Play-in-learning: Studying the Impact of Emotion and Cognition in Undergraduate Engineering Learning

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For the past 25 years, Leon Liebenberg has been engaged in engineering teaching, research, and community engagement. He was a professor of mechanical engineering at two South African universities (University of Pretoria; North West University), before becoming a higher education consultant in Switzerland where he worked with colleges of engineering and technology management. He is currently a senior lecturer in mechanical engineering at the University of Illinois at Urbana-Champaign. Leon is passionate about multidisciplinary research, particularly in the fields of energy engineering, biomedical engineering, and engineering education. His university research has focused on development of industrial energy-efficient technologies and cancer therapies using energy restriction methods. His published research works enjoy an h-index of 25. Leon' first love is however for teaching. He co-developed and taught a unique freshman course on "Innovation", where students work in so-called "whole-brain" thinking teams when addressing technological problems. These helped show that innovation for a sustainable world can be maximised by the convergence of natural sciences, engineering sciences, and the arts. At the UIUC, Leon is currently investigating pedagogies of engagement for use in the engineering curriculum. He focuses on self-directed learning and play-in-learning. Leon is collaborating with colleagues from various disciplines in this venture. He also founded the TechnoLab technology awareness facility for junior engineering students and for school children, where the learners work in small teams to solve problems using Lego Dacta and other didactic equipment. The TechnoLab model has been adopted by several South African schools since its inception in 1997. Leon also founded the Space and Aviation Challenge for school learners in South Africa, which aimed at demystifying the aeronautical engineering profession. The Challenge was annually presented for several years in collaboration with Nasa's Dryden Lab who offered the first prize for a learner to attend Space Camp USA. Leon teaches a variety of subjects, including: Innovation; Statics; Dynamics; Thermodynamics; Fluid Dynamics; Design for Manufacturability; Machine Design; Senior Design; Heat Transfer; Aerodynamics; Aeronautics; and Advanced Heat and Mass Transfer. Leon holds doctoral and master's degrees from Imperial College London and from the University of Johannesburg. Leon and his wife enjoy meeting people, engaging with local communities, reading, photography, hiking, cycling, and spending time with their cat.

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Introduction and Motivation

Undergraduate engineering education requires that students gain a basis in foundational sciences before they can incorporate these skills into more advanced engineering practice [1]. Traditionally, these technical and analytical skills are taught mainly through lectures with little emphasis on self-guided study or application to realistic problems. Students gain experience in these disciplines through problem-sets in which specific, algorithmic methodologies are employed to reach a singular valid answer. This practice has proven historically successful in training engineering students to solve similar problems but does little to help these students connect with the real-world applications [2]. Without this connection, new engineering graduates may struggle to apply these foundational skills as they begin their professional careers [3]. By adopting learner-centric teaching strategies which promote motivation, curiosity and enjoyment of the foundational engineering sciences, we hope to improve student engagement and learning outcomes by fostering a meaningful connection with subject contents. Thus, preparing students to enter the workforce more prepared to apply their theoretical knowledge to solve societal problems.

In his 1975 book, Csikszentmihalyi describes the psychological components required to approach total involvement, and optimal focus, or as he calls it, a flow experience [4]. The activity should be intrinsically motivated, present constant challenge in balance with the skill required and provide clear feedback, Csikszentmihalyi states, “Games are obvious flow activities and play is the flow experience *par excellence*.” [4] In Experiential Learning Theory, play in the form of games and role-playing often emerge in the learning process [5]. The concept of ‘play’ presents itself to perfectly describe a free learning process which is intrinsically motivated, engaging and enjoyable. Perhaps there are qualities of play which can be leveraged to benefit the learning process. This line of inquiry brings us to the guiding research questions for this work. Are there aspects of play which can be used to inform pedagogies which improve learning outcomes and student experience? What aspects of play are important for learning? How can these be emulated in engineering design projects to create meaningful learning experiences?

Literature Context

One of the primary reasons to pursue play in education is that well-designed playful activities are commonly associated with enjoyment, engagement and immersion. In their seminal presentation of The Adult Playfulness scale, Glynn and Webster describe this by stating, “Involvement may be reflected in play so much that individuals relinquish basic needs for its sake; highly playful individuals tend to become so absorbed that their focus of awareness is narrowed and involvement is heighted” [6]. Narrowed focus and heightened involvement parallel a “flow state”. The variables effecting immersion, engagement and flow were investigated by Hamari *et al.* in the context of educational game design [7]. They found that games which are challenging compared to the skill level of the player led to increased engagement and immersion, in agreement with Flow theory.

