Gamification Approaches for Improving Engagement and Learning in Small and Large Engineering Classes

David McIntosh*, Waleed Al-Nuaimy, Ali Al Ataby, Ian Sandall, Valerio Selis, and Shawnee Allen

***Abstract*—Engineering education can be particularly challenging when dealing with abstract or highly technical concepts such as mathematics, signals, digital electronics, electronic systems, and programming. Tutorial sessions are often ineffective as a result of poor attendance and engagement, with these effects exacerbated by large class sizes, non-homogenous student groups, and the pressures of hybrid and remote learning. Gamification of some aspects of formative assessments and tutorials using mobile and app-based quizzes has proved to be successful in improving lecture theatre dynamics, reducing distractions and enhancing student attendance and engagement. Such gamified sessions can be perceived as engaging, competitive, visually appealing, and entertaining, while providing instant feedback and empowering students to navigate their own learning. Careful gamification of problem classes for engineering topics can enable more effective self-regulation of learning through a combination of effort regulation and metacognition. This paper presents both low- and high-threshold gamification strategies adopted in a U.K. higher education setting to enhance student learning in a set of challenging undergraduate engineering courses ranging from less than 30 students to more than 180 students, and qualitatively assesses impact and student reactions. While there is much literature canvassing student opinions on gamification, extensive individual student voice tends to be missing. Therefore, one of our authors, who is a recent graduate, presents a detailed reflection on her experiences of gamification. Finally, we present some conclusions for further exploration and adoption by practitioners, considering the most effective ways to deploy the various types of gamification. These conclusions include recommendations to use app-based quiz games with anonymous participation both within and outside the classroom, gamifying either single sessions or the course as a whole, and the need to continue supplementing quiz-game learning with more traditional problems and worked solutions.**

***Index Terms*—Gamification, engineering education, engagement, interactive, metacognition**

I. Introduction

Games have the right characteristics to actively engage gamers worldwide and encourage problem-solving. In the United Kingdom alone, the association for UK Interactive Entertainment (UKIE) has estimated that the video game market reached a revenue of £7 billion in 2020 during the pandemic, with a growth of +29.9% from the previous year [1]. Games also have the characteristics to allow groups of gamers to collaborate to achieve specific goals [2].

Whilst games have been used in several fields for a long time, including education, gamification is a relatively recent term. The gamification theory is based on applying game-design elements to a specific context, like education. When applied to education, the main aim is to improve students' engagement, achievements, and motivation, and enhance their learning while they are being challenged and at the same time obtaining rewards [3, 4]. Some gamification concepts are summarised in Fig. 1.

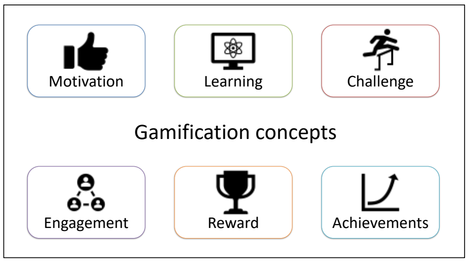

Fig. 1. Gamification concepts.

Gamification is generally used to actively engage students while having fun, giving them the opportunity to take ownership of their learning experience. It also promotes motivation to learn, enhanced creativity, decision-making, and problem-solving. One of the fields in which gamification can be applied is engineering, as engineering education can be challenging, particularly when dealing with large, non-homogenous classes with diverse backgrounds, and where delivery is required to be hybrid in format, for whatever reason.

A core component of engineering is programming, which is a complex subject, requiring students to assimilate abstract notions. A blended learning approach to social learning has been adopted to implement gamification for helping students understand programming concepts and enhance their problem-solving and programming skills. Gamification applied to courses with a programming component has been highly effective, as shown in [5–8].

One particular advantage offered by gamification of problem class sessions in engineering was found to be the microlearning opportunities, where very specific learning objectives are addressed via highly targeted and concise learning interventions packaged in an easy-to-swallow and engaging format. Another key factor behind the success of gamified delivery of content is the immediacy of feedback, as this has been shown [8] to improve student learning to a greater extent than time-delayed feedback, even if the latter were more substantial and personalized. Immediate and constant feedback is often viewed as a fundamental component of an effective academic game-based student

Manuscript received November 17, 2022; revised February 1, 2023; accepted February 9, 2023.

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doi: 10.18178/ijiet.2023.13.9.1935

response system, although the effects on long-term retention are less clear and may be contrary [9].

II. BACKGROUND

Game-based learning has long been used or proposed in education. In ancient Greek writings, Plato claimed that "if a boy is to be a good farmer or a good builder, he should play at building toy houses or at farming and be provided by his tutor with miniature tools modeled on real ones. One should see games as a means of directing children's tastes and inclinations to the role they will fulfill as adults" [10, 11]. In more modern times, the Boy Scouts of America started awarding merit badges in 1911 [12]. By contrast, the first documented appearance of the specific term 'gamification' occurred in 2008, and the term was only achieving widespread usage by 2010 [13]. Two proposed definitions [3] of gamification in the literature are:

"the use of game design elements in non-game contexts" [13];

"a process of enhancing a service with affordances for gameful experiences in order to support user's overall value creation" [14].

