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IDEAL Creative Biomechanics Project and the Impact on Students' Engagement (Phase III)

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Assessment of Students' Engagement and Performance in Biomechanics using the IDEAL Creative Biomechanics Project

Abstract

Purpose: Gamification has been shown to improve students' learning and improve their motivation. We previously implemented Phases I & II of the Interactive Digital Experience as an Alternative Lab (IDEAL) to simulate a real-world scenario. IDEAL uses a gamified structure to automate student-led evidence collection as the lead detective in a fictional storyline. The implementation of IDEAL resulted in students' creative participation and improved the performance on their final reports. Over the past 2 years, we have improved the storyline by including day-before videos, images of the crime scene, as well as audio files of the witness interviews (to supplement the video files). We have also included more hints and feedback on user input throughout the investigation process. In Phase III, we tested the hypothesis that there would be improved learning of the core course concepts through increased engagement with the challenge.

Methods: We evaluated students' engagement with the forensic biomechanics challenge through thematic coding of their investigation reports. We classified blurbs from students' reports based on Fredricks conceptual frameworks of engagement into 3 categories: emotional, behavioral, and cognitive engagement. The engagement score, obtained through coding, for each student was then compared to their grades on this challenge problem.

Results: There is a strong correlation between students' engagement and their grades, with cognitive engagement showing the most significant correlation. Overall higher engagement translated into higher grades on his particular activity. The use of the thematically coded reports as means of assessing students' engagement with the activity was verified by investigating students' actual behavior while working on this problem (progress codes and Kaltura metadata). A strong correlation was observed between emotional and behavioural engagement data from the coded reports as well as their access pattern.

Conclusion: The results of this project continue to show that the forensic biomechanics challenge problem using the IDEAL framework improves students' learning through increased engagement.

Key words: Gamification, Active learning, Students' engagement, Forensic biomechanics

Introduction

Active learning has been shown to improve student engagement levels and, consequently, enhance their learning through increased motivation and positive attitude toward the technical content [1]. Careful implementation of active learning strategies, such as problem-based learning [2,3] and semi-structured design projects [4], increases participation and students' ownership of their learning, helping to sustain student attention and understanding [5–7]. Recently, several studies have demonstrated that implementation of gamification, which is defined as incorporation of game design elements into non-game context [8], can enhance student engagement across a wide range of educational activities and technical content [9–11].

Students' engagement can be viewed as an important benchmark and indicator for the quality of their experience [12]. Redmond *et al*., defined engagement as the extent or quality with which students are committed and actively involved in their learning [13]. Three key areas of behavioral, emotional, and cognitive engagement have been incorporated in many studies focusing on students' engagement levels, as there is a clear correlation between students' attitudes and motivations [14,15]. Examples of cognitive engagement include: critical thinking, activation of metacognition, idea integration, justification, and development of deep disciplinary understandings [13]. Managing expectations, articulating assumptions, and recognizing motivations as committing to learning are indicators of emotional engagement in learning. On the other hand, developing academic and/or multidisciplinary skills and agency as well as identifying opportunities and challenges are usually attributed to behavioral engagement.

At Michigan State University, the elective course in Tissue Biomechanics (ME 495) is taken by less than 10% of mechanical engineering students. This course covered basic anatomy, properties of musculoskeletal tissues, and calculation of joint loading in static situations. Since the spring of 2020, the course has involved 6-7 team-based challenge problems to encourage deeper exploration and learning of key concepts and emphasize the importance of self-directed learning. The class was also offered in a flipped structure, allowing class periods to be devoted to answering questions, solving sample problems and reviewing homework problems, and providing student teams an opportunity to work together in class.

