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Gamification in Power System Education

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Abstract

Gamification consists of introducing game design elements into education and training. Power systems and their reliability are key to modern society, but often are behind the scenes due to their pervasive nature. Additionally, since power systems were the first formal field of electrical engineering, the legacy nature of power systems has resulted in limited novelty in educational materials. In this paper, novel approaches to improving power systems engineering education through gamification are reviewed and explored. This study also explored relevant examples of gamified implementations in education in other subjects, such as math, physics, and programming. From this, the similarities and differences between power system education and the external subjects are explored, and a research agenda to apply gamification to power systems education is developed.

Introduction

Power engineering is the oldest electrical engineering subdiscipline [1] and it is key enabling technology for all other engineering disciplines (without power, there is no computer science, etc.). However, the education in power engineering has consistently suffered as other disciplines become more prominent and interesting [1] [2] and a significant gap exists between power engineering education and power engineering practice [3]. Of interest are thus ways to improve the education quality and link to industry needs.

Gamification is the process of implementing the concepts used in game design into various fields of education. This includes rewards for good performance, competition through leaderboards and other incentives, providing task-based goals, providing stimulus, and more. Gamification presents an opportunity as a method of improving the quality of education while presenting instructors with a new way to manage education that improves student motivation, engagement, and retention [4].

Gamification has improved the educational quality and results in multiple disciplines. Prior work, e.g. [4], investigated the application of gamification in various domains, as presented in Table 1. Overall, 53%, of these studies are predominantly focused on science, technology, engineering, and math (STEM) [4]. This distribution reveals that a large degree of feasibility is placed on subjects where the application of knowledge is the primary focus. Topics such as social sciences are not detailed as a category in this list, whereas the application of gamification in every listed category is simple to determine [5].

While a majority of gamification studies and work has focused on STEM fields [4], relatively little has been applied to power engineering education [6] and these are mostly within 3 categories: power system analysis and operation (PSAO), electricity markets (EM), and behavioral change. Given the growing adoption of gamification in STEM and other technical fields, this paper aims to establish a pathway for incorporating gamification into power system education, emphasizing its alignment with trends observed in other domains.

Table 1. Distribution of Gamification Studies, adapted from [4]

Topic	Proportion of studies
Mathematics	8%
Science	8%
Programming	19%
Language	18%
Engineering	18%
Medical	11%
Business & Marketing	8%
Other	10%

This paper thus aims to answer the following research questions:
RQ1: What is the current direction of gamification in education?
RQ2: What gamification approaches, if any, are used in power engineering education?
RQ3: Can a pathway be developed for gamification in power engineering education?

This paper is organized as follows: after the introduction, a background on gamification is presented. Following this, a discussion on gamification implementations is presented. Finally, a discussion on moving towards gamification for power engineering education is discussed and then conclusions are presented.

