What you see is what you get? – Relating eye-tracking metrics to students' attention to game elements

Amirbahador Shojaee
Department of Engineering Education
University of Florida at Gainesville
Gainesville, FL, USA
bahadorshojaee@ufl.edu

Hyeon Woo Kim
Mechanical and Aerospace Engineering Department
Rutgers, the State University of New Jersey
Piscataway, NJ, USA
hk769@scarletmail.rutgers.edu

Kimberly Cook-Chennault
Mechanical and Aerospace Engineering Depart.
Rutgers, the State University of New Jersey
Piscataway, NJ, USA
cookchen@soe.rutgers.edu

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

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***Abstract*—Though engineering digital game inclusion in undergraduate classrooms has steadily increased over the last two decades for in-person courses, their use has exponentially increased in remote and contactless higher education learning environments. Studies exploring student technological acceptance of and content mastery from the use of engineering digital games have provided mixed results in terms of student enjoyment, engagement, and game effectiveness. The majority of these studies have relied on pre- and post-questionnaires to assess differences in students' gaming experiences and performance in the game and learning environment. However, quantitative methods such as the measurement of physiological responses *during* gameplay have been less explored for the exploration of student engagement and education. The goal of this work is to explore how a set of eye - tracking metrics can be related to gamer attention to in-game stimuli and game interface areas of interest.**

Keywords—engineering education game, undergraduate, digital game, eye tracking, mixed methods analysis

I. Introduction

The study of eye movements began in the second half of the 18th century when Louis Emile Javal investigated eye motion to understand reading patterns. Later, Edmund Huey built a device to track eye movement during reading. Since the discovery of these techniques, use of physiological sensing devices to explore human learning and behavior, has grown substantially due to the development of artificial intelligence, machine learning and portable electronics that enable non-intrusive interrogation of eye travel and gaze[1]. These physiological tools have been used to understand and assess learning[2-4], attention and memory[5, 6], engagement and cognition[7], and neurological impairment[8, 9] in marketing[10, 11], STEM education[1, 4, 7, 12], physical injury [8] and entertainment video games [13, 14]. There have also been a number of review articles pertaining to specific aspects and applications for eye and gaze tracking technologies[1, 15, 16]. Only a handful of studies have examined how these types of tools can be useful in informing the assessment of educational engineering games, though many researchers have concluded that learner outcomes are deeply connected to student cognitive-affective and emotional states [17]. However, *ways of quantifying and assessing near-real-time student interactions with these digital engineering educational games/apps is an area that is less understood*.

Though a number of disciplines, such as mechanical, chemical, electrical and computer science have developed and studied the impact of educational games, the outcomes have been mixed in terms of educational effectiveness and student engagement [18-20]. These prior studies have used pre- and post-questionnaires to examine student enjoyment and engagement of these games, in addition to (in some instances) pairing of these parameters with student mastery of the course topic. However, these studies did not uncover the near-real-time experiences of students interacting with these games, in part due to a lack of appropriate methods and tools. But with the advent of physiological technologies, quantitative methods to understand students' authentic responses to these games as they are playing them is tangible, although its use in engineering digital games is not well understood. The purpose of this work is to initiate the discovery of how undergraduate engineering students' eye movements, gaze, and attention to an area of interest (AOI) on the game interface screen can be used to predict students' scores in the intuition-based engineering game and serve as a way to understand student learning and misconceptions to engineering topics present in these games that are connected to engineering course topics.

II. Eye-Tracking and Gaze Measurement Analysis

The process of eye tracking includes three primary steps: discovery of the eye, interpretation of the position of the eye, and framing detection of the eyes in which the position of the eye is usually measured via the detection of the pupil or iris center[21]. Eye tracking, once identified, is used to measure eye gaze. Gaze tracking is of interest in the learning sciences and neurosciences because it involves time and space. These parameters inform scholars about day-to-day behaviors in students such as learning, memory, and engagement[1, 13, 15].

Gaze tracking is a process that is used to estimate eye position and track the line of sight of the person, i.e., where a person is looking, using one of several methods: *Shape-Based, Feature-Based, Appearance-Based, and Hybrid Methods*[22].

