AC 2012-5456: GAMIFICATION AS A STRATEGY FOR PROMOTING DEEPER INVESTIGATION IN A REVERSE ENGINEERING ACTIVITY

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Gamification as a Strategy for Promoting Deeper Investigation in a Reverse Engineering Activity

Abstract

This paper explores the impacts of gamification on students' investigations in a reverse engineering activity. The activity, which occurs in the first month of a freshman design and communication cornerstone course, challenges students to develop an understanding of how design decisions are made and the trade-offs involved in realizing a work of engineering design. In the most recent iteration of the activity, we created a game whereby students were awarded achievement levels for (1) practicing safety, (2) developing an understanding of key design decisions (construed as Design for X [DfX]), and (3) making inferences for logical argumentation in discussion with instructors. Although the reverse engineering activity did not directly include significant rewards, we employed gamification to challenge students to achieve a broader set of tasks and to achieve these tasks in deeper and more nuanced ways. Our preliminary analysis of the gamification of the exercise investigates the teaching team experience, in particular the nature of their interactions with the students, the students' perception of the quality of the experience, and the students' results in the form of an oral presentation of their device teardown. This simple approach enhanced the students' collaboration, their ability to handle rebuttals and make solid arguments based on physical evidence, and their understanding of the significance of DfX.

1. Introduction

This paper investigates a new and simple game that was incorporated into a reverse engineering activity for a freshman design/communication course in the Engineering Science Program at the University of Toronto. The course includes both lectures and activity-focused tutorials (referred to as studios) and teaches to approximately 300 students. The majority of the students are 17-18 years old, and approximately 20% of the class is female. The class' interest and experience in gaming, in computer, board, or other forms, is not known, however it is assumed to be consistent with their age and demographic.

Our intention in creating a gamified version of the activity was to capitalize on the natural incentives of games as a means to promote deeper engagement and investigation of a design. As in a traditional reverse engineering activity, the students are tasked with deconstructing and developing an understanding of a physical device, specifically a household electromechanical device such as a toaster or blender. However, our focus is not on how the device works, but on identifying and understanding the design decisions and the trade-offs involved a work of engineering design. By putting this activity at the beginning of the design course, we hope to frame the way students view design and all artifacts that they encounter. From 2007-2010 the activity remained fundamentally unchanged. Student engagement was informally assessed by the teaching team as being generally good – depending somewhat on what device they selected – but students tended to demonstrate a fairly simplistic level of understanding. For example, they might simply blame "cost" for any substandard design rather than really investigating the nature of the trade-offs involved. In 2011, the teaching team attempted to gamify the activity precisely to motivate a deeper investigation of the designs.

1.1 Justification of "Gamification"

Games form a significant part of contemporary life, with estimates placing self-identified "gamers" at over 67% of adults between 18 and 34[1]. So it is no surprise that educators have attempted to bring gaming into education. Indeed, games of various kinds have long been part of learning activities – since well before the video gaming era. There appears to be a recent increase in interest in gamification (e.g. integrating game features into other activities) within, and in some cases in lieu of, higher education; Google Trends indicates that the terms "gamify" and "gamification" were essentially not searched for prior to the second half of 2010, and the number of such searches has since increased tenfold[2]. This interest has taken forms including gamifying existing activities, such as the initiative described in this paper, and developing achievement badges for aspiring "makers" interested in designing their own hardware and software[3].

Educational games have four key attributes:

1. an artificially constructed activity,
2. competition,
3. a specific goal, and
4. "a set of rules and constraints that is located in a specific context"[4].

While other features such as graphic interface, obstacles, or rewards are nice features – and features that gamers have come to expect – they are not essential to the experience of game. One feature that some consider essential is voluntary participation[5]; however, in an educational setting that may not always be possible. Its absence, however, does not seem to prevent the game from being a game. Although some research challenges that learning through games is only superficial[6], more often research suggests that "the use of games for learning leads to improved general learning, increased motivation, and improved performance"[7]. So, while the role of gaming in learning cannot be considered of certain benefit, the desire to improve performance and increase motivation through active learning has led educators at all levels to explore the possibility of gaming.

