Elements and Mechanics of Gamification for Engineering Curriculum DRAFT

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Abstract

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1 Introduction

Research on student engagement, a measure of the effort and frequency with which students practice educationally effective activities, has shown it to be a "meaningful proxy for the quality of education imparted to the learner by institutions of higher education[1]. Gamification, the use of game-design elements in designing non-game activities, has been proposed and outlined by a number of researchers and educators as a means of increasing student engagement and has been applied to design of curricula in a variety of settings and with a variety of subject matter [2]. The success of this gamification in increasing student engagement has been studied and shown to be dependent on a multitude of factors, namely the context and students for which the gamification of curriculum is being implemented [3, 4]. It follows that, in order to develop more effective gamified curriculum for highly specific, technical disciplines, such as those found in engineering education, a somewhat precise approach must be identified.

The aim of this paper is to outline various criterion, accompanied by supporting rationale, for gamification of engineering curricula as compared to gamification of higher education curricula. Detailed documentation has been called for by researchers of educational gamification in order to offer "greater transparency so that interested educators can contribute to the literature as well as attempt to replicate results" [5]. The various criterion identified in this paper, coupled with analysis of their constituent components, will serve as a guide for those preparing curriculum, as well as documentation for their approach. Much of the research on the effectiveness of gamification is nonuniform in its implementation, thus offering considerable difficulty for those seeking to draw any conclusions from the resulting data [1, 6]. In addition to serving as supporting

documentation of an approach, this paper will serve as a review of best practices in gamification, including analysis of use in empirical studies successful in achieving positive student outcomes, within various disciplines of engineering education. It should also be noted that this paper will focus on the analysis of pedagogically-neutral and non-digital gamification, that is gamification using digital means such as an instructional video game, in order to better allow applicability to exercises that are not suiting to digital instantiation.

2 Gamification Elements and Mechanics in Higher Education

Review of various meta-analysis studies on the effectiveness of gamification of educational materials and activities has yielded that gamification is most effective when specific content has clear goals and is targeted appropriately [2, 6]. This section will describe the existing gamification elements and gamification mechanics noted by prominent literature in the field of gamified education in order to determine the practices most suited to the gamification of engineering curricula. Although these terms have been used interchangeably in very notable works, such as [2], a distinction in terminology will be made in this paper as has been done by previous research [5, 7, 8].

The concepts of gamification elements and mechanics will be referred to in this paper in a somewhat novel way. Gamification elements, or elements of gamification, will refer to the commonly reoccurring elements of game design that are used in gamification such as leaderboards, points and badges. Gamification mechanics, or mechanics of gamification, will be used to describe the underlying factors identified as the engaging characteristics which facilitate these elements as gameful interactions. One might compare this definition of gamification mechanics to game mechanics, which are defined as "methods invoked by agents for interacting with the game world" [9]. Such is to say, in our case, that the mechanics of gamification are the methods by which a user interacts with the instructor, peers and curriculum independent of the elements of gamification that may implement one or more of these gamification mechanics.

2.1 Gamification Elements

Gamification elements come in many forms from "experience points" that are analogous to traditional grades received for an assignment [8] to narratives that give either intrinsic or extraneous context to subject material [10]. This subsection explores some of the gamification elements commonly applied in gamification of curriculum according to various literature reviews, studies analyzing gamification elements related to education and empirical studies of relevant applications in engineering curriculum. The below is by no means a comprehensive

list of the gamification elements in use today and is rather a collection of those with the most empirical study performed in related applications.

2.1.1 Leaderboards

Leaderboards in games are a list of the top scores along with the player's name or alias to which the score is attributed and were created in order to add a social component to otherwise solitary games [2]. In a course setting, the scores would be replaced by points for an assignment, the overall course or some other task or activity. Leaderboards have showed connection to increased student motivation and engagement [8, 11] in engineering-related courses and have been shown to be among the most motivating of gamification elements in general higher education studies [3, 4]. However, there is often a vocal minority of students that offer the view that the leaderboards are demotivating for various reasons [12, 13]. Potential solutions to this issue are discussed in Section 3.4.

2.1.2 Points, Badges and Other Rewards

Points, badges and acheivements of various sorts are very common to gamification and offer reward structures [2]. Some points, commonly referred to as experience points or XP, are used as a replacement for traditional grades such that the student works from a low grade up to a high grade throughout the assignment or the whole course, imparting the student with a feeling of progress [8, 11]. Conversely, some rewards such as acheivements and badges are often extraneous to grading. "Victory points" [8] and "karma" points [14] awarded for participation in discussions are examples of these extraneous reward structures that encourage students to engage in certain behaviors while remaining neutral to the underlying pedagogical approach.

