GAMIFYING AND EVALUATING FIRST-YEAR DESIGN: DEVELOPMENT OF A QUESTIONNAIRE TO ASSESS STUDENT EXPERIENCE AND MOTIVATION IN A LARGE, ONLINE COURSE

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Abstract – *The purpose of this paper was to describe the development of a survey to evaluate a large, first-year, online, gamified engineering design course. Our literature review briefly summarizes the importance of engineering design experiences in terms of affective outcomes such as belonging and motivation, as well as the potential benefits of game elements and active learning in course design and delivery. However, fully online design courses have yet to be studied. After a brief description of our context, we provide a comprehensive literature review of the scales and surveys used in related education research and describe our questionnaire development process, resulting in a 61-question survey to assess our online course's support of students' intrinsic motivation, self-efficacy, and belonging. We present our survey, composed of newly developed questions as well as modified questions from literature, so that others may use and adapt it to their contexts, and conclude with recommendations for future work.*

Keywords: engineering design, online, active learning, gamified, intrinsic motivation, self-efficacy, belonging, questionnaire

1. INTRODUCTION

Design experiences are key for developing students' design, team, and project management skills. Further, they have been recognized to be crucial for students' sense of belonging and identity in engineering [1], which in turn have direct implications on student engagement and retention [2,3]. Although the design aspect of engineering is foundational to the profession, the incorporation of design elements in the curriculum has historically been restricted to senior year. This can have several implications, such as increased levels of frustration [1] that make the transition to solving design-oriented problems overwhelming. This abrupt change in student attitude can be problematic since negative design experiences have been shown to potentially cause dis-identification from engineering [4]. Furthermore, a consequence of this educational approach has resulted in the design traits/skills

of engineering students being described as lacking; for example, Todoroff et al. [5] demonstrated architectural students significantly outperform civil engineering students in all design thinking traits considered. This discrepancy in creativity and innovation with respect to engineering has been previously established and is a result of the current educational curriculum [6]. Therefore, improving and cultivating design experiences earlier on in engineering programs can have far reaching impacts on the quality of engineering education as well as graduates' success in professional settings. However, challenges of implementing design in first-year are not insignificant; these challenges include the resources required to manage and assess team projects in what are typically large courses, not to mention the additional challenges of moving online.

Attention to students' affective and socio-emotional processes is particularly important in online learning, and especially so during COVID [7]. Self-determination theory (SDT) addresses these affective aspects and has been successfully applied in a variety of online settings [8-10]. According to SDT, learner intrinsic motivation and well-being are enhanced when three basic psychological needs for autonomy support, competence, and relatedness are satisfied [11]. Autonomy is the ability to act in a way that is consistent with one's interests and values; competence is the ability to master an outcome; relatedness is a measure of interactions and connections with others. In order to meet our goals of supporting student intrinsic motivation and well-being in an online context, we decided to redesign and examine our course using the lens of SDT.

For Winter 2021, the course was redesigned using gamification overlaid with active learning strategies. Gamification is a relatively new pedagogical technique intended to increase student engagement, motivation, and therefore performance in a course. The implementation of leaderboards, scoring procedures for levels, badges, etc. have all been reported to improve student engagement and enjoyment in higher education broadly [12], as well as in computer engineering courses [13,14], a first-year design course [15] and a second-year mechanical engineering

design course [16]. Game elements, such as progressive badges, were used to support individual student progress and engagement with the asynchronous aspects of the course. These aspects included recorded lectures and readings linked to the online quizzes, which could be attempted multiple times. The badge awards were automated, gave immediate progress feedback, and did not require completion in order or by certain deadlines, thus providing some *autonomy* in how students progressed through the knowledge-based content. Active learning encompasses a broad range of teaching strategies where students spend class time on authentic problem solving activities which require them to apply their knowledge. Active learning has been shown to be substantially more effective than lectures in achieving learning outcomes in STEM education [17]. In our design course, the synchronous class time was used primarily for students to work in their teams on the two design projects required in the course, thus supporting *competence*. These team learning activities were incorporated into the game structure and the badge map. Since one disadvantage of online classes is that students can feel less engaged and connected with their instructor and peers [18], it was our hope that the connected, active, team-based components of the course would also help foster *belonging* and *relatedness*.

