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Making Learning Fun: Implementing a Gamified Approach to Materials Science and Engineering Education

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During his PhD program, he completed

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Making Learning Fun: Implementing a Gamified Approach to Materials Science and Engineering Education

Abstract:

Materials science plays a critical role in educating future engineers, where knowledge of materials selection is essential for design and problem-solving. However, many programs rely on traditional lecture styles to convey this fundamental knowledge. While these teaching styles can be effective, they provide little opportunity to actively engage and expose learners to memorable experiential learning elements. The COVID-19 pandemic presented a new opportunity to focus on developing unique teaching tools to reach students on virtual platforms. Although the development of these tools was critical in today's technology-driven society, pandemic teaching and learning remained challenging, which likely contributed to the amplification of virtual gamified learning. In redesigning our first-year engineering curriculum within the Faculty of Engineering at McMaster University into the new Integrated Cornerstone Design Projects in Engineering (ENG 1P13) course, an opportunity to re-evaluate our teaching approach was presented, which allowed us to further explore ways to increase student engagement and learner creativity.

This work focuses on the introduction of a gamified active-learning approach to teach materials science within the first-year curriculum. The purpose of this intervention was to enhance the learner experience to demystify the fundamentals by connecting theory to practice. Although pedagogical literature highlights the effectiveness of gamified learning strategies to enhance the learning experience, limited examples were found within the materials science and engineering fields.

In this work, two types of materials science games along with other interactive lab components were successfully implemented in an adaptable fashion for in-person and virtual teaching styles for over 900 learners. The first type is adapted based on popular board games in efforts to design relatable understandable games such that the students could focus on learning the new materials and not the game rules, "Materials Battleships", and "Materials Taboo", where gamified strategies are incorporated to introduce students to materials properties and materials selection. The second involves the design of custom virtual emulators that challenge learners to explore the mechanical and electrical behavior of materials. The games challenged learners to explore various materials and science concepts in a fun way.

Our survey responses from participating students were used to evaluate the approach; these findings highlight that gamification stimulated students' interest in material science and motivation to participate. While the majority of students surveyed found the new activities enjoyable, the results also indicate higher learning engagement and increased interest in materials science for upper-level stream selection choice after the open first year. The analysis of these surveys targets what factors were effective in increasing engagement as well as effectiveness in teaching content. The success of gamified learning for material science coupled with the targeted data for

improvement and adaption creates a space for significant improvement in the material science curriculum.

1. Introduction

Materials science plays a foundational role in engineering education, essential to materials selection. However, by some, materials science education has been described as outdated and one of the overlooked fields in engineering educational development [1] – highlighting the need for reform. Many materials science programs rely on traditional lecturing strategies to teach these fundamentals, which are effective for efficiently conveying knowledge to large classrooms but lead to limited opportunities to actively engage learners and provide memorable learning experiences.

Recently within the pedagogical field, transformative means of reforming traditional teaching styles, such as active and experiential learning approaches, have widely been explored and adopted to improve learner experience [2]–[8]. Where traditional teaching styles tend to rely on the dissemination of fundamental concepts in a lecture-style format with limited learner stimulation, active and experiential learning approaches prioritize both learner engagement and reflection throughout and often include lesson contextualization [9], [10].

Although sometimes used synonymously, active learning and experiential learning are two separate pillars in modern education. The most widely accepted and cited definition of active learning is provided by Bonwell and Eison in 1991 as: "Involving students in doing things and thinking about what they are doing [6]." Millis further elaborates on this definition and adds that it often involves reflection and doing or taking action, and often uses cooperative learning strategies [8]. Often described with active learning, though treated as a separate pedagogical teaching strategy, experiential learning can be simply described as 'learning by doing' and actively engages learners through experience-based learning approaches [5]. Active, learner-centered teaching approaches in large classes have demonstrated decreased failure and drop-out rates, and this project's survey results coincided, showing overall positive attitudes from students and faculty alike [2]–[4].

Both approaches have been studied as singular teaching methods and combinatory approaches. Modern classrooms often employ both active and experiential learning approaches, to create an interactive classroom that relies on a self-learning, group learning, and at times traditional lecture-style teaching. Arguments exist for maintaining traditional-style lectures in the engineering classroom, where these teaching methods remain fundamental to many programs for learning. Nonetheless, heightened efforts have been placed on enhancing active and experiential learning to develop the modern classroom, where learners are given more control of their learning.

One strategy being considered for improving learning is gamification, which relies on the introduction of game-like activities in classrooms that involve active and/or experiential learning elements. Gamification strategies have been popularly explored as a means to enhance learner education experience, improve the positivity of learners towards lessons, and motivate learners [11]–[18]. For large online open courses, Borras-Gene et al. elaborate practical recommendations for gamified learning and found that their implementation leads to increased motivation of learners, deeper learning, and higher success rates [19]. Barata et al. note that applying a gamified approach in teaching, when well-integrated into a course structure, can help motivate learners, keep them engaged, and improve student satisfaction [12]. Others note that competitive aspects found in games can further enhance teaching and engage learners when aligned with the course structure [20]. These overall successes of gamification strategy implementation in literature support its acceptance as a teaching strategy for post-secondary education and prompted us to explore these methods at McMaster University. However, we could find limited examples of gamification methods explored for materials science and engineering education.

In redesigning our materials science curriculum, we asked: *"How can we excite learners and teach materials science and engineering in a more engaging way?"* Herein, we present the start of our answer to this question, involving the development of new gamified approaches for materials science and engineering education. This work aims to share this work to provide these games in an open-access fashion to others and promote gamification within the materials science and engineering community. The goal of the newly developed approaches is to enhance the learner experience in learning through games to demystify the fundamentals by connecting theory to practice. The research presented focuses on the introduction of two types of materials science games introduced to enhance learner experience and engage students in lessons through inclusive fun games. The first is inspired by relatable popular board games, notably Battleship and Taboo, which are adapted to introduce concepts of materials properties and materials selection in a gamified fashion. The second involves the design of a videogame-esque emulator which challenges learners to the mechanical and electrical behavior of materials. All games are described in detail within this article, made to be open-access, and are developed for implementation in an adaptable fashion for in-person, virtual, and blended teaching styles for large learner cohorts – in this case, for over 900 learners enrolled in our first-year engineering program. This is key to the current COVID-19 climate and the anticipated long-term stay of virtual labs [21]. Gamified activities are designed to be design-driven (top-down approach) for engineering materials education versus the traditional science-driven (bottom-up approach) [22].

To evaluate the effectiveness and perceived enjoyment of the implemented gamified strategies described, preliminary results from surveying are shared within this article from respondents within our 2021 first-year engineering cohort. Results shared are informative to answering what learners perceive as the reasons that certain laboratories are favorable and also provide learner insight on the new gamified activities introduced within the curriculum. We note several limitations on the interpretation of these results, the need to collect more data over time and outline different courses of action for future improvements to these measures. Overall, from positive survey results and anecdotal feedback from teaching staff, we are encouraged to pursue more gamified strategies within our first-year curriculum and beyond.

2. Setting Context – Classroom Description & Gamified Approaches

The introduction of project-based learning to evolve our undergraduate engineering design curriculum at McMaster University, known as "The Pivot" initiative, is leading to large-scale changes to the engineering curriculum. In 2020, McMaster's Faculty of Engineering challenged itself to reimagine the classroom through learner-centered transformative teaching and learning strategies. Its central principle involves pivoting away from traditional lecture-based learning to incorporate more problem-based and experiential learning opportunities [23]. The inaugural shift of teaching styles within the engineering environment began with the development and implementation of an interdisciplinary first-year engineering course. This course combined the main concepts taught previously from four previously separate traditional lecture-style courses: Engineering Design and Graphics, Engineering Computation, Engineering Profession and Practice, and Structure and Properties of Materials. These significant teaching changes at the undergraduate level of engineering education have garnered the attention of internal education researchers, including our research team. Many published (e.g. [24] and [25]) and ongoing works have been developed to better understand the student perspectives of the new teaching styles outlined prior.

While the curriculum was designed with active and experiential learning opportunities in mind, we noted that some sections of teaching still relied on traditional lecture styles to convey theoretical knowledge rather than using more interactive approaches. The implementation of the Pivot was impacted by the COVID-19 global pandemic, requiring educators and learners to adapt to an online landscape, and more recently a more fluid hybrid teaching style, incorporating both in-person and virtual classrooms. The integration of project and learner focus in the first-year experience provided an opportunity to supplement traditional lecture-style teaching with gamified learning strategies to improve student engagement, while the projects allow students to apply concepts in an interdisciplinary context. Laboratories were offered in this course at the time in a blended fashion, with approximately half the sessions in-person and half online. The games specifically discussed within this work are summarized in Table 1 and described in greater detail within the following subsections.