In the Spring 2020 semester, Phase I of the Interactive Digital Experience as an Alternative Lab (IDEAL) was successfully implemented in this Tissue Biomechanics elective. IDEAL was introduced as a novel structure for the final challenge problem of the course and was able to further engage students with the course material [16]. Unlike the other challenge problems of the semester, this project was an individual assignment. Through this challenge problem, which included a unique storyline with fictional characters, students were asked to analyze 1) clinical reports, 2) witness recollections, and 3) gait analysis and combine that with knowledge of bone mechanics in order to determine the mechanism of injury and person-at-fault in a fictional forensic investigation. In Spring 2021, the gamification was enhanced by introducing a student-controlled Investigational Interface, which released evidence following the input of text-based commands, similar to the original *Oregon Trail* game of the 1970s [17]. In IDEAL version 2, witness observations were provided through video "interviews" rather than as a static report. The results from both Phase I and Phase II of this study indicated that students ultimately approached the IDEAL project with a greater appreciation and enjoyment than previous open-ended challenge problems—those that were assigned in a traditional problem statement manner—throughout the semester [16, 17]. It was also shown that students who were more engaged in the IDEAL challenge problem, as evidenced by the fact that they requested all of the evidence on their own, also received a higher score on the project report. The novel framework was compared to the traditional assessment structures in the course, both in terms of student performance and perception. A great enhancement in students' creative participation in the storyline surrounding the forensic investigations was observed, which in turn resulted in improved learning with respect to the biomechanical analysis [16].

Based on the preliminary indication that increased engagement was linked to student performance on this challenge problem, the structure of the research question was expanded in Phase III to assess student engagement through a theoretical framework [13]. Students from 2021 (IDEAL version 2) were included in the Phase III assessment, as well as those students from 2022 who were provided with version 3 of the gamified interface. We hypothesized that students' performance on the forensic biomechanics challenge problem would be correlated with their level of engagement, as determined from coding of their submitted materials.

Methods

In this third phase of the research project, the IDEAL Forensics Challenge Problem was implemented similar to Phases I & II, with 17 unique scenarios involving five witnesses and one individual injured due to a witness' action or neglect [16,17]. The cases are designed to have similar levels of difficulty, in that each student was expected to apply content learned in ME495 to estimate the bone mechanical properties (i.e. yield stress of the bones given the age, sex and conditions of the patient) and determine how the incident had happened. Students needed to collect evidence and use their biomechanics problem solving skills from ME495 to identify the mechanism of injury and the person-at-fault, while justifying their conclusions.

In IDEAL version 1 used in 2020, students would reach out via email to the Dr. Knows More to obtain different pieces of information as they conducted the investigations, providing a rapid response during normal business hours (9 am to 5 pm). The average response time for those interactions was 11.3 minutes [16]. Starting with IDEAL version 2 (2021), the same type of evidentiary material was delivered to the students through an Investigative Interface (an automated user interface in Jupyter Notebook). This allowed students to have access to the evidence or interview information with one click at any given stage of the investigation. Version 2 students were given access to witness video interviews and data from a compromised camera on the day of the accident as well as a site photo [17]. However, not all information was made available at the beginning of the investigation; students were required to go through the investigation and each piece of evidence, patient information, or suspect interviews was only made available if certain other steps had been taken beforehand. For example, if one of the suspects mentions the security camera in their interview, it is only after conducting that interview that students would be able to request camera data as evidence.

In addition to their project reports, 2021 and 2022 students were asked to create and submit an Investigator Journal and an Investigator Glossary document. The former was meant to record their notes and progress codes, while the latter was a repository of important words, relevant phrases, or names that they used throughout their investigation. While 2022 students interacted with the material through the same Investigative Interface as the previous year, a few minor changes were made in version 3 of the IDEAL gamified framework to make it a bit more accessible to the students. For example, a few feedback hints were included to help students precisely specify the type of injury that had occurred, day-before videos as well as images of the crime scene were included as complimentary evidence, and more text strings were accepted as input entries based on students' Glossaries (containing all attempted text strings) from the 2021 iteration of the course.