While several tools exist in the literature to measure each of these constructs, no tool or protocol currently exists that was relevant to all our questions related to our goals for the course. We needed a practical instrument, grounded in the literature, that could be used to collect feedback on these aspects of the course.

2. PURPOSE

The purpose of this paper is to describe the development of a user-friendly and theoretically-grounded survey for evaluating an online, active learning, and gamified design course. To that end, the survey development was guided by the following questions:

1. To what extent were students' basic psychological needs satisfied, i.e. autonomy support, competence, and relatedness?
2. How do students perceive that the various course elements influenced their satisfaction of needs and sense of belonging?
3. How do students describe their design team experiences in a 100% online course?

This paper is organized in three further sections: First, we describe our redesigned course, with particular attention to the aspects intended to meet our goals of supporting motivation, self-efficacy (one's perceived competence), and belonging. Second, we summarize the validated instruments available in the literature which measure constructs related to these factors. Finally, we

present our survey instrument and advance directions for future research.

3. COURSE DESIGN

The course, entitled Introduction to Engineering Design, Communication, and Profession, is offered annually in the Winter semester with 3 sections and a total of approximately 1200 students. It was first offered in Winter 2020, in a blended format until interrupted by COVID at which time it went entirely online [19]. For the online Winter 2021 iteration, the gamified format added badges in five different categories: design, teamwork, sustainability, learning, and safety. These game elements were intended to improve engagement by providing immediate feedback, showing progress, and motivating with rewards [20] while ensuring students covered the course learning outcomes.

Several changes were also made with respect to the active learning, team-based components of the course. Team size was reduced from 8 to 6, and a second, short, hands-on build design project was added. Synchronous lecture videos were created for each week, so that the weekly hour of synchronous time could be used for team activities which were facilitated by the instructor and 11 teaching assistants. Finally, some course elements from the first iteration not related to design were dropped to allow space for placing the design process in the context of sustainability and engineering leadership.

4. VALIDATED INSTRUMENTS

The boundaries and relationships between the affective elements of becoming an engineer, such as identity, belonging, intrinsic motivation, and self-efficacy are currently of interest in engineering education because they are important but also complex, overlapping, and not well understood. Most engineering education studies use a selection of questions from multiple validated instruments and/or use a mix of previously developed and context-specific questions in order to answer relevant research questions. Many studies do not make the previous context clear in their literature review, making the validity of the questions used difficult for the reader to determine. In what follows, we summarize the most relevant validated instruments and studies for our purposes, providing sample questions and discussing validation context.

4.1. Self-determination and intrinsic motivation

Standage, Duda, and Ntoumanis [21] utilized the theoretical framework of SDT to evaluate motivation in a British secondary school physical education context. The survey asked students their perceptions of their own autonomy, competence, and relatedness (e.g. *I have a say regarding what skills I want to practice, I am satisfied with my performance at PE, with the other students in this PE*

class I feel supported). Questions regarding autonomy were modified from the Learning Climate Questionnaire [22]; perceived competence was assessed using five items from the Intrinsic Motivation Inventory (IMI) [23,24]; relatedness was assessed using the acceptance subscale of the Need for Relatedness Scale [25]; some questions were also devised for the purposes of the current study. All of the cited scales and questionnaires had been internally validated (in non-engineering contexts) but the survey used in [21] was not validated.

The IMI has been used in many educational contexts and selected questions from it have also been used in engineering studies. Koh et al. [26] used selected items in a study of mechanical engineering students' in simulation-based learning to assess competence and relatedness, however they did not report the specific questions used. The interest/enjoyment, value/usefulness and perceived choice sections of the IMI have been employed to evaluate computer engineering students' motivation for using dialog games for collaborative learning [27]. The interest/enjoyment subscale has also been adopted to determine the influence leaderboards have on learning performance in an experimental study of an introductory computer programming course within engineering education [14]; this study also developed and validated a 15-item self-efficacy scale but did not report the questions used.