In their systematic review of game-based learning, Bodnar et al. found that of 191 papers considered, 54 included a measurement of emotional valence or affect [8]. The commonality of affective assessments underscores the importance of emotion in the learning process, especially in the context of game-based learning where play is an element of motivation. They write that the body of research on game-based learning in engineering, “nearly unanimously agree[s] that students enjoy game-based learning” but there is a significant lack of studies demonstrating the impact on learning outcomes. This is either due to a lack of validated measures (e.g. student self-assessment on individually developed surveys or questionnaires) or small sample sizes and/or missing statistical analysis [8].

While games may inspire thoughts of play, the two are overlapping but distinct topics in the context of education. Game-based learning is often externally directed with a specific set of rules and awards which constitute the game, whereas play is regarded as a much more intrinsically driven, personal process. The concept of play is inherently subjective and difficult to define and therefore measure. Though there are related discussions in psychology, anthropology and education which share the concept that ‘the exact definition of what constitutes play belongs to the player’ [9]–[12]. Nonetheless, there are commonalities amongst the experience of play and playfulness which can be assessed to provide a measure of several factors common to play. Typically, play involves an intrinsic locus of control [9]. The player is free to choose when to engage with play and what the object of play is. Well-designed play is also typically intrinsically motivated, such that the player is engaged in play because the act itself brings about some benefit or enjoyment as opposed to engaging in play to receive some incentive [9]. Play also involves the freedom to suspend reality, although it being a subjective concept, describes the player’s willingness to imagine a new framework or perspective from which to exist and explore concepts. This may manifest as make-believe, or role-play, but could also take the form of asking questions from a new perspective or suspending judgment to explore an idea [9].

Methods

To assess the quality and impact of playful pedagogy on student learning, we adopted these factors and measured student perception along the dimensions shown in Table 1. In this table, the positive side (+) demonstrates the qualities of play and flow, and the negative side (-) demonstrates a lack of these qualities.

With these concepts in mind, a course on introductory thermodynamics was redesigned to promote playful learning. Research participants were consenting students from the course, and the results of this study will be used to refine the course for following semesters. The course redesign intended to increase students' control to promote intrinsic motivation. Students were given the option to participate in one of six team projects which are shown in Table 2. Each of these projects involved a detailed investigation of a well-defined thermodynamic cycle (e.g. Rankine, Otto, Stirling, vapor compression refrigeration).

Table 1: Dimensions which describe the measure of play

(-)	**Factor**	**(+)**
Extrinsic	Control	Intrinsic
Extrinsic	Motivation	Intrinsic
Too easy/Too hard	Challenge	Hard, not impossible
Too low	Skill	Developing
Low	Engagement	High
Low	Concentration	High
Low	Interest	High
Low	Immersion	High
Low	Enjoyment	High
Low	Self-Efficacy	High

As a final project deliverable, students were asked to submit documentation in the form of either a virtual reality (VR) or augmented reality (AR) or mixed reality (MR) app, an online graphic novel, an online portfolio, or a physical low-fidelity prototype. This structure allowed the team projects to be graded with a narrower set of metrics while aiming to give students more control over how they engage with course material. Table 2 also provides hyperlinks to sample student projects.

Recruitment and Research Activities

Participants were recruited from the population of students enrolled in the course. All students participated in the course activities, but only research participants provided feedback via an online survey. This survey was designed to measure the students' experience in the dimensions presented in Table 1. The connection between each factor and the survey question is outlined in Table 3. The survey serves to determine the impact and validity of playful pedagogies employed in the course.