2.1.3 Stories/Narratives

Stories and narratives serve in both games and in gamification to explain or give relevance or meaning to the endeavor [2]. This meaning can come in varying degrees of congruity with the subject material. As noted above, the sucess of gamification in improving student engagement has been shown to be largely dependent on matching the context of the gamification to the context for which it is being implemented [3, 4]. Gamification should utilize an engaging narrative that is related to the task at hand as well as promote thought patterns that support the learning outcomes in their context [2].

2.1.4 Replay

In most any game, there is always the opportunity to repeat a challenge or task, whether it be to improve a score or simply for the enjoyment or prac-

tice. Allowing a student the option of repeating an assigment with minimal consequences imparts the student with a sense of freedom and encourages exploration and discovery-based learning [2]. Acheivements such as those referenced in Section 2.1.2 can be used to encourage replay [10]. Replay, in the case of gamification is analagous to repetition of learned concepts.

2.2 Gamification Mechanics

As stated above, the definition of gamification mechanics used in this paper is analogous to the conventional definition of game mechanics. In the same way that game mechanics are methods for interacting with the game world, gamification mechanics are methods for interacting with the course materials, facilitators and other students. Chang et al., in their study of percieved effectiveness of individual gamification mechanics, utilized Moore's three types of interaction [15]: learner-content, learner-instructor and learner-learner, to categorize commonly applied gamification mechanics that they identified to suit their application [4]. These gamification mechanics were then further decomposed into what would be refered to in this paper as gamification elements and were evaluated by experts and students alike to determine their percieved effectiveness. This organization of gamification mechanics is reflected in the below list:

- Learner-content interaction
  - Self-expression
  - Pattern recognition
  - Time pressure
  - Status
- Learner-instructor
  - Goal setting
  - Instruction
  - Rewards
- Learner-learner
  - Reputation points
  - Peer tutoring
  - Competition
  - Altruism ("a learner's desire to form and maintain relationships")
  - Group identification
  - Peer appraisal

Another list of gamification mechanics was identified by Arnab et al. in a study exploring the process of mapping game mechanics to learning mechanics with the purpose of identifying mechanics for the implementation of *serious games*. [16]. This list of gamification mechanics was organized in terms of Bloom's taxonomy of educational objectives [17] along with the corresponding learning mechanics and is shown below in Figure 2.2.1.

Game mechanics		*Thinking skills*	*Learning mechanics*		
◦ Design/editing	◦ Status	Creating	◦ Accountability		
◦ Infinite gameplay	◦ Strategy/planning		◦ Ownership		
◦ Ownership	◦ Tiles/grids		◦ Planning		
◦ Protégé effect			◦ Responsibility		
◦ Action points	◦ Game turns	Evaluating	◦ Assessment	◦ Reflect/discuss	
◦ Assessment	◦ Pareto optimal		◦ Collaboration		
◦ Collaboration	◦ Rewards/penalties		◦ Hypothesis		
◦ Communal discovery	◦ Urgent optimism		◦ Incentive		
◦ Resource management			◦ Motivation		
◦ Feedback		Analysing	◦ Analyse	◦ Identify	LOTS
◦ Metagame			◦ Experimentation	◦ Observation	to
◦ Realism			◦ Feedback	o Shadowing	HOTS
◦ Capture/elimination	◦ Progression	Applying	◦ Action/task	◦ Imitation	
◦ Competition	◦ Selecting/collecting		◦ Competition	◦ Simulation	
◦ Cooperation	◦ Simulate/response		◦ Cooperation		
◦ Movement	◦ Time pressure		◦ Demonstration		
◦ Appointment	◦ Role play	Understanding	◦ Objectify	◦ Tutorial	
◦ Cascading information	◦ Tutorial		◦ Participation		
◦ Questions and answers			◦ Question and answers		
◦ Cut scenes/story	◦ Behavioural momentum	Retention	◦ Discover	◦ Guidance	
◦ Tokens	◦ Pavlovian interactions		◦ Explore	◦ Instruction	
◦ Virality	◦ Goods/information		◦ Generalisation	◦ Repetition	

HOTS, higher-order thinking skills; LOTS, lower-order thinking skills.

Figure 2.2.1: Classifications by Arnab et al. based on Bloom's taxonomy [16].

In addition, Kapp identifies a set of "game elements" [2] which are mostly representative of the ideas of gamification mechanics presented in this paper. This set of ideas is listed in the below list:

- Abstraction of concepts and reality
- Goals
- Rules
- Conflict
- Competition
- Cooperation
- Time
- Reward structures
- Feedback

- Game levels
- Playing levels (difficulty)
- Player levels
- Storytelling
- Curve of interest
- Aesthetics
- Replay or do over

It is notable that all of these lists contain items that do not fit the definition of gamification mechanics presented in this paper; *Rewards*, *Reward Structures* and *Replay* are examples of gamification elements previously refered to. Some other items in these lists are not suiting for use in gamification of a higher education course. However, these lists will serve as inspiration for the synthesis of a new set of gamification mechanics in Section 3.