Research

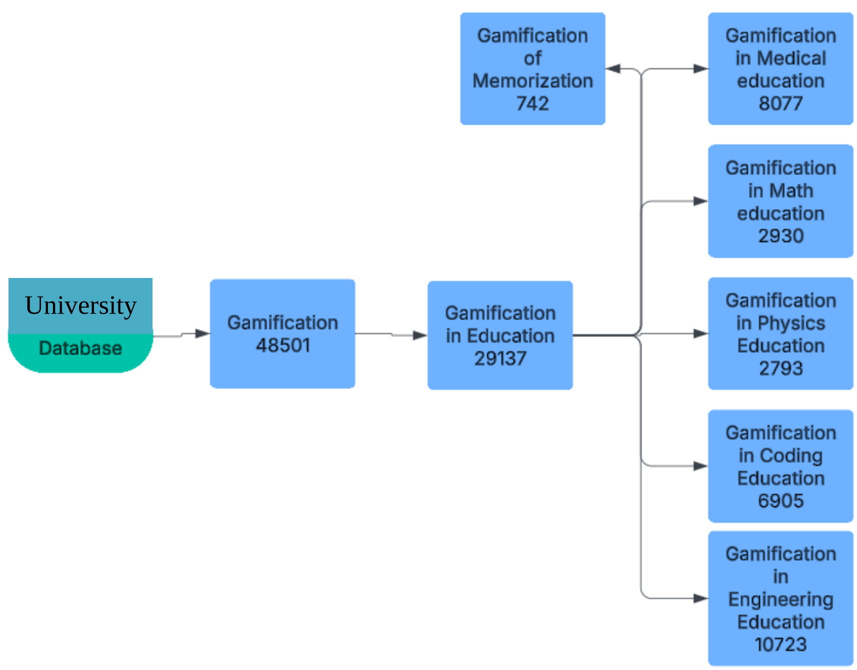


Figure 1. Literature search, selection and assessment process

To scope this study, a literature review was conducted using the authors' access to their university's library database system with EbscoHost, a principal academic search engine [7].

From this search, the process in finding literature is as presented in Figure 1. The first topic "gamification" broadly applied in various fields and had many results, including topics outside of education due to the general tenets and observed benefits of gamification in other fields. Further down selection was performed by including "education" as a term. Finally, several fields were chosen to be delved into, as presented in Figure 1. Of these, many were chosen due to the nature of the subjects in question. The primary criteria include subjects where knowledge is applied, and subjects that relate to power system education. For each subject, several articles have been cross-referenced when possible. The information found in several articles simultaneously were included. The resultant number of papers was still large, and from this pool of papers, the authors selected specific papers that presented an understanding of gamification, gamification in engineering, and power systems pedagogy.

Background

In both animals and humans, play functions as a way for individuals to quickly learn [4]. Beyond childhood, play still has utility and the field of gamification attempts to bring the benefits of play into education [4]. Some of the benefits of gamification are improvement in problem solving abilities and skill in collaboration [4].

Games in education have a long history, emerging 100s of years before the term "gamification" [8]. As a term, "gamification" implies the deliberate development of games for learning purposes and has been a discipline since the 1980s [9]. Gamification has since found use in aiding education, allowing educators to improve student motivation, engagement, and ability to take in information [4]. Gamification functions by giving students rewards for good performance, competition, and concrete goals outside of grades [4].

Gamification has been utilized in various portions of the educational, economic and service sectors. One well known example is cyber security training for businesses and government which has leveraged game-based learning to both enable role-plying in events and explain concepts for wide audiences [10]. Beyond gamification, which heavily uses computer and web-based interfaces, there are also methods of design that aim to incorporate game elements to varying degrees. These include playful and serious play, acting as toys primarily meant for entertainment and broader implementations of game design respectively [11].

Gamification relies upon several components to improve the engagement, satisfaction, and knowledge retention of the user. These components are generally accepted as being based upon rewards for good performance, discreet challenges, empowerment, and social elements. When these are used together effectively, the resulting gamified lesson improves the performance of students. The improvement in engagement and the improved satisfaction and knowledge retention allow for students to learn more effectively [12] [13]. Gamification has several central emotions and traits that are exploited, these are often divided into conceptual groups in gamification models [14]. One framework that has considerable application is the Octalysis framework, Figure 2, where there are 8 core concepts which the remaining implementation is built upon [14] [15].

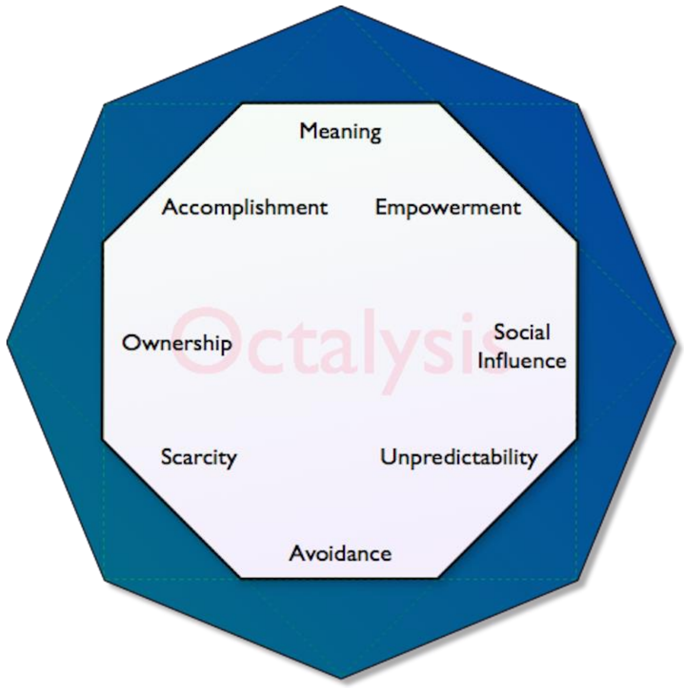


Figure 2. General Octalysis Framework, from [16]