Gaze estimation is used to determine gaze position and direction from data extracted from an object or image. Eye movements are generally classified by metrics such as fixation and saccade. Fixation occurs when a person's gaze is directed to a specific object over a brief period of time (100 to 500 ms and ~250 ms while reading) depending on the materials being viewed[23]. According to [24], there are six frequently used eye-tracking measures*: fixation count, proportion of time spent on each area of interest (AOI), average fixation duration, fixation count on each AOI, gaze duration mean on each AOI, time to first fixation of the AOI of interest, and fixation rate (counts/second).* A *saccade* occurs when the gaze moves quickly between objects. An overview of parameters that are important for eye and gaze detection are provided in TABLE I.

TABLE I EYE TRACKING ATTENTION METRICS, UNITS, DESCRIPTIONS, AND INTERPRETATIONS OF MEASURED VARIABLES [25-27].

Metrics	Units	Description	Interpretations
Fixation Count	Frequency	Number of times participant's eye fixates in an AOI	• Noticeability of area • Processing difficulty • Availability of information
Regressive Fixation count	Frequency	Re-fixating a previously fixated region	• Specific processing difficulty of participant • Ambiguity of UI/game • UI/game interactive element
Fixation duration	ms	How long the eye fixates on a AOI prior to a saccade	• Difficulty in processing information in a particular region • Value of information available in region
Time to first fixation	s	Time it takes a participant to look at a specified AOI from stimulus onset	• How well an AOI influences the attention of a participant or how well a participant locates an AOI

III. RESEARCH QUESTIONS AND DESIGN

A mixed method sequential exploratory research design[28] was used to explore how eye tracking and gaze metrics can be related to student attention to and performance when playing an engineering digital game, chosen by the instructor due to its connection to existing course content. One research question was posed for this work-in-progress.

1) *How do eye-tracking metrics correspond to in-game metrics in the engineering game across various difficulty levels?*

A. Research Protocol, Instrumentation and Tracking Software

Students who participated in the study were given a pre-questionnaire to ascertain the prior experience with using gaming technology for entertainment and in classroom settings. After completing the pre-game questionnaire, students were seated in front of a desktop PC computer that was instrumented with a Tobii X2-30 Compact eye tracking instrument (Tobii Pro) and iMotions 8.0 software (iMotions, Inc.). The eye tracking device was operated at 30 Hz and calibrated for each student prior to playing the engineering game per recommendation from the company. After the calibration step, students were asked to play the game for twenty minutes as their eye motion and gaze were captured via the tracking unit. Students were instructed to minimize body movements and maintain relatively consistent postures to minimize instances when their eyes would fall out of the appropriate vantage range of the eye tracker. The eye-tracking data presented herein (time to first fixation, time spent looking at a specific AOI, etc.) were generated from gaze and frequency plots derived from algorithms developed by iMotions software that is compatible with the Tobii eye tracker. Areas of interest (AOI) and eye-tracking data were manually coded and extracted, respectively. Students were given a post-game questionnaire after they finished playing the engineering game.

B. Research Environment and Data Sampling

The project took place at a Research-1 institution on the east coast of the United States. The research protocol described herein was accepted by the institution's internal review board for human subjects. A total of two hundred and one undergraduate students were recruited for the study. One hundred and thirty-two students completed the pre- and post-questionnaires (results presented elsewhere;[29-31]) while twenty of these participants were recruited for an additional study involving eye trackers in exchange for a $25 monetary incentive or course extra credit based on their preference.

The eye tracker recording involved an on-campus study that introduced the online engineering educational game, Build-Truss*. Note that a pseudonym was used to refer to the engineering digital game of interest and additional pseudonyms were used to protect students, game designers and instructors' identities. The study took place during Fall 2019 in a sophomore-level mechanical engineering mechanics, statics, and dynamics courses, which are gateway courses for many engineering majors. Students were given extra credit for participation in the study. Selection of the students to participate in the study was based on scheduling and student availability. Due to the large amount of quantitative data that needs to be processed for eye tracking (30 data points per second for a 20-minute game session equaling 36,000 per participant), this work in progress will demonstrate the results for nine undergraduate students who had not previously played this game. Digital Serious Engineering Game – Build Truss

The game Build Truss is an educational tool that allows students to examine the structural stability of truss structures. This topic is covered in the majority of undergraduate engineering mechanics statics courses. Build Truss was selected for this study because it is presently used in an existing statics course at the university. The instructors that presently teach this class opted to use this tool in the classroom because they believe it supports students in learning engineering statics. This tool was used as a supplement to the course textbook and in-class lecture materials.

