# Using Gamification to Promote Student Engagement in STEM Project-Based Learning

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***Abstract*— This exploratory quantitative research examines how meaningful gamification could be used for student motivation and engagement in the context of STEM project-based learning (PBL) courses. A survey was developed using self-determination theory, including themes of relatedness (sense of belonging), competence and autonomy to understand student attitudes toward gamification elements being embedded in the PBL course design. We received 43 responses to the survey, which were analysed using descriptive statistics to measure agreement levels across diverse student groups. We also explored the attitudes of students identifying as strongly self-directed and not self-directed learners. Our results showed that students tend to favour practical implementations such as online forums and bonus marks over intangible gamification elements, such as personal connections and imaginary rewards. The findings are presented in the form of design recommendations that can serve as a guideline for course designers and developers of the ICT platforms on how to use gamification to promote student engagement in STEM PBL courses.**

***Index Terms*— Higher education, STEM, Student engagement, student motivation, gamification, meaningful gamification, self-determination theory**

## I. INTRODUCTION

Student engagement in post-secondary classrooms is a topic of interest for universities and colleges, yet faculties and administrators still struggle to implement it effectively at a course level (Mandernach, 2015). Research by Jabbar and Felicia (2015) and Handelsman et al. (2005) suggests that effective student engagement is linked positively to desirable learning outcomes such as critical thinking, student motivation and student learning, but if neglected, can lead to disengagement, cheating and learned helplessness (O'Donovan et al., 2013). Project-based learning (PBL) courses are widely used in STEM disciplines to improve students' self-directed learning and prepare them for professional life (Mills & Treagast, 2014; Sabhaba et al., 2016). In PBL courses especially, there is a need to improve self-motivation and proactiveness in students. Compared to problem-based learning, students in PBL courses must manage their time, and resources and understand their role and task differentiation based on strong self-direction (Mills & Treagust, 2003).

To succeed in PBL, one critical skill students must develop is information literacy. In a study of an undergraduate course, Bankermans and Plotke (2018) found that it is necessary to incorporate activities in the course curriculum to actively support the development of skills that promote assessment and evaluation but curriculum designers for PBL courses face the challenge of embedding features that engage both the intrinsic and extrinsic motivations of students. An emerging trend in this regard is the application of gamification to promote student engagement (O'Donovan et al., 2013; Tan & Hew, 2016). Deterding et al. (2011) define gamification as the use of game-design elements in a non-game context such as embedding of intrinsic motivation in meaningful activities and self-learning checkpoints. In a review of Performance-based assessment for Machine Learning at the K-12 level, Rauber and Gresse von Wangenheim (2022) found that gamification activties were used in several contexts to increase student learning. However, only a few empirical studies have examined the effects of gamification in universities and higher education (e.g., Dicheva et al., 2015; Hanus & Fox, 2015; Souza et al., 2019).

Antonaci et al. (2018) reflect that while gamification models have been applied in schools and online classes, the problem of implementing gamification techniques into less game-oriented project units is still under-discussed in the literature (Laskowski, 2015; Tan & Hew, 2016). There have been efforts to incorporate gamification at the undergraduate level with a particular focus on skills-specific areas such as data science and machine learning (Durán-Rosal et al., 2023), which are areas where structured activities and competition can clearly link to knowledge gains and assessment performance. Thus, there remains a clear need to explore gamification in courses with a broader skillset or multidisciplinary focus, particularly where there are not only diverse students but diverse learning needs. Researchers such as Smiderle et al. (2019) and Hanus and Fox (2015) also highlighted the need to map the success of gamification models with different student diversities and student cohorts.

This research used a quantitative survey design to understand the possibility of applying gamification to a post-graduate STEM course in an Australian institution. The aim was to gather insights into how curriculum designers can embed meaningful gamification into a project-based learning course to support intrinsic and extrinsic motivation. We use the theory of self-determination to analyze the survey data as there is strong evidence that this theory can understand motivation through its

concepts of autonomy, competence and relatedness (Martin et al., 2018). To this end, our survey also aims to differentiate between self-directed and not self-directed learners, a necessary insight in a course that is highly dependent on self-motivation and self-directedness. The outcomes of our study are used to suggest the inclusion of certain gamification elements in STEM PBL courses. Our study is guided by the following two research questions:

*Q1: What role does meaningful gamification play with respect to self-determination theory in the context of project-based learning courses?*

*Q2: How can gamification be used to foster relatedness, competence and autonomy in students from different demographics and diversified educational backgrounds enrolled in project units?*

The next section provides a Literature Review of relevant studies to define our concepts and position our research contributions. Following this we present our Methodology, detailing the study setting and the data collection phase. Our Results analyze and interpret the data, with our findings the basis for a set of design recommendations for using gamification in a STEM PBL courses. The Conclusion summarizes the paper and indicates limitations and future research.