In Octalysis, the first concept is “meaning,” which revolves around giving tasks a greater meaning [12]. The second concept is “accomplishment” which is seen in implementing ways to progress and develop skills to overcome challenges. The third is “empowerment” of creativity, which allows for experimentation and for the user to entertain themselves through the tools available [12]. The fourth is “ownership” and is focused on giving the users control of an item [12]. The item can be a physical item, though digital or abstract possessions are also viable options. The fifth element is the use of “social influence” to motivate the users through companion, competition, and social feedback [12]. The sixth is the implementation of “scarcity,” which can be understood through one common method of implementing gamified systems is having rewards be probabilistic or require the expenditure of a reward acquired otherwise [12]. The seventh is “unpredictability,” which uses randomization or avoidance of patterns to stimulate the curiosity of the user [12]. The final element is that of loss and “avoidance,” which takes the form of improving engagement by enforcing a loss of progress due to stopping or a loss of previous work due to poor performance [12]. Each of these elements improves engagement by giving the gamified system greater meaning, social interactions, a reason to continue, and creating a sense of ownership and accomplishment with the actions the user has taken.

Brief Overview of Some Implementations of Gamification

As a wide variety of end implementations and use cases exist for gamification in STEM education. Reviewing selected examples from technical domains provides insights into the application of gamification in education, particularly for science, technology, engineering, and mathematics (STEM) fields. These examples not only highlight the versatility of gamification but also justify its exploration in power system education. In answering RQ1, we will see that the direction is broad and includes board games, online games, offline games, and memorization games; however, one underlying theme is the continued and expanding development of gamification applications.

Memorization and Group Based Subjects

While not specific to STEM, a wide variety of gamification applications are in fields that need heavy use of memorization or group learning activities. Language learning has benefited significantly, at least commercially, from gamified concepts as seen in services and apps like DuoLingo [17]. Such gamified approaches focus on memorization and usage of material. Similarly, subjects such as history, biology, law and medicine also utilize gamification due to the heavily memorization-based learning involved [18] [19] [20]. For such purposes, both custom games as well as extensions of known games are used. For instance, the trivia game Kahoot (where individuals can create quizzes or sets of trivia for several individuals to answer) is often used as a template for memorization based gamified applications [21]. When used in an educational setting, Kahoot can create a sense of competition and achievement if applied effectively [21].

Additionally, gamification that encourages or requires students to work in teams or groups presents a reason and method to develop the ability to effectively work in teams without the students being required to work on sets of individual tasks [22]. Such applications show that gamification does not need to be applied to individual assignments of a class. Instead, it can function as the framework for extra-credit work and self-study. Additionally, the spread of motivations previously revealed indicates that students actively took part in additional class work for the purpose of learning without being primarily motivated by the other benefits.

Math Education

Mathematics is a subject that is central to a wide range of careers and STEM classes. One component of gamification is the aim towards making education more enjoyable, improving engagement, and allowing more information to be retained [23]. Developments in gamification of math education include digital gamification where students were given a test after the gamification was applied, with the changes in their anxiety and attitude towards math being recorded. When comparing the anxiety and attitude of each group both pre-test and post-test, it is observable that the experimental group experienced reduced anxiety and improved attitudes after the test. The control group experienced the inverse of these changes with an increase in anxiety and a reduction in their attitudes [23].

When implementing gamification in math education, many studies have examined the most influential components [24]. In one of these the components investigated are design, feedback, leaderboards, and rewards [24]. Design consists of the general structure of the game and the rules the game operates on. The specific rules and gameplay influence how the players engage with the game and what is learned. Feedback is an acknowledgement of how an individual does their tasks. Without feedback, a student would not know what they are doing correctly or incorrectly. Feedback is generally able to be implemented in gamified systems where there is a desired goal, with tools that have no inherent goals there is not an effective way to provide feedback. Leaderboards act as a source of information that allows for students to observe their relative progress and can encourage competition. Rewards provide a tangible return on the effort of completing the game and can greatly improve motivation [24].