The Build Truss game was designed to help students develop engineering intuition (application of concepts into applications) in the design of truss structures when structures are subjected to forces. The software is rooted in finite strain theory, and was designed to allow users to visualize geometric and material nonlinearities and dynamic movement of structures as they fail or are compromised after being subjected to a weight (force). 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. The game may be played in two different modes: "Challenges" and "Freestyle". For this study, all participants played in the "Challenges" mode, where the player progresses through increasingly difficult "Challenge Levels", that are numbered from 1 to 24 where level 1 is the easiest level and 24 is the hardest level. Players are rewarded with *nut(s)* and *points* based on the player's ability to minimize the weight of the structure while supporting an external load. The number of nuts that a player can receive per challenge level ranges from 1 to 3, where 1 nut indicates that the structure did not fail (succumb to the weight load), but is not the optimal load weight design and 3 nuts indicate the most light weight structural design that is able to securely and stably hold the weight. Also, higher points at each challenge level is tied to a user's understanding of minimizing material usage while ensuring safety standards during an engineering design as suggested by the minimum weight needed to support constraints of weight and rollers/pins provided at the given challenge level. Participants can move the location of the bars and joints freely 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 and feedback is provided through the game's point system and auditory sound effects. For example, 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 and differentiate between compression and tension of the bars.

The game was designed to teach students about the connection between the structure of trusses, selection of material and geometric nonlinearities that can lead to system dynamic success or failure. The game does not provide written clues or a tutorial with game rules in the game interface. Some resources are available on the software website and videos describing how to better play the game are on YouTube. No supplemental resources were provided as a part of this study to maintain the intent of the game designers, e.g., 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.

C. Data Cleaning and Analysis

The data analysis approach used for this work leverages the approaches described by [32, 33], where these scholars investigated the relationship between eye-tracking and gaze of students towards educational in-game objects/hints in the game and <u>student performance in the game</u>. Prior to analyzing the results from the study, data from two of the nine participants were removed due to an insufficient number of readings from the eye-tracker. Negative values that reflected an inability of the eye-tracker to capture eye gaze were also removed. The data presented for the challenge levels e.g., *Time to First Fixation*, *Time Spent* (time spent in an AOI as a percentage of the total time), *Fixation Count*, *First Fixation Duration* (duration of the first fixation), and *Average Duration* were obtained for the first three challenge levels of the game for all seven participants.

The AOIs that were observed in this study are the *Load*, *Middle*, *Clear Stage Button*, and *Stage Info*. The *Load* and *Middle* AOIs are the areas around the mass and truss structure (members and pins), respectively. These areas communicate the truss shape structure and color (compression/tension), to the player. The *Stage Info* AOI gives the mass of the structure in kilograms (kg) and the Challenge Level. The *Clear Stage Button* AOI indicates how often the participant resets the structure to begin anew, which may be indicative of a trial-and-error problem-solving strategy.

Descriptive statistics, i.e., the mean and standard deviation, for each AOI at each challenge level of the game are presented in the Appendix, in TABLES II - VI. A two-factor ANOVA with AOI and Challenge Level (Stage) as the factors for each eye-tracking measurement was conducted to determine the differences in means due to AOI vs. Challenge Level for each of the eye tracking metric measured.

IV. Results and Discussion

A. Descriptive Statistics Results and Discussion

The statistical descriptive data are provided in the Appendix in Tables I – VI. In general, the *Stage Info* AOI, (which communicates the mass of the structure, which is to be minimized as the critical objective of the game, to the player) has high mean values for *Time to First Fixation* and increases as challenge difficulty (Challenge Level) increases. The high mean for *TTFF* suggests that students do not readily notice this crucial AOI. This AOI is important because it is supposed to help players minimize the size of their structures. Similarly, for the *Time Spent* and the *Fixation Count*, the *Stage Info* has the lowest mean (or on par with *Clear Stage Button*), which also decreased with increasing challenge level. The low mean values for the *Fixation Count* and *Time Spent* indicate that game players neglected to pay attention to the valuable information presented in this part of the game interface. In other words, the players do not engage with this aspect of the game or use it in a meaningful way to assist them in advancing to the next stage in the game.

