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An Exploration of Game-Based Learning in Enhancing Engineering, Design, and Robotics Education via ”The Legend of Zelda: Tears of the Kingdom”

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Abstract

The concepts of "Gamification" and "Game-Based Learning (GBL)" have garnered increasing attention by educators as a pathway to improve motivation, engagement, and learning outcomes among their students. For engineering education, however, the use of entertainment video games for GBL has received less enthusiasm, which may be due to difficulties in identifying games that could reasonably provide authentic and relevant learning experiences for students. In the Fall Semester of 2023, we developed and offered a new second-year undergraduate engineering course that was designed to leverage the video game, "The Legend of Zelda: Tears of the Kingdom" (Nintendo, 2023), as a virtual platform for students to design, prototype, and test mechanical systems, including bioinspired amphibious robots and aerial catapults. We evaluated the efficacy of the course by examining the results of two machine design projects completed by the students, conducting and analyzing student surveys, and assessing student feedback. The results revealed the potential of GBL in cultivating interest and skill in STEM-related fields, suggesting that integrating entertainment video games that involve engineering-relevant gameplay into the curriculum can help to engage students and enhance proficiency. Although this initial study comprised only a single semester with a limited sample size of students due to resource constraints, the approach and results serve as an important milestone in exploring the use of a popular video game as a unique means to enhance student learning and, ultimately, expand the horizons of pedagogical strategies for engineering education.

1. Introduction

"Gamification" in higher education refers to the integration of game-inspired elements and principles into the curriculum of a course to enhance student motivation, engagement, and learning outcomes [1-3]. Historically, such pedagogical practices have primarily involved applying features commonly found in games—*e.g.*, points, badges, leaderboards, levels, challenges, and rewards—to academic activities and coursework [4-6]; however, there is increasing interest in "Game-Based Learning (GBL)" [7-9], which encompasses learning through the use of serious games, traditional board and card games, as well as digital, mobile, and/or video games [10, 11]. Several recent reports offer insight into the potential of GBL in engineering disciplines such as railway engineering [12], optimization techniques [13], solid mechanics [14], and other areas [15]. In terms of video games specifically, one of the most prominent approaches involves researchers developing new educational games from scratch for their studies [16], such as for GBL in sustainability [17]. Notably, Beck *et al*. recently reported a modification or "mod" of the popular video game, Minecraft, in the form of an elasticity solver which they implemented in the biomedical engineering curricula for teaching statics and mechanics of materials [14]. To the knowledge of the authors of this paper, however, studies evaluating the potential benefits of implementing popular entertainment video games directly (*i.e.*, without modifications) for GBL in higher education, engineering education, and/or machine design remain scarce in the literature [14]. Such video games designed explicitly for entertainment purposes offer an ideal medium through which to engage and motivate students [18-20], but for engineering education in particular, these types of video games often present challenges in terms of direct relevance to course subject matter [21].

In May of 2023, the video game, "The Legend of Zelda: Tears of the Kingdom", was released for the Nintendo Switch and within three days, sold over 10 million units to become the fastest-selling Nintendo game of all time in the Americas [22]. In addition, the video game received near-universal acclaim, launching as the best-reviewed game of the year [23]. Although Nintendo's "The Legend of Zelda" franchise has maintained its popularity since the 1980's, "Tears of the Kingdom" marked a major departure from previous installments by including a prominent focus on gameplay centered around machine design and engineering. As a result, the "The Legend of Zelda: Tears of the Kingdom" established itself as arguably the highest-profile video game that could be readily leveraged for GBL in engineering curricula.

There are three main features of "The Legend of Zelda: Tears of the Kingdom" that are particularly amenable to GBL in the context of engineering education. First, the video game includes a simplified computer-aided design (CAD) assembly interface (**Fig. 1**)—referred to as "Ultrahand" in the game—which is similar to the "Assembly" module of SolidWorks CAD software (Dassault Systèmes, France) in which discrete components can be mated (*i.e.*, joined or connected) to one another to resolve a unified assembly [24-26]. One caveat to the in-game interface is that it lacks the high degree of customization for mating conditions associated with

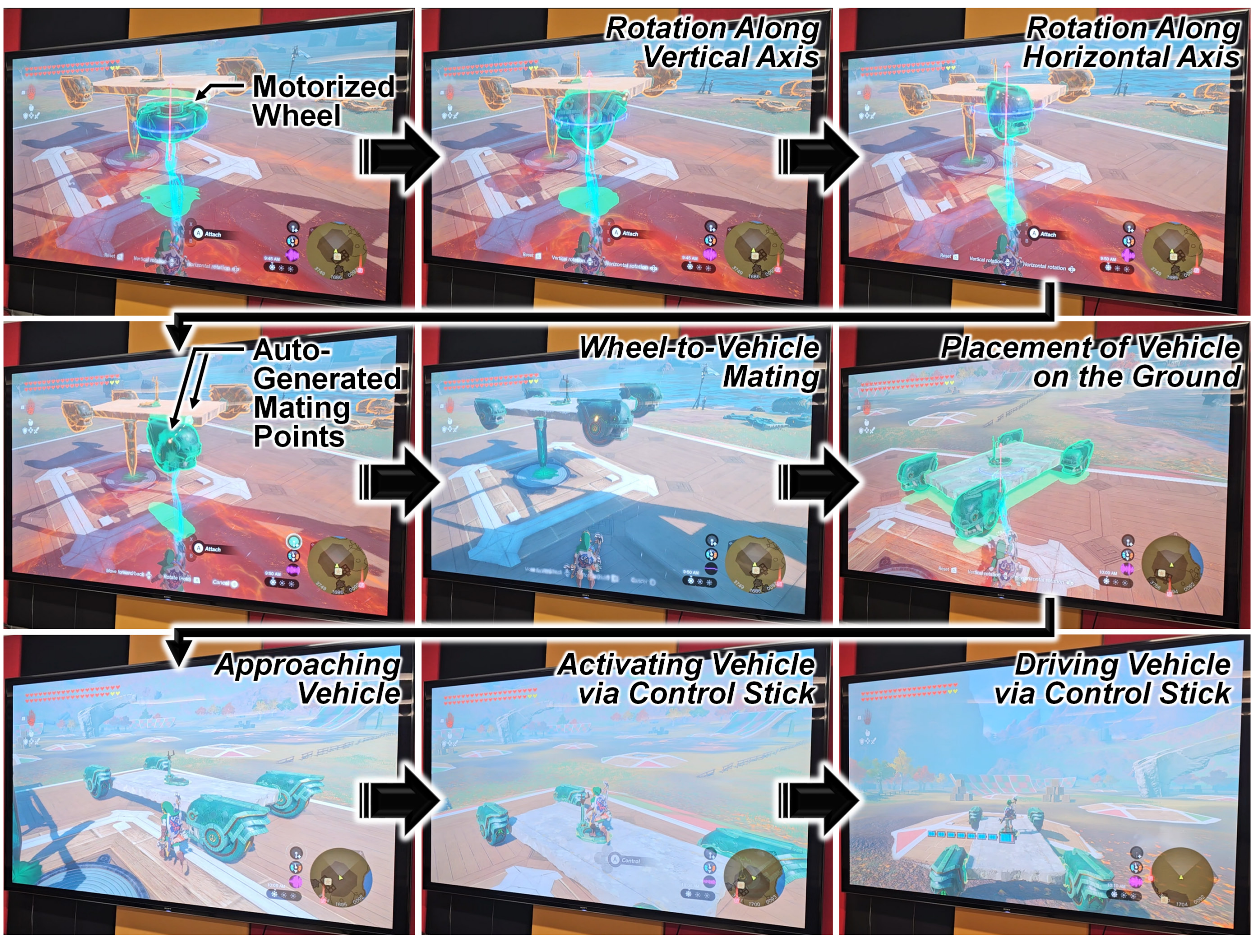

Fig. 1. Sequential images of the process for using the in-game computer-aided design (CAD) assembly-like interface of "The Legend of Zelda: Tears of the Kingdom" to construct a drivable demonstrative four-wheeled vehicle—performed by the course instructor in the classroom.

traditional CAD software; however, because the video game relies on an automated snapping algorithm, part-to-part mating can often be more straightforward and intuitive. An example of an in-game assembly process for a demonstrative vehicle composed of a base plate, four small motorized wheels, and a steering stick is presented in **Fig. 1**. Notably, the vehicle can be driven by the player directly after completion of the assembly process (**Fig. 1** – *bottom row*).