## II. Literature Review

Student engagement is a broad concept, with faculties and administrators still struggling to effectively implement student engagement at both, the institutional and course levels (Mandernach, 2015). O'Donovan et al. (2013) found that student engagement is frequently neglected, which can lead to disengagement, cheating and learned helplessness. The literature reveals that there has also been a steady decline in the number of students who finish their studies on time, which highlights the importance of student engagement (Iosup, & Epema, 2014). Student engagement is often considered a product of student motivation and is presented by the self-determination theory of motivation, which has a strong foundation as a basis for fostering the intrinsic motivation of students (Martin et al., 2018).

### *A. Self-Determination and Student Engagement*

Self-determination theory assumes that all individuals, regardless of gender, age, or culture, possess three fundamental psychological needs that move them to act or not to act: autonomy, relatedness, and competence (Tan & Hew, 2016; Gagné & Deci, 2005). Skinner (2008) suggests that autonomy, or having a sense of freedom to pursue choices based on interest, is expected to have an effect on higher levels of emotional engagement. Tan and Hew (2016) explain that competence or mastery of a topic being studied encourages the learner to further participate in project activities, and Furrer and Skinner (2003) find that relatedness or sense of belonging is linked to increased levels of behavioural and emotional engagement which is also identified as an effective component of student engagement by Mandernach (2015). In a study of MOOC students, Martin, Kelly and Terry (2018) found that self-determination is critical for designing frameworks for online courses as it engages learners more successfully than previous approaches, and when done effectively, contributes positive functional outcomes in terms of quality of motivation, self-regulation, learning, organization and integration, vitality, and well-being.

Project-based learning pedagogies are gaining attention, with more research exploring how classroom conditions and learning environments influence student choices, which in turn can inform practices and foster outcomes such as self-efficacy, metacognition, effort regulation and collaboration (Stefanou et al., 2013). Stewart (2007) explored the relationship between self-directed learning among students and project-based learning in post-graduate courses, with a key finding being that students with high self-management achieved higher learning outcomes in project-based learning courses.

In general, the self-determination theory has been applied to a wide range of educational contexts in previous studies and results indicate that the satisfaction of these basic psychological needs had a mediating effect on learning outcomes, by supporting intrinsic or other autonomous forms of motivation.

### *B. Meaningful Gamification in Education*

Antonaci et al. (2018) define gamification as the application of game elements to a non-game scenario to create an effect on or change in user behavior. Laskowski (2015) describes the main goal of gamification as applying a specific structure of tasks based on game objectives and rules that are to be completed by users. Gamification can take a variety of forms, including the creation of social competition and the incentivizing of behavior through game-based mechanisms such as badge and reward systems, and the creation of challenges and leaderboards (Hanus & Fox, 2015; Souza et al., 2019).

At its core, gamification corresponds to extrinsic motivation and a variety of human desires, such as the need for reward, status, achievement, self-expression, competition, and belonging (Tan & Hew, 2016). Meaningful gamification not only uses game mechanics to provide extrinsic incentives but also applies student-centred activities to make a course meaningful to participants and provide intrinsic motivation. These activities are related to the self-determination theory of motivation and can be used along with game mechanics to boost student motivation. Fig. 1 shows a high-level gamification model summarizing common elements found across the literature.

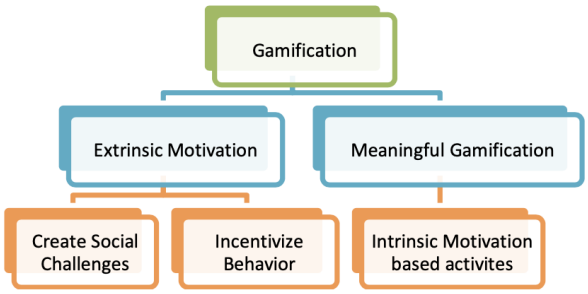

Fig. 1: Core elements of a gamification model.

O'Donovan et al. (2013) suggest that the gamification model has been successful in medical, social, lifestyle, business and educational contexts, and further applying gamification techniques in a university setting can improve students' understanding. From their study, Tan and Hew (2016) found that there was a difference in the uptake of gamification between high-performing students and students considered non-achievers. Laskowski (2015) used an experiment in a higher education setting where the author employed gamification techniques in two different courses during two academic years to demonstrate that the gamified group of students resulted in higher involvement, attendance levels and increased homework completion. Further, Iosup and Epema (2014) also applied gamification to undergraduate and graduate courses and found that gamification not only correlated with an increase in the percentage of passing students but also in participation in voluntary activities and challenging assignments. In the context of project work and development in high schools, Souza et al. (2019) developed a gamification-based assessment methodology called GAMED which is an assessment methodology that introduces systematic steps to improve student engagement through gamification by improving aspects such as motivation and teamwork. In a K-12 context where gamification was used to build teamwork among students learning machine learning and AI approaches, Sakulkueakulsuk et al. (2018) found that it was particularly useful for helping students adopt the futuristic and interdisciplinary thinking that is required in STEM courses.