In spring 2020, two large studies of 7,724 university students conducted in Austria and Finland tested the applicability of self-determination theory during COVID and found that competence and connectedness were positive predictors of well-being; competence and autonomy positively predicted intrinsic learning motivation, and connectedness predicted intrinsic learning motivation in Finland [9]. These studies adapted existing scales or developed new items to suitably address the novel online situation; the survey was validated but items were not reported. One reason that connectedness yielded small or no effect on intrinsic motivation may have been because the studies were conducted at the very beginning of the pandemic.

4.2. Intrinsic motivation and self-efficacy

Pintrich et al. [28] developed the Motivational Strategies and Learning Questionnaire (MSLQ) to measure motivational orientations and learning strategies in college courses. He found, for college students, that intrinsic motivation and self-efficacy had substantial effects upon self-regulated learning, and that intrinsic motivation had a strong effect on self-efficacy. Questions include rating agreement with statements such as *I think the course material in this course is useful for me to learn*, *I'm certain I can master the skills being taught in this class*, and *When I become confused about something I'm reading, I go back and try to figure it out*. The MSLQ has been used extensively since its construction [29] including in

engineering education where it has been translated, modified, and validated for an undergraduate Colombian context (e.g. [30]). Studies conducted in online environments have typically used only portions of the MSLQ; one online, multidisciplinary study of the full motivation and learning strategy scales of the MSLQ found that its factor validity did not hold, however this was highly attributed to the asynchronous environment it was tested in [31].

Baldwin, Ebert-May, and Burns [32] created the Baldwin Confidence Survey Form to measure self-efficacy in STEM, which was then validated by investigating the confidence of non-biology majors in biological literacy. The survey has also been employed (but not validated) to evaluate the self-efficacy of high school students before and after a Summer Engineering Institute designed to promote and educate on engineering education and the profession [33].

More recently and specific to engineering design, Carberry, Lee, and Ohland [34] developed and validated a survey to measure engineering students' design self-efficacy. Questions were based on an iterative, 8-step model of engineering design, from identifying a need to communicating the solution and redesigning. Students were asked to not only rate their self-efficacy (belief in their own competence), but also their motivation, expectations of success, and degree of anxiety for each step. Self-efficacy was shown to be positively correlated with motivation and outcome expectancy and negatively correlated with anxiety at a statistically significant level. Additionally, it was demonstrated that engineering design self-efficacy is largely dependent on engineering experience, providing further evidence of the importance of early and continuous design experiences in the engineering curriculum.

Mamaril et al. [35] also constructed an engineering-specific questionnaire to evaluate self-efficacy. Two scales were developed and validated: the General Engineering Self-Efficacy Scale and the Engineering Skills Self-Efficacy scale. The general self-efficacy portion was created by modifying six items to an engineering context from Bong's [36] Self-Efficacy for Academic Achievement Scale. The skill specific self-efficacy portion was formed by adapting questions from previous literature, 9 items from Schreuders, Mannon, and Rutherford [37], 3 items from Carberry, Lee, and Ohland [34], and 1 item from Schubert, Jacobitz, and Kim [38] as well as creating 6 new items. Additionally, motivation variables, academic achievement as well as intent to persist in engineering data was collected to help validate and correlate with the developed self-efficacy scale.

4.3. Belonging and identity

Hurtado and Carter [39] originally developed survey items to investigate how background characteristics and

college experiences in the first and second year influenced the sense of belonging of 272 Latino students. Measures of belonging in an online and engineering context have only been more recently developed and tested. For example, in a qualitative study of graduate students at one university, Peacock et al. [40] investigated the importance of a sense of belonging within online learning and found it remains an essential factor for overall academic engagement, similar to traditional in person environments [41]. Three significant themes (interactions/ engagement, culture of learning and support) were recognized as being important for promoting a sense of belonging in online education. For engineering, Godwin et al. (2016) [42] developed a questionnaire and performed an exploratory factor analysis to confirm three constructs of engineering identity: recognition (e.g. *my peers see me as an engineer*), interest (e.g. *I enjoy learning engineering*), and competence (e.g. *I am confident that I can understand engineering in class*). More recently, Rohde et al. [1] developed a survey which included a single item measuring overall engineering identity (*I see myself as an engineer*) and six items to measure belongingness (*I feel comfortable in engineering*, *I feel I belong in engineering*, *I enjoy being in engineering*, *I feel comfortable in my engineering class*, *I feel supported in my engineering class*, and *I feel that I am part of my engineering class*) to which students rated their agreement on a 7-point scale. They did not find a correlation between identity and belonging, however theirs was a mixed method study and the survey itself was not validated.