A second notable feature of the game is the variety of fundamental machine elements and structural components that can be combined to build wide-ranging vehicles, robots, and additional classes of machines. For example, the game includes propellers, motorized (and non-motorized) wheels, rockets, springs, gliders, hot air balloons, stabilizers, as well as numerous additional elements far beyond the selected assortment shown in **Fig. 2**.

Fig. 2. Examples of various machine elements and structural components from the game.

Correspondingly, a third key feature of "The Legend of Zelda: Tears of the Kingdom" is that various machine elements exhibit unique energy (*i.e.*, battery) depletion dynamics. For example, while a single motorized wheel (big or small) has an energy depletion rate of 0.045 batteries/s, a fan—which operates akin to a propeller—has a much larger energy depletion rate of 0.468 batteries/s. In addition, the game rewards machines that comprise multiples of the same elements with reduced energy consumption rates. In the case of fans, for instance, each added fan (after one base fan) will increase the total energy depletion rate by half its base value, so five fans used in a machine will have a total energy depletion rate of only 1.404 batteries/s (*i.e.*, 1×0.468 batteries/s + 4×0.468/2 batteries/s) rather than 2.340 batteries/s (*i.e.*, 5×0.468 batteries/s). Thus, when combined with the relatively sophisticated component- and system-level physics, the video game offers a distinctive milieu for GBL in the context of engineering education.

In this paper, we introduce an undergraduate engineering course that centers on using the video game, "The Legend of Zelda: Tears of the Kingdom", as a virtual platform with which students can design, prototype, and test complex mechanical systems as a novel means for GBL in higher education. We evaluate the results of two team machine design challenges developed for the course and examine the effects of participation in this course on students' engagement in Science, Technology, Engineering, and Math (STEM) and machine design as well as their sense of inclusion in the engineering community. Although the results presented herein are restricted by the course enrollment numbers—which were constrained by the limited number of Nintendo Switches, video game cartridges, controllers, and available classroom TV screens that could be provided by the university for each team—this particular course, the survey data, the student feedback, and the preliminary lessons learned serve as an important benchmark for GBL involving entertainment video games for undergraduate engineering education.

2. Course Structure

The course, "The Legend of Zelda: A Link to Machine Design", was developed and launched for the Fall Semester of 2023 as a 1-credit Mechanical Engineering elective course for 2nd-year undergraduate students. The course schedule included one 50-minute in-person combined lecture and laboratory per week—with the caveat that the instructor's "office hours" were held in the same classroom for a full hour directly following class time, thereby allowing students to continue their efforts without interruption as desired. The assigned classroom included six large-screen TVs and was able to accommodate up to 30 students, corresponding to a maximum distribution of six teams each comprising six students. In addition, departmental funds were used to purchase six Nintendo Switches, six "The Legend of Zelda: Tears of the Kingdom" video game cartridges, and six Nintendo Switch Pro Controllers (*i.e.*, to ensure at least one of each was distributed to each team in the case of maximum enrollment with six teams).

The course was divided into four main phases. In Phase I (Weeks 1–5), the students gained experience with the video game by completing problem-solving challenges—referred to as "Shrines" within the game—to learn the basics of the various machine elements and machine prototyping functionalities. In Phase II (Weeks 6–8), each team of students was assigned a core machine element as well as three additional elements (*i.e.*, corresponding to each row of **Fig. 2**) to model as a part in SolidWorks CAD software. The primary activity of Phase II involved student teams designing in-game experiments to elucidate relevant performance metrics (*e.g.*, force, torque, thrust, power, and/or weight) for their assigned core machine element (*i.e.*, the first column of **Fig. 2**). Phase II concluded with the student teams sharing their CAD files with the rest of the class and then delivering a 5-minute oral presentation using Microsoft PowerPoint slides to explain the methodology by which they conducted their investigations, the key results from these in-game studies, and discussion with regard to any unexpected results (*e.g.*, in-game operations that contrasted with real-world physics).

Phase III (Weeks 9–11) centered around the Midterm Team Machine Design Challenge: "Transforming Bioinspired Amphibious Robotic Vehicle". The assignment description given to the students was:

> *The primary objective of this assignment is to design a reconfigurable robotic amphibious vehicle (i.e., by leveraging "Autobuild" capabilities) that includes two principal machine configurations: (1) Biped or Quadruped Walking Robot while on land, and (2) Aquatic Vehicle while in water. The goal is to traverse a set course as quickly as possible, which requires balancing the choice and placement of machine and structural elements with the resulting energy (i.e., battery) depletion rates. There are two important caveats to this design challenge: (i) both config-urations must be bioinspired (i.e., their designs and/or movements mimic those of living animals/organisms); and (ii) although teams can include up to 21 total parts for their reconfigurable machines, all of these parts must be used in the designs for both machine configurations. The secondary objective of this assignment is to build the vehicle in SolidWorks computer-aided design (CAD) software.*

Initially, the instructor delivered lecture materials focused on advanced in-game building tips (*e.g.*, how to use stakes for visibility as shown in **Fig. 1**, "zonaite" for "Autobuild", and dragon parts to increase allowable player distance from "Autobuild" machines as well as how to manipulate automated snap points); however, the majority of Phase III was designated as lab time to allow students individually and in teams to work on their midterm projects. The deliverables and grading breakdown (35% of final grade) included: (*i*) Individual Vehicle Testing (5% graded on an individual basis); (*ii*) Team Oral Presentation (10% graded on a team basis); (*iii*) Machine Performance (10% graded on a team basis); and (*iv*) Individual Teammate Performance (10% graded on an individual basis based on teammate peer review feedback).

Phase III concluded with the student teams first delivering 10-minute oral PowerPoint presentations describing their machine's design and methodology, which included: (*i*) listing all of the machine and structural elements used (up to 21 total); (*ii*) showing videos comparing the assembly process in SolidWorks CAD software *versus* within the game (for both configurations); (*iii*) showing videos of in-game operation and listing performance for both velocity and energy (*i.e.*, battery) depletion rate (for both configurations); and (*iv*) showing videos of (and listing anticipated performance for) the course completion time. After all of the oral presentations were delivered, there was a class "race" during which all teams attempted to complete the course (**Fig. 3**) as fast as possible (simultaneously) in front of guest judges from machine design and robotics disciplines. Grading of the race was based on a curve from the fastest to slowest completion time.