McGonigal has observed that games have actual neurological and physiological effects as success – particularly the "epic win" – that trigger a positive emotional response that is heightened beyond what is experienced in everyday life[5]. Such a response can be triggered by overcoming any obstacle of the game. The goal in education is to capitalize on these response mechanisms to invite the learner to probe more deeply than he or she might otherwise. In Kolb's model of learning, learners transform concrete experience into knowledge through a cycle[8], but the cycle begins in concrete experience. Gaming for learning aims to make this concrete experience as tangible, meaningful and engaging as possible with the hope that such stimulation facilitates the uptake of experience to knowledge. Uptake of knowledge is a complex process influenced by myriad factors from the learning environment to the cognitive preparedness of the individual, so expectations of any game need to be kept reasonable. Simply, the game can motivate learning through the positive response, and perhaps – depending on the nature of the game – it can allow students to make the kind of integration of thinking that allows them to generalize from a single experience to a conceptual understanding.

2. Learning Objectives for the Teardown Activity

The activity takes place early in the students' engineering education while they still have limited technical expertise. However, rather than focusing on how the device works, the activity focuses on identifying specific design decisions and trade-offs made by the device designers. The consequences of those decisions are then explored, and the students are prompted to propose alternate decisions that embody different trade-offs and that have different consequences. For example students may identify that a toaster has been assembled using screws, which provide rigidity but increase assembly time. They may then propose moving to slotted assembly, trading structural rigidity for ease of assembly. The students are not graded directly on their findings in the activity, but instead are required to use the evidence gathered and results from the activity in their midterm examination.

The uniqueness of the teardown activity has led to the development of an unconventional set of learning objectives relative to similar activities. There are four primary and four secondary learning objectives. For the purpose of this discussion, only primary objectives will be considered. The primary learning objectives of the activity are:

(1) Force the students to contextualize the results of Studio 01 to an actual artifact, and to refine the students' understanding of quality engineering design.

In the first studio activity of the course, the students are challenged to define the term "engineering design". This activity then challenges the students to consider their definition in light of real world experience. Often, students end up modifying their initial decision based on their concrete experience.

(2) Help students understand design as justified decision making, and the consequences of the design decisions (as well as the consequences of alternate design decisions)

This objective is especially important. The students are challenged to consider the design decisions they believe the design engineer has made. In the process, they subconsciously must develop their own set of requirements that supposedly drove the design. High performing students will realize this subconscious process at work, and will explore the assumptions behind the requirements they create. Understanding the impacts of requirements on decision making, and then the impacts of decision making on the final design, allow students to explore a huge range of engineering design activities within a single concrete example.

(3) Establish appropriate evidence gathering procedures and practices (especially documentation).

The students are pressed to document their activity closely, as the midterm in the course focuses on their experience in this activity. Documentation involves not only defining their steps in the teardown, but also taking photographs and measurements, generating drawings and diagrams, and trying to record justifications for their understanding.

(4) Begin to develop sophisticated and credible claims about the quality of an engineering design.

This goal aims to take students away from knee-jerk responses to evaluating an engineering design and to make more measured, defensible, and considered evaluations of works of engineering design. We believe that students must be able to sensibly critique other works of engineering design if they themselves wish to become component engineering designers. The students were encouraged to use the Toulmin[9] model of argumentation to ensure that all claims they presented were backed up with appropriate and sufficient evidence.

3. Gamifiying the Device Teardown

Originally, the device teardown activity was designed as an unstructured activity in which all learning was experiential and where the students had complete flexibility to pursue their own interests, subject to the overall objective of identifying the design decisions embodied in their device. The only explicit scaffolding came in the form of a set of keywords, identified by the students in their first week of study, that in their minds exemplified quality engineering design (e.g. “elegant”, “safe”, “usable”, etc.). Instructors would circulate and ask probing questions of the students, however those questions were based on the individual instructor’s background and interests.

Based on informal instructor and student feedback, a number of issues with the activity were identified, and formed the basis of the gamification initiative. Foremost among these issues was student focus. Because there was neither formal structure nor scaffolding, student attention varied depending largely on their intrinsic interest in deconstruction and gaining understanding. While intrinsic motivation was adequate for a majority of the students, a significant minority either required continuous prompting on the part of the instructors, or simply lost focus.

In response to this issue, a set of achievements was designed (see Section 4.2) and was provided to the students prior to the activity. During the activity students were challenged to earn as many achievements as possible, and their progress was both actively monitored and validated by their instructors. The specific achievements were designed in response to other issues with the activity: student attention to issues of safety, student preparation prior to the activity, student selection of devices, and integration of engineering design concepts – most notably the concept of Design for X (DfX).