Table 1. A detailed description of the gamified activity components focused on in the 2021 Fall semester.

Activity No.	Lesson Engineering Principles	Learning Objectives of Gamified Component	Gamified Component – Brief Description
1	Material properties, material property charts, materials selection	Connect concept of material property chart to materials organization, analyze material properties in materials selection	**Materials Taboo.** The educator chooses in their head a ball made from a specific material a tray of available options. Learners must guess the material by asking questions related to its properties to distinguish it from the rest.

Activity No.	Lesson Engineering Principles	Learning Objectives of Gamified Component	Gamified Component – Brief Description
2	Materials properties, material property charts, materials selection	Recognize the concept of material property chart, categorize materials based on properties,	**Materials Battleships.** Using an emulator game, learners are paired and must guess the position of their partners' ships. Ships are arranged in an x-y quadrant based on the material properties of the axis, to win, learners have to successfully guess the material of their partners' ships.
3	Tensile testing, work hardening, thermocouples, materials selection	Describe how changes in material selection and testing conditions can influence material performance, apply concepts to design stronger component as well as a better thermocouple	**Material Lab Simulation Tool: Virtual Emulators.** Using an emulator, learners are tasked to explore two modules: "Mechanical Workshop" and "Thermocouple Simulator". The two provide dynamic options for learners to explore how changing testing parameters and materials through selection influence performance. The emulator is paired with a laboratory assignment which tasks learners to explore different parameters in a gamified manner.

2.1. Gamified Module 1 "Materials Taboo"

The first game presented is called "Materials Taboo" and is similarly inspired by the popular board game Taboo®, also produced and sold by Hasbro, Inc. [26]. The premise of this activity is: the educator chooses a material, and the learners have to intuitively guess it by asking only questions geared toward its material properties. The learning objectives of the game, introduced in Table 1, revolve around introducing material properties and early concepts of materials selection, notably materials selection charts (Fig. 1A). In answering questions, the educator cannot reveal obvious characteristics about the material that would separate it from the others. In essence, it is "Taboo" for learners to ask about the materials, they can only inquire about their properties. Examples of common questions that relate to material properties that could be answered are featured in Fig. 2. Unlike the boardgame Taboo®, learners are presented with a tray that features a variety of rounded materials, all the same size, distributed within its partitions, shown in Fig. 1B. Learners are encouraged throughout the game to touch the material balls presented and to "play around with them" to inspire themselves to come up with questions.

After a few rounds of the game, the teacher begins a reflection activity through a discussion which challenges learners to think about how the materials are distributed among the tray and whether they note a trend. They are not told at the start of the game that the materials are arranged in an x-y axis system, y being stiffness and x being mass (Fig. 1B). The organization is likened to a material property chart with elastic modulus vs density, shown in Fig. 1A which is then presented to learners. The lesson continues to explore these charts and build onto these themes, bridging into the introduction of the utility of material property charts for materials selection. This gamified strategy intends to be used as an "ice-breaker" in this introductory first-year materials section course to build a positive relationship between learners and educators, working together as a team and promotes an inclusive environment for questioning through fun means. The following

Gamified Module "Materials Battleships" builds on this activity, with a similar set of learning objectives in a laboratory environment with learners working in pairs.

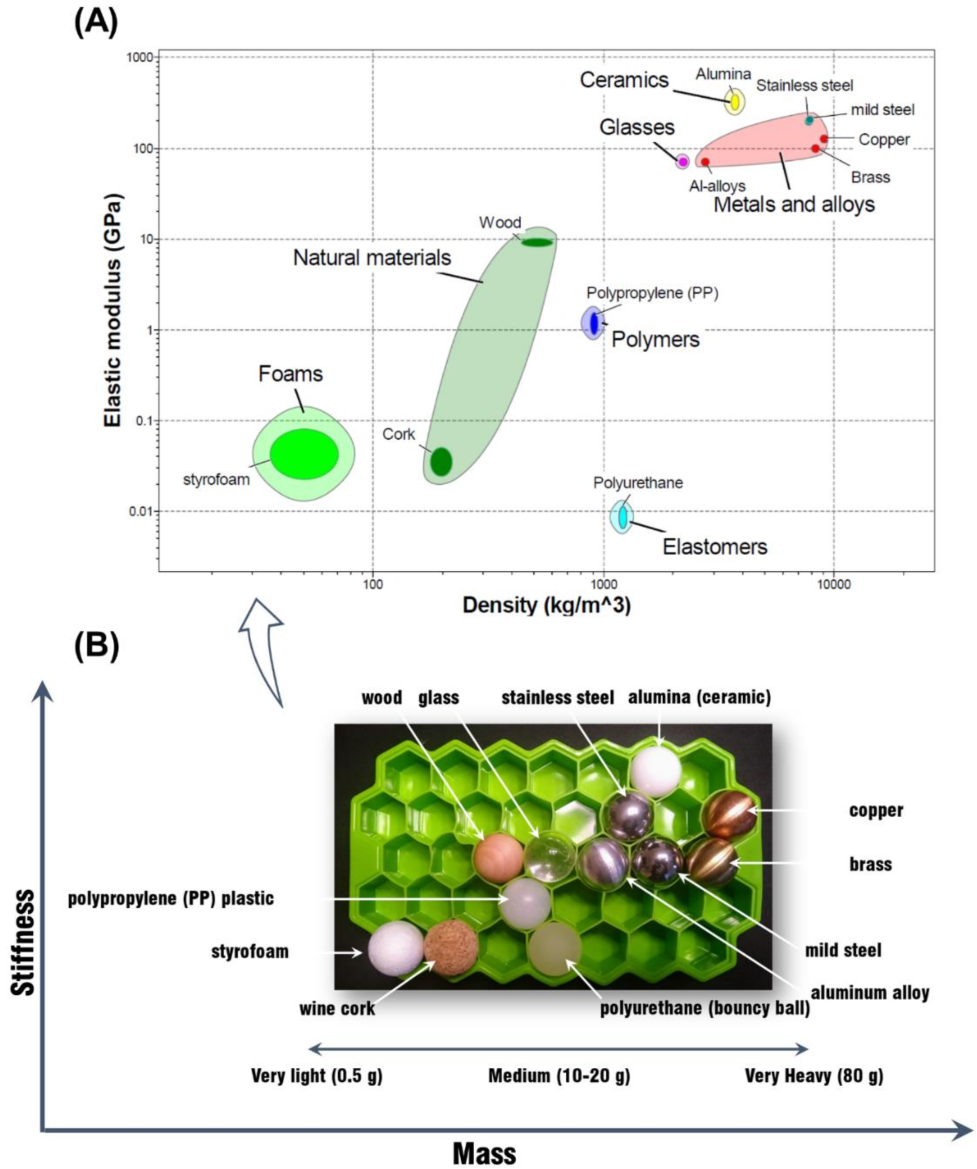

Figure 1. Materials Taboo. (A) Overview of a materials property chart, elastic modulus vs. density, featured as the inspiration behind our Materials Taboo game. (B) A green tray featuring rounded balls of the same dimension made from different materials for Materials Taboo. Balls are organized in a quadrant coordinate system to mimic the materials property chart featured in (A).

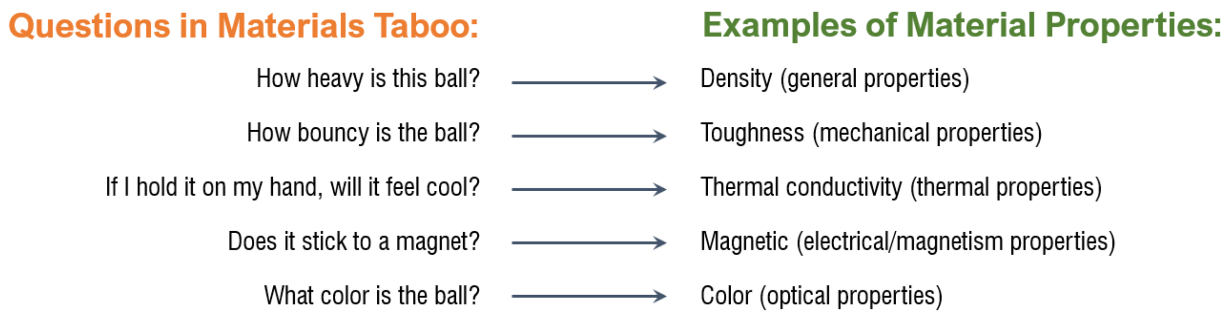

Figure 2. Materials Taboo Question Examples. Examples of questioning that learners can ask that related to the material properties of the balls featured.