### C. *Self-determination Theory and Gamification*

According to Zichermann and Cunningham (2011), gamification includes a challenge-achievement-reward loop that promotes the production of dopamine which in turn, creates satisfaction and positively impacts student engagement. Iosup and Epema (2014) suggest that gamification gives the educator several powerful and predictable tools for influencing human motivation and behaviour. As student engagement is identified with self-determination theory that includes autonomy, relatedness and competence (Tan & Hew, 2016; Gagné & Deci, 2005), game mechanics can be used to cater to these needs. For example, using an 'early bird' badge for motivating students to download and read lecture material before class can fulfil the student's needs for autonomy while awarding a 'reply warrior' badge to motivate students to respond to each other queries' can be a way to boost relatedness. This is consistent with the research findings by O'Donovan et al. (2013) in two undergraduate courses that were gamified and encouraged students to remain more engaged in the coursework.

Various researchers such as Dicheva et al. (2015), Hanus and Fox (2015) and Souza et al. (2019) found that very few empirical studies have examined the effects of gamification, particularly in the context of universities and higher education. Hanus and Fox (2015) highlight that while gamification leads to engagement, future gamification research should investigate specific elements of gamification rather than as an overarching concept so that the effectiveness of different mechanics can be parsed out. Additionally, there has not been significant research in the past that maps any gamification model with different student diversities and cohorts based on demographics and previous education backgrounds (Marques et al., 2019; Hanus & Fox, 2015). The concept of meaningful gamification presented by Tan and Hew (2016) suggests that it has a positive impact on student engagement but there is a need to explore its effect in the context of project units with a mixed student cohort which is presented in this paper.

## III. METHODOLOGY

We investigated student attitudes towards the possible inclusion of meaningful gamification elements in a PBL course through an exploratory survey administered to students enrolled in the course. The analysis is completed using descriptive statistics to identify different student cohorts and their preferences. Triangulation is used to compare these findings with the results presented by Tan and Hew (2016) in their research and validate if meaningful gamification can be used to promote student engagement in project-based learning.

### A. *Study Setting*

The survey was administered in a post-graduate STEM course at a major Australian university in Semester 2, 2020. The course was 24 credit points and involved interdisciplinary ICT research projects that ran for the 13-week semester. The course was being delivered online due to the COVID-19 pandemic, which was a new experience for many of the students and may have influenced how they interpreted and responded to questions. The curriculum for the course is similar to the research context of Bankermans and Plotke (2018), in that students need to deliver key assignments based on their discipline and information literacy skills.

To complete all assessment items, students must apply for a research topic that is supervised by an academic staff member. Topics are diverse and can be interdisciplinary and span a range of different fields, such as data science, networking, security, machine learning and AI, information systems, engineering and social issues. The assessment items were iterative research-based written pieces, including a proposal, a journal article and a research seminar. While students were part of project groups,

each assessment was individual, with each student required to develop their research question and research design. Students attended lectures and tutorials throughout the semester, were expected to access libraries for help with information retrieval and engage with their project group in a way that doesn't compromise academic integrity. These students were selected through convenience sampling since the researchers were involved in the course. However, all surveys were anonymous and there was no coercion involved in their recruitment. Because students are expected to be self-directed, proactive and develop a broad array of skills, the study setting serves as an appropriate forum to gain new insights into possible gamification designs for a STEM PBL curriculum.

### *B. Data Collection*

An online survey was approved by the university's Human Research Ethics committee. Out of 267 students enrolled in the course, 43 completed the survey. The instrument was structured into three themes (T1, T2, T3) mapped against self-determination theory to align the results with the research questions: T1: Relatedness (Sense of Belonging), T2: Competence and T3: Autonomy. There were six Likert scale questions developed by the researchers on a scale of strongly disagree to strongly agree (1-5) and three multiple choice questions (MCQ) that were gamification options for assessment that students either needed to select one or the other. The survey questions and responses from six Likert scale questions are presented in Table 1, where M=mean and SD=standard deviation to show students' levels of agreement.

TABLE I: Likert scale questions structured by themes.

| **T1: Relatedness** | **M** | **SD** |
|---|---|---|
| *Q1: I feel engaged if my peers and supervisor in my project group know me on a personal level* | 3.63 | 0.14 |
| *Q2: I will feel more engaged in group work if there's an online forum where all the students of my project group can ask questions and interact with each other* | 4.14 | 0.15 |
| **T2: Competence questions** | **M** | **SD** |
| *Q3: I would find the course motivating if I earned imaginary points and badges for any accomplishment or task completion* | 3.46 | 0.17 |
| *Q4: I will be more competitive and perform better in my assignments if grades are released in the form of 'leader board' rankings* | 3.00 | 0.19 |
| **T3: Autonomy Questions** | **M** | **SD** |
| *Q5: I would be happy if I could earn some extra marks through bonus readings and mini-tasks for the course apart from assignments* | 3.95 | 0.13 |
| *Q6: I would feel more engaged in my studies if I could participate in the design and development of a project unit* | 3.74 | 0.12 |

The three MCQ questions are also segregated based on the above themes and were used to understand student perceptions using post hoc analysis. The questions and options associated with them are shown in Table 2.