4.4. Course-specific feedback (mixed constructs)

Finally, Owston, York, and Murtha [43] investigated the relationships between students' perceptions of satisfaction, convenience, and engagement with their in-course achievement (grade) in blended learning format courses. The survey they developed incorporated modified questions from several previously constructed questionnaires as well as questions created specifically for the research project. Questions include asking students to rate whether they felt connected with other students during the course, to rate the amount and quality of interactions with other students and the instructor, and whether the online and face-to-face components of the course enhance each other. The resulting questionnaire, included in the publication, contained 31 items, of which 25 were on a 5-point Likert-style scale and 6 were multiple-choice. The questionnaire has been used in many blended learning studies (e.g. [44]), and the student satisfaction portion of the questionnaire has also been adapted to a chemical engineering context where blended learning was implemented for a capstone design course [45]. Many of the items are also suitable for an online course.

5. QUESTIONNAIRE

We have described the literature which captures the complexity of finding an instrument which is appropriate for use in a specific teaching and learning context; as a result, this literature has informed our own development of a student questionnaire to assess our first-year, online, active learning, gamified design course. Based on this literature review, we were interested in four mediating variables: intrinsic motivation (autonomy, competence/self-efficacy, relatedness) and belonging. Therefore, our questionnaire includes items drawn and modified from Pintrich et al. [28], Hurtado and Carter [39], Baldwin, Ebert-May, and Burns [32], Owston, York, and Murtha [43], and Mamaril et al. [35]. We developed the survey through an iterative process of reviewing the validated instruments and modified questions from the literature described above, and aligning them with our questions about the course. Each of the authors (current and past instructors, and one engineering graduate student) assessed the relevance of the items for both the research questions and our context; item use, deletions, and modifications were suggested by at least one author and approved by the other(s). We also ensured a mix of scale, domain-specific (engineering) and task-specific items, as recommended by Mamaril et al. [35], included some reverse-scored items, and added open-ended, short answer questions to provide flexibility and explanations for responses. This resulted in a total of 61 items: 47 Likert-scale items about aspects of students' learning and experience, 7 short-answer questions, and 6 demographic questions. Likert-scale items were scored on a 5-point Likert Scale ranging from strongly disagree (1) to strongly agree (5). Our questions are presented below.

5.1. Student information

- 1 What is your current age?
- 2 How many hours a week on average are you employed?
- 3 How many courses are you taking this semester?
- 4 What is your current overall GPA?
- 5 How do you identify in terms of gender (e.g. woman, trans, genderqueer, gender fluid, etc.)?
- 6 What racial and ethnic/geographic origins do you identify with?

5.2. Autonomy and learning strategies

In this section we ask you general questions about your learning process in this course (Likert). Please indicate your agreement with the following statements:

- 7 I have strong time management skills.
- 8 I was overwhelmed with information and resources in this course. (Reverse Score)
- 9 I was overwhelmed at the beginning but was able to figure it out.
- 10 I made sure that I kept up with the weekly readings and assignments for this course.

11 When preparing for the course activities I try to determine which concepts I don't understand well.

12 If I did not understand a concept in the course, I did something to figure it out.

13 I was likely to ask questions in this course.

14 I felt like I had some freedom in deciding how to learn in this class.

15 (Short Answer) Is there anything else you'd like to tell us about your learning strategies in this course?