This study was conducted in a standard classroom setting with all students within a semester receiving the same instruction and assessment. Student assignments, including the survey of student perceptions, were administered as part of the class. The experimental design was reviewed by the Michigan State IRB and found to be exempt.

Students' Engagement – Thematically Coded Reports

Student engagement levels were evaluated based on the student submissions on the forensic biomechanics challenge problem. Students' reports and the required Investigator Journal were coded for their emotional, behavioral and cognitive engagement. The Investigator Journal documented the actions taken by the student as they worked to solve the problem. For each submission, students' assumptions, calculations, estimations, speculations, drawings and figures, tables, evidence collection, and conclusions drawn were considered as an element of cognitive engagement with the content. On the other hand, being in character as a detective and taking ownership of the investigation as well as referring to the characters as real persons throughout the report were considered to be elements of emotional engagement. Finally for the behavioral engagement, we looked at how students approached the problem, whether they sought help, whether they just used a trial-and-error approach with inputting different requests and key word combinations into their investigator journal, and if they took the effort to extensively capture each of the interviews through detailed notes. A numerical score was determined for each of the three domains of engagement by counting the number of coded segments in each student's submitted work and normalizing it by the maximum number identified in that cohort of students. Thus, each engagement score ranged between 0 and 100 percent, with 100 reflecting the highest amount of engagement. Total engagement was calculated in a similar way.

Students' Engagement – Content Interactions

The Investigative Interface was designed to generate a progress code at every step of the process. The code consists of a two-character alphanumeric combination, assigned to each piece of information being requested throughout students' investigations. Moreover, a code was defined for the session number as well as the initial request. Students were required to include these progress codes in their Investigator Journal as an indication of their investigation strategy. These codes were not used in grading of these assignments, but they did provide information for later assessment of student engagement.

Following submission of the assignments, the students' reported progress codes were evaluated and each of the alphanumeric combinations was categorized into one of 4 groups: 1) returns to the investigation, 2) evidence collected, 3) interviews conducted, and 4) patient information. Though it may seem obvious that to complete the investigation one would need to collect all of the evidence and interview all of the suspects, surprisingly, many students didn't request all of the data. Thus, these categorized progress codes were used to further assess students' behavioral engagement with the creative project.

A behavioral engagement score was defined using: (the total number of steps in each individual's investigation) plus (the number of times that students returned to the investigation) minus (each piece of evidence or interview that was missing from the investigation). Given the narrative of the study, certain steps and actions should have been taken in a particular order rather than randomly. To account for engagement through following the script, 5 points was subtracted from the behavioral engagement score every time someone deviated from the storyline (up to a maximum total of 10 points). This 5-point value was chosen to emphasize the student's engagement with the narrative.

An emotional engagement score was also defined based on how invested and excited students were about completing this project and was determined by looking at the access data from Kaltura (a centralized, video-hosting hub that is tailored to the users' needs and content and allows for tracking metadata on engagement with the videos). For each video and each case, Kaltura provided an extensive report on different aspects of the user interaction with the media. Among all data available from Kaltura, this project focused specifically on a subset of information, including data on the number of times a particular individual had clicked on the video, the number of times they had watched the video (completely or partially), and the dates on which each of these actions took place. This particular subset of data was chosen as it was hypothesized that students who are more invested in the course would be particularly more excited about the project as well, and thus they would get started far in advance of the due date and would come back to the assignment multiple times throughout the period to work on it. Thus, the emotional engagement score was defined as the number of returns to the investigation plus the number of weeks between the start date and the submission deadline.

Students' Performance

A student's grade on the forensic biomechanics challenge problem was used as a measure of actual performance in this assignment. Each report was evaluated in terms of the solution presented, the assumptions, and the decision-making process, along with the presentation of the equations, sketches and figures (Table 2 shows the rubric used for evaluating the students' reports for all of the course's challenge problems). The grades are indicative of the correctness of the calculated and inferred solution as well as the description of the process to reach the solution. Though the student grade is more of a representation of the cognitive domain, it is a good measure of the student engagement level and, when compared to grades in other assignments, reflects the impact of the gamified problem on their learning.