TABLE II: MCQ questions structured by themes.

| **T1: Relatedness** |
|---|
| *Q7: Which of the following would make you feel more engaged with a project?*<br><br>*A dedicated platform to interact with team members and supervisor OR a general communication tool for interaction* |
| **T2: Competence** |
| *Q8: Which of the following would make you participate in tutorials more?*<br><br>*An option to earn recognition in the form of points/badges for small tasks and activities I complete during the tutorials OR A standard guideline sheet issued by my tutor for the tutorial tasks* |
| **T3: Autonomy** |
| *Q9: What do you think would increase your motivation to be engaged in a project unit?*<br><br>*The flexibility to choose and complete from multiple assignments and earn marks based on difficulty OR A single assessment option with standard marking for all the students.* |

These questions came from conversations between the researchers about possible gamification applications that would work in the study setting. For example, for Q7 in Table 2, the dedicated platform referred to communication systems such as Slack. This question was asked due to some project groups using this platform, while other groups relied on general communication tools such as email.

Demographic data and background information was also gathered through the survey. This included prior education and industry experience. This information enabled us to explore diversity among respondents and how students from different backgrounds feel towards certain gamification themes. We also asked the students to consider to what extent they identified as self-directed learners on a scale of 1-5 (Strongly Disagree to Strongly Agree). For analysis, we classified students who selected agreed or strongly agreed as self-directed (SD) learner, and students who chose neutral, disagreed or strongly disagreed as not self-directed learners (NSD). The diversifications of our respondents with numeric results are shown in Table 3.

TABLE III: Diversifications of the survey respondents.

| **Diversification** | **Type** | **%** | **N = 43** |
|---|---|---|---|
| *Enrolment* | International | 65% | 28 |
| | Domestic | 35% | 15 |
| *Gender* | Male | 70% | 30 |
| | Female | 30% | 13 |

| | | | |
|---|---|---|---|
| *Background* | No Experience | 25% | 11 |
| | With Experience | 75% | 32 |
| | • IT Background | 28% | 9 |
| | • Non-IT | 72% | 23 |
| *Learner style* | Self-directed | 69.7% | 30 |
| | Not-self-directed | 30.3% | 13 |

For our analysis, the main diversifications we considered are international, domestic, SD and NSD learners since these are common student types in a PBL course in Australia.

## IV. Results

The survey responses were analyzed using post hoc analysis. Student responses to the questions were filtered and students were clustered into different diversifications as defined in Table 3. Due to the small sample size, we used simple descriptive statistics to gain insight into the attitudes of each diversification. Because diversifications stem from the same dataset, there is overlap between students – for example, a domestic student could also fall into SD or NSD learner. The relationship of student choices with different parameters was observed and profiling was done to enhance the interpretation of results. This approach was chosen because a similar study in gamification by Tsay et al. (2018) used this form of triangulation to measure the effectiveness of a gamified curriculum, which led to increased engagement in online learning in an undergraduate course.

We use stacked aggregated bar charts to show the results for survey questions across the four groups. For this analysis, we reduce the 5-point survey scale to three categories – Disagree/Strongly disagree, Neutral and Agree/Strongly agree to cluster responses.

### A. *Relatedness (Sense of belonging)*

The theme of Relatedness describes the students' sense of belonging to a project within the course in particular. In Figures 2, 3 and 4, we present the results of the students' responses to the questions in this theme.

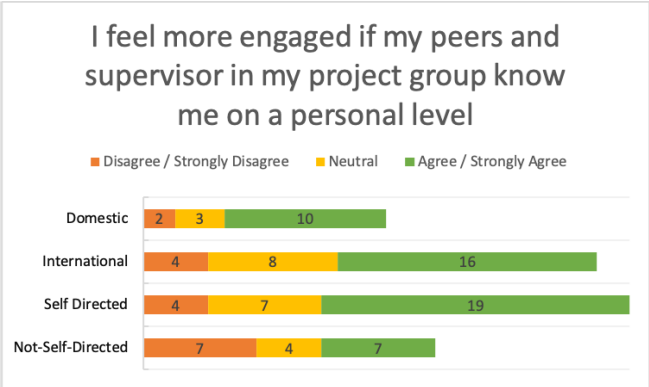


Fig. 2: Being known on a personal level.

Fig. 2 shows that students had reasonable agreement that being known on a personal level would increase engagement.