2.2. Gamified Module 2 "Materials Battleships"

The second game presented called "Materials Battleships" is inspired by the popular boardgame Battleship® [27]. Battleship®, also referred to as Battleships and Sea Battle throughout the years is a two-player naval-themed guessing game with accounts of its inspiration and creation dating back before World War I, and is now produced and sold by Hasbro, Inc. [27]. For this gamified educational laboratory component, a virtual emulator has been developed to align with the laboratory learning outcomes described in Table 1, where the primary goal is to introduce material property charts through a hands-on game and have learners guess the position of their opponent's ships based on material properties. A portion of the application-based graphical user interface (GUI) is shown in Figure 3, where detailed instructions provided in the game's "How to Play" guide (available on launch) are featured in Supplemental Material: Appendix 1. The game application is also provided in an attached supplemental zip file for open access and is available through the GitHub link in Ref. [28]. Like the board game, learners are tasked to guess the position of their partners' ships, which are inspired by materials (Fig. 3A). A tracking board is provided to track the hits and misses they face on guessing their peers' material battleship positions.

Then, once they have guessed their opponent's ship locations, to win they must successfully guess the materials being considered in their opponent's ships (e.g. bamboo battleship or the aluminum destroyer). This can be intuitively done provided the x and y-axis properties provided for their tracking board and a list of materials at the end (Fig. 3B). A "Hint" button on the GUI is also available that leads learners to a hint of a materials property chart with the same axis as in the game (Fig. 4). Using the "Hint" button, learners can fully connect that the position of the ships coincide with how materials are organized in the chart in Fig. 4. Learners can also click the GUI button "Get New Ships!" to play again to obtain a new set of ships. There are three levels of play available in the game, organized from most to least intuitive to guess from what learners have been introduced in their education, which are as follows: "Easy: Mass vs. Price" (shown in Fig. 3 and 4); "Medium: Mass vs. Stiffness"; and "Hard: Thermal Conductivity vs. Yield Strength." Upon completion of the game, a reflection activity is facilitated by teaching assistants for the laboratory, where material property plots are explored in greater detail as a post-game discussion. This is followed by other laboratory activities begin related to the materials selection of different mechanical components. The intention behind this pedagogical game is to connect new theory intuitively through interactive relatable means, which from the teaching perspective seemed to help facilitate preliminary engagement and intrigue and create a memorable space for learners, supported by survey findings discussed later in this article.

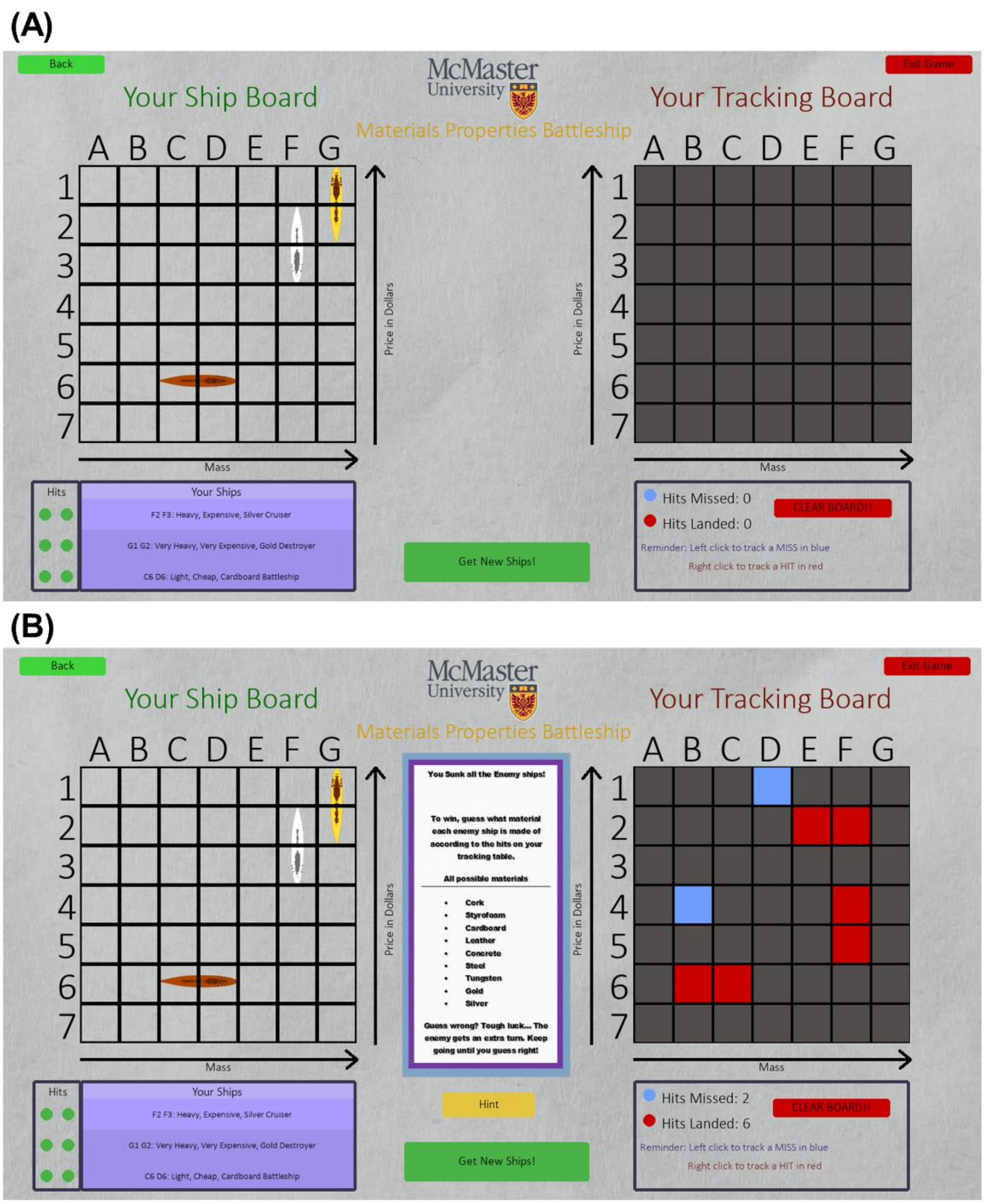

Figure 3. Materials Battleships. (A) Gameplay on the initial launch of “Easy: Mass vs. Price” difficulty level. (B) Upon guessing all your peer’s ship positions, a list of all the materials in the game is provided and as well as a “Hint” button. To win, the player must successfully guess the materials that their peers’ ships are made out of.

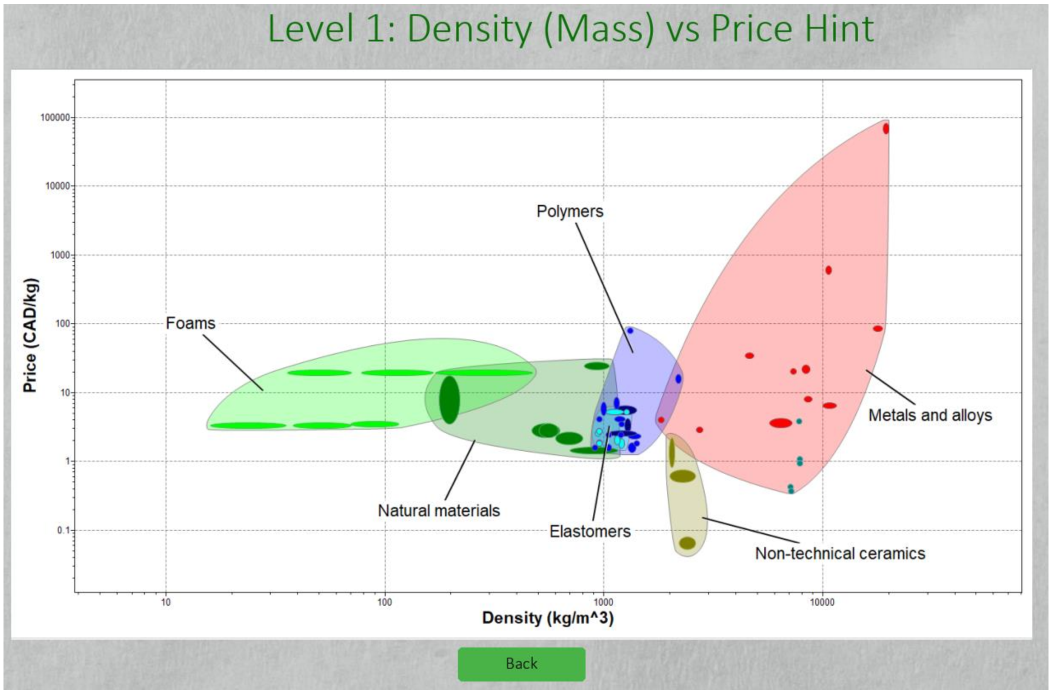

Figure 4. Material Battleship hint page. This is the page that appears upon pressing the "Hint" button on the GUI featured in Fig. 3B. A materials property chart is featured with the corresponding x and y-axis material properties to the game to help learners guess what materials groups would be distributed where.