Phase IV (Weeks 12–15) centered around the Final Team Machine Design Challenge: "Aerial Catapult". The assignment description given to the students was:

> *The primary objective of this assignment is to design an aerial machine that can perform two primary, sequential functionalities: (1) Ascend vertically into the air to a desired height, and then (2) Fire a catapult—designed as part of the machine—to launch a projectile of your choosing (e.g., a korok) through the middle of an assigned ring structure (located at 1684, -0910, 0248) from an assigned lateral distance associated with the takeoff*

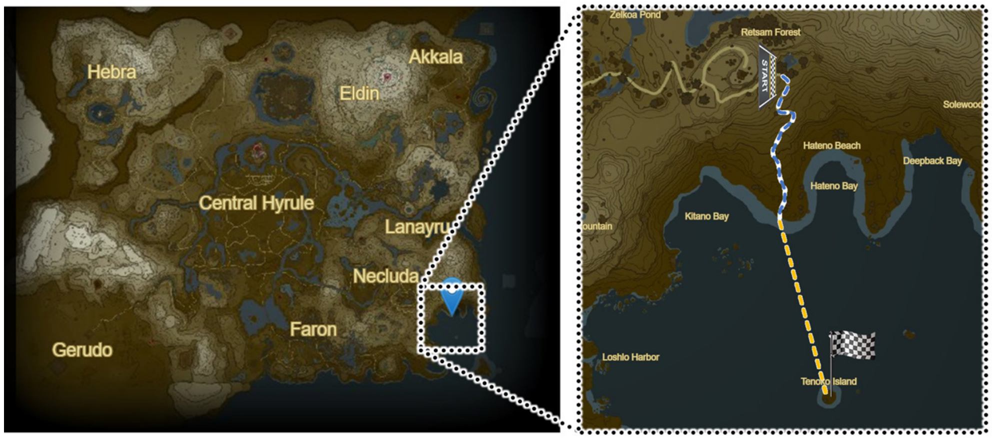

Fig. 3. The assigned in-game race course—with a land and water portion—for the Midterm Team Machine Design Challenge: "Transforming Bioinspired Amphibious Robotic Vehicle".

> *site (located at 1819, -0985, 0112). The goal is to accomplish this feat in less than 30 seconds. A challenge is that only vertical motion is allowed during the first vertical ascension step—i.e., no lateral/rotational movement is allowed. The secondary objective of this assignment is to build the machine in SolidWorks computer-aided design (CAD) software.*

The deliverables and grading breakdown for Phase IV were akin to those of Phase III. Similarly, Phase IV concluded with the student teams first delivering 10-minute PowerPoint presentations describing their machine's design and methodology, which included: (*i*) listing all of the machine and structural elements used (up to 21 total), (*ii*) showing videos comparing the assembly process in SolidWorks CAD software *versus* within the game, and (*iii*) showing videos of in-game operation. After all of the oral presentations were delivered, the student teams performed in-class demonstrations during which each team was allowed up to three attempts to launch their chosen projectile through the assigned ring structure (**Fig. 4**). For grading of the machine performance, full credit was given if any of the three in-class attempts were successful.

3. Research Method

3.1. Course Enrollment and Student Make-Up

Due to the limited maximum enrollment (30 students) and the immense level of student interest in the course (>100 students expressing interest in registering for the course), a randomized lottery was held to determine which students would be given permission to enroll in the course. Among the students that received permission following the lottery, one third identified as female while the remaining two thirds identified as male (which is consistent with the breakdown of the department). To support balanced team selection with respect to past and/or relevant experience with the game, the students were asked about their previous experiences with "The Legend of Zelda" franchise as well as "The Legend of Zelda: Tears of the Kingdom" specifically. The results revealed that not only had a majority (57%) of the students never played "The Legend of Zelda: Tears of the Kingdom", but also a considerable portion of students (37%) had never played any games in the "The Legend of Zelda" franchise (**Fig. 5**).

Fig. 4. The assigned in-game ring structure (*top*) and takeoff site (*bottom*) for the Final Team Machine Design Challenge: "Aerial Catapult".

As a result, the minority of students who responded that they had either beat the game or "played it a lot (>20 hours)" were distributed into different teams at the onset of team formation.

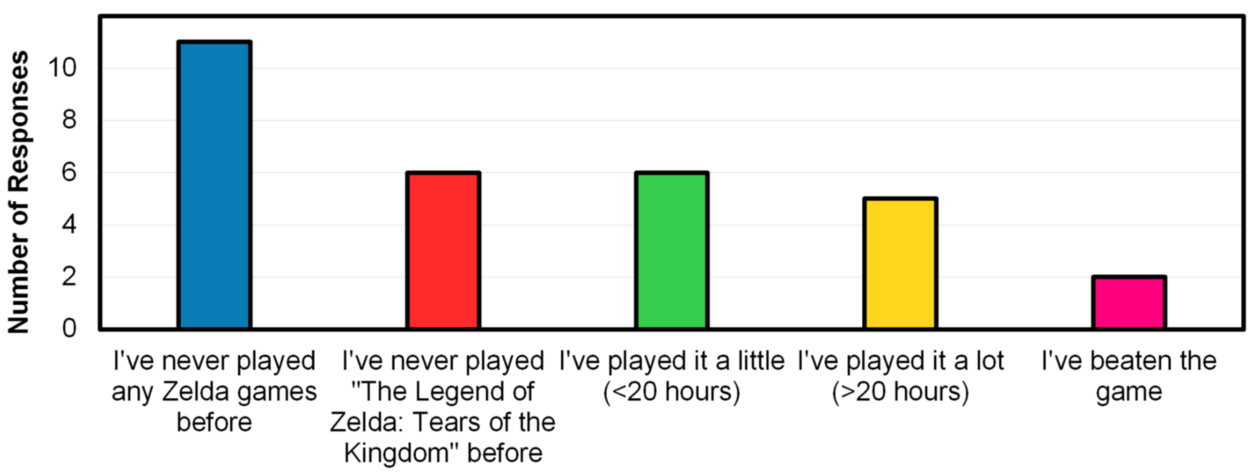

Fig. 5. Student responses to complete the statement, "My experience with "The Legend of Zelda: Tears of the Kingdom" is best described as:", for the initial students selected by randomized lottery to receive permission to enroll in the course (n = 30 students).

3.2. Evaluation of Project Deliverables

An important feature of the machine design projects is the use of objective performance metrics in grading, such as the speed with which the robotic vehicle can traverse the land and water regions or the course and the accuracy and precision with which the aerial catapult can launch the projectile through the center of the target ring structure. We assessed the effectiveness of the course, in part, through the objective measures of performance associated with these machine design challenges, which entailed teams of up to six students working together to accomplish the assigned objectives.

3.3. Voluntary, Anonymous Surveys at the Beginning and End of the Semester

We designed an Institutional Review Board (IRB)-approved survey to evaluate the potential impact of enrollment in the course on students': (*i*) career aspirations, (*ii*) confidence in machine design and engineering, (*iii*) role in engineering team settings, (*iv*) communication skills, and (*v*) sense of inclusivity and belonging among engineering students. A link to the online survey (as a Google Form) was sent to the students at the beginning of the semester as well as at the end of the semester by the course instructor. Students were informed that the survey was not only anonymous, but also entirely voluntary. Consent was obtained verbally from the students. Specifically, the following statement was read aloud to the students:

> *"As part of a research project, we are conducting a survey within this course. The survey aims to investigate the effect of video games as a medium on students' learning skills in designing, prototyping, and testing mechanical systems. We are keen to understand how taking this course might influence your interests in STEM, graduate school, and design. Please note that the survey is anonymous, and your participation is entirely voluntary. Taking part in the survey will NOT influence your grades or performance in any way. The principal investigator of this study is [Redacted], a lecturer from the Department of Mechanical Engineering. You are eligible to participate since you enrolled in this course. Completing the survey should take no more than 15 minutes. There will be no audio or video recordings at any stage of this study."*

The survey employed a Likert scale ranging from 1 to 7, where 1 indicates strong disagreement with the statements and 7 indicates strong agreement. The survey asked the students, "To what extent do you agree or disagree with the following assertions?", for ten questions:

1. I am interested in pursuing a career in a Science, Technology, Engineering, and/or Math (STEM) field.
2. I am interested in pursuing a Masters-level graduate degree (e.g., M.S. or M.Eng).
3. I am interested in pursuing a Doctoral-level graduate degree (e.g., Ph.D.).
4. I am interested in obtaining a position in industry.
5. I am interested in design.
6. I am confident in my ability to design, prototype, and test machines and/or complex systems.
7. I am confident in my ability to work productively as part of a team.
8. I enjoy working as part of a team.

9. I am confident in my ability to deliver oral presentations and present design solutions effectively.
10. I feel a sense of inclusivity and belonging in the engineering community at my institution.

