics in the designing of truss structures. Focus group discussions and questionnaire responses were used to ascertain initial answers to the research questions. The responses obtained from this study will be used to modify a subsequent questionnaire and design method to better understand the motivation behind participant responses regarding their formation into engineers, inclusion of identity and culture into serious engineering online games/apps and acceptance of these gaming technologies as engineering educational tools for classroom settings.

For example, it was noted by one participant that Latinx should be further segmented into race, i.e. of African, Native, European descent etc. The authors recognize these are important considerations to self-identification. Also, the lack of usage by some intersectional groups (e.g., African American women) as shown in this study also points to the need of better inclusion of various experiences in online educational games to support both perceived usefulness and acceptance of these games in supporting their engineering formation.

The preliminary findings also suggest that students expect that learning games reinforcement technical content from the course and that inquiry-based tools are more effective when they are coupled with a multifaceted schema of tools. These tools include interfacial feedback on both successful and failed game attempts, opportunities to review and correlate game materials to course materials, and provision of explanations to explain game predictions. Also, these preliminary results indicate that gaming technologies that do not include supplemental explanations or game rules/explanations may unfairly advantage or introduce bias in favor of those with video game and serious educational game technology experience, where many African American and Latinx women are not exposed to games such as these prior to college.

Also, those with video game experience may perform better and engage more readily. The results also indicate that students have different expectations of engineering educational serious games in comparison to games that are designed for entertainment. Though the results of this study illuminate aspects of serious games that students deem important for use as educational tools in a classroom environment, concrete recommendations for development of games better suited for intersectional women will require additional study and modification of the questionnaire. Finally, skills association with engineering intuition in the game that are not directly linked to course assessment (exams, etc.) are less accepted technologies than those that do.

Acknowledgment

This material is based upon work supported by the National Science Foundation under Grant No. (NSF grant number: 1830812 and 1830788)

References

[1] D. M. Adams, C. Pilegard, and R. E. Mayer, "Evaluating the Cognitive Consequences of Playing Portal for a Short Duration," *Journal of Educational Computing Research*, vol. 54, no. 2, pp. 173-195, Apr 2016, doi: 10.1177/0735633115620431.

[2] J. Martin-Gutierrez, J. L. Saorin, N. Martin-Dorta, and M. Contero, "Do Video Games Improve Spatial Abilities of Engineering Students?," *International Journal of Engineering Education*, vol. 25, no. 6, pp. 1194-1204, 2009. [Online]. Available: <Go to ISI>://WOS:000275295400014.

[3] T. A. Philpot, R. H. Hall, N. Hubing, and R. E. Flori, "Using games to teach statics calculation procedures: Application and assessment," (in English), *Computer Applications in Engineering Education*, Article vol. 13, no. 3, pp. 222-232, Oct 2005, doi: 10.1002/cae.20043.

[4] J. I. Alonso, L. de la Ossa, M. J. Flores, J. A. Gamez, J. Martinez-Gomez, and J. M. Puerta, "SUPPORTING INTELLIGENT SYSTEMS TEACHING BY MEANS OF COMPUTER GAMES PROGRAMMING," in *Edulearn10: International Conference on Education and New Learning Technologies*, L. G. Chova, D. M. Belenguer, and I. C. Torres Eds., (EDULEARN Proceedings, 2010.

[5] B. D. Coller and M. J. Scott, "Effectiveness of using a video game to teach a course in mechanical engineering," *Computers & Education*, vol. 53, no. 3, pp. 900-912, Nov 2009, doi: 10.1016/j.compedu.2009.05.012.

[6] B. D. Coller and Ieee, "Work in Progress - A Video Game for Teaching Dynamics," in *2011 Frontiers in Education Conference*, (Frontiers in Education Conference, 2011.

[7] B. D. Coller and Ieee, "A Video Game for Teaching Dynamic Systems & Control to Mechanical Engineering Undergraduates," in *2010 American Control Conference*, (Proceedings of the American Control Conference, 2010, pp. 390-395.

[8] M. Pantoja, "Designing a New Video Game App as an aid for Introduction to Programming classes that use C Programming Language," *Proceedings of the Head'17 - 3rd International Conference on Higher Education Advances*, pp. 10-16, 2017, doi: 10.4995/HEAd17.2017.4606.