2.3. Gamified Module 3 "Material Lab Simulation Tool: Virtual Emulators"

The last game shared within this work includes our McMater University Material Lab Simulation Tool. The emulator itself is designed as a part of a laboratory assignment, where the emulator acts as a self-guided tutorial for learners to play with different material properties and part dimensions to explore their effect on performance. As described in Table 1, this relates to learning objectives focusing on introducing concepts of work hardening, tensile testing, and thermocouple thermal-electrical behavior. Within the GUI of the game, there are two emulator modules that learners can explore to help stimulate their understanding of materials concepts, the "Mechanical Workshop" (Fig. 5) and "Thermocouple Simulator" (Fig. 6). These game applications are also provided in an attached supplemental zip file for open access and is available through the GitHub link in Ref. [29]. The Mechanical Workshop module focuses on introducing learners to cold rolling as a work-hardening tool, where a learner is challenged to explore different variables which affect grain size and tensile performance. After cold rolling a specimen in the emulator to a certain degree, learners then watch as the parameters they chose impact the grain structure of their material and subsequently the simulated engineering tensile stress-strain diagram and the ductility of a dog-bone tensile shape made from their material, all dynamically in an interactive manner (Fig. 5). Results from the tensile tester are also able to be exported. It is worth noting that the embedded material physics of the tensile response were estimated based on a combination of imperial data and analytical model, available broadly in most materials science textbooks. The generated tensile data is not based on real experiments conducted and should not be taken for consultation in real life for educating design decisions. The estimated values are provided for the delivery of the learning objectives within this laboratory for this introductory course. For the Thermocouple Simulator module, learners can select from a list of two different metals, where their respective Seebeck coefficients, also known as thermopower, thermoelectric power, and thermoelectric sensitivity, are shared. The Seebeck coefficient describes the thermoelectric voltage response induced by temperature differences. Learners can interactively explore the effects that temperature and material selection have on the measured voltage difference between two rods made from each selected material, which within the emulator are connected to a thermocouple. The electrical potential is then displayed for the set and can be changed based on materials selection and temperature.

The emulator was originally designed during the global COVID-19 pandemic, though has proven in teaching to be an easy way to supplement or complement in-laboratory testing. Typically, for such a large undergraduate course with over 900 learners with limited laboratory training, this type of laboratory experience would be limited to a demonstration based on time and material restrictions. This would involve a teaching assistant or technician performing a tensile test for example in a crowded room with limited interaction or chance to perform the test themselves to better understand the impact of cold working. Here through this emulator, learners can quickly alter parameters, providing a fast alternative for them to try to understand how it is impacting the material performance and reinforce learning. Ultimately, this gamified emulator experience promotes individual exploration and provides the learner more control of their lesson, with guided questions to encourage them to explore different features of the emulator.

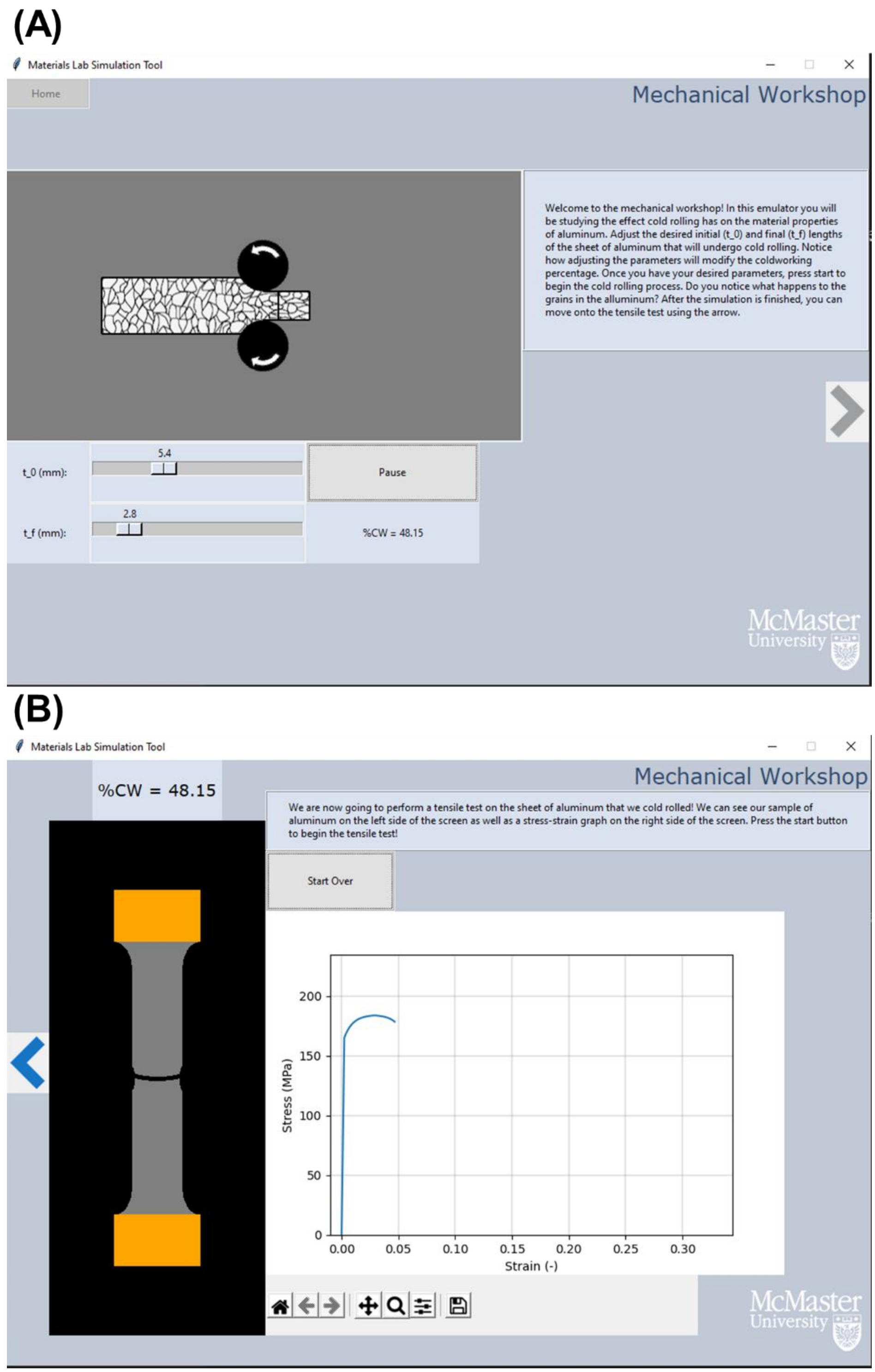

Figure 5. Material Lab Simulation Tool Mechanical Workshop. (A) Mechanical Workshop emulator section where learners can simulate dynamically visual changes in grain size virtually through cold rolling, where aluminum is considered. (B) Following cold rolling, learners progress through the module and can visualize a simulated tensile test of their cold-rolled structure. Simulated data can be saved from the emulator.