The first definition draws out the broad central aspect of gamification, namely the application of a game (or its features or principles) for a different purpose than simply playing games. The second definition is similarly abstract, but highlights an important purpose: supporting value creation. One could argue that educators seek to share, inspire and embed knowledge, understanding, skills and attributes which intrinsically carry value, and from which further value can be created. In the context of education, then, we might loosely define gamification as the use of games or their design elements for the promotion of knowledge, understanding, skills and attributes. Kapp offers the following more accessible general description of gamification: "the process of using game-based mechanics, aesthetics and game thinking to engage people, motivate action, promote learning, and solve problems" [15].

An important distinction between the modern concept of gamification for learning, and the type of game-based learning proposed by Plato [10] in the above excerpt, is that in gamification, the game's ostensible objectives need not necessarily align with the learning objectives of the session. In other words, rewards and motives may be completely extrinsic rather than having intrinsic aspects. To give a fictional example, educators might use a game themed around superheroes to embed learning about building or farming. This draws out a significant aspect of many types of gamification: the use of potentially unrelated, 'fun' content or objectives to engage learners in the topic at hand [16]. Indeed, the Boy Scouts case cited above points to a wider truth: that even without conscious gamification, modern education systems tend to be, intentionally or otherwise, fundamentally structured around extrinsic rewards (be they merit badges, or degree certificates.) Moreover, the tendency towards a focus on secondary extrinsic rewards such as career prospects, status or earning power, over and above the intrinsic rewards of academic endeavour, is palpably a growing one.

The extrinsic reward/motive aspect of gamification is sometimes scrutinised [17] because it might dilute intrinsic motivation (i.e., desire to learn for its own sake). However, this criticism can also be levelled, to some extent, at modern education systems in general, in keeping with the discussion in the previous paragraph. Indeed, as our investigation has found, the prospect of the remarkably game-like structure of examinations is one of the very reasons why gamification of learning—or at least revision—can be attractive to students (see Section V). Operating, then, within such a system, the challenge of implementing gamification is to gamify in a way which either amplifies, or at least, does not divert focus unacceptably from, intrinsic value.

'Social gamification' has been described by Simoes *et al.* [18] in educational contexts as "the use of game mechanics and game-thinking from social games to be applied in non-game applications, specifically in social learning environments". Social gamification is often associated with the advent of social media apps, or similar apps accessible through mobile phones. These naturally promote interconnectedness [11] (particularly between large groups) and collaboration, and can therefore be valuable tools in e-learning. Technology can thus be harnessed to engage learners, leveraging social drivers which may encourage a student to greater application than they would usually show [19].

Reviews of gamification in education have been conducted by various workers [e.g. 20, 21]. While there is a wealth of literature in this area, many studies concentrate on a (sometimes essentially binary) examination of the impact of a specific gamification technique(s) on engagement, achievement, etc. Studies often focus on assessing the effectiveness and impact of a specific approach or tool [22]. Using sometimes highly rigorous analytical methodologies, gamification in different forms has been shown by many to have an apparently positive impact on engagement and performance—if deployed in the 'right' way (though long-term effects are debated [9]). This being reasonably established, we sense a possible opportunity for more nuanced and reflective investigations about the best deployment modes of accessible gamification tools, leading to clear, simple recommendations for interested workers who may not have an abundance of research time or sophisticated technology. How best can busy higher education practitioners deploy a range of easily-available forms and levels (see next section) of gamification? We also present gamification of an entire course, but without utilising dedicated game-style software as seen, for example, in [22].

Furthermore, while the literature tends to include extensive student surveying and analysis of engagement and performance metrics from student data (sometimes in considerable depth—see for example [23]—or with extensive reporting of student comments [24, 25]), substantial individual student reflections appear to be rare. Extensive reflections by learners, as opposed to educators, are not only an important form of student voice which allow the student genuine control of the narrative, but have the power to unlock valuable insights into the student experience and the possible rationales behind learners' preferences or engagement levels. Wilkinson *et. al.* [26] gave greater control of the narrative to students, and followed this up with thematic analysis, but such more open-ended approaches do not seem to be common. In this study we describe and assess (and make the case for) a range of easily available gamification techniques, and also higher-threshold gamification of an entire course. Following this, we seek to draw conclusions about the advantages of the various types and levels of gamification, and make recommendations about their deployment, drawing not only upon student feedback and lecturer experiences, but an extensive individual student reflection, and a considered discussion of the evidence and opinions gathered.

III. Methods

In this study, we explore several modes of gamification, (predominantly falling into the broad category of social gamification) in a U.K. higher education setting when teaching both large and small engineering classes. We also seek to understand the impact of gamification, and arrive at a deeper understanding of student preferences regarding it, so as to be able to make informed recommendations to other workers in higher education. Our description of methods is two-fold, first covering the deployment of the activities themselves, and secondly, covering the assessment of their impact.