Computer Science and Programming Education

The primary example of gamification in programming education is the Hour of Code. Hour of Code is an online event and collection of activities dedicated to teaching the concepts of programming through a simplified drag and drop syntax [25]. These tasks are intended to be completed over the course of approximately one hour. These activities generally consist of a set of levels of a game where the player controls a character or the game world through code [25]. Outside of the website, there has also been collaboration with other organizations. The developers of Minecraft worked with Code.org to include a tool to teach programming in the education edition of the game [26]. This implementation allows students to engage with the code to accomplish self-set goals and tasks.

In many games where programming is a central part of gameplay, programming is commonly used as the primary way to solve puzzles. This is notable due to the differences between programming and math education. In gamified math education, math is used as the entire obstacle; however, programming education relies upon secondary puzzles where programming is used to implement the solution [27]. In programming education, in general, the primary benefit of gamification was found to be on the motivation of the students, with academic achievement and critical thinking skills following [27]. Additionally, of the types of games tested revealed that strategy games have the greatest positive impact, while puzzle games primarily enhance motivation and critical thinking skills [27].

Physics Education

Gamification for physics education is commonly implemented in the form of non-serious play whereby lectures are supplemented by online laboratories. Physics Education Technology (PhET) is one of the most used examples of this [28] [29]. PhET consists of a set of many individual simulations that allow the user to modify various elements, such as the coefficients a system operates on or the elements included in the simulation. One example, of many [30], is presented in Figure 3 whereby experimentation of capacitor variables can be explored. These simulations represent a method for educators to easily allow students to experiment safely [29].