Table 2: Project Descriptions

Project	Description (and Sample Projects)
1	Thermodynamic modelling of the […] steam power plant and production of a related VR or AR app, or a graphic novel. **Sample Project:** https://drive.google.com/file/d/15KR_vaPgVBEtLvsSRqCz_Qh_-bxjHmtq/view?fbclid=IwAR2NreYFcTKX5-FwOK4gaCCUP8yNEe-ecXPqoaFfZ3xwndJ64GK8PCZ3Wgc
2	Thermodynamic modelling of the […] steam power plant and production of a virtual guided tour for the power plant visitor's center. **Sample Project:** https://roundme.com/tour/373767/view/1278498/
3	Dynamometer-testing, engine teardown, and thermodynamic modelling of a Harley-Davidson motorbike engine, and production of a related VR or AR app, or a graphic novel. **Sample Project:** https://youtu.be/LM9ql0_a4FQ
4	Simulation and optimization of an air-conditioning system at […] and production of a related VR/AR/MR app, or a website. **Sample Project:** https://hannah199.wixsite.com/me200-buildequinox
5	Monitoring of the central chilled water system on campus and production of a related AR app or a graphic novel or an ePortfolio. **Sample Project:** https://me200cookiemonstercomic.blogspot.com/
6	Fabrication of a small Stirling engine using only one tea light candle to raise several quarters (25 cent pieces) to the highest possible height (typically, 2 meters). Report in ePortfolio or in a graphic novel. **Sample Project:** https://drive.google.com/file/d/1YnznQiSeCkzzynOduIRi5udqFASBMAd1/view

Since each student will experience play differently, we assume that play can be correlated to students who have a sense of control and are able to act toward their own intrinsic motivation. The challenge and skill required for the team project are used to assess the ability for the project to remain engaging and are derived from flow theory and based on similar questions from Hamari and colleagues [7]. Engagement is also asked directly and is additionally comprised of elements of concentration, interest, immersion and enjoyment. Together, questions from concentration, interest, immersion and enjoyment should proxy engagement in the learning process. Self-efficacy is used as a proxy for learning outcomes, though for participants who provide consent, course grades will also be used to measure learning outcomes. The learning assessment questions (see Table 3, "Learning", #1-4) target the learning objectives of the team projects and responses should reflect participation in and learning from the associated team project.

Table 3: Overview of survey questions and the factors which they intend to measure

Factor	**Contributing Questions**
Control	I feel in control of what I am doing for the team project
	I feel in control of the ideas I generate as part of this class
	The team project allowed me to decide what to do
Motivation	I am motivated by learning about thermodynamics
	I am motivated by knowing how to apply thermodynamics to real world problems
	I am motivated by getting my degree
	I am motivated by good grades
	The team project was motivating
Challenge	The team project was challenging
	The team project stretched my capabilities to the limit
Skill	The team project required me to use skills I already had to accomplish my goals
	The team project required me to gain new skills to accomplish my goals
Engagement	I found the team project engaging
	The team project required me to consider things in a new way
Concentration	While working on the team project, I am concentrated
	While working on the team project, I am easily distracted
	The team project focused my attention to a specific topic
Interest	I would rather work on the team project than do my other coursework
	This course is interesting
	Other courses are as interesting as this course
Immersion	Working on the team project made me lose track of time
Enjoyment	How much did you enjoy the team project
	The team project was entertaining
Self-Efficacy	I understand how to apply my knowledge of thermodynamics to unstructured engineering problems
	The team project helped me understand how to apply my knowledge of thermodynamics to unstructured engineering problems
	I am able to solve thermodynamics problems

Table 3 (continued): Overview of survey questions and the factors which they intend to measure

Factor	Contributing Questions
Learning	Content assessment questions: 1. All heat engines: a. can attain thermal efficiencies of 50% b. are reversible c. convert only a part of their heat intake into work and discard the remainder to the surroundings d. add heat very quickly so that the heat-addition process always happens at constant volume. 2. The Stirling engine can in principle reach the Carnot efficiency limit. In addition, Stirling engines are: a. quieter in operation as they operate on continuous combustion of fuel b. potentially cleaner and quieter than many other types of engines c. can operate on a wider range of fuels which are combusted externally of the cylinder. d. All the above. 3. In an ideal Rankine power cycle: a. the boiler and condenser accomplish fluid changes which are isentropic (and adiabatic) b. the processes in the turbine and feed water pump are adiabatic and nearly reversible c. the condenser pressure is usually way above atmospheric pressure d. the enthalpy of steam increases from turbine inlet to outlet. 4. In a vapor compression cycle of an effective refrigerator, the coefficient of performance: a. is typically much larger than 1 b. does not depend on the ambient (environmental) temperature. c. will show that electrical energy input to the compressor will be much more than the heat absorbed from the refrigerated space d. can be determined by the ratio of heat rejected from the condenser coils to electrical work input at the compressor.