At the beginning of the course, approximately 25 students enrolled in the course. Among these students, 11 participated in the survey at the beginning of the semester. During the semester, the time and difficulty associated with completing the Midterm Design Challenge led to a considerable portion of the students dropping the class, resulting in only 12 enrolled students remaining in the course by the Final Design Challenge. Correspondingly, only three participated in the survey at the end of the semester. The instructor team identified the course load of three projects for a one-credit class as the main reason for the high drop rate. To address this issue, the course load was adjusted for the next offering, including reducing the number of projects to two, which has so far led to none of the initially enrolled students dropping the course. No demographic information was collected from the participants.

3.4. Student Feedback

We also evaluated the efficacy of the course based on two sources of student feedback: (*i*) student responses to Likert scale statements and questions as a part of voluntary, anonymous university-administered course evaluations submitted at the end of the semester, and (*ii*) student feedback from both the beginning and end of the semester (section 3.3). The Likert scale included five options: “Strongly Agree”, “Agree”, “Neutral”, “Disagree”, and “Strongly Disagree”. The survey results data was analyzed using an Excel spreadsheet, plotting the number of students who responded “Strongly Agree”, “Agree”, “Neutral”, “Disagree”, and “Strongly Disagree” with each statement in ***Section 3.3***. The voluntary survey at the beginning and the end of the semester was developed by the research team to assess the effect of the course on self-efficacy as well as their interests in STEM, design, and robotics; while the university-administered evaluation is the standardized course evaluation that are conducted for all courses across campus. The objective of the university-administered evaluation is to gather feedback from students regarding their learning experiences, the effectiveness of the instructor, and the overall quality of the course. The evaluation serves as a valuable tool for the instructor and administrators to assess teaching methods, identify areas for improvement, and make informed decisions about curriculum development and faculty performance. The anonymous university-administered course evaluation was distributed to students during the last week of classes, with the deadline for responses set prior to the release of student grades. Due to the voluntary nature of participating in the survey, seven (out of 12) students completed the course evaluation.

4. Results and Discussion

4.1. Evaluation of Midterm Team Machine Design Challenge Deliverables

In the weeks preceding the oral presentations and the live race for the Midterm Team Machine Design Challenge, “Transforming Bioinspired Amphibious Robotic Vehicle”, each student presented their own concepts for both the land-based and water-based robot configurations to the rest of their teams as well as the course instructor. These initial prototypes led to necessary clarifications of the project scope to maintain the spirit of the "bioinspired" project requirement. For example, it was clarified that a robot that looked like an animal, but did not move like an animal (*e.g.*, including a motorized propeller on the back of a machine with wheels to generate forward movement) would not be allowed. Rather, as it was the method of movement (*e.g.*, a bipedal walking gait) that was needed to satisfy the assignment's bioinspired criterion. It is important to note that this stipulation greatly increased the difficulty of the design challenge.

Nonetheless, the student teams developed a range of creative robotic vehicles for the project, drawing inspiration from diverse sources. For example, one team created a roadrunner-inspired bipedal walking robot (**Fig. 6a**) that transformed into a lobster-inspired swimming robot (**Fig. 6b**). Another team designed both of their robot configurations to mimic human movements,

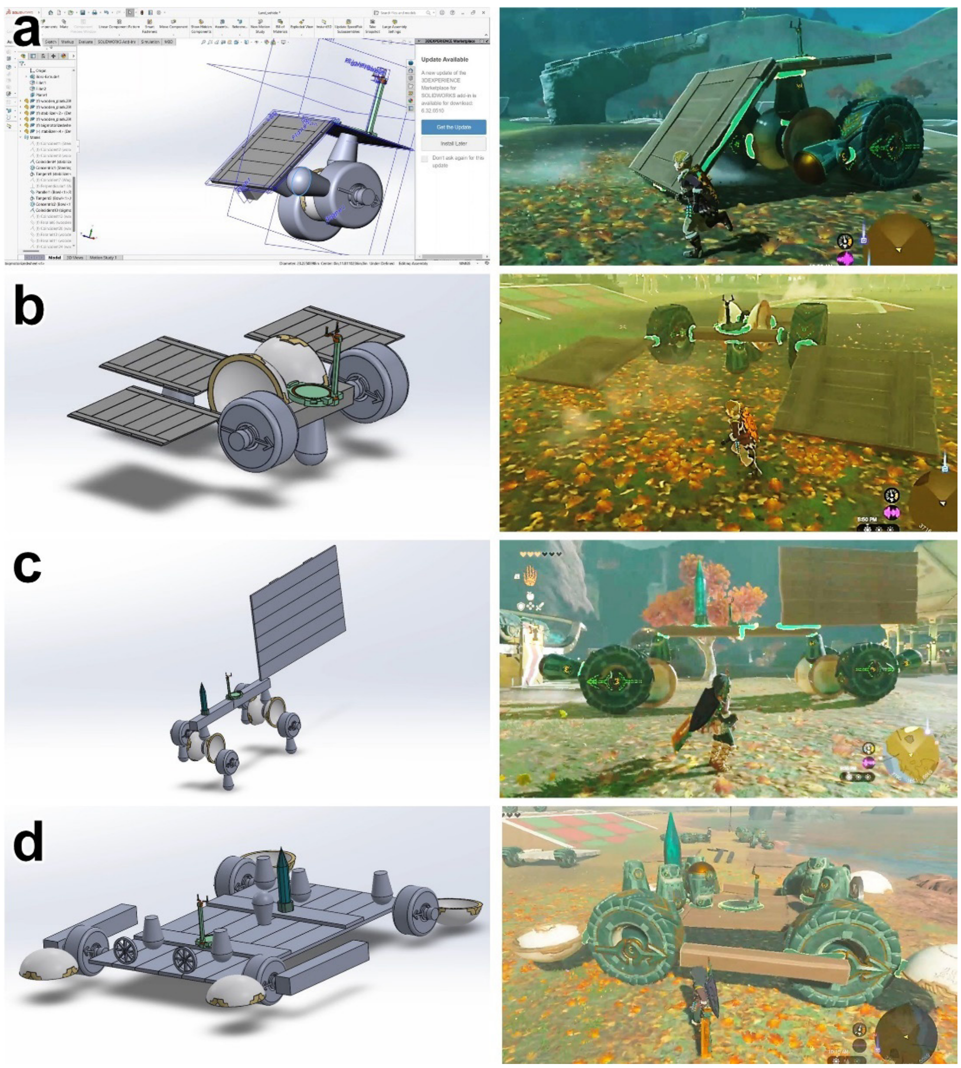

Fig. 6. Examples of student teams' comparisons of machine assemblies in SolidWorks CAD software (*left*) *versus* within the video game (*right*) for the Midterm Team Machine Design Challenge: "Transforming Bioinspired Amphibious Robotic Vehicle". **(a,b)** A team's **(a)** roadrunner-inspired bipedal walking robot that transforms into a **(b)** lobster-inspired swimming robot. **(c,d)** A team's **(c)** lizard crawling-inspired quadrupedal robot that transforms into a **(d)** human backstroke-inspired swimming robot.

including a bipedal walking on land and the freestyle and butterfly stroke-based swimming (*i.e.*, just arms) in water. Only one team elected to design a quadruped robot, which was intended to mimic a lizard crawling while on land (**Fig. 6c**) and then backstroke-based swimming (despite having four rotating limbs) while in water (**Fig. 6d**).

There were two primary trends from the design challenge. First, biped designs represented the predominant approach for the land-based configuration. It is possible this preference was due to the ease with which such robots can be constructed and steered during the race (**Fig. 7** – *top row*). Machine designs with alternative locomotion strategies would have been allowed; however, none were proposed or prototyped by the students during the semester. The second trend was that every team's water-based robot configuration harnessed paddles (*e.g.*, wooden boards) attached to corresponding motorized wheels to swim during the water portion of the race course (**Fig. 7** – *bottom row*). This decision stemmed from the bioinspired requirement (*e.g.*, preventing the use of propellers and fans for propulsion) combined with a degree of inaccurate in-game physics that prevented real-world drag phenomena used for propulsion in water from being recapitulated within the video game.