[9] M. Okutsu, D. DeLaurentis, S. Brophy, and J. Lambert, "Teaching an aerospace engineering design course via virtual worlds: A comparative assessment of learning outcomes," *Computers & Education*, vol. 60, no. 1, pp. 288-298, Jan 2013, doi: 10.1016/j.compedu.2012.07.012.

[10] Z. Kosmadoudi, T. Lim, J. Ritchie, S. Louchart, Y. Liu, and R. Sung, "Engineering design using game-enhanced CAD: The potential to augment the user experience with game elements," *Computer-Aided Design*, vol. 45, no. 3, pp. 777-795, Mar 2013, doi: 10.1016/j.cad.2012.08.001.

[11] R. Joiner *et al.*, "Digital Games, Gender and Learning in Engineering: Do Females Benefit as Much as Males?," *Journal of Science Education and Technology*, vol. 20, no. 2, p. page 182, Apr 2011, doi: 10.1007/s10956-010-9244-5.

[12] K. Crenshaw, "Demarginalizing the Intersection of Race and Sex: A Black Feminist Critique of Antidiscrimination Doctrine, Feminist Theory and Antiracist Politics," *The University of Chicago Legal Forum*, vol. 140, pp. 139-167, 1989.

[13] K. Crenshaw, *MAPPING THE MARGINS - INTERSECTIONALITY, IDENTITY POLITICS, AND VIOLENCE AGAINST WOMEN OF COLOR* (Stanford Law Review Vol 43, No 6, July 1991: In

Memoriam: Carl Bernhardt Spaeth; Women of Color at the Center). 1993, pp. 1241-1299.

[14] F. D. Davis, "PERCEIVED USEFULNESS, PERCEIVED EASE OF USE, AND USER ACCEPTANCE OF INFORMATION TECHNOLOGY," *Mis Quarterly*, vol. 13, no. 3, pp. 319-340, Sep 1989, doi: 10.2307/249008.

[15] K. Cook-Chennault and I. Villanueva, "An initial exploration of the perspectives and experiences of diverse learners' acceptance of online educational engineering games as learning tools in the classroom," presented at the 2019 IEEE Frontiers in Education Conference (FIE), Covington, KY, USA, 2019.

[16] K. Cook-Chennault and I. Villanueva, "Preliminary Findings: RIEF – Understanding Pedagogically Motivating Factors for Underrepresented and Nontraditional Students in Online Engineering Learning Modules," presented at the 2019 ASEE Annual Conference & Exposition, Tampa, Florida, USA 2019. [Online]. Available: https://peer.asee.org/32323.

[17] J. Bourgonjon, M. Valcke, R. Soetaert, and T. Schellens, "Students' perceptions about the use of video games in the classroom," *Computers & Education*, vol. 54, no. 4, pp. 1145-1156, May 2010, doi: 10.1016/j.compedu.2009.10.022.

[18] C. E. Porter and N. Donthu, "Using the technology acceptance model to explain how attitudes determine Internet usage: The role of perceived access barriers and demographics," *Journal of Business Research*, vol. 59, no. 9, pp. 999-1007, Sep 2006, doi: 10.1016/j.jbusres.2006.06.003.

[19] M. Y. Hwang, J. C. Hong, H. Y. Cheng, Y. C. Peng, and N. C. Wu, "Gender differences in cognitive load and competition anxiety affect 6th grade students' attitude toward playing and intention to play at a sequential or synchronous game," *Computers & Education*, vol. 60, no. 1, pp. 254-263, Jan 2013, doi: 10.1016/j.compedu.2012.06.014.

[20] P. Rajan, P. K. Raju, J. T. Gill, and Asee, "Impact of Engineering Design Serious Game on Student Learning in a K-12 Curriculum," in *2014 Asee Annual Conference*, (ASEE Annual Conference & Exposition, 2014.

[21] J. Saldana, J. Seaman, Ed. *The Coding Manual for Qualitative Researchers*. Thousand Oaks, California: Sage Publications Inc., 2015.