In order to separate the assessment of the data (including coding of the reports) from the evaluation of grades, the authors split these responsibilities. MG, who was the instructor in the course, assessed all reports with the rubric. RVG, who did not meet the students and therefore held no biases towards any of them, coded the reports for engagement.

Statistical Analysis

When comparing two groups of numerical data (e.g. enumerated engagement scores), a two-tailed Student's t-test was used. If more than two groups were compared, a one-way ANOVA with post-hoc Tukey analysis was conducted. Differences between the groups (student cohorts) were considered to be statistically significant when the p-value was less than 0.05 ($p < 0.05$).

When linear correlations were assessed, standard R^2 values were reported, as each correlation included only a single dependent variable. For each of these assessments, the correlated scores both ranged between 0 and 100. The value of the slope of the linear regression equation (m) was examined to see how close it was to 1, indicating a 1:1 agreement.

All statistical analyses were performed in GraphPad Prism.

Table 1. The rubric used to evaluate the challenge problem and minimize bias in grading. Students were provided with this rubric in advance of the project being assigned.

Criteria	Exceeds expectation	Meeting Expectation	Partially meeting expectations	Some aspects of expectations met	No attempt to meet criteria	Points available
Solutions - as described in the summary	20 points Solution makes complete sense and is solidly backed by the additional discussion	16 points Provided solution is correct but there are gaps or missing components	10 points One part of solution is correct but there are several gaps or incorrect components	5 points No aspect of solution is correct based on science	0 points No solution provided	20
Assumptions - back up	10 points All assumptions backed by references	7 points Most assumptions backed by references, but one that should be stated without backing	5 points Some assumptions backed by references but several others that should be are just stated without backing	2 points Only one or two assumptions are backed by references	0 points All assumptions made without including references to back them up	10
Assumptions - description	10 points Assumptions completely described	7 points 70% to 80% of anticipated assumptions described	5 points 50% of anticipated assumptions described	2 points One assumption described	0 points No assumptions described	10
Decision making process	20 points Process to reach solution clearly described in logical, stepwise fashion	16 points Process steps are listed and described but not in a logical order	10 points All steps listed but only some described	5 points Some steps listed but not explained	0 points No description of process used to reach solution	20
Equations	10 points Equations all appropriate	7 points Most equations appropriate, but 1-2 not relevant	5 points Some equations appropriate but significant number not relevant to solution	2 points Equations provided but not relevant to solution	0 points No equations provided	10
Sketches and Figures	10 points Sketches, figures, and graphs used to fully support decision making process		5 points Some sketches, figures, and/or graphs provided - but some parts of decision-making process could be better supported		0 points No sketches, figures, or graphs provided	10

Results and Discussion

The assessment of the students' engagement and performance were analyzed both separately and in comparison, with each other.

Students' Engagement – Coded Reports

The submitted report and Investigator Journal were assessed in order to identify occurrences that could be coded as evidence of cognitive, behavioral, and emotional engagement. Several students included hand-drawn or digital drawings to complement their biomechanical analysis and calculations. Figure 1 shows an example of a student's work that was coded as engagement in the cognitive domain.