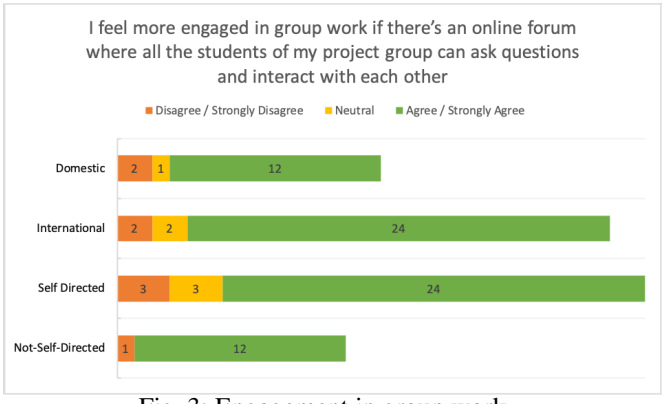


Fig. 3: Engagement in group work.

In Fig. 3, it is observed that an online forum was very important to all types of students.

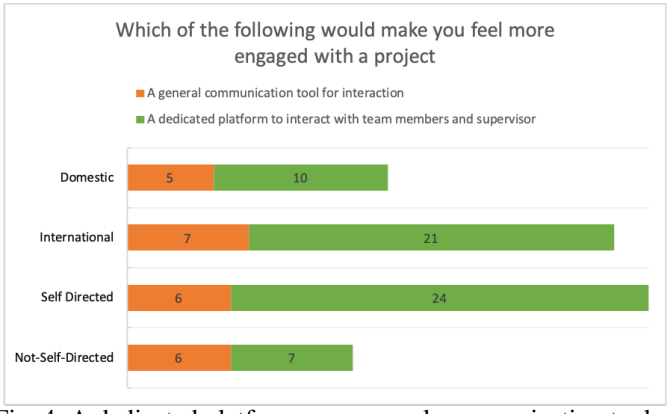


Fig. 4: A dedicated platform vs a general communication tool.

In Fig. 4, apart from mixed responses from NSD learners, all other groups preferred a dedicated communication channel to interact with peers and supervisors instead of legacy options like email.

### B. *Competence*

Competence relates to intangible gamification rewards, with responses shown in Figures 5, 6 and 7.

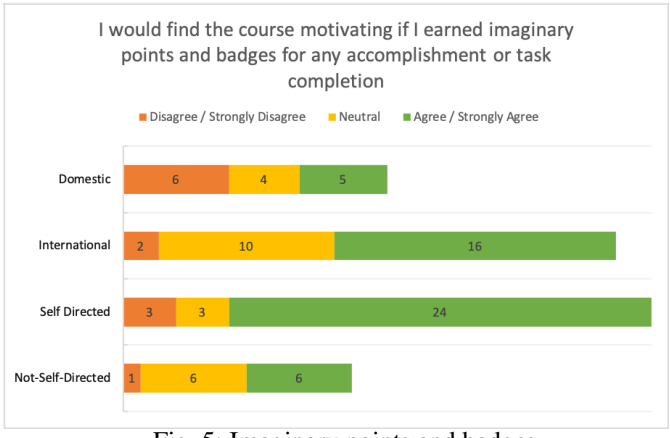


Fig. 5: Imaginary points and badges.

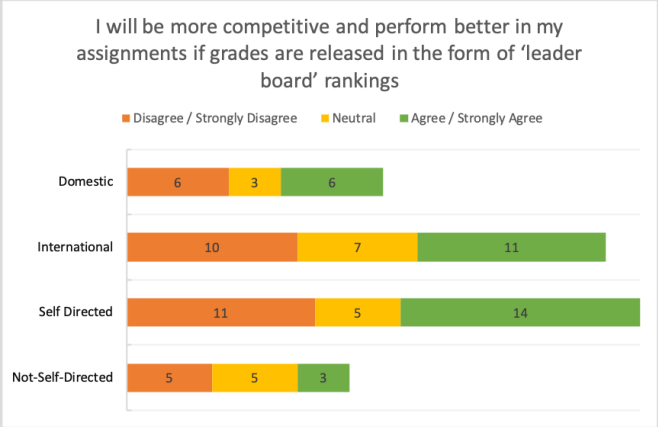


Fig. 6: 'Leader board' rankings.

In Figures 5 and 6, we can observe that there is a split between students in terms of intangible gamification rewards. Imaginary points and badges seemed to be preferred by SD learners as expected. However, for all other student groups, there was less enthusiasm, with domestic students and NSD learners far less interested in this element. Fig. 6 shows a clear disinterest in a 'leader board' ranking system, indicating that most students in the PBL were not motivated by this particular intangible reward.

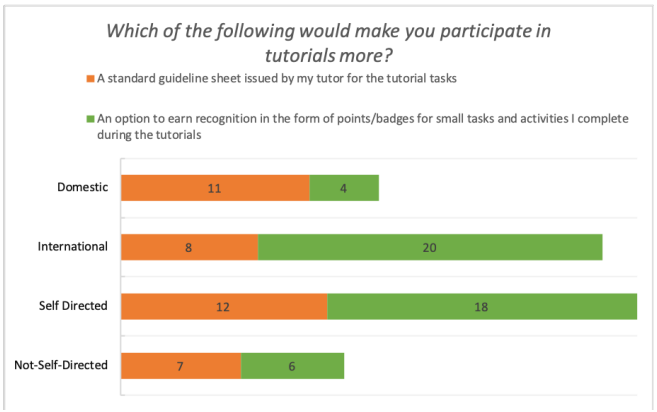


Fig. 7: Standard guidelines vs earning recognition in tutorials.