Gamified activities were deployed with commonly accessible software including Microsoft Teams [1] and OneNote[2], Kahoot![3], Mentimeter[4], PollEverywhere[5], and the Canvas[6] virtual learning environment (VLE), as well as, for the higher-threshold approach, an internet of things (IoT) kit comprising learning-specific hardware and software (see section IV). Three broad 'types' of gamification were employed in four first-year, second-year and Masters courses in our Electrical Engineering & Electronics department between 2018 and 2021 (predominantly here 2020–2021), on the following topics: *Digital Electronics and Microprocessor Systems*, the *Internet of Things*, *Electronic Circuits and Systems* and *Mathematics for Electrical Engineers*.

The three types of gamification are described as follows according to the level of relevance of the game objectives to the learning objectives. In all four courses, gamification was trialled in which the game is simply a quiz whose ostensible objective is to 'win' by achieving the most points i.e. a quiz carrying extrinsic motivation/rewards. In the second course (*Internet of Things*, Masters), gamification was also carried out in which the mechanics of the game itself is directly related to the learning objectives of the course, in an attempt to amplify intrinsic value. In the fourth course (*Mathematics A for Electrical Engineers*, undergraduate Year 1), some sessions were also structured as games with a 'story' theme (as opposed to simple quiz-games); this time, the story and theme had no direct relevance to the learning objectives.

The level of gamification was also variable. Quiz-games were limited to 50-minute sessions maximum or, in the first course (*Digital Electronics and Microprocessor Systems*, undergraduate Year 2), often even just short bursts of activity lasting only a few minutes each. In the second course (IoT course with intrinsic game goals), in addition to the first strategy, an overarching gamified structure was applied to the entire course. In the fourth course (mathematics), although there was a common theme to the stories used throughout the module, each game-structured session was still a standalone session, and there was no overarching gamified structure to the course itself. Group sizes across the four courses ranged from very small (<30 students) to very large (>180 students).

To assess the impact of the gamification attempts, we documented the informal observations and reflections of each lecturer about student engagement and responsiveness, combining these with varying degrees and modes of student feedback garnered through surveys and individual communications. We qualitatively compared the effectiveness of the gamified activities with non-gamified or differently-gamified learning activities. Finally, our recent graduate author (Allen) analysed results of a departmental student survey on lecture polling technologies from her final year project, and reflected on the effectiveness of gamified sessions during her degree from a student perspective.

Although the conclusions we present are necessarily subjective, due in part to the opinion data on which they are based and the lack of formal comparison with control samples, we believe that they are nuanced and reflective, and contain valuable practice-based recommendations for higher education practitioners. They are supported by narrative examples of several possible ways to gamify learning, in varying levels and approaches, along with an unusually detailed window into an individual student perspective.

IV. Results

A. Undergraduate Year 2: Game-Based Formative Assessment

In *Digital Electronics and Microprocessor Systems* (ELEC211) students had been exposed since 2018 to interactive poll-style questions embedded at strategic points in lectures. This is a large module, with enrolled student numbers ranging from 186 to 285 during the period studied. The polls used PollEverywhere and Mentimeter and sought to engage learners with the lecture material, offer them the opportunity to practice new concepts, and provide a means of formative assessment. In each year of deployment (2018/2019 and 2019/2020) it was noticeable that while students engaged reasonably well with the polls during the first few lectures, participation dropped away to only a few percent in most sessions after that. This could be attributed to a loss of novelty, suggesting the need for some further incentive to maintain learner engagement in formative assessment.

In 2020/2021, a different approach was adopted which took advantage of the condensing of lecture material from three sessions to two each week. The remaining session was entirely devoted to problem-solving. (A fourth weekly session was also created to help students maintain interaction during

[1] https://www.microsoft.com/microsoft-teams
[2] https://www.onenote.com
[3] https://kahoot.com
[4] https://www.mentimeter.com
[5] https://www.polleverywhere.com
[6] https://www.instructure.com/canvas

remote learning; however, this was not essential to the implementation of game-based learning.) This created the opportunity for an extended period of polling for formative assessment in each problem class. Problem classes were conducted online using Microsoft Teams, and deployment of polling was initially trialed with three approaches:

- Using the MS Teams Chat facility
- Using Kahoot!
- Using PollEverywhere

In the approach using the MS Teams Chat facility, students were split into several sub-channels, each one representing a team. Teams were pre-allocated by the lecturers, based as far as possible on students' Academic Advisor groups. When a problem was presented, students were asked to split off into their teams to work collaboratively on the problem, and then return to the main session after a short period to share their solution in the meeting Chat. Contributions were thus non-anonymous.

The approach using the Chat facility was not intended as a permanent approach, and was complicated to operate. During its deployment, some students asked whether polling software could be used instead. This request coincided with a pre-existing plan to utilize polling software in future sessions. Going forward, some sessions were deployed using Kahoot!, while others made use of PollEverywhere.