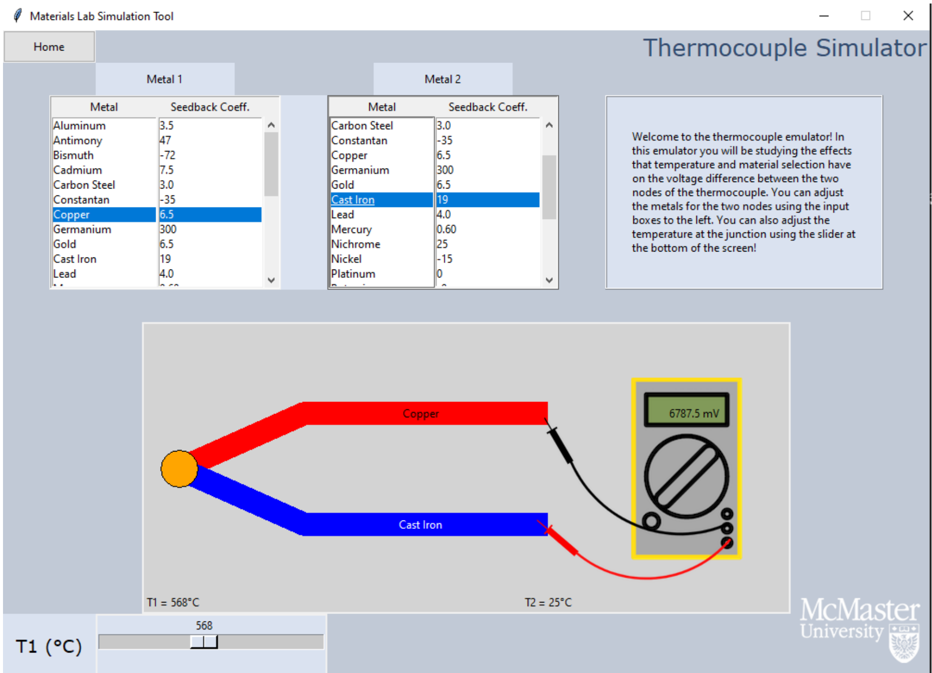

Figure 6. Material Lab Simulation Tool Thermocouple Simulator. Thermocouple Simulator emulator section where learners can simulate dynamic changes that temperature has on voltage based on material selection of the two materials forming the thermocouple.

3. Methods

3.1. Survey Questionnaire

Ethical approval of the survey was obtained from the McMaster Research Ethics Board (MREB #5630). The survey includes questions regarding their experience in the materials science tutorials (see Supplemental Information: Appendix 2). Students were sent a short survey link via email through the McMaster University-approved software LimeSurvey, whereby students could decide to participate in the survey and submit their answers anonymously. This survey link was sent out by administrative staff and not by the course instructor to mitigate instructor influence on survey results. All data was stored securely within the university through LimeSurvey host servers, without reliance on a third-party external data storage surveying tool. The survey was created such that learners would be able to reflect on their experiences on a semesterly basis. This was done in an effort to not over-survey learners after each tutorial, as students in newly developed courses can often be over-surveyed with ongoing educational research conducted institutionally.

In efforts to eliminate bias, terminology such as “gamified” or “games” were not included in the surveys. Instead, the surveys were worded to inquire about the student’s overall satisfaction with the tutorial activities and why they enjoyed the activities. These questions included multiple-choice questions, ranking questions, and short answers where applicable.

3.2. Data Management and Processing

Data was exported from LimeSurvey and initially processed using R (R Core Team 2013) to organize the data. All survey results collected were stored only on LimeSurvey, internally on servers within the university, and in accompanying anonymized files. After data reorganization, the data was processed using Excel to allow for comparisons between the gamified learning approaches, learning outcomes, student experience and an evaluation of demographic data for the responding population. The survey collected information on learner demographics, prior experience level, course and future engineering discipline stream relation questions, and questions related to their experience with the materials science laboratories, which all can be found in Appendix 2.

The survey was conducted at the end of the first engineering term when learners have completed the first semester of ENG 1P13. The total class size for the 2021-2022 year for this course was 906. Participation in this survey was advertised to students external to the instructor and the resulting number of participants were 66 partial results and 114 full, for a total of 180 participants. Data analysis was conducted using the full responses only to allow for consistency in the number of respondents per question. The 114 full responses from surveying accounted for thus a representative amount of 12.6% of learners from the course.

4. Results & Discussion

The evaluation of survey results summarized a variety of demographic information questions that were collected at the beginning of the survey. A summary of the participant population broken down by these factors is shown below in Table 2, based on complete results only.

Table 2: Summary of demographic information collected from survey respondents.

Demographic Information	**Answer Options and Associated Number of Respondents**				
Age	**>17**	**18**	**19**	**20+**	**Other/No Answer**
Respondents	2	85	24	3	0
Gender	**Man**	**Women**	**Non-Binary**	**Other**	**No Answer**
Respondents	67	45	4	2	0
Racial Identity	**White**	**Black or African American**	**Asian**	**Indigenous**	**Other/No Anwer**
Respondents	57	8	40	1	18
Citizenship Status	**Canada**		**International**		**Other/No Answer**
Respondents	105		9		0
Disability Status	**Yes**		**No**		**Other/No Answer**
Respondents	7		3		3

This demographic information when compared to information from the 2022 annual report released by McMaster University in terms of gender identity of the incoming appears to be representative, with a reported percentage of women-identifying respondents to be 39% compared to the published 41% of the incoming class [30]. Other information is not released by the institution, however, which includes the spread of the population reported in Table 1.

The survey results focused on the materials science components of the course and broadly analyzed the effectiveness of the materials laboratories. Materials Taboo was conducted in lecture and not in laboratory, thus data can only be correlated with the implementation of Materials Battleships and the virtual emulator Material Lab Simulation Tool. Limitations related to the interpretation of these results are discussed in greater detail within the following section based on the data collected. The analysis conducted is considered preliminary at this stage in terms of understanding the total effectiveness of our gamification approach. It has served as a means to provide a formal understanding of learner satisfaction with laboratories with implemented gamified learning strategies.

After surveying respondents on demographic information, the survey probed learners to select their favorite and most enjoyable of the four first-term materials-focused engineering laboratories (Appendix 2, Question B1). The laboratory containing the virtual emulator Material Lab Simulation Tool (Laboratory 3 mentioned in Appendix 2) ranked among the favorite for learners, with 35.9% of respondents answering that it was their favorite of the four laboratories. Another laboratory which focused on materials selection of biomedical devices (Laboratory 4 mentioned in Appendix 2) was ranked by 28.2% of learners as their favorite laboratory. Laboratory 2 (Appendix 2) involving mechanical structures ranked first by 21.9% of learners and finally, Laboratory 1 (Appendix 2) involving the introduction of materials selection and Materials Battleships was ranked by 14% of learners as their favorite laboratory. This speaks positively about the implementation of the Material Lab Simulation Tool within Laboratory 3. Fewer learners ranked the laboratory containing Materials Battleship as their favorite. A limitation of interpreting the results of this question is that the survey did not ask learners to rank their favorite laboratory in order of preference. Thus, it can only be said that more learners preferred Laboratory 3 as their favorite laboratory. Conclusions cannot be made regarding the average ranking order of the laboratories and whether Laboratory 1 containing Materials Battleship was the least popular, though it can be said it was the laboratory that fewer learners ranked as their favorite.

The following question in the survey prompted learners to reflect on the choice of their favorite laboratory and the reason(s) for their decision (Appendix 2, Question B2). Specifically, learners were asked if the following characteristics apply to their feelings on their favorite materials lab experience and what made an activity stand out, where an “Other” answer was provided as an option for learners to add an additional typed-out answer not otherwise listed. The specific question prompts are numbered as follows, referenced in the horizontal axis of Figure 7:

1. The activities were fun
2. Your attention was kept for the duration of the lab

3. The session was interactive
4. You were able to learn new engineering concepts in the labs
5. You were able to retain knowledge that was taught in the lab
6. You had a positive and inclusive learning environment
7. The IAIs and MSE TAs did a good job at leading the lab
8. Working with your team made the lab more enjoyable
9. You felt supported by teaching staff (IAIs and MSE TAs)
10. The activities related to real-world applications
11. You had a personal connection with one or more of the elements presented in this lab
12. Not Applicable
13. Other: ______________

Figure 7 overviews a summary of these results for each numbered prompt on the horizontal axis, normalized with respect to respondents in the survey. We note from this question in the survey, the results highlight that the three most prominent factors resulting in favorite laboratory experience, in order of ranking, were: 1) the activities were fun, 2) your attention was kept for the duration of the lab, and 3) the session was interactive. This positively reinforces the learning concepts which inspired the incorporation of gamified means in our laboratories involving making learning more fun, keeping learners engaged, and interacting with learners. Moreover, it supports the idea that the favorite laboratories as chosen by learners were directly related to their interpretation of how much fun the presented activities were, followed by how well the activities kept their attention and interactions with learners throughout. This is informative for educators on what should be prioritized in laboratory lesson planning to enable learners to have an improved and memorable educational experience.