In Fig. 7, while international students prefer extrinsic forms of gamification elements and prefer to earn points and get recognised for the activities they complete, domestic students showed no such interest. This is also the case with NSD learners who do not like the idea of earning recognition through points and badges as shown in Fig 7.

### C. *Autonomy*

In Figures 8, 9 and 10, we compare the responses relating to autonomy, which are the tangible and physical investments students can make into a PBL course. Students in Fig. 8 showed strong support for receiving extra marks based on performing additional functions to their standard assignments. However, in Fig. 9, we observe split between groups towards participating in developing and designing PBL assignments.

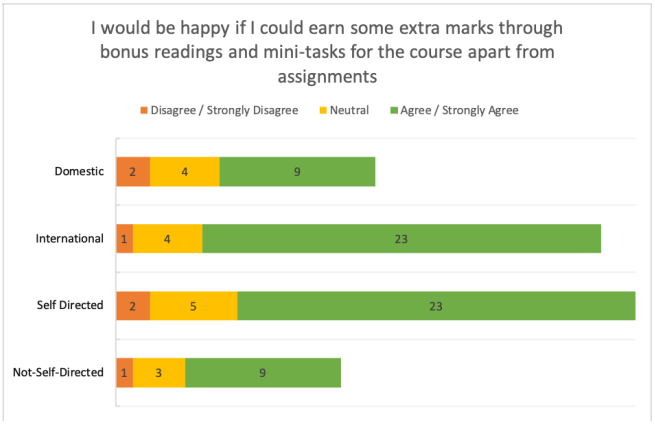


Fig. 8: Bonus readings and mini-tasks for extra marks.

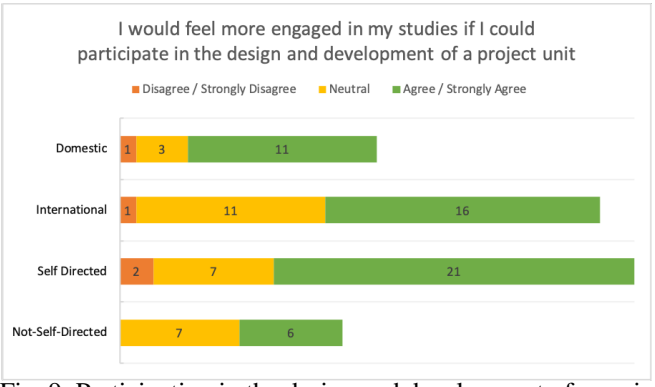


Fig. 9: Participating in the design and development of a project unit.

Domestic and SD learners showed generally strong enthusiasm, but international and NSD learners were less interested in participating in the development of research topics. Fig. 10 shows the results of the MCQ for this theme.

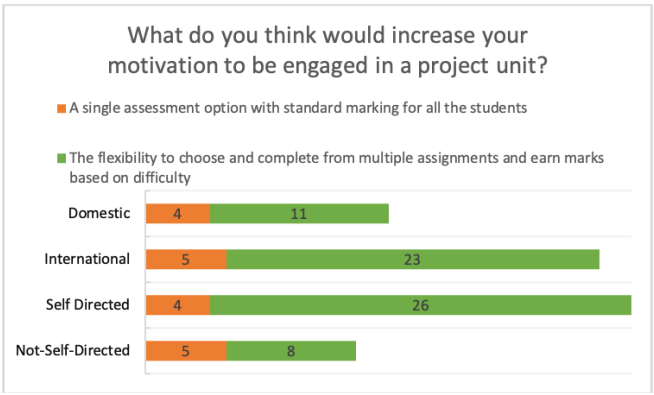


Fig. 10: Flexibility of choice vs a single assessment option.

Fig. 10 depicts that all students prefer having the flexibility to choose assignment levels and earn marks based on difficulty. This is also particularly favoured by SD learners who generally remain proactive and like the idea of earning marks based on the difficulty of the problem. Similarly, international students prefer having the option to choose the difficulty level of the assignments because of their diversity and technical

experiences.

Following the descriptive statistics comparisons, we utilize a Mann-Whitney test to compare the groups of students who consider themselves self-directed (SD) and not self-directed (NSD). The Likert scale questions were tested across the themes of Relatedness (T1), Competence (T2) and Autonomy (T3), as seen in Table 4.