In the approach using Kahoot!, students were free to work individually or as part of one of the teams mentioned above. Questions were embedded in the presentation slides and also available to students directly in the Kahoot! interface. Students chose their team (or individual) name, allowing effectively 'optionally anonymous' responses (although it should be noted that choosing fictional names is a form of anonymity that could cause distractions [24]). Kahoot! comes with a built-in game theme including time limits, background music, transition graphics, interim leader boards, and eventual rankings of first, second and third. Just as with PollEverywhere, students can use the web app or the mobile phone app, enhancing a sense of social gamification.

The approach taken with PollEverywhere was similar to that with Kahoot!, but without exploiting built-in game-style features. (It is important to note that PollEverywhere does allow the creation of 'Competitions', but this feature was not used, whereas features such as leader boards and rankings used with Kahoot! encouraged a competitive feel.) Students were still able to respond anonymously, and questions were delivered as individual polls, one by one. Following the first three weeks, students were anonymously surveyed within the Canvas VLE on a range of issues including their preferences surrounding live polling. Response rates tended not to exceed 30% but the responses consistently supported the following conclusions:

1) Students tend to find quiz-style problem classes helpful for their learning.
2) Students tend to prefer 'fun' quizzes i.e., outright gamification: game-style quiz formats such as the format chosen within Kahoot! in these problem classes.
3) Students tend to prefer quizzes to be deployed within a context of problems solved by the lecturer.

Students were surveyed again following a further 7 weeks of quiz deployment in problem classes. A general question confirmed that students still appreciated quiz-style problem classes, although their preference for a game style was not explicitly checked again in this second survey. There was also a reduction in the percentage of students requesting that the lecturer solve more problems. This tended to support a change that had been made in the intervening period in response to the first survey, to incorporate more lecturer problem-solving alongside the quizzes.

B. Masters: Overarching Gamification of the Course

Gamification was also applied to the MSc course on the *Internet of Things* (ELEC423) with a programming component targeting embedded systems. Between 2019 and 2021, diverse cohorts were enrolled, with a high percentage of international students with different backgrounds and degrees. Overall, students found difficulties in coding and keeping up with the content of the module and assignments for a range of reasons such as:

- No previous or limited knowledge of programming.
- Several years had elapsed without coding.
- Several years had elapsed since obtaining their undergraduate degrees.

In 2021, the gamified course was delivered to a cohort of 21 students by adopting a blended learning approach. An anonymous survey was carried out at the beginning of the course to understand how diverse the cohort was. The survey was based on general questions about students' background and more focused questions about their coding skills and degree. Rating scales, closed and open questions were used to gather specific information to evaluate students' knowledge and experience in programming. From the entire cohort, more than half of the students responded. Results from the responding students showed that:

- The vast majority were from abroad.
- 5% of them did not obtain an electrical engineering and electronics related degree.
- Around one quarter of them received their undergraduate degree more than two years ago.
- A similar proportion of the respondents had not done any coding in the last two years.
- Over one third of them did not have sufficient confidence in coding.

These results show how challenging it can be to teach programming at MSc level. The course was delivered through two to three online short lecture videos, 50 minutes of face-to-face tutorials, and three hours of laboratory sessions weekly. The game-design component was included by creating weekly 'levels', each released during a practical laboratory session.

The game's main aim was to help students design and create simple IoT solutions using Linux and Python. An IoT kit was provided to each student for laboratory activities consisting of a Raspberry Pi [7] board, temperature and humidity sensors, and wireless interfaces (Wi-Fi and LoRa). Students also had access to an online IoT testbed, a replica of the IoT kit, in which a shared folder was used to exchange files and perform tasks. Game tasks ranged from playing with

[7] https://www.raspberrypi.com/

the Raspberry Pi OS and connecting sensors to sending and receiving messages using machine-to-machine protocols.

As regards learning to program, the most crucial aspect is practice. Students were asked to collaborate to achieve specific tasks (goals) for each level during each session. Students had two ways to collaborate: using the IoT testbed, and an online discussion board on the Canvas VLE. Students were challenged by increasing the difficulty of each task. This aimed at enhancing and reinforcing their learning by applying theoretical concepts; these had been obtained by watching the lecture videos, and backed up during tutorial sessions. Each 'level' consisted of four to five practical tasks for real-world applications using a Raspberry Pi board and the Python[8] programming language. A Python IDE for beginners, called Thonny[9], was used to write and run Python code. To achieve each goal, students had the opportunity to engage by sharing ideas and their designed code, and asking questions to peers and the teacher, as outlined above.

An example of a task was creating and sharing two hidden files on the IoT testbed: a file containing a password and a password-protected file with an aphorism of their choice. Other students were asked to find the hidden password files, decrypt the password-protected files and share their contents on Canvas. Another example of a task was obtaining values from the sensors, sending them through the network, and turning on/off an LED connected to the IoT testbed[10].