The *Average Fixation Duration* for *Stage Info* had mean values that were lower than the *Load* and *Middle* AOIs, which also suggests that the players did not value the information presented in this AOI in comparison to the *Load* and the *Middle*. These trends are continued for the *First Fixation Duration* values for the *Stage Info*, which decreased as the player progressed from a lower challenge level to a higher challenge level. However, as the Challenge Level increased, the *TTFF* increased for the *Stage Info AOI.* In other words, this finding suggests that though it took participants longer to notice the AOI, their gaze at this AOI was not prolonged.

Similarly, the *Average Fixation Duration* for *Load*, which increases with increasing difficulty level, contrasts with the decreasing *Average Fixation Duration* for *Stage Info*. We had speculated that *Fixation Count* and *Average Fixation Duration* would increase with game complexity. However, the preliminary results do not support this notion, which may indicate that students did not understand the value in the information provided or the fundamental objective of the game, i.e., structural stability and minimized weight of the structure.

B. *Analysis of Variance (ANOVA)*

The two-way ANOVA data is provided in the Appendix in Table VII and VIII to determine whether the means for factors of AOI and Stage (i.e., difficulty level) are statistically significant. No significantly relevant information was gained from performing 2-factor ANOVA for eye-tracking measures *Time Spent*, *TTFF*, and *Fixation Count* (Appendix). There is a statistically significant difference (95% confidence) for the percentage of *Time to First Fixation* and the *Average Fixation Duration* for AOI as the factor, as shown in TABLE VII and TABLE VIII. More interestingly, Challenge Level (i.e., game complexity) as a factor was not statistically significant for any of the eye tracking metrics. In other words, all the differences in means of the eye tracking metrics was due to the choice of AOI. This could be due to the large difference between the "Middle" and "Stage Info" AOIs, or because only the first three of twenty-four difficulty levels were analyzed. It could be that the difficulty of the first three stages is approximately the same, and, as such, there was no observable difference between the levels. Challenge Level 3 was chosen as the limit primarily because all the participants reached this difficulty level. Looking at a larger range of difficulty levels could elucidate more interesting patterns. In addition, the learning outcomes namely understanding of the purpose for a pin and roller were the primary learning goals of the first three challenges. The challenges following the third level integrated other aspects of engineering mechanics, zero force members, redundant supports, etc. that may potentially render more observations from participants.

To determine the source of this statistically significant difference within the AOIs, a Welch Post-Hoc analysis test should be performed however, this could not be done due to the small number of participants studied. With more participants and with higher number of stages, 2-factor ANOVA and Post-Hoc may give more insight into determining a viable set of eye-tracking measures for quantifying participant performance and attention in *the engineering game.* We will explore this in future work with more participants and data on student performance, including qualitative assessment of students.

V. CONCLUSIONS AND FUTURE WORK

This paper explored whether eye tracking metrics could be used to quantify participant attention to a *digital engineering game*. Towards achieving this goal, a study was formulated to understand whether there were any differences among the eye tracking metrics of participants while playing the game. Application of this form of quantitative analysis for engineering games is fairly novel. Hence, the other purpose of this preliminary work is to understand which eye tracking metric(s) would be appropriate for a given set of stimuli (AOIs). The results indicate that *Time to First Fixation* and *Average Fixation Duration* are statistically significant for AOIs, but not for the Challenge Level. However, this lack of differentiation is most likely due to the low challenge level analyzed. Furthermore, the *Stage Info* AOI, which we expected to have high fixation durations and fixation counts as it offers valuable in-game information to the participants, actually had the lowest *Average Fixation Duration* and *Fixation Count* along with lowest *Time Spent*. While this analysis is for a specific game, the observation can be useful in the design of intuition-based engineering learning games used to enhance classroom learning of content. Specifically, game designers should consider the highlighting aspects of the game that map to fundamental engineering parameters, e.g., structure weight. Overall, eye tracking metrics provide a useful way of quantifying participant attention to the various stimuli (AOI) within *the engineering game*, which can be useful to game designers and educators.