Preliminary Findings

Of 56 students who consented to participate in the study, 46 responded to the survey. Note that no identifying information was included in the data set during analysis. Student responses were grouped according to the project that the student participated in. The size of each group is as follows – Project 1: 7 students, Project 2: 7 students, Project 3: 6 students, Project 4: 6 students, Project 5: 4 students, Project 6: 16 students. For questions outlined in Table 3, responses were collected using a 5-point Likert scale. This data was then ranked on a scale from -2 to +2, with positive numbers corresponding to the more positive or playful responses (see Table 1).

For each participant, the average factor scores were then determined by averaging the scores from all questions corresponding to each factor (see Table 3). The Kruskal-Wallis test was used to determine if the responses differed significantly between projects. This test is used to determine if the median value is the same between multiple non-parametric distributions [13]. To implement this test, the python function *scipy.stats.kruskal()* was used. When the groups differ to

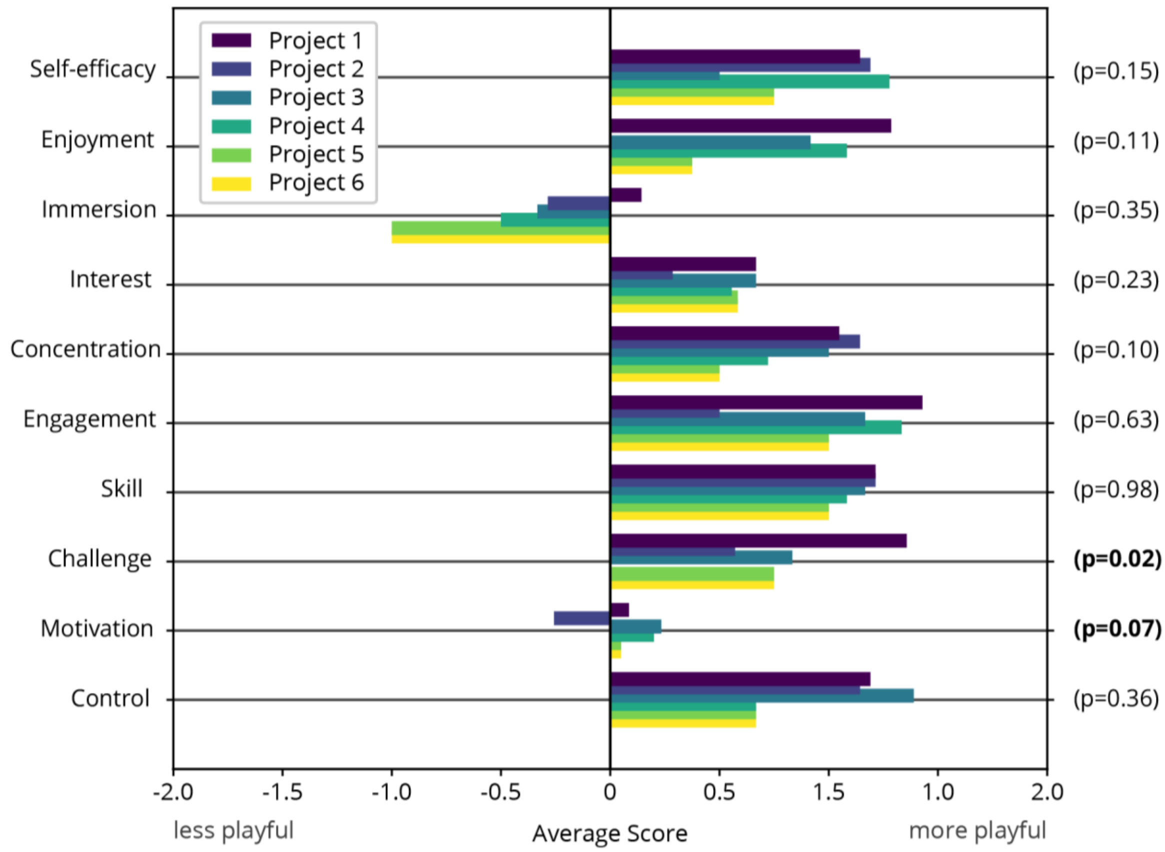

Figure 1: Average scores for each of the factors of play identified. Scores are averaged across all participants who completed the same project. Statistical significance is shown by bolded p-values on the right hand sign. These are the factors in which the projects had differing impacts.

a statistically significant extent, the test will return a p-value which is below a threshold value, which we choose to be a generous $p < 0.10$ for this preliminary investigation. The p-value for each factor is listed on the right side of *Figure 1*; those which meet the significance threshold are bolded.