During the laboratory sessions, instantaneous motivational feedback was provided to students and suggestions were given to enhance their coding practices via Canvas. These were aimed at motivating students, observing differences in program design and helping them to improve their coding skills. Most importantly, it aimed at allowing students with a lack of programming skills to observe the code made by their skilled peers, model what they have done and finally imitate them to be able to perform new, advanced tasks. Further personal support was provided to students by laboratory assistants (demonstrators) during each laboratory session when required. This helped students further analyse the Python interpreter's errors obtained via Thonny.

The short lecture videos, released the week before the laboratory session, aimed at providing the theory behind the tasks that students were supposed to carry out. Furthermore, tutorial sessions aimed at briefly revising the taught material on which the upcoming laboratory session was based. The tutorial consisted of two parts: a revision and a formative assessment. The latter consisted of quizzes using Kahoot! to challenge students on theory and practical aspects. Students were asked to briefly analyse code, find mistakes, and provide the expected output from their executions. A summary of the gamified course is shown in Fig. 2.

During the course delivery, two summative assessments were carried out. These assessments were built on top of the 'levels' released during the laboratory sessions prior to their deployment, with an increased challenge. So, students were required to use previously created snippets of code, connect them, and add a few features to obtain the required program for the assessments.

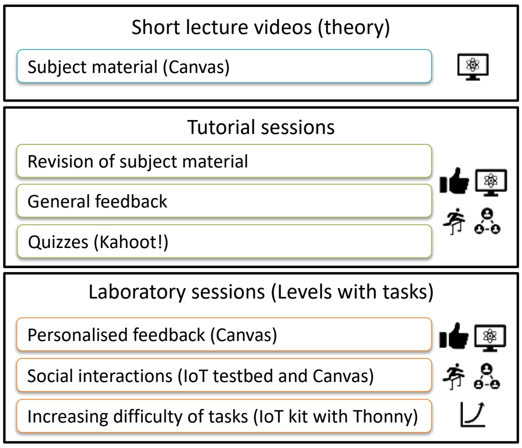

Fig. 2. Overarching gamification of a course, as applied to Internet of Things (ELEC423).

At the end of the module, another survey was carried out to understand how the gamification approach helped students. Around 40% of the students from the cohort responded, and results from the responding students showed that:

- 88% found the laboratory sessions with embedded tasks and feedback received via Canvas 'very' and 'extremely' helpful. The remaining students found them somewhat helpful.
- 50% found the tasks for each level 'fairly' and 'too' challenging, the remaining students finding them not very challenging.
- 88% found the approach used during laboratory sessions based on gamification 'somewhat' and 'very' engaging.
- 88% found the short lecture videos set at the right level of difficulty and pace. The remaining students found them a bit too easy and bit too slow.
- 88% evaluated the support provided by demonstrators 'very' and 'extremely' helpful. The remaining students found them somewhat helpful.
- 88% found the tutorial sessions using Kahoot! 'very' and 'extremely' helpful. The remaining students found them somewhat helpful.
- 88% felt that the approaches used helped them to be prepared for the practical assessments.
- 64% found the assessments set at the right level of difficulty, 24% of respondents found these 'a bit' and 'way' too easy, and the remaining students found these a bit too difficult.

A few comments received were along the following lines:

"*On a personal note, I was able to go from no programming skills to being very comfortable now.*"

"*I would like to start by saying that the methodical and systematic approach of the module made it extremely engaging. The lecture videos length was just right, laboratory exercise and class quizzes reinforced what was learnt in the lectures.*"

Results and comments show that students generally liked the overarching gamification approach used to deliver the module, which helped them be engaged while learning. Tutorials with a revision of the topics and the use of Kahoot!

[8] https://www.python.org/
[9] https://thonny.org/
[10] For more details about the IoT testbed and gamification procedure, please contact Dr Selis.

quizzes also enabled them to reinforce their learning. The main comments for improvements were related to the second assignment, which students felt more time was required to carry out.

C. Undergraduate Year 1 and 2: Gamified Problem Classes

In 2020/21 a gamified approach was used for problem classes in the Year 2 *Electronic Circuits and Systems* and Year 1 *Mathematics A for Electrical Engineers* modules (ELEC271 with approximately 180 students, and ELEC191 with 122 students, respectively). These primarily consisted of theming the session around a single Kahoot! quiz. A range of questions were used such as analysing circuit diagrams, solving equations, deriving expressions and giving true/false answers. These were similar to the styles of questions that had previously been used in problem classes; however, by setting them to a quiz this greatly increased student participation. In past years, from anecdotal observation, setting questions and allowing students to work on them resulted in many students switching off for the class and talking to peers, using phones for other purposes, etc. From tracking the responses on Kahoot!, by taking a gamified approach approximately 75% of the class remain engaged throughout the session; observation has also noted that the short periods of more relaxed fun as the result is revealed after each question then seem to result in more concentration when working on the actual problems. To further aid this, occasional joke questions are also included, typically involving “name the song” where songs with very tenuous links to the concepts being covered are included, or using hidden maths content from episodes of The Simpsons. Feedback from students has been very positive and attendance has remained high through the term.