Fig. 7. Examples of a student team's (*Top Row*) land-based walking robot (inspired by an ostrich), and (*Bottom Row*) water-based swimming robot (inspired by a sea robin fish)—both with the exact same set of machine elements—for the Midterm Team Machine Design Challenge: "Transforming Bioinspired Amphibious Robotic Vehicle".

It is also important to note that one key constraint of the video game is that the maximum number of machine elements that can be combined as a single system is 21. As a result, students had to carefully select and justify which machine elements they would use in their designs—*e.g.*, based on energy depletion rates, propulsion capabilities, and weight—as well as why each was essential for both the land- and water-based configurations. This 21-element restriction is balanced, however, by the particularly useful "Autobuild" functionality of the game. This feature allows for up to eight previously built machines to be saved and stored. When a saved design is selected, the complete machine can be assembled from either existing machine elements in front of the player or synthesized from scratch for an in-game cost (*i.e.*, "zonaite"). Thus, once the students had built their robots corresponding to each configuration using the same exact machine elements, they were able to rapidly switch between states in a matter of seconds (**Fig. 8**). This

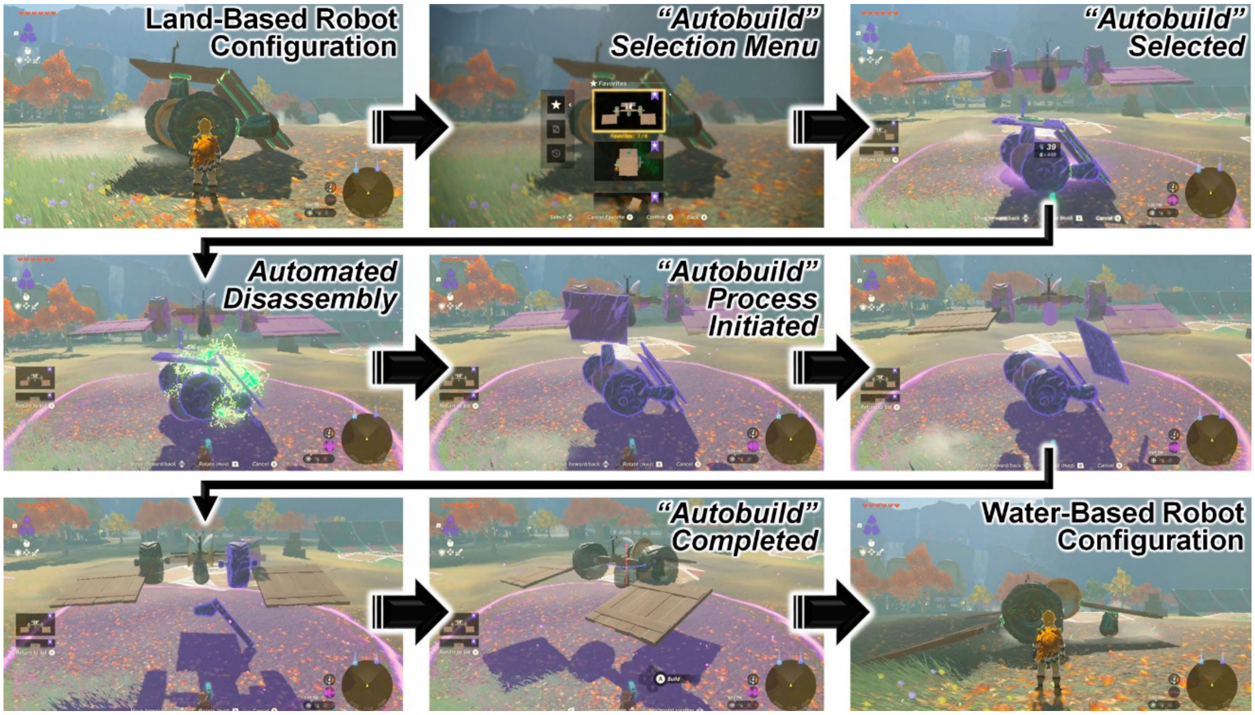

Figure 8 | Example of a student team's in-game "Autobuild" process for reconfiguring their land-based bipedal walking robot into a (previously built) water-based swimming robot—using the exact same set of machine elements—for the Midterm Team Machine Design Challenge: "Transforming Bioinspired Amphibious Robotic Vehicle".

capability provided an opportunity for GBL in the context of designing machines that are require to perform multiple functionalities, yet face external constraints. In this case, the key constraint was the maximum number of elements that could be used to build a machine—and the trade-offs involved in making those design decisions—which is akin to real world applications involving similar challenges that stem from limiting total machine elements to, for example, reduce system cost, energy usage, and weight.

In their presentations, each of the teams had included their anticipated time to complete the assigned race course (**Fig. 3**); however, only one team accurately predicted their live, in-class race time. Specifically, the team with the roadrunner- and lobster-inspired robot (**Fig. 6a,b**) predicted a 5-minute completion time and ended up finishing the race in first place with a time of 4 minutes and 40 seconds. The team with a human-inspired robot had predicted a time of under 3 minutes, but ended up finishing close in second place with a race time of 5 minutes. The team with the ostrich- and sea robin fish-inspired robot (**Fig. 7**) finished in third place with a time of 10 minutes. Notably, the only team that elected to attempt a quadruped robot (**Fig. 6c,d**) was not able to complete the race before the class ended.

The live, simultaneous in-class race appeared to generate considerable excitement and enjoyment among the students, even for those who did not come in first or second place. The combination of gamification, hands-on application, competition, and collaboration likely contributed to the excitement and enjoyment generated by the experience. It should be noted that such multiplayer-style competitive races are not a part of "The Legend of Zelda: Tears of the Kingdom" itself, which is a single-player video game. Thus, the use of a team-*versus*-team live, in-class race essentially combines principles of gamification with GBL. Such strategies could be used to further augment the efficacy of GBL.

4.2. Evaluation of Final Team Machine Design Challenge Deliverables

In the final weeks of the course, each student presented their own design for the Final Team Machine Design Challenge, "Aerial Catapult", to the rest of their teams as well as the course instructor. In this case, however, the assignment requirements needed to be refined to accommodate challenges associated with visibility of the projectile. Specifically, students were allowed to modify the "takeoff site" location set in the project description (**Fig. 4**) within reason to ensure that visualization of the projectile being launched through the target ring structure would be apparent and discernable. In addition, the total number of teams was reduced from four (*i.e.*, for the midterm project) to three (*i.e.*, for the final project).

The approaches to meeting the objectives of this design challenge were slightly more expansive than that of the midterm design challenge despite multiple teams using similar mechanisms for both vertical ascension (*e.g.*, rockets) as well as catapult-like operations (*e.g.*, stabilizers connected to lever arms) For example, one team harnessed multiple hot air balloons to ascend vertically and then activated a large motorized wheel connected to a series of four long metal beams to launch their projectile. Another team designed a machine based on two subsystems that used one subsystem with rockets to ascend to a desired vertical height, after which they activated the second subsystem composed of four stabilizers connected to a series of four beams to launch their projectile. Both teams, however, achieved limited accuracy with their designs both on their own and in the classroom during the live demonstrations following their presentations.