4. Activity Description

Students were asked to bring in electromechanical devices that could be taken apart during the 110 minutes of the activity. The students were encouraged to bring devices that could be destroyed in the course of the activity.

4.1 Students Arrive

The activity begins with the students entering the room and meeting with their team prior to beginning the activity. As the students enter the room and meet with their team, the instructors hand out tool kits to be used in the activity. This typically takes five to ten minutes.

4.2 Activity Introduction

The next phase of the activity is to introduce the concept of safety to the students. This is accomplished through a brief, slide-supported discussion with the students on the potential ramifications is safety considerations are not addressed. Figure 1 shows two of the slides used during the safety discussion.

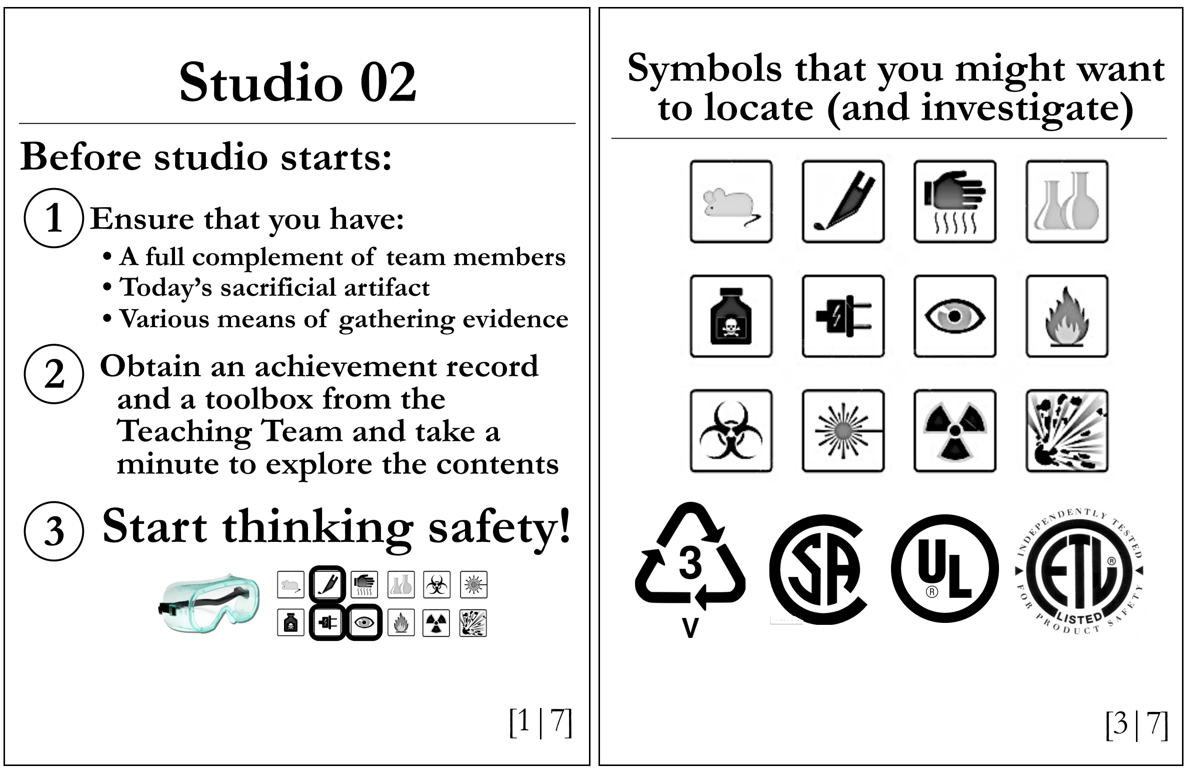

Figure 1 – Extract from the slides shown to students at the start of the activity

Post-safety, the students are introduced to the activity in general. In the current, gamified, iteration of the event, students are given the achievement sheet that goes along with the activity (Figure 2 and Appendix).