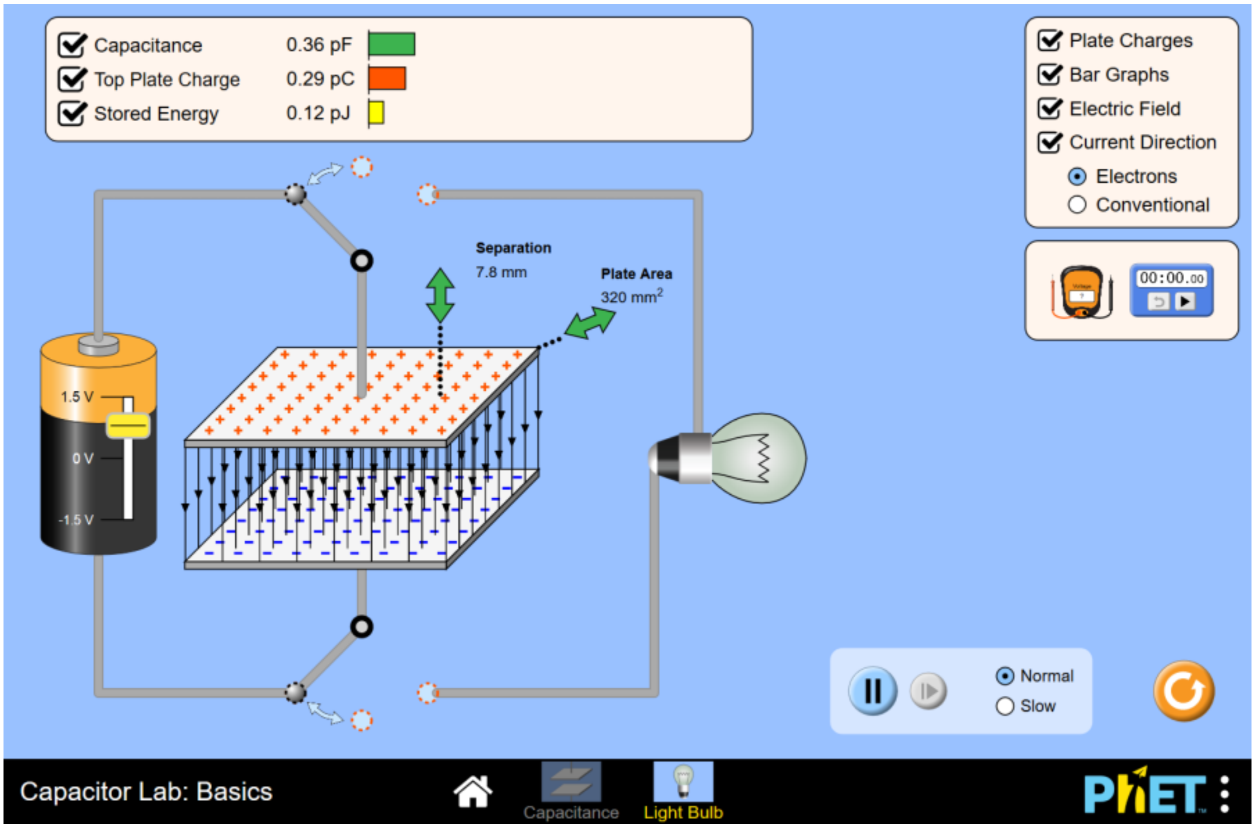


Figure 3. Physics Gamification Example, the PhET Capacitor Lab [31]

When comparing the performance of students that used a PhET simulation in addition to their lessons to those that used real equipment, the students that used the simulation expressed a higher mastery than their peers that used exclusively actual labs [29]. One reason for this is the ability for students to more easily spontaneously experiment without the requirement of having additional material or permission from instructors [29].

Medical Education

Medical uses of games largely includes two paradigms: games that teach proper protocols and procedures (serious games) [32] and games that teach concepts and terms (memorization) [33]. Memorization-based gamification is similar to other domains, as discussed above, but medical protocols and procedural education deserve discussion. In these applications, knowledge of medicines, procedures and discipline specifics (such as surgery, pediatrics, epidemiology, and practice) are gained in game like formats [32]. The formats for such gamified education in medicine is also diverse and ranges from board games, video games, and online games [32].

Engineering Education

Engineering education has made considerably use of gamification across various disciplines. Early applications of gamification through online games include the Civil Engineering focused West Point Bridge Designer [34]. This game, released in 1997 as downloadable freeware, enabled one to develop and test bridges and learn statics and dynamics concepts through experimentation. Considerable gamification applications have been made in industrial engineering whereby some concepts, such as transportation and logistics lend themselves naturally to game concepts [35]. Beyond these games, simulation-based approaches to engineering education trend towards gamification, as depicted in Figure 4. Some examples include the Mouse Factory, an interactive pedagogy focused simulation of a computer mouse factory that is useful for education in Design of Experiments [36], Control Charts [37], and process improvement [38], and AnyLogic, as seen in Figure 4, which provides an agent based simulation environment used in industry and academia to experiment with various design and decision considerations in customizable and tailorable environments [39]. While AnyLogic has seen use in power system research [40], such efforts highly focused on using the agent based simulation abilities and not on presenting a game-based environment.

Figure 4. Screenshots of AnyLogic Simulations [39]

Further examples of gamification used in engineering education focus on allowing individuals or groups of students to complete over an academic term [22]. In such applications, points are provided in return for proof of completing these tasks [22]. If a student desires, they can then purchase badges with their points, with badges able to be used in order to claim academic benefits, such as extra credit points, dropping a low quiz grade, choosing partners, and more [22]. In the class that this was implemented in, an appreciable percentage of the class participated in the optional tasks [22]. Additionally, of the students that were in the class the majority of students that failed the course did not participate in the tasks. There were also a set of task types, each of which focused on a different aspect of the task. Student motivations included working to get better at the classes, challenging themselves, gaining points, and socializing [22].