3 Adapted Approach for Target Curriculum

In this section, a new set of gamification mechanics, sytnthesized from the gamification mechanics currently in use in related applications, is presented along with the rationale behind the definition and utility of these mechanics. This set of mechanics, along with their descriptions is meant for use in the generation and application of gamification elements in the target curriculum. Many of the game mechanics listed above such as *Instruction/Tutorials* and *Pattern Recognization* are not only inherant to traditional curriculum but explicitly used to describe learning interactions by Bloom's taxonomy via the concepts of *Remembering* and *Understanding*, respectively [17]. These mechanics will be excluded in this section as they are not novel to education in any way. Some of the other mechanics in these lists are, as previously stated, synonimous with what has been referred to in this paper as gamification elements, rather than mechanics.

3.1 Context

The stories, narrative, role playing, and realism of gamification can be summarized as the context of that gamification. Some elements of context, such as role playing, are seen to be inherantly dependent on other elements of context, such as the stories and narrative [8]. As mentioned previously, the context of the gamification as well as that of the course for which it is being implemented has been shown to be of primary influence on its sucess [3, 4].

Barata et al., in their empirical study on the implementation of gamification, identified one of the strengths of games over traditional education materials to be ability to "deliver information on demand and within context" [11]. In the case of engineering curriculum, the context of the learning is very narrow and traditionally taught as a collection of technical fundamentals along with some pre-professional skills [18]. If then context is to be matched in the gamification to that of the course curriculum, much care must be taken when developing gamified curriculum. Indeed, mismatching of context has been observed by students to be either limiting or unnecessary [19].

3.2 Goals

In games, goals give participants a "sense of purpose," orienting and focusing attention throughout the game [20]. When compared to goals traditionally presented in education, game goals are unambiguous and specific [2, 11]. Sherrif et al., in their study of gamification elements' effects on student modtivation, found that students were motivated to engage in discussion by the prospect of earning "victory points" which have little to no effect on their grade in the course [21]. Acheivements and rewards such as those described in Section 2.1.2 can be used to encourage a specific task or activities or as "meta-goals" to encourage completion of a collection of tasks or continued engagement in an activities [8]. By making the process of goal seeking explicit, one allows the participant to make goal seeking the primary reward itself [22]. While the inclusion of these elements function as extrinsic rewards, they serve to align the goals of the student with those of the course [11].

3.3 Feedback

Feedback structures in games serve to show a participant how close they are to acheiving their goals [20]. In contrast to traditional learning environments, the feeback provided in games is intense and nearly constant [2]. The constantly transperant approach to goal acheivement allows students access to the primary reward of goal seeking discussed in Section 3.2, offering a strong source of motivation.

Kapp distinguished between the traditional feedback described above and another, more instructional feedback [2]. This sort of feedback not only shows the student whether their actions are resulting in progress, but also the nature of that progress or failure so as to guide the student to the appropriate actions. In order to acheive this level of information without the feeback coming off as forced or unnatural, it must be *coherent* with the context and emerge with any stories or narrative being utilized [23].

3.4 Competition

Forms of competition are present in most games and can be included in games which do not inherently contain it in order to increase motivation and engagement [2]. Competition between learners, in such forms as leaderboards (see Section 2.1.1), has been shown to increase motivation and engagement in a number of different instances of gamification of engineering curriculum. However, as mentioned, there have been some minority of students that are reportedly demotivated by the presence of such elements involving competition. Seaborn et al. propose a *prosocial* form of competition through such elements as "karma" points awarded by students to other students and team leaderboards [14]. Such collaborative efforts are detailed in the following section.

3.5 Group Identification

Group identification is a mechanic that is highly popular in gaming, often refered to as "clans" or "guilds" [4]. These groups can be used to foster learner collaboration in a variety of ways such as peer appraisal groups or team competitions[14]. In fact, gamification mechanics involving collaboration were found to be among the most engaging [4]. It should be noted that in order to utilize group identification, one does not need to form divisive groups. Aforementioned systems such as "victory points" and "karma" (see Sections 3.2 and 3.4) can serve to form a group from all of the course participants, encouraging collaborative behaviour.

The sort of behaviors fostered by group identification are becoming central to engineering education. A commonly called-for pre-professional aspect of engineering education is the notion of teamwork and communication. Bodnar et al., in their review of gamification of engineering curriculum noted that mechanics involving teamwork and communication to be of great importance and as lacking study in gamification of engineering curriculum [5].

4 Conclusion

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