The most effective and, arguably, inventive machine for the final design challenge was composed of three distinct subsystems (**Fig. 9**). The overall process included three stages. First, the team activated a base subsystem with rockets to ascend vertically (**Fig. 10 – *1st row***). Once the rockets began to run out of power, they activated a second subsystem with a "hoverstone"

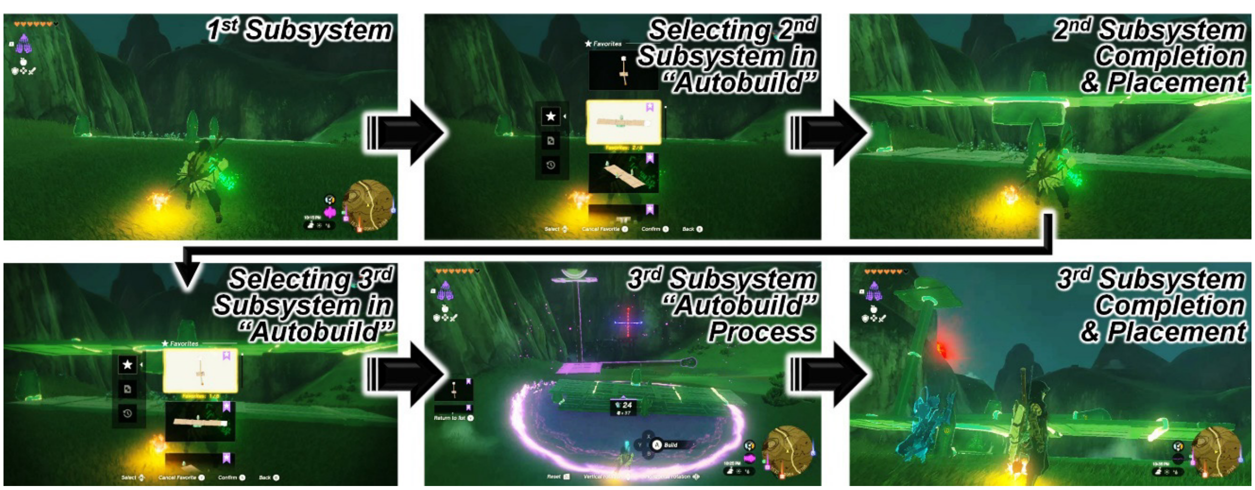

Fig. 9. An example of a student team's in-game "Autobuild" process for constructing a machine from three distinct previously assembled subsystems for the Final Team Machine Design Challenge: "Aerial Catapult".

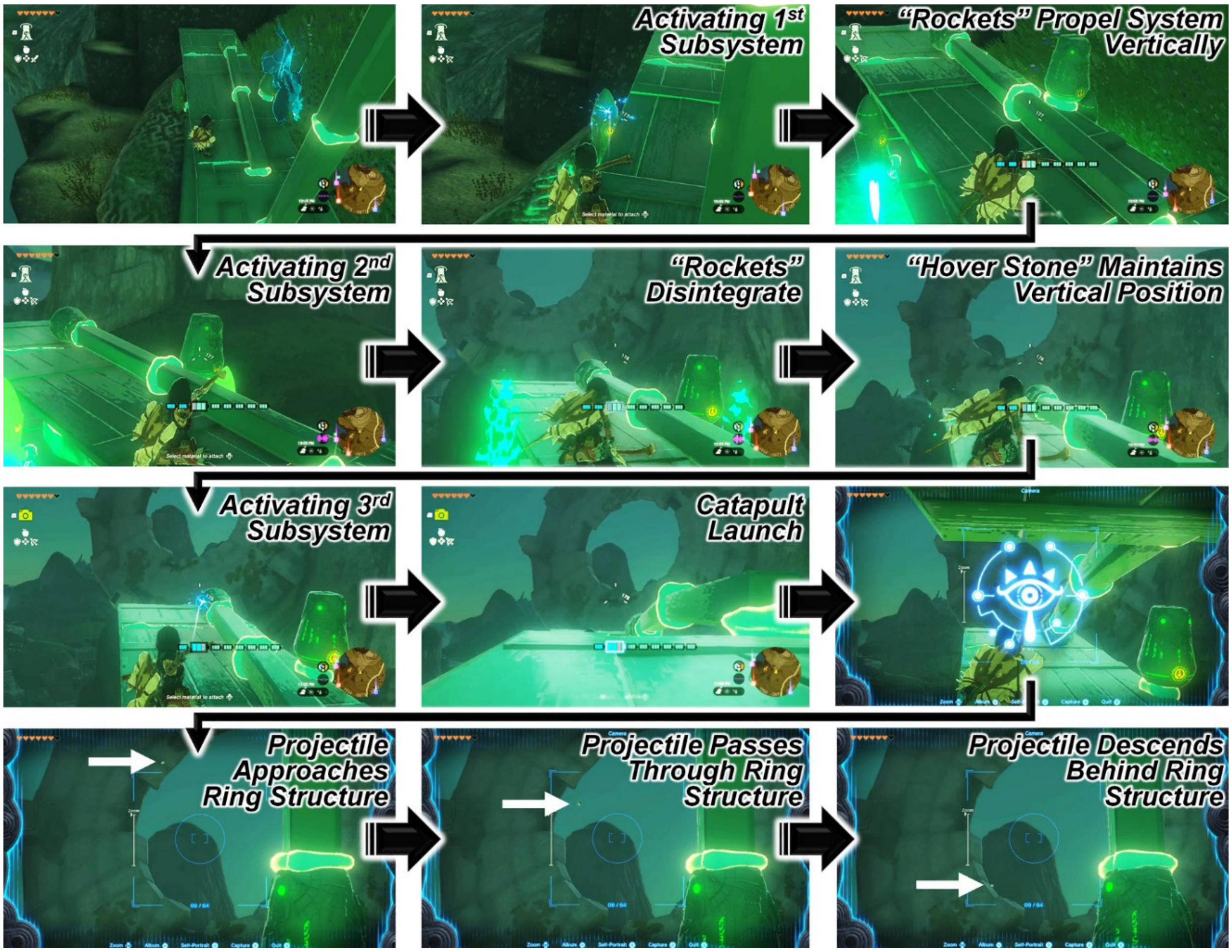

Fig. 10. An example of a student team's in-game projectile launching process for the Final Team Machine Design Challenge: "Aerial Catapult", which includes: (*1st Row*) Activating the first machine subsystem to ascend vertically, (*2nd Row*) Activating the second machine subsystem to stabilize the machine at the desired height, and then (*3rd Row*) Activating the catapult to (*4th Row*) launch the projectile (denoted by *white arrow*) through the assigned ring structure.

machine element to stabilize the subsystem at the desired height (**Fig. 10 – *2nd row***). Lastly, the team activated the third subsystem comprising a stabilizer connected to a series of four wooden beams to launch their projectile (**Fig. 10 – *3rd row***) and then zoomed in their view to be able to see the projectile go through the target ring structure (**Fig. 10 – *4th row***). In their oral presentation, the team claimed to achieve this capability with 33% accuracy and, indeed, when it came time to demonstrate their machine in class, they were able to successfully launch a projectile through the ring structure during one of their three attempts—the only team able to accomplish this feat.

In contrast to the midterm design challenge, with involved a simultaneous competition element, during the final project's in-class live demonstrations, all of the students ended up gathering around to watch together as each team made their three attempts. When the team with the aerial trebuchet shown in **Fig. 10** successfully launched their projectile through the target ring, we observed applause and cheers from students from the other teams. In the current study, we did not investigate or analyze the potential benefits and limitations of more competitive projects, like the midterm design challenge, compared to less competitive projects, like the final design challenge, but such differences may be worth interrogating in future studies of GBL.