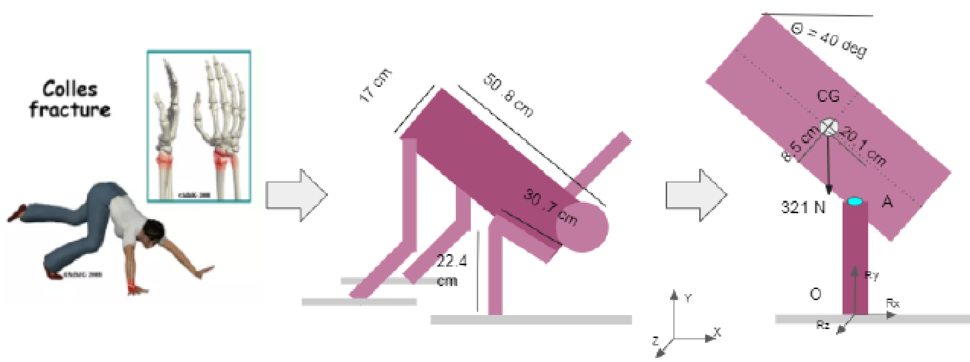

Figure 1. Example of student drawing supplementing their biomechanics analysis as an indicator of their cognitive engagement

Many students engaged emotionally with the story and wrote the report referring to the characters as real persons and referring to themselves as the principal investigator /detective of the case. One such example was explained this way in the Investigator Journal:

> "*I was tasked with finding out the injury Michael Doe suffered along with the cause behind this injury. Inside the software the first thing I did was request for the witness list and the patient's information. From there I requested for the X ray of the injury (seen in Figure 2). After looking at the image of the injury I could immediately tell I was looking at a fracture that occurred in the elbow. Since I needed to gather more information before I began to determine the exact cause of the injury I moved onto interviewing the witnesses*."

> *"Once this data was gathered I made my first theory. I hypothesize that Abigail left her bike outside on a lamppost due to her intoxication before heading into the party. Doe then somehow tripped over the bike and fell while becoming ensnared in the bike."*

In addition to their own research, students reached out to a wide range of people – from their classmates and the instructor to professional doctors and nurses in their families, seeking help with their case. Some had transcribed the witness interviews in detail, while others listed those interviews in the required disclosure of "external contacts". These actions again supported students' emotional engagement. Another example of students' buy-in with the gamified project was their methodology to look for and collect relevant information for the challenge problem:

> "*Our consultant team would like to thank the West Lansing Police Department (WLPD) for its thorough job of collection of evidence, and assistance for solving this case. We would also like to thank the work of Dr. Michele Grimm, Lizzy Mays (PhD), and Liz Pollack (Doctoral Student) for their involvement with educating the consultant team*."

> *"As the initial report states, Michael Doe was cross country skiing so he would have a velocity to him, making this dynamics problem. He is falling around point G in Figure 8. I could not find any article on the average time it would take a person to fall, so I conducted my own experiment. I stood on top of my bed standing straight up and fell five times while my roommate recorded the time it took, the times are shown in Figure 7. The average time of the five trials came out to be 2.82 s."*

In terms of overall engagement level (which was calculated as the sum of the 3 categories), students had an average score of 32% in 2022 (calculated as the ratio of engagement to the maximum engagement score obtained in the same cohort). In 2021, behavioral engagement scores were approximately 10 percentage points higher than those scores in 2022; this higher score in version 2 of the IDEAL framework was mainly the result of students' trying multiple different combinations of the keywords to unlock the evidence. The Investigator Journals demonstrated that the feedback provided to some of the "close" responses was an improvement to the user interface, and that the feedback provided was sufficient for the students so that they did not need to request external help in order to be able to complete this portion of the challenge problem. Cognitive and emotional engagements showed a 20-point and 50-point increase in 2022 compared to 2021, which again speaks to students' buying-into the problem and being more invested as a result of the adjustments made in version 3 of the interface.

To further investigate the inter-cohort differences and the possible impacts of the version 3 modifications, the distribution of the coded engagement scores in each cohort was examined. Figure 2 compares levels of the different types of coded engagement in the 2 cohorts. Although not significant, there seems to be an improvement in all of the domains in 2022 (IDEAL version 3) as a result of the modifications, and the lower bounds of each domain seem to be slightly higher in 2022. Students appear to have been more emotionally and cognitively engaged with the addition of the supplemental elements: the video of the scene of the accident on the previous day, as opposed to a still "photo"; the expanded list of accepted text when identifying the injury; and the audio file options for the witness interviews. The range of behavioral engagement narrowed significantly in 2022 – as there were fewer students who tried a large number of text options when identifying the injury before requesting assistance or giving up. Thus, the guiding feedback for close answers appears to have been effective. In combination, the addition of more gamified elements and efforts to reduce student frustration with the accepted text strings improved overall engagement.