While only the factors of challenge and motivation are statistically different between our project groups (note that concentration has a p-value of 0.10 but this is truncated, not rounded up and well-above the standard $\alpha < 0.05$), this does not mean the other results are not significant; it simply states that the different projects did not elicit differing responses.

That said, it is interesting to note that all the factors, except for immersion and motivation for Project 2, are positively correlated. Immersion likely received such a low average score due to a poorly phrased survey question. Only one survey question targeted immersion (see Table 3), and the phrasing may have negative connotations. As for motivation, a positive score corresponds to the more intrinsic motivators (knowledge of the content and the ability to apply it) while a negative score corresponds to more extrinsic motivators (grades and degree requirements), though these may be argued to not adequately represent the intrinsic and extrinsic spectrum, they are a convenient stand-in for this study.

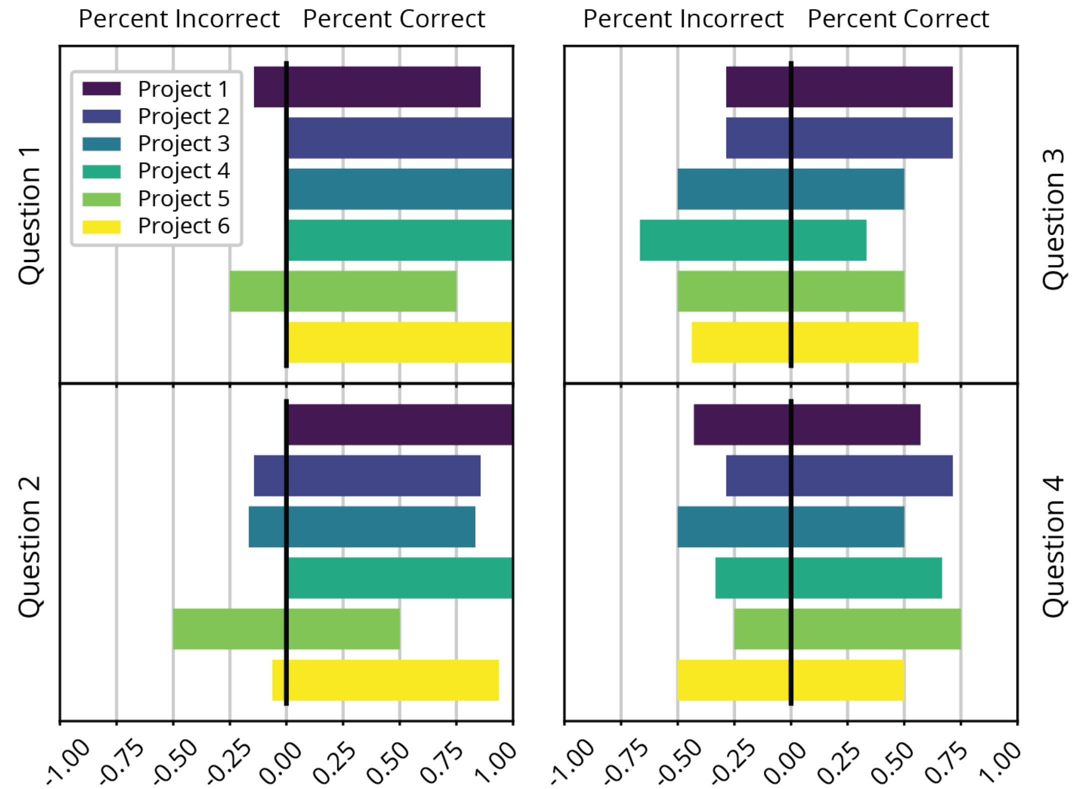

Figure 2: Content assessment questions intended to demonstrate learning outcome from projects. The right hand side of each plot shows the percentage of students who correctly answered that question. No correlation is observed, though high success rates suggest that students learned these concepts regardless of which project they completed.