4.3. Survey Responses and Student Feedback

We evaluated the efficacy of the course through student feedback *via* several avenues. From the survey developed by the research team and described in ***Section 3.3***, the results indicate that participants generally concurred with statements regarding the enhancement of their interests in STEM, design, machine prototypes, testing, as well as teamwork and oral presentations (**Fig. 11**). There appeared to be a lesser impact on students' inclination towards pursuing a graduate degree, particularly in Ph.D. programs, which aligns with expectations given the one-credit elective course was not designed specifically to encourage students to pursue Ph.D. programs; however, it remains possible that GBL could be leveraged to promote student interest in engineering fields that could, in turn, increase interest in pursuing graduate studies. Additionally, the results indicate that all of the students who enrolled in the course expressed interest in STEM majors, with the majority expressing aspirations for positions in industry, design, prototyping,

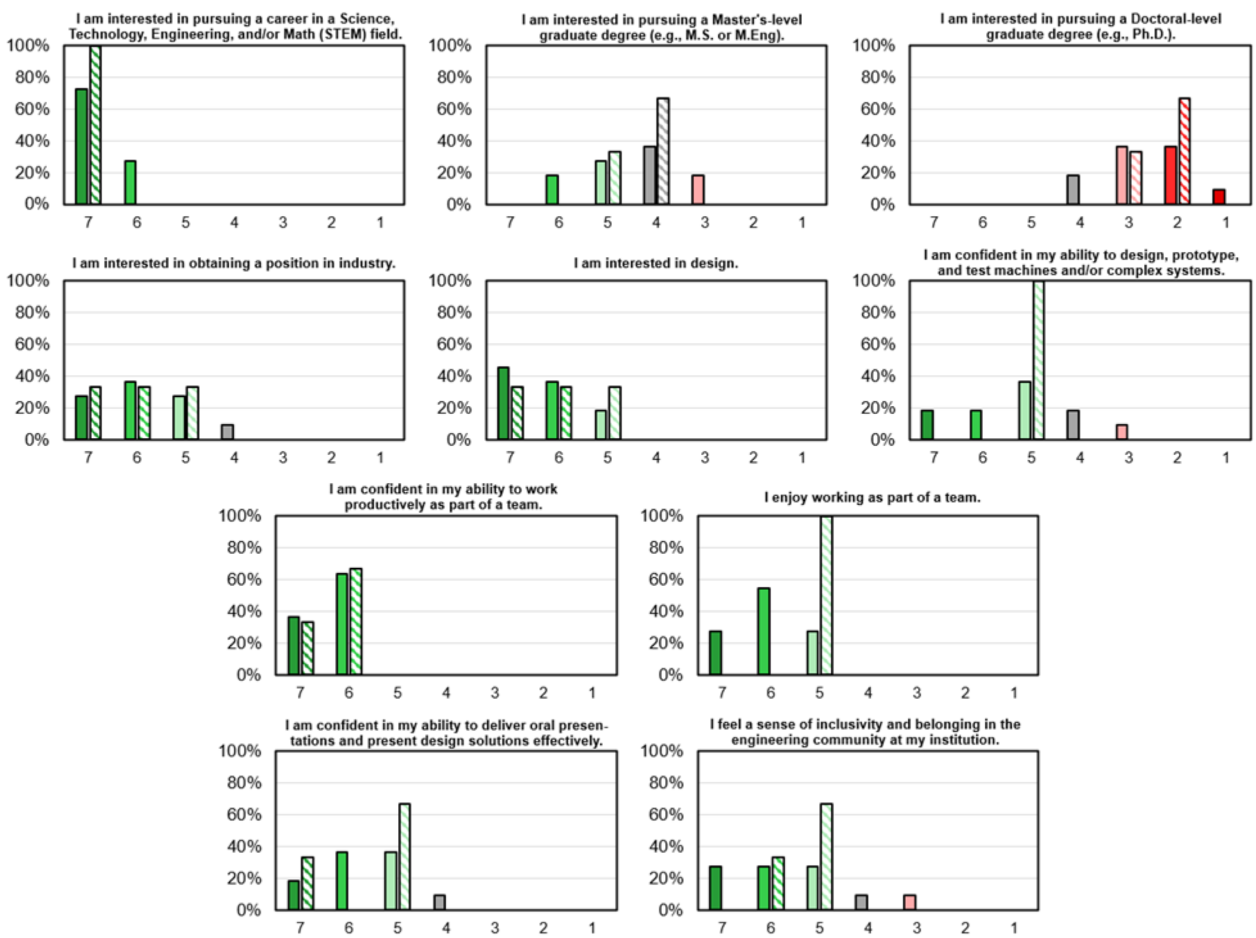

Fig. 11. Survey results. A score of 7 indicates that the participants mostly agree with the statements, while a score of 1 indicates mostly disagreement. Solid bars represent the percentage of participants who completed the survey at the beginning of the semester (n = 11), while hatched bars represent those who completed it at the end of the semester (n = 3).

and testing mechanical systems. Furthermore, nearly all students were able to effectively collaborate within their teams and contribute to their project. Notably, the majority of participants strongly agreed or agreed with statements on the Likert scales (rated 7, 6, and 5), underscoring the consensus among participants regarding the survey statements (**Fig. 11**). These generally positive responses to statements related to STEM, design, and teamwork suggest that the integration of popular entertainment video games into the curriculum can effectively engage students in these areas.

We also examined student responses to the university-administered final course evaluations (**Fig. 12**) due to the limited number of voluntary survey participants at the end of the semester. These results revealed a consistent trend: students overwhelmingly indicated strong agreement or agreement across all facets, affirming that the course materials, activities, and projects were not only effective, but also lead to a distinctively rewarding educational experience. It is also important to highlight that every student responding to statements regarding an inclusive, supportive, and caring learning environment selected “Strongly Agree” (**Fig. 12 –** *3rd row*). The following are student feedback received *via* an article in the press [27] as well as the university-administered course evaluations:

- *“The biggest impact this course has had on me was that it offered me a different approach to machine design, allowing me to more easily think about constructing mechanical systems as a sum of the components rather than the (far more complex) whole.”*
- *“This has helped me in other major-related courses because, similar to groups of animals moving together, the individual components are following relatively simple rules which lead to very complex motion on the whole.”*
- *“It felt like I was actually experiencing an engineer's job firsthand by doing calcu-lations, designing, building and even going back to square one and starting over.”*
- *“The course showed me what it's like to be an engineer and how what we're learning in other classes can be tied together and applied.”*
- *“The course topic itself provides a very unique and valuable opportunity to learn about machine design and interconnecting mechanisms in a no–risk, fun environment. Through playing this game I believe I have developed a better understanding of 3D spaces and basic mechanical principles.”*

The student comments provide valuable insights into the impact of the course and the use of the video game on their learning experiences and skill development. The recognition of a shift in approach towards machine design, from viewing it as a complex whole to breaking it down into manageable components, underscores the effectiveness of the course in facilitating a deeper understanding of mechanical systems. Moreover, the analogy drawn between groups of animals moving together and the simplicity underlying complex motion highlights the course’s ability to foster creative thinking and problem-solving skills. The hands-on nature of the course, involving calculations, design, and assembly, offers students a practical understanding of engineering principles and reinforces the relevance of their academic studies. These comments collectively emphasize the course’s success in bridging theoretical knowledge with real-world applications, providing students with a holistic understanding of the engineering profession and its interdisciplinary nature.