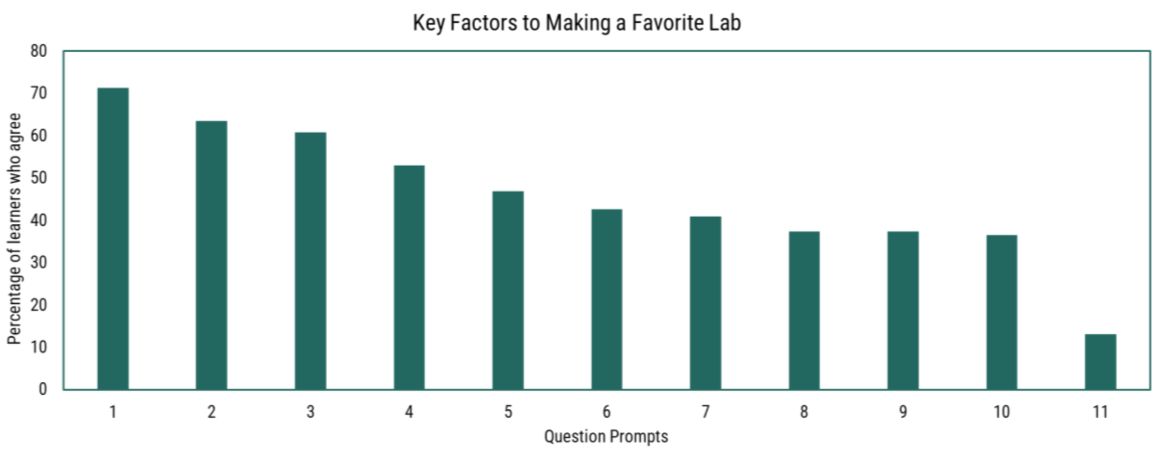

Figure 7. Survey Result Summary of Question B2 (Appendix A2). Overview of survey answers summarizing key factors to making a favorite lab from learners, with the percentage of students who agree versus numbered question prompts. Numbered question prompts are elaborated previously in the text.

While gaining an understanding and insight into the factors that lead to the best student experience in terms of laboratories is vital for planning future learning activities, limited information can otherwise be obtained from question B2. We note that due to limitations regarding how broadly this question about laboratory experience was proposed, not specifically mentioning the gamified measures, this survey question cannot be further correlated to say that gamified experiences helped decide the learners' favorite laboratory. Rather, two other survey questions, C2 and C3 (Appendix 2), prompted learners to reflect and rate the Materials Battleship and Tensile Emulator (Material Lab Simulation Tool) specifically in terms of: 1) increasing motivation, 2) engagement, 3) stimulating interest in material science, 4) enjoyment, and 5) supporting learning outcomes. These questions were asked in a Likert scale ranking manner, with rankings from (1) very ineffective, (2) ineffective, (3) neutral, (4) effective, and (5) very effective, as well as "Not Applicable" available as an option. Summarized averaged Likert data for each question for the two gamified methods are presented in Figure 8 and summarized data is provided in Table 3.

From these results, it is noted that learners found the activities effective in all categories on average, with both activities surpassing the 42% threshold of respondents (Table 3) reporting an increased motivation to participate (Materials Battleship Likert avg. 3.79; Material Lab Simulation Tool Likert avg. 3.43), learning enjoyment (Materials Battleship Likert avg. 3.82; Material Lab Simulation Tool Likert avg. 3.45), and kept learners engaged (Materials Battleship Likert avg. 3.73; Material Lab Simulation Tool Likert avg. 3.50). Anecdotal feedback from teaching assistant staff suggested that the gamified activities were generally well-received by learners and that they had fun working on the activities collaboratively with their peers. When compared to one another, Materials Battleship scored higher on average than the tensile emulator in all categories besides stimulating interest in material science, where the two scored similarly on average within that category slightly above neutral (Materials Battleship Likert avg. 3.37; Material Lab Simulation Tool Likert avg. 3.39). This highlights a need for improvement in the Material Lab Simulation Tool gamification strategy, while also showing a need to improve how these games stimulate the interests of learners in materials science education.

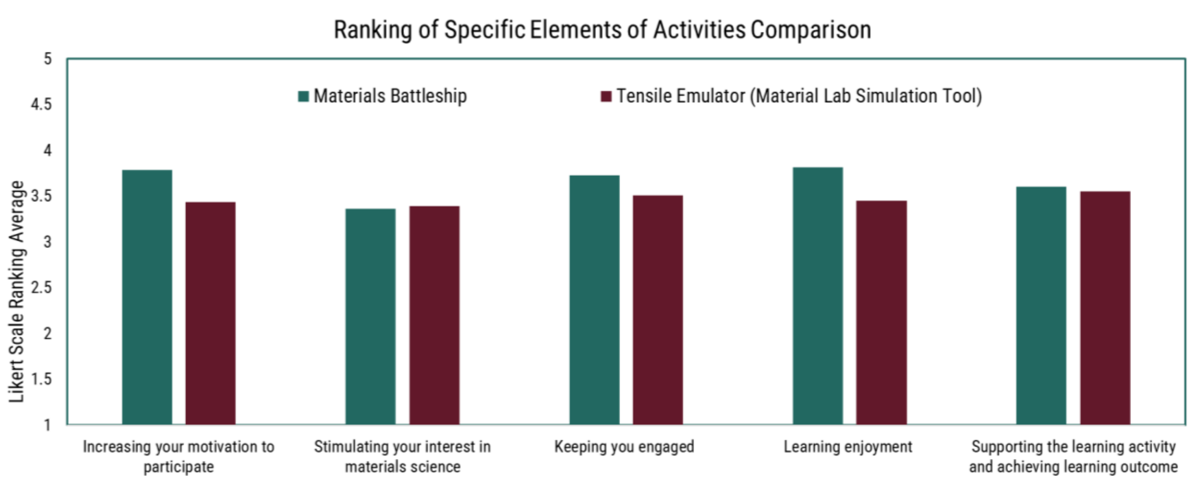

Figure 8. Ranking of Specific Elements of Activities Result Summary Comparison from Questions C2 and C3 (Appendix A2). Overview of survey answers summarizing Likert scale ranking of specific elements related to gamified activities. Likert scale varies from (1) very ineffective, (2) ineffective, (3) neutral, (4) effective, and (5) very effective.

Table 3. Result summary comparison of questions C2 and C3 (Appendix A2). Likert scale averages are shown as well as the percentage of respondents that ranked the activities in the specific elements as (4) effective or (5) very effective.

		Increasing your motivation to participate	Stimulating your interest in materials science	Keeping you engaged	Learning enjoyment	Supporting the learning activity and achieving learning outcome
Materials Battleship	Likert scale average	3.79	3.37	3.73	3.82	3.61
	Percentage of respondents that ranked (4) effective or (5) very effective	63.4%	42.0%	60.4%	64.0%	53.6%
Tensile Emulator (Material Lab Simulation Tool)	Likert scale average	3.43	3.39	3.50	3.45	3.55
	Percentage of respondents that ranked (4) effective or (5) very effective	44.9%	53.3%	55.1%	53.3%	56.1%

Careful planning and structure are essential to effectively deliver student-centred active learning to large classes. Failure to align laboratories with course content can result in poor conceptual learning, highlighted by Mackechnie et al. [20]. From Figure 8, it is noted that learners also ranked that the activities were nearly equally effective in supporting the learning activities within the laboratories and at achieving learning outcomes (Materials Battleship Likert avg. 3.61; Material Lab Simulation Tool Likert avg. 3.55). In discussing the ease of use of the newly implemented gamified software options (Appendix 2, C4), the survey asked learners to rank each of the two options through a Likert scale with available options from (1) very difficult, (2) difficult, (3) neutral, (4) easy, and (5) very easy, as well as “Not Applicable” available as an option. Survey results highlight that on average, learners ranked the activities as easy to use, with Material Battleship's Likert avg. 3.94 and the Material Lab Simulation Tool’s Likert avg. 3.43. Barata et al. note that taking a gamified approach to teaching with proper integration within a course structure can help motivate learners, keep them engaged, and improve student satisfaction [12]. This ease of use paired with the alignment of learning outcomes of the two activities are attributed as being essential to the facile integration of these activities within the large classroom setting.

5. Study Limitations

The survey conducted provides an overview of the collected data, though several limitations can be discussed. These results only describe one semester's experience from the first-year engineering population and focused on materials laboratories, not specifically on gamified means. As noted, this was done to avoid bias, so learners were not being specifically asked about games, as well as to reduce survey fatigue in learners within a new program. However, this limited what could be interpreted within the survey study, diluting the content, and providing only a preliminary understanding of learner experience with the new gamified methods. Moreover, the Materials Taboo game was not included in the survey as it was conducted in lecture and not in laboratory, thus data can only be correlated with the implementation of Materials Battleships and the virtual emulator Material Lab Simulation Tool.