Device Design Record of Achievements for team

During the two Device Design studios each team has the opportunity to earn achievements (both positive and negative). These achievements link to specific skills, thinking, and attitudes that an engineering design should be able to demonstrate. Completing certain achievements may "unlock" additional resources that your team can use in subsequent studios. An achievement template, with embedded instructions, appears below:

Studio 02	Studio 03		Studio 02	Studio 03
Stamped by the Teaching Team either **after you call one of them over** or after they witness something **positive** that you've done		**Catchy Positive Title** **(Slightly Derisive Title Signifying the Opposite of the Positive Title)** Description of what you should do, be seen doing, have done, avoid doing, etc., possibly accompanied by some tips on how to ensure that you succeed or avoid failure. Sometimes multiple elements will be included, and you will have to exercise you judgment as to how many to complete before calling over a member of the Teaching Team. **When you call them over, be certain to have evidence of the achievement that you can present.**	Stamped by a member of the Teaching Team after they witness or experience something **negative**	
		Prepared for Battle **(Lambs to the Slaughter)** Your entire team arrived promptly with at least one sacrificial device (that met the requirements given in class and in the lecture notes) and with a plan of attack to ensure efficiency and effectiveness. You had reflected on the previous studio and on the lectures, and had used those reflections to prepare for this studio.		

①

Figure 2 – Extract from the Device Design Record of Achievements form provided to the students

As mentioned, these sheets introduce a series of achievements the students can earn throughout the course of the tutorial. The achievements vary from safety related achievements (e.g. Did your team arrive with proper personal protective equipment?) to achievements directed at the learning objectives (e.g. Persuasively argue the designers of your device considered a given DfX.) The instructors should emphasize that the DfX stamps are the most coveted - in an attempt to spur the students to absorb the learning objectives of the activity. Some of these DfX's are explicitly stated, and some are open to being identified by the students. (e.g. Design for Sustainability is a requirement as a focus of the course learning objectives.) This part of the activity typically takes less than ten minutes.

4.3 The Students First Crack at Deconstructing a Device

The next step in the activity sees the students making a first attempt at deconstructing their device. Typically, students quickly move past the typical outer shell or casing and dive right into the mechanical innards of the machine. Historically, instructors have found it efficient to allow the students to select an area of interest (e.g. allowing the students to focus on the mechanical paper feeding mechanism of an ink jet printer). Allowing the students to select their preferred focal point allows the instructors to start asking deep and meaningful questions while the students plod away at something they consider fun and interesting. At this point, it is the instructors' responsibility to get the students thinking about design decisions and why they were made.

For gamification to work as an incentive to progress and thinking, the instructors need to begin acknowledging the achievements that students have already earned. The mechanism chosen was to physically stamp specific locations on the achievement sheet once the achievement was earned, along the lines of stamping a passport. Many of the early stamps represent binary checks (e.g. Did the students arrive wearing long sleeved/legged clothing?) These are the ideal achievement stamps to focus on at this point as they get the students in the game without detracting from their initial teardown activities. Additionally, the initial collection of these stamps draws student interest toward the activity sheet, and assists in motivating them towards collecting other more complex achievements throughout the remainder of the activity.

The initial exploration of the device typically takes the students about forty minutes to complete. This number is, however, highly variable on the device the students bring to class.

4.4 Obtaining Achievements – Decisions, Consequences, Requirements, and DfXs

This section of the activity focuses on asking the students demanding questions that force them to consider the engineering design process. The Socratic method can be useful for course instructors, as students are typically unfamiliar with the topics at hand. Directional questioning allows the instructors to introduce new ideas without lecturing the students. Instructors should design impromptu questions that deal with the aspect of the device the students have focused on. The questions should guide the students through the unfamiliar pathways of design decisions, the consequences of design decisions, probable requirements that led to the design decisions, and finally, a possible DfX that can summarize the whole process. Each iteration of this cycle, in which the students can identify the appropriate decisions and reasoning, earns the students one of the coveted DfX achievement stamps.

Once the students have completed this cycle once, the teaching team encourages them to focus on a new aspect of their device. Each time the cycle is completed, the students should require less time and prodding from the course instructors. In the ideal case, the final DfX is evaluated by the students independently of the course instructors, and when prepared, the investigation is summarized to the course instructors so as to earn an achievement stamp.

This part of the activity typically takes forty minutes, but again is dependent on the device the students bring to the classroom.

4.5 Team Reflection

The teams are asked to cease working on their devices and are provided with a small cue card. On this card, the students are asked to individually reflect on how they felt their team performed during the activity. Specifically, the students are asked to provide three things the team did well and three things the team did poorly. The students then rejoin their team and share their thoughts. This aspect of the activity is designed to get the students thinking about teamwork and the intangible implications their actions within a team can have. This part of the activity typically takes ten minutes.