In 2020 additional challenges were presented due to the COVID-19 pandemic and the need to develop remote teaching practices. For Year 1 Mathematics (ELEC191) this required the development and delivery of synchronous online problem classes. To help engagement with these, a serious of ‘escape room’ style story games was developed. These were created using Microsoft OneNote to aid integration with Canvas and consisted of text-based stories with embedded images, gifs, video clips, etc. The story was created in a series of sections which acted as chapters; the end of each section posed a question/problem the answer to which formed the password to access the next section. These were then deployed in problem classes by splitting the class into a number of small breakout rooms within Microsoft Teams, with 5 or 6 students in each ‘room’, and running a competition in which students work together to see which group completes the game first. The lecturer was then able to navigate between the rooms and speak to each small group.

As well as allowing the lecturer to help practically with the problems, this also allowed the students to raise other more general questions / concerns, given the small nature of the groups and the more relaxed atmosphere. Feedback from students was very positive about these story-themed games, including requesting other lecturers to develop similar games. This may suggest appreciation for a slightly higher-level gamified structure, as opposed to merely incorporating games or quizzes within sessions. Two students also approached the lecturer the following year when on-campus learning had resumed to thank him for creating these activities and highlighting how enjoyable they were.

Incorporating these activities was carried out for particular purposes, broadly summarised in the below:

1) To function as ice breakers at the beginning of the year or course, serving to lighten the mood, lower the threshold for further interaction and questions, and create trigger points to return to later for discussions during the session.
2) To pre-assess levels of knowledge before starting on a tranche of teaching.
3) To enhance and reinforce learning via targeted problems and examples.
4) To provide instantaneous feedback and snapshots of ability and preparedness.
5) To review and recap pertinent information prior to summative assessments.
6) To collect feedback about the course.
7) To facilitate self-paced, individually personalised learning by asynchronous delivery, typically after a missed synchronous session or for subsequent reinforcement.
8) To test the effectiveness of game-based sessions.

V. Further Student Voice and Individual Reflection

In parallel with (but not directly connected to) some of the above activities, an anonymous survey of taught students in the Electrical Engineering & Electronics Department at the University of Liverpool was conducted via email and Google Forms by Allen (co-author of the present study, and at that time a final year student in the department), and analysed. The survey was designed to gauge student opinions on three polling applications discussed above (Kahoot!, PollEverywhere and Mentimeter). Opinions were also sought on wider issues surrounding live polling as a teaching and learning technique, including which features students most and least liked. The survey was designed to take only around a minute to complete, as students are more likely to respond to questionnaires that take a small amount of time [27]. A small number of taught students in the department took part. Despite the low response rate, the results offered tentative support for several conclusions:

1) In a pool of students, most of whom had encountered both a fundamentally game-based polling application (Kahoot!) and a polling application typically delivered to them without game-based features (PollEverywhere), there was an overwhelming preference for the former. (As noted previously, PollEverywhere does offer a Competitions feature, but this was unlikely to have been typically exploited.)
2) Game-based learning emerged as both the most popular feature, and the feature least disliked by the responding students.
3) Anonymous response was the second most popular feature chosen, and so anonymity was clearly important to students involved in live polling.

One apparent inconsistency was that the least popular feature among the respondents was the time limit for answering questions, despite the most popular polling application being one typically delivered in a game style with built-in time limits (Kahoot!). It is impractical to deploy competitive, game-based polling in a live class context without a time limit on questions. This aspect of the survey results thus reflected what the respondents wanted, as opposed to what may necessarily be feasible. However, this response may be taken to highlight the importance of accompanying live, game-based formative assessment with worked examples (solved by the lecturer), as discussed previously, either in the same session or a linked session. This can help to ensure that learning is not exclusively competitive and under the pressure of the clock, not to mention guarding against the trap of over-distraction from intrinsic value. This feedback also suggests that course gamification which is wider than a single session—for example, across several sessions or the whole course, as discussed previously—may be beneficial for students who find short time limits distracting to their learning.

A. Student Reflection

Following the above presentation of experiences from the points of view of several lecturers, and the presentations of findings of various student surveys, it is perhaps now instructive to share the personal experiences and reflections of a student. One of the co-authors of this paper (Allen), who was an instigator and curator of the research into polling methods presented in the previous section, is also a recent graduate of this department, from the BEng in Mechatronics and Robotic Systems (2021). During her University degree, Allen took part in lectures that included both 'traditional' polling (i.e. online polling but without a game theme) and game-based learning (such as 'Kahoot!' quizzes). In her personal experience, she found lectures that utilized game-based learning to be more engaging than when traditional polling was used. One reason for this, in her view, is that having a problem class act as a low-stakes competition between students made the experience of testing her knowledge more enjoyable than it would have been with a simple poll. This competitive element tended to drive engagement. For example, she and her peers would often compare their places in the rankings after each question. Furthermore, Allen often noticed that the number of participants displayed on the poll was much higher for a Kahoot! quiz (a game-based series of questions) than it was for simple, one-question polls. This agrees well with the findings discussed above for ELEC211.