Additionally, the results were collected after the first term laboratories were completed. However, as time progresses through the semester, the details of some of the earlier laboratories may be harder to recall than more recently completed laboratories. Another factor limiting the results of this analysis is the large change in course structure and its impact on learning experience and outcomes due to the launch of our PIVOT program. Survey respondents represented only the second cycle of their new first-year program, where many large educational changes were made to the program structure – resulting in many new educational experiences that both learners and educators were going through for the first time. Similarly, the data collected from the 2021 fall academic term was the first in-person offering of ENG 1P13 since the COVID-19 pandemic. Particularly with blended options offered in the course, this could have an influence on learner engagement depending on their administration (virtual or in-person). Thus, to better understand these effects, more surveying is planned over time the next few years to evaluate these strategies long-term. Finally, we note that this gamified aspect is representative of only a fraction of the course experience. Limitations in study participation occurred as not the entirety of the population of ENG 1P13 learners completed the form.

6. Conclusions and Future Directions

Teaching and learning in materials science and engineering is a challenge, however, it need not be boring. We highlight within our work three pedagogical gamified strategies presented in detail for materials science education. The activities incorporate active and experiential learning strategies in implementation and are fun for both learners and educators. Two of the strategies, both materials-focused games made available as supplementals for this work, were evaluated through surveying in the context of the laboratories they were implemented within. Learners from our first-year engineering cohort provided positive results related to their implementation, noting that the methods contributed to increased motivation to participate, learning enjoyment, and learner engagement. They also found the methods to be easy to use and that they were nearly effective at supporting the learning activities within the laboratories and at achieving learning outcomes.

Slightly lower Likert average rankings towards neutrality on whether the two gamification strategies stimulated an increased interest in the materials field highlights an area for improvement to focus on for future implementations.

Moreover, while not specifically in reference to gamified strategies, learners indicated that their favorite laboratories are chosen most often due to fun, the ability of the activity to keep their attention, and interactive components. This feedback positively reinforces themes of gamification, anecdotally suggesting that using gamification strategies that are both fun, interactive, and keep learner attention, may be a key manner to creating more memorable laboratory experiences.

We note there were several limitations summarized within the text which cause the need for future surveying to understand the impact of these cohorts, introduction on curriculum, and COVID-19, which may have had on results. Future iterations of this research plan to incite more participation in the survey through an incentive for their engagement and further survey promotion. This would increase the percentage of learners that take part in the study and allow for the results to in turn be more robust and valuable at gaining insight into the experience of first years as more gamification is implemented and courses further develop.

Overall, gamification has proven effective in creating an engaging, thought-provoking supplement to traditional lecture styles in the materials science and engineering space, with several opportunities to expand into other facets of the first-year curriculum. This presents a key opportunity to make learning more fun in the classroom and increase engagement in learners in memorable ways. With evolutions in the pedagogical engineering field occurring every day, materials science and engineering need to continuously adapt to educational shifts and not get left behind. While gamification is not a complete solution for this problem and cannot, at this time, replace entire materials curricula, games are one way that we suggest for making learning more engaging and fun to support learning outcomes.

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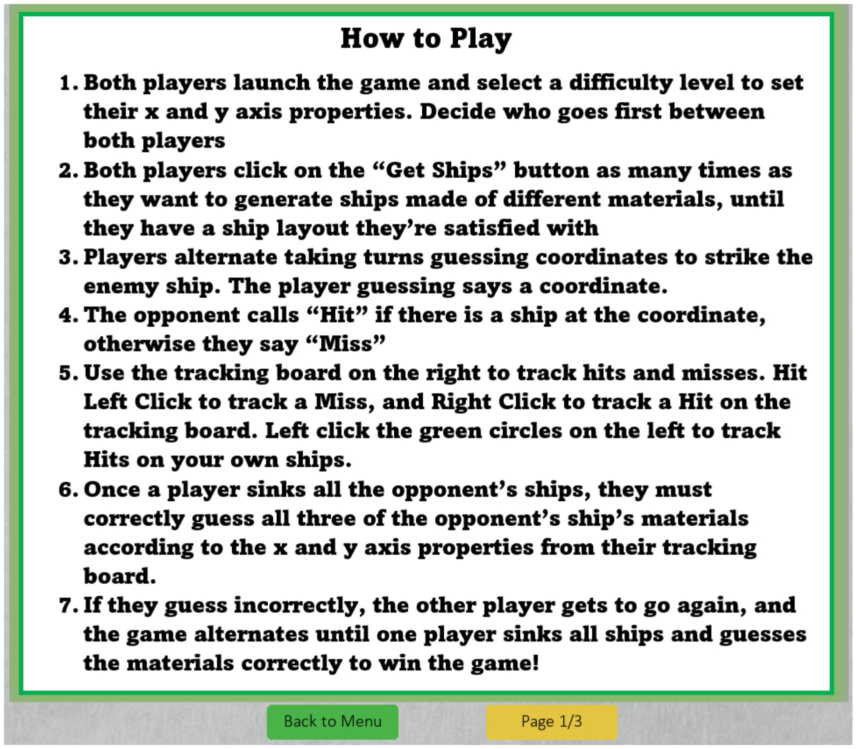
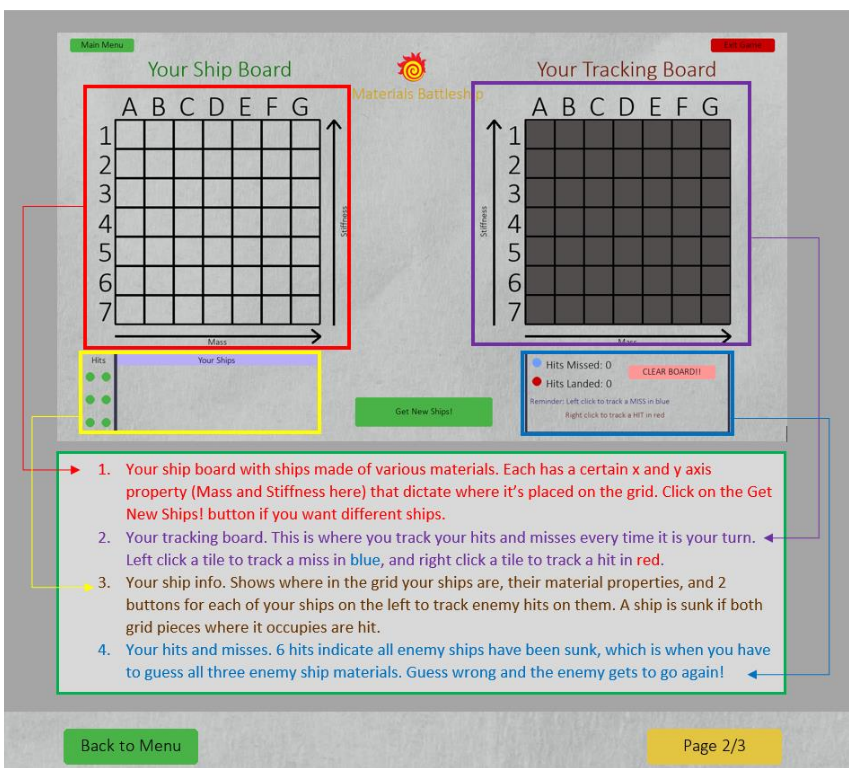
Supplemental Material: Appendices

Appendix 1: Materials Battleship "How to Play" Guide





Team Instructions

This game is primarily designed to be 1 vs 1, but two teams of 2 (or more) can play against each other in a very simple way.

If Playing In-Person: Each team would simply share one computer running the game and alternate taking turns between each team, and each player in each team would also alternate guesses.

If Playing Virtually: One group call between all players would be started, and a team leader would be decided for each team. Once it is decided, the leader chooses a specific ship layout and privately messages it to their team-mates. Then the game would proceed as normal with the team-leader announcing hits and misses, and players within each team alternating guessing. All players can track team hits and misses on the tracking board.

Appendix 2: Full Survey Questionnaire

The following lists of survey questions that were asked during this project to evaluate gamified activities. Learners were recruited for the survey through a first-year engineering course mail list and volunteered to participate without external incentives. Surveys were administered through an internal McMaster University through LimeSurvey, where the survey data is collected and stored locally (on-campus). The survey was not mandatory for learners. In the questions, a * indicates that the question was mandatory for learners to complete.