4.6 Activity End

Finally, the students are provided with ten minutes to clean up their work spaces and to return the tool kits to the course instructors. The instructors also provided the locations of dumpsters on the university campus so that: (a) students could appropriately dispose of their devices, and (b) the university's cleaning staff would not have to contend with over-filled garbage cans that were not designed for the disposal of mechanical equipment.

5 Assessment of Student Learning

As mentioned previously, the primary goal of gamifying the activity was to enhance student focus and engagement. Anecdotal evidence from the classroom instructors suggests that this goal was largely met. However the activity also has associated learning objectives, and the investment of effort to gamify the activity needs to have a payoff in terms of those objectives.

In the absence of a formal, longitudinal, and experimental approach to assessing changes in student outcomes, we have attempted to quantify the value of the gamified activity for the students by comparing the output of two similar assignments. Specifically, we looked at assignments from the academic years of 2010 and 2011. In both years, the students were asked to evaluate a local bridge from the perspective of engineering designers. In 2010, the assignment was formative. In other words, the students were evaluated rigorously but the evaluation had no impact on their final grade. In 2011, the assignment was worth 10% of the student's final grade.

5.1 Method

Our analysis uses a simple scoring method to determine the efficacy of the gamified device teardown tutorial. We began the analysis of the student's performance by asking the question – did the students present an analysis of the design that began from the design engineer's perspective? For presentation that included analysis from the designer's perspective, the presentation was awarded a single point. Ten presentations were examined in each year. A year's score was determined by adding the individual scores for each year's presentations.

Presentations were selected for analysis based on two criteria. To begin with, we created two grading silos: (a) Average performing students, and (b) Low performing students. This was done to eliminate the bias that might result from comparing high performing teams from one year to low performing teams in another. We based our silos' grade range on the University of Toronto's Transcript Guide and the course's historical average. A presentation was deemed to belong to the average performing silo if it received a B (between 73% and 76%). Likewise, a low performing presentation scored a C (between 63% and 66%). From these grade silos, we then randomly selected presentations with distinct evaluators. The need for distinct evaluators was our second criteria for selecting presentations for analysis. This was done to eliminate the bias that may be present had we analyzed presentations from a single evaluator. In sum, our analysis groups included ten presentations per year, with 2010 and 2011 forming our analysis years. Within each year, we considered five presentations that scored a B during the term, and 5 presentations that scored a C during the term.

For the 2010 iteration of the activity, the students were not graded, as mentioned above. Therefore, to determine which grade silo a presentation belonged in, we used a grade the students received on a similar presentation as a proxy grade for the formative assignment.

5.2 Results

In the 2010 analysis group, a score of three was awarded to the students – indicating that three distinct presentations included analysis from the perspective of the design engineer. The 2011 analysis group presented eight discussions from the perspective of the design engineer. Within the limits of this approach to quantifying student outcomes, this suggests a significant increase in the use of design engineer thinking from one year to the other.

5.3 Discussion

Acknowledging the limitations of our analysis, the gamified device teardown tutorial can be linked to a significant increase by first year engineering students in the use of analysis based on a design engineer's perspective when examining an existing work of engineering design. Furthermore, when comparing solely the low performing teams, the activity has an even more pronounced affect. In 2010, no low performing team showed evidence of considering the design engineer's perspective. In 2011, four low performing teams were able to show evidence of the design engineer's perspective. This marked increase in the low performing teams is especially encouraging, as it indicates that gamifying tutorials may serve to catch low performing teams and introduce them to important learning objectives.

This analysis could be strengthened in a number of ways. Specifically, the use of a proxy grade for determining grading silos limits the value of the grade silo. Additionally, the analysis of the presentations was not blind, in that the analyst knew which presentations were given in 2011 and which were given in 2010. Additional and improved data collection, including (e.g.) student self-assessments of their design, reverse engineering, and gaming skills, could also lead to more reliable results.

6. Perception of Student Engagement and Learning

At the end of the term, teaching assistants and studio instructors were surveyed on their perception of student engagement and learning during the teardown activity, and of student's ability to identify and argue for specific design decisions after the activity. Those who had taught the course in previous years were additionally asked to comment on how the gamification of this year's activity changed the way in which the students engaged with the activity and with the material. Responses from over eighty percent of the teaching team have been compiled to develop this discussion.