It appears that students who participated in Project 3 were the most intrinsically motivated, and those who participated in Project 2 were more extrinsically motivated. Project 3 involved teardown and testing of a Harley-Davidson motorcycle engine, which could explain this result, but is not a realistically sustainable feature to suggest that it should be adopted by others to attain the same result. These early findings show promise, especially with respect to the high self-efficacy and enjoyment scores for all projects, in agreement with the findings related to game-based learning [8]. These early findings show promise, especially with respect to the high self-efficacy and enjoyment scores for all projects, in agreement with the findings related to game-based learning [8].

We also considered learning outcomes by asking students four questions which related to the thermodynamics content learned through the projects (see Table 3, "Learning"). The percentage of students who correctly answered each of these questions is shown in *Figure 2*. We predicted that students who participated in a project which focused on a particular thermodynamic cycle would be better able to answer questions related to that cycle. However, each of the targeted cycles were also covered in the class lectures, and there does not appear to be a strong correlation of content mastery with a particular project. Ultimately, this is a sign that students learned the course material regardless of their project team, but it does not show a significant impact from the playful nature of the projects themselves. We also considered the course grades of students who provided consent, but these did not differ significantly from the average.

Conclusion

We considered the relationship between self-directed team-based problem-solving activities and students' perception of their ability to solve real-world thermodynamic problems and apply concepts in challenging contexts. Students could choose from six projects topics which all involved real-world thermodynamic systems. Despite performing detailed thermodynamics analyses and simulations, students expressed their understanding of thermodynamics concepts using "playful" concrete representations like graphic novels, virtual- or augmented reality apps, websites, and ePortfolios. In these, students literally played with their ideas.

These play-based activities apparently changed the timbre of relationships between students (and between students and faculty) by moving away from a didactic teaching and learning model to one that fosters collaboration with peers and the benefit of faculty as learned guides. Playful pedagogies ostensibly offer multiple benefits to teaching and learning, including the promotion of reflective and independent thought, the improvement of mental flexibility and ideation, and the development of intrinsic motivation. Further, if students perceive that they have intrinsic control over the content, context, and pace of their learning, they begin to believe that they can be successful, and they will invest more effort toward the academic task. We therefore believe that play-based activities offer opportunities for students to engage in skillsets which are both cognitive (dealing with thinking) and affective (dealing with emotion) and that it contributes to the development of self-efficacy.

Introducing playful pedagogies in our engineering courses will hopefully help promote a wider repertoire of knowledge-based information and ideas—theoretical, technical, intuitive, practical, organizational, and emotional—while encouraging our students to develop a more playful attitude toward learning as part of their curricular experience.

If play-in-learning activities can be said to foster progressive changes in the ways that students express themselves, might this behavior signal higher levels of confidence and expertise? We think so, and we therefore believe that this work merits further investigation.

Future Work

This work-in-progress study is part of a larger exploration of teaching strategies to promote motivation, curiosity and enjoyment in undergraduate education. In this effort, diverse courses will be used as research beds to employ a variety of pedagogies of engagement, and these will be collectively assessed to determine the utility of play, among others, as a tool for learning in various settings.

This work will be expanded in the current semester of the thermodynamics course. Students will participate in similar projects. In addition, all students will be required to complete individual ePortfolios on their team projects. This will allow students to not only showcase their knowledge and skills, but also to reflect on their learning. In this current iteration, participants will further complete the "Positive and Negative Affect Scale" (PANAS) [14] to provide data describing emotional or affective state to see if this is impacted by or influences the efficacy of play as a learning tool. We also aim to measure the individual's willingness to engage in playful activities using The Adult Playfulness Scale [15].

We will also investigate diversity issues related to this kind of project-based learning. For instance, it will be interesting to assess the correlation between students from low-income families (and first-generation college students) and others regarding their perception of more authentic, real-world, problem-solving. Does playful pedagogy appeal to one group more than the other and does it help to 'level the playing field', literally?

Limitations

Limitations of the current work will be mitigated by refining the survey questions, in particular the questions testing immersion. Additionally, the assessment metrics for challenge and skill will be revised to give a more relevant view of the influence of these factors on a flow experience. Acknowledging the practical limitations associated with overhauling class projects, the projects will be refined to provide more insight into which factors of play influence learning most. Also, number of participants will be increased due to larger class size in the present semester; this will facilitate more powerful statistical factors.

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