Despite the cautionary feedback above about time pressure, Allen actually found that there is also a benefit to this: the time pressure of the quizzes was useful for practising swift recall of information, in preparation for an examination setting. The instantaneous nature of feedback was particularly helpful in this respect: often, she was more likely to remember why she had got a question wrong in a game-style quiz in which the correct answer was immediately displayed, allowing students to quickly comprehend their mistakes. Allen found this to be a helpful way of realistically identifying knowledge gaps to inform her future revision, since a time-pressured quiz, much like a mock exam, allows no room for complacency or self-delusion.

Allen points out that pressure of time sometimes also caused her to mis-read a question and make 'silly mistakes'. She notes that this can be seen as both positive and negative; although it meant getting the question wrong in the moment (reinforcing the need for lecturers not to abandon more traditional problem classes with worked solutions), it was also good practice for the pressure of an examination, in which very similar 'unforced errors' can occur. Another limitation of game-based polling noted by Allen was that for longer questions requiring more detailed working-out, the instantaneous feedback was not as helpful. For these types of questions, she found that she preferred a traditional problem class with a 'question and answer' session built in, allowing more time for the method to be explained and explored in detail. Although she did not herself experience gamification of an overall course, Allen believes that the integration of an overall game theme throughout lectures would have been beneficial to her learning experience.

VI. Discussion

Each of the case studies presented in Section IV exhibits unique styles of delivery, interaction and assessment. These styles can be designed to be appropriate to the desired outcome, the target audience and the particular setting involved. For example, in case 'C', online 'escape room' activities not only facilitated weekly learning, but also served as 'ice-breakers' at the beginning of the course, especially important during a pandemic year in which students found it more challenging than usual to interact. 'Ice-breaker' type activities have been deployed by some of the authors in other settings, in the form of group scavenger hunts for new students, light-hearted puzzles for academic advisor sessions, or entertaining questions for lightening the mood of a tutorial and aiding concentration. Alternatively, ice-breakers might simply take the form of an opportunity for students to express their current mood, level of preparedness for a session, or (for remote sessions) the location from which they are joining. Thus, ice-breaker activities, when deployed in a way that is appropriate to the outcome, audience and setting, can allow students to have their voice heard, feel a sense of investment in a session, or aid their concentration.

As another example, pre-assessment tasks can be used with the primary intention of demonstrating prior understanding at the beginning of a session or series of sessions, or ahead of a summative assessment. The immediacy of the results can offer both the learners and the instructor an indication of where they stand. This can assist in the identification of areas that may require extra attention, further explanation or study.

In some other cases, enhancement and reinforcement of learning was achieved by strategic placement of very similar questions, with slightly different wording. For example, a poorly-answered question may be followed by a tailored explanation slide, and then an almost identical question can be presented to give those who were unsuccessful the first time a chance to demonstrate their understanding. The feedback obtained can be valuable to both parties, as common mistakes are avoided and students see immediate improvements. In some cases, questions were deliberately structured to elicit incorrect responses, thereby drawing attention to a particular concept and creating a unique learning opportunity. One such question is presented in Fig. 3 below.

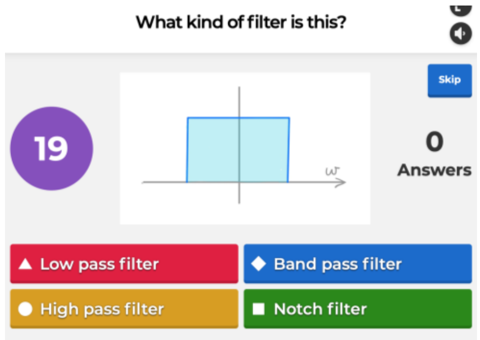

Fig. 3. Example of an 'easy' question deliberately presented to elicit incorrect responses; a trick question.

Gamification of problem classes for engineering topics can enable more effective self-regulation of learning through a combination of effort regulation and metacognition. Metacognition, in this context, refers to thinking about thinking, assessing one's knowledge and skills, or the awareness to monitor, plan, and regulate learning. All of these habits are understood to contribute to enhanced management of the learning process.

Table I suggests ways in which the authors find that gamified sessions can mitigate challenges posed by conventional sessions. Effective design of a gamified problem class in an academic context (such as engineering in this case) involves a careful navigation of the treacherous valley between overload and underload. Learning and skills must be balanced in the attempt to reproduce or emulate the elusive state of flow common in the gaming industry. This necessitates that the design of the activity ensures the acquisition of learning, allowing for the type of cognitive balancing that promotes the intended learning outcomes.