The following is a transcript of the administered survey to learners:

Evaluation of Materials Science Focused Labs - Fall 2021

Thank you for participating in this survey that examines the effectiveness of the new materials science and engineering laboratories that were completed this term in ENG 1P13.

The anonymous survey can be completed approximately in 5 minutes. It will ask about how students like found the new materials science laboratories presented in ENG 1P13 this academic year (2021 – 2022).

This survey was developed by a small team of gradate and post-graduate researchers, and myself. This group is the only one that will access and manage your responses. Findings will be disseminated to the PIVOT team, university stakeholders, and research platforms in anonymized and aggregated form.

Your participation is entirely voluntary, and you may refuse to participate or withdraw from the study at any time. Your survey responses will only be recorded once you finalize your answers by pressing the "submit" button. Any responses not submitted will be lost and therefore not used in the study. Participating in this study will not have any influence on your status as a student, grades, performance, etc.

Please note that by proceeding to answer the survey signifies that you have provided your consent to allow us to use your survey data for this study.

This study has been reviewed and cleared by the McMaster University Research Ethics Board. If you any have concerns or questions about your rights as a participant or about the way the study is being conducted you can contact:

The McMaster University Research Ethics Board Secretariat
/o Research Office for Administration, Development and Support (ROADS)
E-mail: ethicsoffice@mcmaster.ca

I would like to thank you in advance for your time and consideration. After a week, the program in-charge will send you a one-time follow-up reminder.

Thank you very much.

Bosco Yu, PhD
Assistant Professor
Department of Materials Science & Engineering
Faculty of Engineering, McMaster University

There are 15 questions in this survey.

A. Demographic Information

A1. How old are you? * Choose one of the following answers:
- Under 17
- 18
- 19
- 20
- 21
- 22
- 23
- 24
- Over 25
- Prefer not to answer

A2. Please indicate your gender identity (you may select more than one),* Check all that apply:
- Man
- Woman
- Non-binary
- Other
- Prefer not to answer
- Other: _______________

A3. How do you racially identify? * Check all that apply:
- White
- Black or African American
- Asian
- Indigenous
- Prefer not to answer
- Other: _______________

A4. Do you identify as someone who is disabled (visible or invisible)?* Choose one of the following answers:

- No
- Yes
- Prefer not to answer

A5. Please indicate whether you are a domestic (Canadian citizen or have permanent resident status) or international student. * Choose one of the following answers:

- Domestic student
- International student
- Prefer not to answer

A6. At this point in time, what interests you as a top choice of Engineering Department for your upper year studies? * Check all that apply:

- Chemical Engineering
- Chemical Engineering and Bioengineering
- Civil Engineering
- Computer Engineering
- Electrical Engineering
- Engineering Physics
- Materials Science and Engineering
- Mechatronics
- Health, Engineering, Science and Entrepreneurship (HESE)
- Mechanical Engineering
- Undecided
- Other: _______________

B. General Evaluation of New Materials Science Lab Modules in ENG 1P13

B1. Considering the four materials labs offered in the past term, what lab would you have considered your favourite and enjoyed the most? * Choose one of the following answers:

- Materials Science Lab 1: Materials Selection of Mechanical Designs. Brief description of activities: Materials Battleships, introduction to Granta, MPI calculations of various mechanical structures and assignment with wind turbine blade.
- Materials Science Lab 2: Scientific Principles of Mechanical Structures and Devices. Brief description of activities: Crystal oscillator dissection lab, tuning forks, copper rod bending, beam deflection exercise, and virtual emulators.
- Materials Science Lab 3: Scientific Principles of Phase Diagrams and Flexible Sensors. Brief description of activities: Copper-zinc phase diagram and “gold” pennies, indium-gallium eutectic solder, phase fraction calculations, and flexible sensor demo.
- Materials Science Lab 4: Materials Selection of Biomedical Materials. Brief description of activities: Biomaterials intro, fracture toughness with paper demo, materials selection of dental crown, material selection of hip implant.

B2. Based on your answer in the previous question, for what reason would you say the lab you selected was your favourite of the four? Please check all applicable answers. * Check all that apply:

- The activities were fun
- Your attention was kept for the duration of the lab
- Working with your team made the lab more enjoyable
- The session was interactive
- You were able to retain knowledge that was taught in the lab
- You were able to learn new engineering concepts in the labs
- You had a positive and inclusive learning environment
- You felt supported by teaching staff (IAIs and MSE TAs)
- The activities related to real world applications
- You had a personal connection with one or more of the elements presented in this lab
- The IAIs and MSE TAs did a good job at leading the lab
- Not Applicable
- Other: _______________

B3. From your perspective, on a scale from 1-5 where 1 being very ineffective and 5 being very effective, overall, how would you rank the following characteristics of the fall term materials science labs? * Please choose the appropriate response for each item:

	Very Ineffective (1)	Ineffective (2)	Neutral (3)	Effective (4)	Very Effective (5)	Not Applicable
Enjoyability						
Meeting learning objectives of the lab						
Engagement						
Touching on real-world applications (e.g. relatability)						
Your knowledge retention of the concepts taught in the labs						
Teaching concepts relevant to projects featured in ENG 1P13						

C. Evaluation of the Learning Experience in Materials Science Labs in ENG 1P13

C1. Reflecting on your experiences in the ENG 1P13 materials science laboratory sections, from your perspective, how would you rank the following elements of the activities that were introduced and their effect on your learning experience in this course at:* Please choose the appropriate response for each item:

	Very Ineffective (1)	Ineffective (2)	Neutral (3)	Effective (4)	Very Effective (5)	Not Applicable
Increasing your motivation to participate						
Stimulating your interest in materials science						
Keeping you engaged						
Facilitating your learning experience in comparison to traditional laboratory teaching approaches						
Supporting the learning activity and achieving learning outcomes						
Making the laboratory sections more enjoyable						

C2. Reflecting on your experiences in ENG 1P13 materials science laboratory sections, from your perspective, how would you rank specific elements of the course-specific software implemented throughout the FALL semester in the MATERIALS BATTLESHIP activity? *
Please choose the appropriate response for each item:

	Very Ineffective (1)	Ineffective (2)	Neutral (3)	Effective (4)	Very Effective (5)	Not Applicable
Increasing your motivation to participate						
Stimulating your interest in materials science						
Keeping you engaged						

	Very Ineffective (1)	Ineffective (2)	Neutral (3)	Effective (4)	Very Effective (5)	Not Applicable
Learning enjoyment						
Supporting the learning activity and achieving learning outcomes						

C3. Reflecting on your experiences in ENG 1P13 materials science laboratory sections, from your perspective, how would you rank specific elements of the course-specific software implemented throughout the FALL semester in the TENSILE EMULATOR activity? * Please choose the appropriate response for each item:

	Very Ineffective (1)	Ineffective (2)	Neutral (3)	Effective (4)	Very Effective (5)	Not Applicable
Increasing your motivation to participate						
Stimulating your interest in materials science						
Keeping you engaged						
Learning enjoyment						
Supporting the learning activity and achieving learning outcomes						

C4. Reflecting on your experiences in ENG 1P13 materials science laboratory sections, from your perspective, how would you rank the ease of use for the course-specific software implemented throughout the FALL semester? * Please choose the appropriate response for each item:

	Very Difficult (1)	Difficult (2)	Neutral (3)	Easy (4)	Very Easy (5)	Not Applicable
Materials Battleship						
Tensile Emulator						

C5. Reflecting on your experience in ENG 1P13 materials science laboratory sections, from your perspective, how would you rank the effectiveness of the use of ANSYS EduPack GRANTA software? * Please choose the appropriate response for each item:

	Very Ineffective (1)	Ineffective (2)	Neutral (3)	Effective (4)	Very Effective (5)	Not Applicable
Increasing your motivation to participate						
Stimulating your interest in the tutorials or laboratory section						
Supporting the learning activity and achieving learning outcomes						
Providing additional study tools						

C6.Reflecting on your experiences in ENG 1P13 materials science laboratory sections, from your perspective, how would you rank the ease of use of ANSYS EduPack GRANTA? * Please choose the appropriate response for each item:

	Very Difficult (1)	Difficult (2)	Neutral (3)	Easy (4)	Very Easy (5)	Not Applicable
GRANTA						

Thank you for your participation, your survey response has been noted and we greatly appreciate the time you spent providing us your feedback.

Submit your survey button.

Thank you for completing this survey.