The achievement of stamps on safety topics such as personal protective equipment, and clean work areas were easy to achieve and created a preliminary sense of accomplishment within the students that did not necessarily continue throughout the rest of the activity. The use of these achievements did; however, create a consciousness about safety through deliberately instructing based on it. While all other achievements had students either achieve or fail to achieve a positive stamp, the safety aspects were generally the only tasks where students would achieve a negative stamp instead of not achieving the positive stamp. Between the first and second iterations of the activity this year, there was a greater decrease in the number of students not paying attention to the safety needs of the activity than there were in previous years.

Overall, the use of the gamification sheet as a checklist of aspects of the design to look for during the teardown alerted students to the types of observations the teaching team were looking for, and hinted at the depth of the arguments that were required to achieve a stamp. The gaming system provided students a visual to see what they had successfully done and ways to aim for topics they had not yet covered; this prevented students from tearing apart their devices blindly. The gaming system was also perceived to motivate students to fill in gaps in their knowledge; students were eager to achieve stamps and this motivated them to develop an understanding of the aspects they had unstamped. The achievement descriptions provided on the gamification sheet set standards for the type and depth of understanding required, which was useful for those teams and individual students who could focus simultaneously on the device teardown and the sheet.

While there is debate amongst the teaching team as to whether the gaming increased the engagement or not, there is agreement that it helped students to articulate their identification of the design decisions. The gamification sheet provided a structured design language to the students with which to articulate their identified decisions, and additionally provide them with a reason to articulate and discuss these observations – the achievement of stamps. For teams that were struggling to identify the type and depth of decisions we wanted them to observe, the lack of requests for stamps flagged those students for us and allowed us to facilitate their engagement in that level of investigation. While the gaming may not have enhanced their direct ability to identify design decisions, it did enhance their ability to learn from the teaching team; the best understanding about design decisions was developed through conversations, prompts, and digging for reasoning on the part of the teaching team when students tried to achieve a stamp.

For this type of activity to work, the teaching team needs to facilitate the students to "play the game". The aspect of achieving stamps alone was not sufficient to motivate all the students to engage in the activity; instructors needed to challenge the students to achieve a more difficult stamp, or add-on time based challenges to force them to focus – "I'll be back in five minutes, and I expect you to be able to earn this stamp then." That being said, it takes a fair amount of time on the part of the members of the teaching team to determine the appropriate levels of challenge for each team to keep them motivated, while simultaneously not leaving other teams behind.

On our first iteration of the activity, there was a distinct lack of appreciation of how much time it takes to interrogate a group of students to evaluate if they have met the requirements of a specified achievement, especially given the need to question their arguments and reasoning to verify an understanding of the topic they are presenting. This made it clear that the effect of gamification or how much students can enjoy such an activity would depend on how skilled their instructors are at framing argumentative discussion with their students in a way that students are motivated to play the game (i.e., construct solid arguments) and win.

Overall the gamification increased student engagement in the activity; it kept students on task and interested in presenting their findings to the teaching team. Some student groups cared about collecting stamps so much that they approached members of the teaching team after the activity to argue more to collect stamps that they couldn't get because of the limited time during the activity. For some students, the gamification provided too many things for the students to focus on and as a result, focused too intently on one aspect or attempted to deal with both in an incomplete manner. By the second iteration of the activity, however, students appeared to be in more control of their teams, and were better able to use the gaming system as a way of structuring their work time, and verifying their observations.

On a more course-focused note, the location of this activity during the second and third weeks of class provided a very light-hearted but quality introduction to the way in which the course works. The gamification forced students to voice and discuss the observations they were making in a manner that was easily and comfortably facilitated by the instructors – because the students were competing for a stamp they appeared more open to direct confrontation on their arguments. Occurring early in the term, this exercise established the courses learning model, whereby students must justify and argue for their claims, often in response to the teaching team's interrogation.

7. Future Improvements

Thatcher observes the need to debrief the game – as that is the place where the "fundamental learning" [10] occurs. This activity did not have a formal discussion with the students that debriefed the game of this activity. While discussions to debrief the devices that were torn down and the types of decisions identified, no debrief explained how the game was meant to subconsciously facilitate a deeper learning experience.