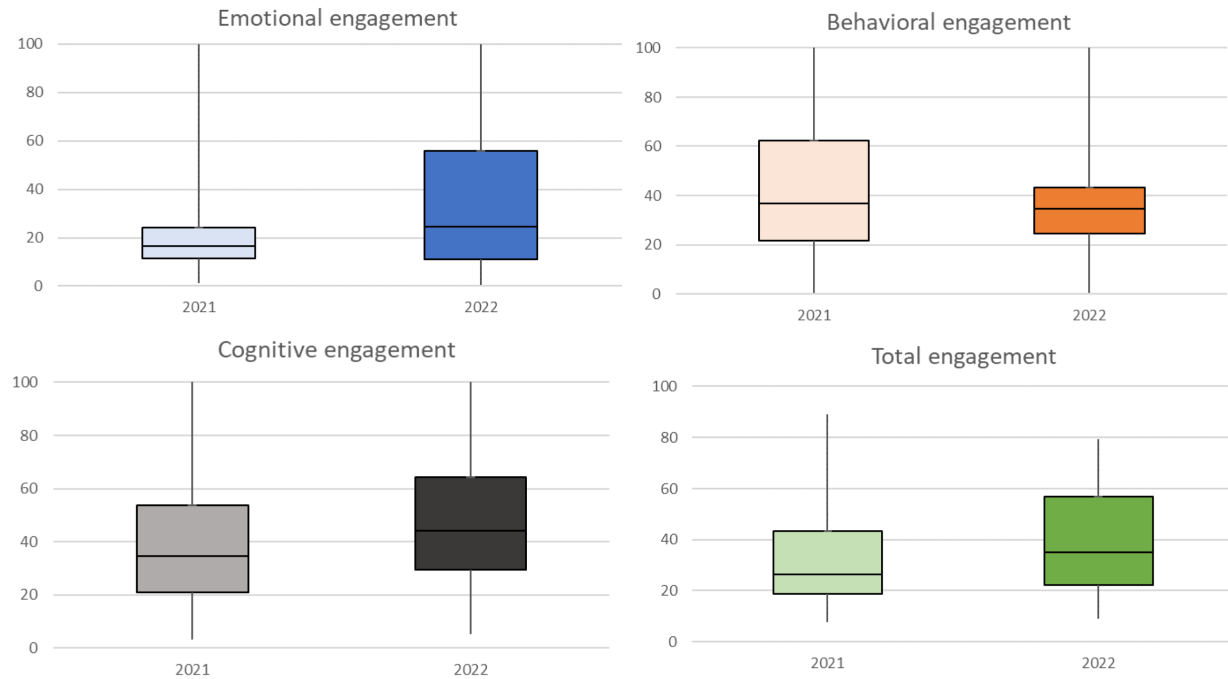

Figure 2. Overall coded engagement level by year, n=30 in 2021 and n=28 in 2022. Center line indicates the median score, the box indicates the upper and lower quartiles (25% of population) around the median, while the vertical lines indicate the range of engagement scores.

Student Performance – Project Grade

The range and average scores earned by the students on this project were very similar between the two cohorts. In 2021, using IDEAL Interface version 2, the mean score on the Forensic Biomechanics report for the 34 students was 57.9 points out of 80 (72.3%) – taking into consideration the categories of the rubric that encompass the aspects of the report other than the writing quality. The range of scores in 2021 was from 5 points to 76 points. In 2022, the 29 students who submitted the report earned a mean score of 55.3 points (69.2%), with a range from 13 to 80. Thus, while the mean score was slightly lower in 2022 (with version 3 of the IDEAL framework), both the minimum and maximum grades earned had increased (by 8 and 5 points, respectively).