TABLE I: WAYS IN WHICH GAMIFIED SESSIONS CAN MITIGATE CHALLENGES POSED BY CONVENTIONAL SESSIONS

Challenges with conventional sessions	**Possible mitigation using gamified sessions**
Teacher-led and teacher-centred sessions with limited interaction and student participation	Learner interaction and contribution effectively relegate instructor to session facilitator
Not readily amenable to hybrid delivery	Particularly well-suited for remote and hybrid delivery
Instructor has limited awareness of students' knowledge and understanding – particularly likely in large classes	Question responses yield immediate snapshots of class understanding of any particular concept
Student reluctance to demonstrate knowledge or to attempt questions	Low cost of failure and the anonymity afforded by game participation encourage engagement
Student reluctance to ask questions	Questions, even when unspoken, can be expressed and answered by the instructor in response to poorly-answered questions
Limited peer interaction, particularly in hybrid or remote sessions, and large classes	Team-work and competitive nature of gamified sessions can facilitate greater peer interaction
Limited rapport-building opportunity, particularly in hybrid or remote sessions, and large classes	As above, competitive team-work in an engaging and mildly entertaining session can help build rapport between the lecturer and the class.
Students are 'invisible' resulting in poor attendance	Students play an active part, effectively leading the session with their contributions, motivating higher engagement and attendance
Students are not well-motivated to keep up-to-date with course material	Competition, either within sessions or embedded in the course structure itself, encourages students to stay engaged

VII. CONCLUSION AND RECOMMENDATIONS

Gamification, either of aspects of tutorials, or of entire sessions, using mobile and/or online app-based quizzes, has appeared to be successful in improving lecture theatre or online dynamics, reducing distractions, and enhancing student attendance and engagement. In these contexts, gamification particularly lends itself to formative assessment and revision (including revision for exams). Gamified activities or sessions can be perceived as engaging, competitive, visually appealing, and entertaining, while providing instant feedback and empowering students to navigate their own learning. This is particularly true when the conventional delivery style is teacher-led and/or ill-suited for larger class sizes, in which case the quality of teaching and learning is notably improved by gamified approaches. There also appears to be significant value in gamifying an entire course, including summative assessments, especially if the design maintains or amplifies intrinsic value.

1) The adoption of a range of gamification approaches to teaching engineering topics to large and small non-homogenous classes, as presented here, has resulted in a number of recommendations for consideration by educators faced with similar challenges, presented in the form of a list:
2) Educators should encourage mobile app-based quiz-games to facilitate interaction, engagement, short-term learning, formative assessment and revision – including for exams, where the time-pressure of a quiz simulates the stress of an exam hall. Gamification of this type is particularly useful for fostering engagement and competition, and tracking progress, in large classes where this would traditionally be more difficult.
3) Educators should consider the merits of anonymous participation in some settings, for maximising engagement and freedom of participation.
4) Educators should consider 'theming' entire sessions or groups of sessions with a game-like structure, as an alternative to merely including gamified activities within sessions, to promote engagement, interest and continuity. The level and type of gamification should be designed to be appropriate to the sought outcome, target audience and setting.
5) Educators should, nevertheless, consider supplementing quiz-game learning with more traditional problems and worked solutions – not necessarily substituting one for the other – either within the same session or in parallel sessions. This can balance the effects of time pressure and competition within a quiz, not to mention ensuring adequate preparation for the quiz itself. That is, students still need to be taught, and traditional problem classes with worked solutions are often a necessary part of this in an engineering context. Such

an approach may, additionally, help to balance out the possible dominance of extrinsic motivation encouraged by some quiz-games.

6) Educators should consider facilitating mobile learning quiz-game opportunities to encourage learning outside the classroom, not just within the classroom.
7) These could include an overarching game-style course structure, or protracted challenges (such as code-cracking) that may be undertaken outside the confines of lectures or problem classes. Such gamified course structures and protracted challenges may lend themselves most easily, at least initially, to smaller classes, particularly in view of the higher effort threshold for setting them up and probable greater number of points of failure. If intrinsic relevance to the course material is sought, such overarching structures and challenges may lend themselves especially well to courses with a strong programming element.
8) Such wider challenges which either gamify the course itself in an overarching way, and/or take learning outside the lecture hall, tend to allow students to work at their own pace. This may help to balance the effects of time-pressured quiz-based learning within sessions. Such wider challenges or overarching gamification may also support the embedding of long-term learning, and amplify rather than detract from the intrinsic value of the course material.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

WA formed the research aims and rationale of the study, created the original manuscript (including Abstract, Sections I, VI, VII and most figures) and administered the project prior to submission for publication. WA and AA conceptualized, framed and initiated the research, as well as mentoring some authors in pedagogy, student voice and innovative education technologies. DM copy-edited the original and final manuscripts, wrote Sections II-III, expanded the above sections, and was responsible for submission and subsequent project administration. DM, VS and IS conducted investigations into the efficacy of gamification techniques within their teaching modules, reporting on these in Section IV as follows: DM and VS = A (ELEC211); VS = B (ELEC423) including Fig. 2; IS = C (ELEC271, ELEC191). SA researched lecture polling under the supervision of DM, including a survey of departmental student opinion. The final version of Section V put together by DM was based on the survey data, analysis and original student reflection of SA. All authors had approved the final version.

Acknowledgment

The authors would like to thank the University of Liverpool for support from the Faculty of Science and Engineering Faculty Enhancement Fund, which has indirectly influenced this work.

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