In terms of the actual achievements to be acquired by the students, this first try at the gamification provided students too many things to achieve. This resulted in students attempting to surface-argue their way through achieving stamps. In future iterations, the number of achievements will be decreased, with a greater emphasis to be placed on the required quality to achieve the stamps.

Additionally, the negative achievements were not used in this activity as we had initially thought. While negative achievements were given for safety issues (which needed to be sternly commented on) they were not given for any other aspects. As a result, a distinction between the types of achievements to be attained needs to be noted, such as whether the student is attempting to achieve a behaviour, a type of preparation for the activity, or identifying a perspective on design/argumentation. In this iteration of the activity, all achievements had positive and negative stamps, which was not effective. Only the behaviour achievements ever received negative stamps. In the future, the activity should be reconstructed to only have behaviour and preparation achievements have negative and positive aspects, whereas design/argumentation achievements should only have positive stamps.

Finally, the number of pop-culture references needs to be reduced. These were included in the descriptions of the positive and negative achievements for the purpose of explicitly introducing levity to the activity and reiterating the gaming aspect. However, many students did not understand these references and as a result they provided a source of confusion and stress instead of levity. In future iterations, clearer and more explicit descriptions of what is desired to achieve the stamp will be stated in plain English.

With regards to the broader question of the value of gamification, this exploration strongly suggests the need for a more rigorous and structured experimental approach to assessing the impact on student learning and engagement. Elements such as pre- and post-testing, specifying the devices to the torn down, separating the achievements from the structured guidance they implicitly provide, and ensuring proper experimental and control groups, are all necessary to verify our initial assessment of the value of gamification in this context.

8. Conclusion

If the goal of the learning is to help students move from having discrete pieces of understanding – a knowledge of facts or points, what Vygotsky calls "everyday knowledge" – to generating a system of understanding – what Vygotsky calls "scientific knowledge" [11] – there is, effectively, no way to rush that process. It requires cognitive development that no game can overleap. However, what the game *can* do is to motivate that development. In a stimulating, playful and exploratory learning environment, the game can motivate a shift from piecemeal by creating the desire to see past where the learner can currently reach with his or her present understanding. Thus, the game provides an impetus to learners to encourage them to want to understand more deeply. The learners move from concrete knowledge to the more abstract knowledge when their understanding shifts from being an understanding of individual points to become an understanding at the level of strategies and approaches whereby the acquired knowledge is organized into a system that can be applied into a new context [7].

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Appendix – Device Design Record of Achievements

{Assessors, Designers} For X

Your team **identified** and **explained the consequences of** (at least) one decision made by the designer that impacted (positively or negatively) on the quality of your device from a particular perspective (designated 'X'). For each 'X' you also **proposed (at least) one change** (e.g. alternate decision) that you thought would improve the quality of the device from that perspective. Note that these "{A,D}Fx" achievements are "second-order" in that you can earn other achievements as a component of earning these.

Studio 02 Studio 03 | **X =** | Studio 02 Studio 03

Write in the 'X' that you will use for this achievement in **both** Device Design studios

Studio 02 Studio 03 | **X =** | Studio 02 Studio 03

Write in the 'X' that you will use for this achievement in **both** Device Design studios

Studio 02 Studio 03 | **X =** | Studio 02 Studio 03

Write in the 'X' that you will use for this achievement in **both** Device Design studios

③

Studio 02 Studio 03 | **X =** *Sustainability* | Studio 02 Studio 03

You will use "sustainability" for this achievement in **both** Device Design studios

Studio 02 Studio 03 | Studio 02 Studio 03

Multi-

(Uni-)

Your team approached the studio across multiple **dimensions**, **scales**, and from the perspectives of multiple **stakeholders**, such as:

- physical, informational, social, etc.
- parts, components, assemblies, device, etc.
- users, assemblers, manufacturers, regulators, etc.

Studio 02 Studio 03 | Studio 02 Studio 03

Shoulder Standers

(Wheel Re-inventors)

Your team engaged in independent research prior to and (possibly) during the studio. You may have consulted handbooks, guidelines, standards, books, articles, web sites, family members, engineers, or other resources that could bring additional insights to your activities.