TABLE IV: Mann-Whitney test results comparing self-directed and not self-directed learners.

| Item | Type | Mean Rank | Sum of Ranks | U | P |
|---|---|---|---|---|---|
| *Q1. I feel engaged if my peers and supervisor in my project group know me on a personal level* | SD | 22.53 | 676 | 179 | 0.68 |
| | NSD | 20.77 | 270 | | |
| *Q2. I will feel more engaged in group work if there's an online forum where all the students of my project group can ask questions and interact with each other* | SD | 21.9 | 657 | 192 | 0.94 |
| | NSD | 22.23 | 289 | | |
| *Q3. I would find the course motivating if I earned imaginary points and badges for any accomplishment or task completion* | SD | 21.5 | 645 | 180 | 0.7 |
| | NSD | 23.15 | 301 | | |
| *Q4. I will be more competitive and perform better in my assignments if grades are released in the form of 'leader board' rankings* | SD | 23.3 | 699 | 156 | 0.3 |
| | NSD | 19 | 247 | | |
| *Q5. I would be happy if I could earn some extra marks through bonus readings and mini-tasks for the course apart from assignments* | SD | 21.6 | 648 | 183 | 0.76 |
| | NSD | 22.92 | 298 | | |
| *Q6. I would feel more engaged in my studies if I could participate in the design and development of a project course* | SD | 23.12 | 693 | 161 | 0.38 |
| | NSD | 19.42 | 252 | | |

The results of the Mann-Whitney test showed no meaningful comparisons across the diversifications. The most noticeable differences were in questions 4 and 6. SD learners favoured leader board rankings (23.3) as compared to NSD learners (19), while SD learners indicated they would feel more engaged if they could participate in the design of a course (23.12) compared to NSD learners (19.42). There was no significance across any of the items however, with $p>0.05$ for each item.

## V. Meaningful Gamification in STEM PBL

Our results reiterate that individuals have distinctive needs, which is a common theme in student engagement research. For gamification to work in a PBL course, supervisors must understand the characteristics of their cohort, and students need to feel connected to the topic and their group. While the assessments in this course were individual, socialization was extremely important for students to succeed, as peers and extracurricular services such as library liaisons are critical to students building relevant skills.

For this study, the first research question was "*What role does meaningful gamification play with respect to self-determination theory in the context of project-based learning courses?"* In terms of Relatedness, most students indicated they wanted an online space for the project group but there was a split between needing to be known at a personal level. This is understandable in an ICT course since students are expected to be self-directed and approach people on their own. This could be a barrier, particularly for introverted students. Students who make no attempt to learn from peers or approach extracurricular services may develop an over-reliance on project supervisors or develop learned helplessness (O'Donovan et al., 2013). Rewards and gamification elements that encourage students to access library support to develop information literacy and academic writing need to be embedded into a STEM PBL. This is in line with the findings by Tan and Hew (2016), where a Mann-Whitney test revealed that the students who accessed a gamified interaction forum were more engaged in the course than the students enrolled in a traditional course.

Comparing the Competence and Autonomy results, it is clear that actual rewards like bonus marks are preferable to the student groups rather than virtual or intangible rewards. All student groups strongly favored this element as in Figure 8, compared to the badges and leader boards in Figures 6 and 7. Leader boards were largely unfavored by students, indicating that competitiveness was not a desired element in this PBL course. This may have been inferred from interpreting the question to mean a system in which marks and names of students were exposed to the whole cohort, which was obviously not desirably to most of the students. This is a similar observation to Tan and Hew (2016) in their research in which they concluded that competitive activities may only be appealing to performance-oriented students (individuals who are interested in doing better than others). Adding tangible benefits such as extra marks for additional tasks could be a viable option for a PBL course of this nature, as it is structured around developing research skills. Students who do not access the library or do extra readings of their own volition may lose out on marks or develop deficiencies anyway, so these extra marks may incentivize their willingness to engage socially or put in extra effort, which should be the goal of a research course.

Autonomy also included a question about whether students would like to participate in the design of the PBL course research topics. As shown in our analysis, SD learners strongly favoured this, whereas NSD learners did not which again provides a key insight into the distinction in attitude between these groups. Ultimately the goal is to encourage NSD learners to become more active and self-directed in their approach to research-based assessment.

The results in Autonomy indicate that a majority of students would be open to the flexibility of choosing assignments based on difficulty, which is reflected in the research by Tan and Hew (2016) where they conclude that the use of game mechanics has a positive effect on motivating students to engage with more difficult tasks in the course. In addressing the first research question, we found that meaningful gamification can assist with student self-determination when there are tangible, beneficial rewards. Students also responded positively toward contributing toward their projects through giving themselves and classmates choices to help define their experience.