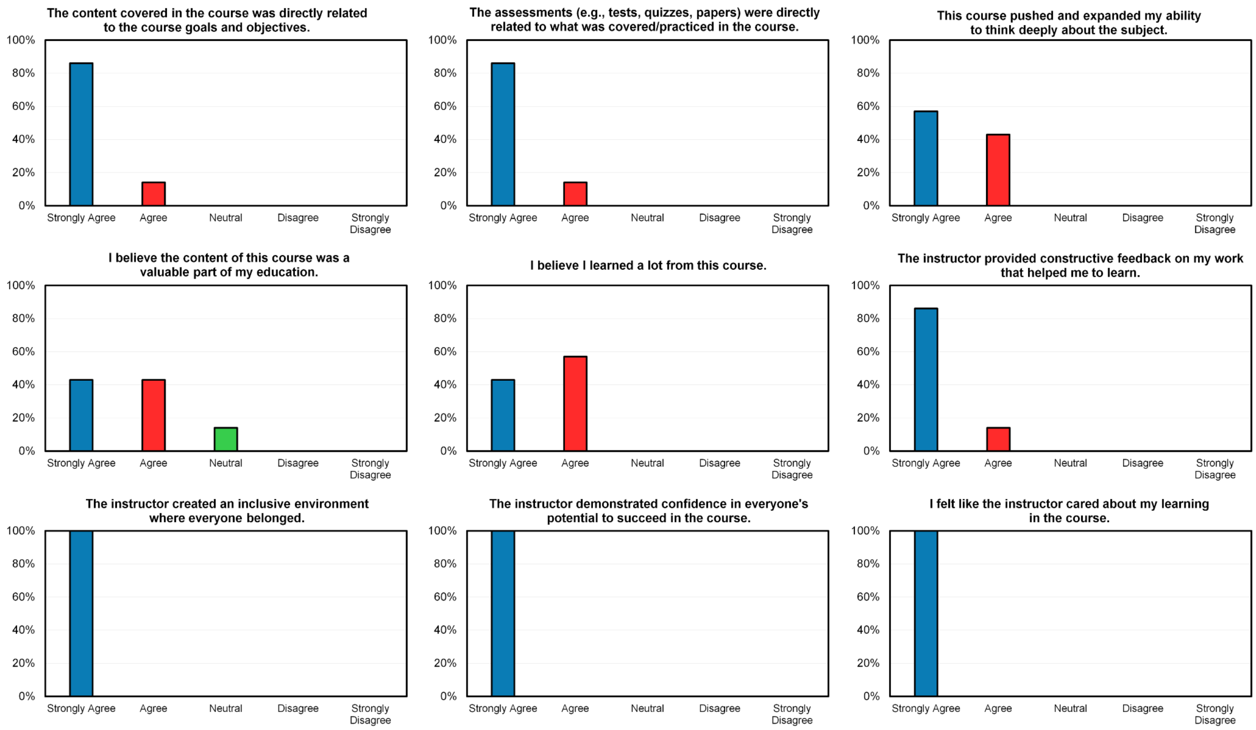

Fig. 12. Responses from anonymous, voluntary university-administered student evaluations of the course at the end of the semester (n = 7 students).

Such unanimity of positive responses from the students suggests that efficacy of the course in enhancing their educational journey; however, it is important to note that further data collection is required to draw statistically significant conclusions. As a result of the operation constraints of the course (*e.g.*, to purchase Nintendo Switches, game cartridges, controllers for each team and provide in-class TV screens), the current study was inherently restricted in terms of sample size, which was further confounded by standard obstacles to voluntary survey participation, such as at the end of the semester when student availability is limited. Still, the results (*e.g.*, from students' quotes in this section and the responses presented in **Fig. 11** and **Fig. 12**) along with the enthusiastic student feedback suggest that the presented approach for using "The Legend of Zelda: Tears of the Kingdom" for GBL holds promise to warrant continued and future investigations as a possible pathway to student motivation, engagement, and learning.

5. Limitations and Future Work

Because the course revolved around the use of the video game, "The Legend of Zelda: Tears of the Kingdom", as the primary virtual platform for course activities, it is necessary to highlight the benefits as well as the limitations of the game as it relates to engineering education. A key advantage is the simplified in-game CAD assembly-like interface and the moderately sophisticated physics, which allows for students to rapidly and easily build, test, and iterate their prototypes in a highly interactive way, such as being able to immediately steer a machine directly after the build process. One constraint of the game, however, is the inability to construct a fully assembled machine with more than 21 elements, thereby setting a limit on the attainable complexity of a single machine. A second, more important limitation is that while much of the game's physics engine is able to mimic real-world physics fairly accurately in certain scenarios, there are many cases in which the game's physics do not bear relevance to that in the real world. For example, activating the spring-mass system shown in **Fig. 13** leads to movements that correspond to several instances in which the total energy of the system increases, thereby violating the law of conservation of energy [28]. Although such inaccuracies are not necessarily desired, they can offer unique learning opportunities for students. For example, the curriculum could include projects and activities in which students interrogate in-game physics and functionalities and then have to think critically about how such operations differ from identical cases in the real world. Discovering these in-game laws of physics could be a rare occasion for students to experience what it was like for early physicists to uncover such laws in the real world, requiring students to design and analyze in-game experiments to elucidate such principles.

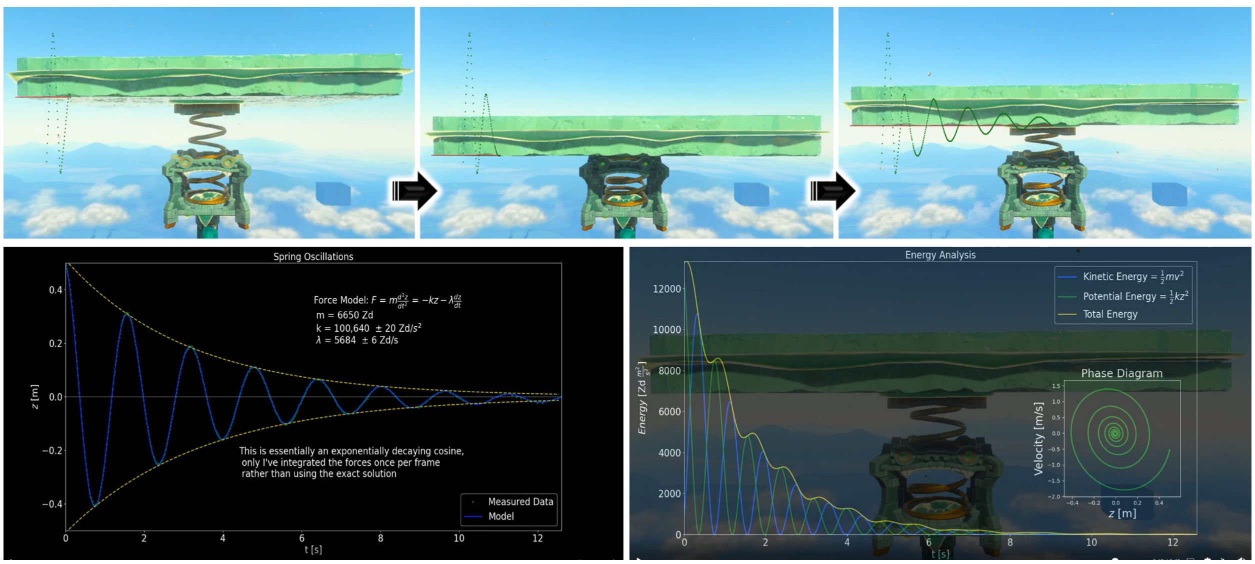

Fig. 13. Example of inaccurate in-game physics for a spring-mass system that results in instances in which the total system energy increases, which violates real-world physics principles of energy conservation. Adapted from [28].

6. Conclusion

In this study, we investigated the use of a high-profile entertainment video game—that included gameplay relevant to machine design and engineering—as a foundation for a second-year undergraduate mechanical engineering elective course. Through multiple course projects, the curriculum was designed to help students gain experience designing, prototyping, and testing complex robots and mechanical machines within the virtual environment of the game. The goals of the course projects (*e.g.*, in-game robot races and hit-the-target objectives) provided an opportunity to go beyond GBL within the context of a single video game to allow for principles of gamification to be harnessed in tandem to further motivate and engage the students. In addition, course activities that involved modeling machine elements as well as fully assembled machines in SolidWorks software allowed the students to continue building their proficiencies with CAD as such unusual structures and systems from the video game are not typically assigned for modeling tasks in conventional CAD courses at this educational level.

As the first study to examine the use of "The Legend of Zelda: Tears of the Kingdom" as the primary medium for GBL, this paper established an important milestone for integrating entertainment video games into undergraduate engineering curricula. Because classroom and resource restrictions limited the total sample size of the current study, future efforts should seek to address such barriers (*e.g.*, through externally funded educational research) to provide further insights into the utility of the presented GBL approach. Despite this sample size, the distinctively positive student feedback suggests that this approach holds potential to extend beyond the walls of academia as a new means to reshape the narrative of STEM education. Ultimately, such GBL approaches could hold promise to help engage students historically underrepresented in fields including machine design, robotics, and engineering.

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