④

Device Design Record of Achievements for team

During the two Device Design studios each team has the opportunity to earn achievements (both positive and negative). These achievements link to specific skills, thinking, and attitudes that an engineering design should be able to demonstrate. Completing certain achievements may "unlock" additional resources that your team can use in subsequent studios. An achievement template, with embedded instructions, appears below:

Studio 02 Studio 03 | Studio 02 Studio 03

Stamped by the Teaching Team either **after you call one of them over** or after they witness something **positive** that you've done

Catchy Positive Title

(Slightly Derisive Title Signifying the Opposite of the Positive Title)

Description of what you should do, be seen doing, have done, avoid doing, etc., possibly accompanied by some tips on how to ensure that you succeed or avoid failure. Sometimes multiple elements will be included, and you will have to exercise you judgment as to how many to complete before calling over a member of the Teaching Team. **When you call them over, be certain to have evidence of the achievement that you can present.**

Stamped by a member of the Teaching Team after they witness or experience something **negative**

Studio 02 Studio 03 | Studio 02 Studio 03

Prepared for Battle

(Lambs to the Slaughter)

Your entire team arrived promptly with at least one sacrificial device (that met the requirements given in class and in the lecture notes) and with a plan of attack to ensure efficiency and effectiveness. You had reflected on the previous studio and on the lectures, and had used those reflections to prepare for this studio.

①

Studio 02 | Studio 03 | **Heroes on the Half-Shell** | Studio 02 | Studio 03

Heroes on the Half-Shell
(Exposers of Soft Underbelly)

Every member of your team arrived wearing a long-sleeved shirt, long pants, and closed shoes. Necklaces, rings, watches, and other adornments were removed (although stud-type earrings are OK). Everyone's hair was arranged to keep it out of the work space. Bonus for telling someone outside your team (e.g. a member of the Teaching Team, a member of another team, or a visitor to the room) to remove their adornments or to affix their hair.

Studio 02 Studio 03 Studio 02 Studio 03

Bubbles
(Cyclopean Wannabes)

Every member of your team kept their eye protection on throughout the studio. Bonus for telling someone outside your team (e.g. a member of the Teaching Team, a member of another team, or a visitor to the room) to put their eye protection on.

Studio 02 Studio 03 Studio 02 Studio 03

Safe Workplace
(Occupational Hazard)

Your team's workplace was always organized. Disassembled components were kept contained, and food and drink were kept separate from the disassembly area. Disassemblies with the potential for catastrophic results were performed in a separate area away from potential victims.

②

Studio 02 Studio 03 Studio 02 Studio 03

One for All and All for One
("There's no 'we' in team")

Your team ensured that each member was able to experience every aspect of the studio, from disassembly through to capturing information, undertaking research, and reflecting on the studio while it was still in progress. No member felt constrained to a single role, and every member was able to both grow their skills and practice a skill that they already had.

Studio 02 Studio 03 Studio 02 Studio 03

To Thine Own (Evolving) Self be True
("You mean I'm supposed to practice what I preach?")

Your team tried (valiantly) to apply its theories (at a minimum in the forms of your definition of and criteria to assess "engineering design) to it's practice. In response to success, your team explored the limits of it's theories by considering other devices; in response to challenge (or failure) your team modified it's theories and gave the new ones a try.

Studio 02 Studio 03 Studio 02 Studio 03

Disciples of Kolb
(Dull Stare of the Dairy Cow)

Your team took an active role in the studios by actively working through multiple iterations of the Kolb cycle (perhaps with some assistance from the Teaching Team). At no point did your team all stare at each other with blank, lifeless eyes and ask "What should we do now?"

⑤

Studio 02 Studio 03 Studio 02 Studio 03

Discretion Over Valor
(Leeroy Jenkins)

Your team practiced discretion rather than charging ahead without considering the consequences. For example your team may have asked for assistance from a member of the Teaching Team when undertaking a particularly challenging disassembly, or have consciously chosen an approach to disassembly that was less likely to result in a negative outcome.

Studio 02 Studio 03 Studio 02 Studio 03

Clear, Concise, and Credible
(Wielders of the Compost Shovel)

In discussions with the Teaching Team, your team developed arguments that contained no (or very, very {little, few}) excess verbiage, suspect logic, bluffing, improbable assumptions, outright falsehoods,or other elements that would make your argument effectively baseless statements.

Studio 02 Studio 03 Studio 02 Studio 03

Reliable Witnesses
(We Saw Nothing)

Your team captured a rich variety of information throughout the studio. Examples include photos, sketches, written descriptions, web pages, library books, etc. Bonus if your records are so complete that someone else could follow them to reconstruct your device.

⑥