5.3. Self-efficacy

In this section we ask you questions about how competent you felt in the course (Likert). Please indicate your agreement with the following statements:

16 I'm certain I understand the ideas taught in this course.

17 I can apply what I learned about leadership to teamwork.

18 I can apply what I learned about communication to teamwork.

19 I can apply what I learned about planning and project management to design.

20 I'm certain I can master the skills taught in this class.

21 Compared with others in this class, I think I'm a good student.

22 Compared with other students in this class I think I know a great deal about the subjects in this course.

23 I'm confident I could critique a design report written by another team.

24 I'm confident I could tutor another student for this course.

25 I'm confident that after reading an article about engineering design, I could explain the main ideas to another person.

26 I think the course material in this class is useful for me to learn.

27 After engaging in this course I am motivated to develop further as an engineer.

28 (Short Answer) Is there anything else you'd like to tell us about what you learned (or not) in this course and how it influenced your confidence and motivation to be an engineer?

5.4. Belonging and relatedness

In this section we ask you questions about your sense of belonging in the course (Likert). Please indicate your agreement with the following statements:

29 I feel that the amount of my interaction with other students in this course was good.

30 I feel that the quality of my interaction with other students in this course was good.

31 I feel connected with other students in this course.

32 I felt isolated during this course. (Reverse Score)

33 I feel that the amount of interaction with the instructor was good.

34 I feel that the quality of interaction with the instructor was good.

35 I feel that the amount of my interaction with the teaching assistant in this course was good.

36 I feel that the quality of my interaction with the teaching assistant in this course was good.

37 The Teaching Assistant (TA) team being diverse in discipline, sex, and ethnicity was a positive aspect of the course.

38 This course helped me understand what engineers do.

39 This course helped me see myself as part of the engineering community.

40 This course helped me feel that I am a member of the engineering community.

41 This course makes me feel like an outsider in engineering. (Reverse Score)

Short answer:

42 The TA team is diverse with respect to multiple factors including discipline, sex, and ethnicity. Did this impact your ability to see yourself as an engineer. Please explain.

43 Is there anything else you'd like to tell us about the amount and quality of interactions in this course and your sense of belonging in engineering?

5.5. Course format

In this section we ask you questions about the effectiveness of various aspects of the course (Likert). Please indicate your agreement with the following statements:

44 The course eClass site is well organized and easy to navigate.

45 The Discord platform helped improve interactions in this course.

46 The individual and team components of this course enhanced each other.

47 The individual activities allowed me some control over my learning process.

48 The game elements improved my motivation to do the work in the course.

49 The team activities allowed me some control over my learning process.

50 The team activities improved my motivation to do the work in the course.

51 The team activities helped me develop a sense of belonging in engineering.

52 Overall, I am satisfied with this course.

53 (Multiple choice) If I had a choice between attending classes face-to-face or online, I would choose Face-to-face, online, a combination of both.

Short Answer:

54 Why did you select your response above (face-to-face, online or a combination of both)?

55 Is there anything else you'd like to tell us about the format and organization of the course?

5.6. Team experience

In this section we ask you questions about your team experience (Likert). Please indicate your agreement with the following statements:.

56 When I was working with my team, I felt a connection with the engineering community.

57 When I was working with my team, I felt respected.

58 When I was working with my team, I felt comfortable.

59 When I was working with my team, I enjoyed being an active participant.

60 I am satisfied with my online team experience.

61 (Short answer) Is there anything else you'd like to tell us about your team experience?

6. CONCLUSIONS AND FUTURE RESEARCH

As design experiences and online teaching both become more common in first-year engineering, it is imperative to understand what factors influence students' experiences. We have described the development of a comprehensive questionnaire based on previous research, literature, and theory. This work is an important first step in preparing to evaluate an online design course; our illustration of the development of this instrument within a specific context is key because there is no one-size-fits-all instrument. Therefore, we share our literature review, process and survey questions so that others may adapt them for use in their contexts. Since the questionnaire has not been validated, the inclusion of short answer questions is critical to gain greater understanding of student responses. In fact, since cursory responses are a potential drawback of surveys, we are using the questionnaire in combination with in-depth, follow-up interviews in an exploratory convergent mixed methods study; interviews can also be used to provide validity evidence. Preliminary findings will be included with the presentation of this paper. Another possible area of future research is to validate more of the constructs and scales described above for the online learning environment.

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