Towards Gamification in Power System Education

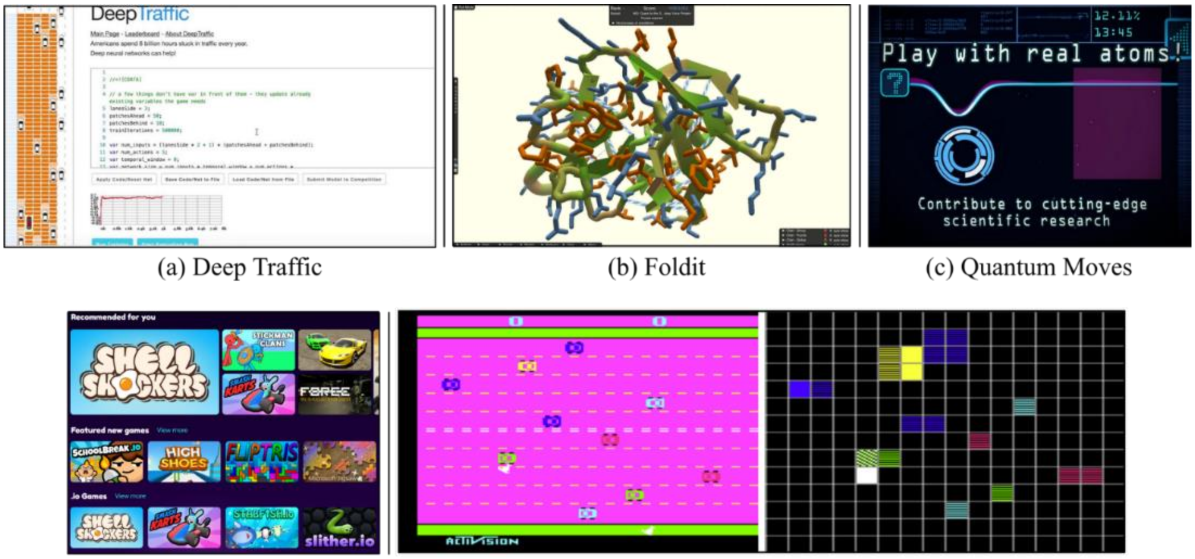
While some applications of gamified concepts exist in power system education, see [6], there have been limited overall adoption of such methods in pedagogy. Power education has several key components that provide similarities and differences to other subjects. Power system education primarily relies upon understanding how to apply provided functions and when each function is relevant to solving for the state of a particular system. These comparisons are the primary source of analysis that allow for the interpolation of the effects of gamification on power system education.

One issue, like many engineering disciplines, power system education is one of the subjects, with the concepts leveraged and extended from math and physics, causing a dependency and the application of math in power system education implies a relationship between how education would function for each. Additionally, while programming is not typically a core part of power system education, tools such as MATLAB and other programming languages are used both to rapidly analyze electrical systems and to simulate them. Similarly, simple physical concepts, as explored by PhET, are core to power systems; however, these concepts are used in large scale and complex situations making the core concepts a prerequisite and simulation of circuits and arrangements of power systems more applicable.

While memorization is not the primary goal of power system education, there are a number of benefits to all subjects that Kahoot and similar activities share. These benefits include improved attendance, engagement, individual review of class material, and reduced late arrivals [21]. One of the first incompatibilities from other implementations is the relative lack of memorization in education for power systems and other related topics. However, memorization is expressed as a necessity is when learning what cases specific methods and functions are required to solve, or when memorizing the meaning of variables inside of a function with a non-obvious meaning. Furthermore, most of the equations that must be completed take more time and effort than most trivia games can easily handle. These factors distance the implementation of gamification in power systems from tools such as Kahoot and other related websites.

Bridging Educational-Industrial Divide

While the focus above is on pedagogy, gamification can advance science and industry itself through modeling the domain of interest. Such applications can be explored in both educational or continuing education settings and possibly bridge the mentioned gap between power systems industry and power systems education. For example, gamification has seen very successful use in a few scientific disciplines, notably protein folding [41] and quantum computing [42]. In protein folding, FoldIt [41] has directly impacted the scientific community by having a game space that closely models real proteins where players attempt to find the best folds a protein can have by moving and folding individual sidechains of the protein into various configurations. Foldit games are scored higher for more closely matching properties of real proteins experimental data. In quantum computing, QuantumMoves [42] has players move quantum atoms to simulate the logical operations of a quantum computer and is used to directly model quantum computing processes. Every time a user plays QuantumMoves it creates a solution which appears on the game developers/researchers end as data describing the movement of a laser beam and quality of the solution. The challenges in the game are based on closely modeling cutting-edge research problems in quantum computing. Both FoldIt and Quantum Moves are examples of games funded by CitizenScience [43]. Screenshots of Foldit, Quantum Moves, as well as those of CrazyGames, DeepTraffic and ALE are shown in Figure 5.