The preliminary results indicate that students may benefit from meaningful game interaction and hints that facilitate their learning and awareness of tools and user feedback towards achieving game and educational goals. In theory, this interaction would introduce gamers to the *Stage Info* and describe the information provided on this portion of the screen. levels. This work illustrates that game designers of intuition-based games should consider how to communicate aspects of the game interface that allow for students to carefully consider and facilitate learning of engineering fundamentals.

This work primarily explored the first research question. In future work, we plan analyzing data from more participants using a larger set of challenge levels and using eye tracking metrics on other in-game stimuli. Further, we plan on relating the eye tracking metrics described in this paper to participant performance using their in-game performance and collected qualitative assessments.

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APPENDIX

Table II The descriptive statistics for the first fixation time for the first three challenge levels of the game.

AOI	Time to First Fixation (TTFF)					
	Challenge Level 1		Challenge Level 2		Challenge Level 3	
	Mean	SD	Mean	SD	Mean	SD
Load	1744	2490	1766	1489	3546	2531
Middle	9434	13126	5800	3943	4650	3645
Clear Stage Button	13297	12468	30440	38642	19497	16787
Stage Info	22024	30440	109066	105557	109382	34753

Table III The descriptive statistics for the time spent for each AOI as a function of Challenge Level.

AOI	Time Spent (ms)					
	Challenge Level 1		Challenge Level 2		Challenge Level 3	
	Mean	SD	Mean	SD	Mean	SD
Load	17440	11910	17876	25645	4060	3088
Middle	24495	9532	34758	44071	11806	16127
Clear Stage Button	1585	827	3788	4558	1962	2604
Stage Info	1469	1038	1113	1474	420	61

TABLE IV The descriptive statistics for the fixation count for each AOI as a function of challenge level.

AOI	Fixation Count					
	Challenge Level 1		Challenge Level 2		Challenge Level 3	
	Mean	SD	Mean	SD	Mean	SD
Load	51	44	41	52	11	10
Middle	70	43	81	93	31	36
Clear Stage Button	7	3	15	18	8	11
Stage Info	8	6	5	6	3	1

TABLE V The descriptive statistics for the first fixation duration for each AOI as a function of challenge level.

AOI	First Fixation Duration (ms)					
	Challenge Level 1		Challenge Level 2		Challenge Level 3	
	Mean	SD	Mean	SD	Mean	SD
Load	287	183	452	373	796	570
Middle	199	81	256	187	176	59
Clear Stage Button	272	169	214	55	329	109
Stage Info	209	93	127	14	201	5

Table VI The descriptive statistics for the average fixation duration for each AOI as a function of challenge level.

AOI	Average Fixation Duration (ms)					
	Challenge Level 1		Challenge Level 2		Challenge Level 3	
	Mean	SD	Mean	SD	Mean	SD
Load	392	104	514	200	528	334
Middle	396	89	359	84	334	76
Clear Stage Button	233	65	248	21	270	67
Stage Info	198	65	173	48	170	10

Table VII 2-factor ANOVA for Time to First Fixation (TTFF)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
AOI	5.62E+10	18	3.12E+9	2.34	0.015	1.899
Stage	2.74E+9	2	1.38E+9	1.02	0.370	3.259
Error	4.82E+10	36	1.34E+9	-	-	-
Total	1.07E+11	56	-	-	-	-
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	5.62E+10	18	3.12E+9	2.34	0.015	1.899
Columns	2.74E+9	2	1.37E+9	1.02	0.370	3.259
Error	4.82E+10	36	1.34E+9	-	-	-
Total	1.07E+11	56	-	-	-	-

Table VIII Two-factor ANOVA for Average Fixation Duration.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
AOI	1.34E+6	18	7.43E+4	3.76	**0.0003**	1.898
Stage	2.23E+4	2	1.11E+4	0.564	0.5736	3.259
Error	7.11E+5	36	1.97E+4	-	-	-
Total	2.07E+6	56	-	-	-	-
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	1.33E+6	18	7.43E+4	3.76	0.0003	1.898
Columns	2.23E+4	2	1.11E+4	0.564	0.5736	3.259
Error	7.11E+5	36	1.97E+4	-	-	-
Total	2.07E+6	56	-	-	-	-

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