Given the relatively small class sizes, looking at the distribution of the test scores can be more insightful that just mean scores. In 2021, the top quartile of the scores earned ranged from 67.5 to 76 points (84.3 to 95 percent). In 2022, the scores for that top quartile of the course increased – ranging from 72.5 to 80 points (90.6 to 100 percent). While the mean score dropped slightly from 2021 to 2022, the top quarter of the students improved their performance. Interestingly, among the lower two quartiles of each cohort, the difference in the scores was due primarily to how they described and backed up their process (rubric components other than the solution itself) – in 2022, a greater share of the students (75% vs 50%) provided a correct answer to at least one part of the challenge problem. When combined with the fact that the lowest overall grades also increased from 2021 to 2022 (5 to 13 points), there is solid evidence of improved learning using version 3 of the IDEAL framework.

As a second indicator of overall learning in the class, students' grades on the final exam were also compared. While not significantly different, as determined by a Student's t-test ($p = 0.065$), the scores for the 2022 (IDEAL version 3) trended higher than the scores of the students in 2021 (IDEAL version 2). Not only did the mean on the exam increase (61% to 73%), the proportion of students receiving a grade of 90% of higher increased (0% to 23% of the class) and the proportion of students receiving a grade below 60% dropped (46% to 30% of the class). While the Forensic Challenge problem obviously was not the only mechanism through which the students learned the concepts in this class, the course structure and lecture material did not change between those two offerings. Thus, the increased engagement with the Forensic Challenge Problem correlates with the improved learning – although determining the causal relationship will still require more research.

Comparison of Results from Different Frameworks

The correlation between the coded engagement score in each domain and students' grades on the project are provided in Table 3. If the 2 parameters are correlated, the slope of the fitted line to the data would be close to 1, while any deviations from this value of the slope indicates that the parameters are not necessarily correlated. We see a relatively strong correlation between the coded cognitive engagement and their grade on the forensic challenge problem (m=0.86 in 2021 and 1.05 in 2022), which – given that the assessment of student performance was mainly focused on cognition (i.e. a lot of the points on the rubric for this challenge problem were based on evaluating the cognitive response to the problem) – is logical. In contrast, for the emotional and behavioral engagement, we do see correlations, but they are not as strong as the cognitive domain (e.g., m=0.54 for emotional engagement in 2022 and m= 0.55 for behavioral engagement in 2021).

Table 2. Correlations between students' performance, perception, and engagement levels in different domains of engagement.

	2021, n=30		2022, n=25	
Coded engagement vs Performance	m	R^2	m	R^2
Emotional	0.36	0.095	0.544	0.123
Behavioral	0.553	0.110	0.412	0.117
Cognitive	0.857	0.439	1.048	0.665

Figure 6 shows the correlation between overall coded engagement and performance in the forensic biomechanics challenge. As shown, there is a relatively strong correlation between overall engagement and students' performance on the challenge problem.