## VI. Design Recommendations

The second research question was "*How can gamification be used to foster relatedness, competence and autonomy in students from different demographics and diversified educational backgrounds enrolled in project units?"* This question is answered by our gamification design recommendations, presented in Table 5. These are design for project supervisors and course designers who may consider

TABLE V: Design recommendations for STEM PBL course designers

| **Factor of Influence** | **Autonomy** | | |
|---|---|---|---|
| ***Guideline*** | ***Diversification*** | ***Method*** | ***Frame of Reference*** |
| **Flexibility** | All students | Provide options for students to choose from a list of questions based on level of difficulty instead of a fixed assessment structure with standard marking guidelines. | Provision of optional tasks or allowing students a method of self-reflection and perceived choice boosts intrinsic motivation (Martin et al., 2018). |
| **Bonus Marks** | All Students | Award points for recommended readings in the course, once the points reach a certain threshold, these can be converted to actual marks. | Martin et al. (2018) suggest that unexpected rewards may increase course enjoyment and motivation which also corresponds to the results of this research. |
| **Student Inclusion** | Students with academic experience | Involve students over a certain GPA in their previous studies in setting up the course structure and identify student expectations from the unit. | Tan and Hew (2016) suggest that students like to have control over their learning path which gives students interest-based preferences which is crucial for achieving autonomy. |
| **Factor of Influence** | **Competence** | | |
| **Rewards and Recognition-based tasks** | Students with IT background | Inclusion of badges (reply warrior badge, high-achiever badge), progress bars, difficulty level-based tasks in the course and the use of motivational messaging. | A perceived sense of progression and recognition of success is a key design practice that has a strong influence on competence (Martin et al., 2018) |
| **Refrain from trivial forms of gamification** | All students | Use meaningful gamification to identify students' need for competence. If students in a course, do not support competitive environments, do not use extrinsic gamification elements such as leader board rankings | Tan and Hew (2016) concluded in their research that the creation of highly competitive environments or public recognition platforms is not appealing to all students. This also served as a hypothesis in the research by Martin et al., 2018 that suggests that such forms of contingencies potentially undermine intrinsic motivation. |
| **Factor of Influence** | **Relatedness (Sense of Belonging)** | | |
| **Communication Channel** | International Students | A dedicated online forum where the students specific to a group can sign up and interact with the team members and the supervisor, make explicit the expectations of the supervisor's role and the level of socialization required to succeed. | Co-construction of knowledge and sharing of ideas is a crucial factor of motivation as witnessed in findings of the Mann-Whitney test by Tan and Hew (2016) which revealed that access to a gamified interaction forum led to an increase in engagement. |
| **Cohort Considerations** | All Students | Creation of rich profiles with avatars, varying backgrounds, interests and language preferences to be present in the ICT tool implementation. | Martin et al., (2018) reflected that including a frame of reference of the learners and creation of personas help in gauging the perspective of possible course participants when there is no direct access beforehand. |

implementing gamification to enhance student engagement in a STEM PBL course. Generally, stakeholders need to:

- Understand the needs of the enrolled students early in the course. Providing an option for students to make decisions related to their course structure and giving them the flexibility to engage with the course coordinator as much or as little as they want would foster a sense of presence, also highlighted by Martin et al. (2018) in their design recommendations for improving autonomy.
- Prepare for student cohorts and use gamification elements relevant to the students and their needs. Tan and Hew (2016) found that public recognition and ranking systems may only be appealing to specific students, and in our study, we also found that there was little interest in imaginary or virtual rewards.
- Project supervisors should encourage socialization and create dedicated platforms where the students within a project group can interact and initiate conversations, which is highlighted by Martin et al. (2018) in their research results as students wish to interact with peers more often in the course.
- Gain student choices and preferences for marked assessments and tutorials and provide assessment flexibility to students. This is similar to the creation of an optimal challenge (Martin et al., 2018) for students and allows them to set their own goals based on their personas.
- Provide options to students to earn bonus marks apart from regular assessments. The results indicate that a majority of students would like to have the option to earn bonus marks through task completion which can be implemented as unexpected rewards that may enhance enjoyment and have an effect on intrinsic motivation.

## VII. Conclusion

This study analyzed the survey results from 43 students to understand how meaningful gamification through self-determination theory can be embedded in a research based STEM PBL course. We divided our respondents into different diversifications to gain insight into their attitudes across three key themes: Relatedness, Competence and Autonomy. Importantly, in our classification of self-directed (SD) and not-self-directed (NSD) learners, we found differences in attitudes toward virtual and tangible rewards. Previous studies in gamification were mostly restricted to students in high school or undergraduate courses. This study extends research into PBL courses at the tertiary level, which has broader demographics and diverse student backgrounds, providing challenges for the academic staff.

One limitation of the survey was the lack of specifics around the questions, such as under what conditions the students will be awarded badges. For example, in this course, it may be feasible to provide virtual rewards to them for completing a library module on information searching. If such conditions had been outlined, the levels of agreement may have been different. In addition, the study only presents a post hoc analysis of the survey results. The study did not explore why students from different cohorts prefer certain options as it does not capture qualitative data from students. The small sample size of students filtered into these sub-groups further limits the generalizability of the results.

Future research should focus on the implementation of these guidelines to identify if the recommendations work in actual study settings. Further investigation should use qualitative approaches to understand student decisions and behaviours; the use of design-based research by Anderson and Shattuck (2012) is suggested. Design-based research would enable the researchers to iteratively improve the gamified project unit over time while identifying the obstacles. This approach could potentially yield more generalizable practical design principles for using gamification in STEM PBL courses as opposed to a one-off theoretical study.

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