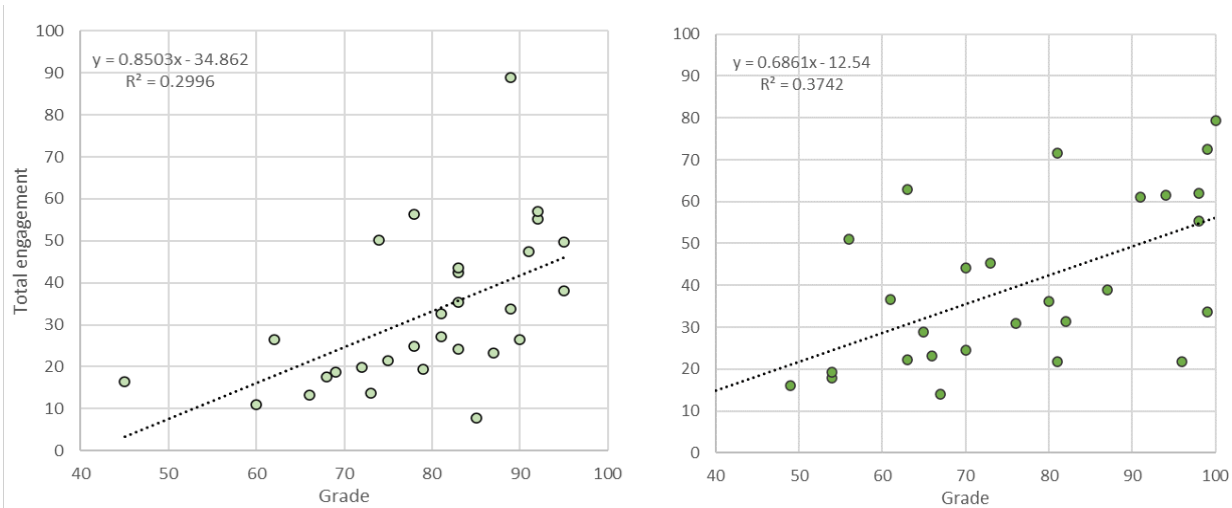

Figure 3. Overall coded engagement level vs project grade in 2021 (left panel) and 2022 (right panel)

Comparing engagement scores determined from students' interactions on the investigator journal and user interface (behavioral engagement) with the coded reports, there is a relatively strong correlation between being invested in the process (as indicated by how long in advance of the deadline they have started their investigations and the number of times an individual has come back to the portal) and their behavioral and emotional engagement as assessed through the written report (Figure 4).

Limitations from Experimental Design

Kaltura user interaction statistics provide an extensive insight into content engagement. For example, we observed that for 2021 the 5 videos for case 17 were played a total of 36 times (by 2 students assigned to this case), and overall students spent 7.7 min watching all 5 videos -- which translates into an average of 90s viewing per video. However, the main limitation while using Kaltura data for this sort of assessment is that if a certain case was assigned to more than 1 individual (which is the case here 17 cases for ~34 students in each cohort), distinguishing between the timelines and actions of individual students becomes challenging. Therefore, for individuals working to replicate or expand upon this study, it is highly recommended to include distinct ways to track individuals interacting with the media. In fact, there is much more data from Kaltura to be drawn on if we had it set up to isolate each student. While students were asked to include their progress codes in the investigator journal, these entries were often not dated. Including dates for each of those progress codes could have also been helpful in tracking them down on Kaltura media.

Figure 4. Relationship between behavioral and emotional engagement assessed through codified reports and the behavioral and emotional engagement determined through analysis of progress codes and Kaltura data, respectively

Conclusions

IDEAL was implemented in a junior/senior-level tissue biomechanics course over the past 3 years, and every year we continued to increase student engagement with the content and hence improve students' performance. Our findings highlight that as these activities become more engaging in design and implementation, more students are willing to put in the additional effort and provide a substantive discussion of their solution process, and it is more likely they will come up with the right answers. This is in agreement with previous findings reporting that higher engagement levels improved student grades. With improvements of the project throughout the years, we can clearly see students have much smoother interactions with the challenge problem, and they have also demonstrated improved learning through the assignment (e.g., higher proportion of students providing correct solutions in 2022 compared to previous years using the same rubric, higher minimum score, and higher scores for top quartile of class). A correlation between student performance and coded evidence of engagement was identified through the data collected.

Overall, this project provides evidence that the gamified structure designed to automate student-led evidence collection was an efficient intervention for enhancing students' creative participation and improving their performance. This structure can be easily adapted in other technical courses to further increase student buy-in and motivation to learn the content.

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