(a) Deep Traffic (b) Foldit (c) Quantum Moves

(d) Crazy Games (e) Arcade Learning Environment

Figure 5. Screenshots of Deep Traffic, Foldit, Quantum Moves, Crazy Games, and Arcade Learning Environment

Future Gamification in Power Systems Education

Developing gamification for future power systems education purposes, answering RQ3, can leverage methods from other domains as well as design science research approaches [44]. Firstly, as mathematics is key to engineering, it also has a number of key similarities to power system education. This is due to the general focus on the application of knowledge rather than memorization of facts. Due to the presence of math in power system education, several of the same game elements may be used in both. The primary divergence between these systems is in the duration a single problem requires to complete. Gamification for math can take the form of tools like Kahoot in early math education due to the speed at which many simple algebraic equations can be completed in. For higher level mathematics and power systems, the formulae take a significantly greater amount of time to calculate. Because of this, standard games with the subject as a single element do not function as effectively for power system education when compared to their use in math education.

Programming is expressed primarily as a secondary tool for use in checking work and to emulate large scale systems without the dangers and costs associated with the real implementations. While this is useful in power system education, the programming necessary to emulate a power system is minor when utilizing programs such as MATLAB. Additionally, the method of teaching programming through gamified methods does not function for power systems due to most power system education relying on applying a set of equations to a variety of circuits. This is distinct from the usage of programming in gamified systems due to the focus on critical thinking that programming utilizes. It is for these reasons that examples of gamification applied to programming education does not function effectively for power system education.

PhET simulations are the foremost example of implementing gamification on physics and other engineering topics. During early power system education, premade simulations are sometimes provided by instructors. Despite this, most of these simulations are created in a program that does not allow for the same type of rapid experimentation. For a simulation to be effective to aid in learning the properties of power systems beyond acting as an example, it would likely be required to or be greatly beneficial to function in a manner similar to PhET simulations. One simple example are tools similar to circuit simulations with pre-built modules and fewer components. More complex simulations, such as those enabled by PowerWorld [45], generally exceed the requirements to replicate the properties of the three phase system while additional details and control over the simulations would reduce the ability of students to spontaneously experiment when first learning how the systems function.

One of the primary difficulties in comparing power system education and other subjects is the wide complexity and specificity. In each of the previously detailed topics, the subject is self-contained. Power system education contains several other topics and categories of knowledge. Beyond the spread of topics power systems rely upon, there is also the issue of creating games for teaching power systems. Due to the significant amount of time required to solve a power system problem, as well as the presence of complex numbers, a power system game requires tools for students to complete the equations faster than by hand.

Beyond simulations and games that directly implement the concepts of power system engineering, a modification to the structure of the course can be easier to implement and allow for students to receive benefits from completing unassigned classwork. One such implementation is providing a benefit for completing unassigned work from the book a class uses. Additionally, providing optional group or class goals can encourage teamwork and encourage students to cooperate in learning.

Discussion

Summarizing the review, the authors found the following for their research questions. Relative to RQ1 on the current direction of gamification in education, the authors found that it is expansive, with applications across multiple disciplines. In STEM fields, gamification is primarily focused on improving student engagement, motivation, and knowledge retention. The approaches include digital games, simulations, leaderboards, rewards, and collaborative tasks. Subjects like mathematics, physics, and programming have seen significant integration of gamification tools. Examples include PhET simulations in physics, the Hour of Code in programming, and memory-based games like Kahoot for various subjects. The trend indicates an increasing use of gamification in both primary education and higher education.

On RQ2, which was focused on gamification in power engineering education, the authors found that it is limited but exists in three primary areas: power system analysis and operation (PSAO), electricity markets (EM), and behavioral change. While interactive simulations and MATLAB exercises are used, they lack the spontaneous experimentation and engagement provided by gamified tools in other domains like PhET for physics. Tools like PowerWorld offer complex simulations but are not designed for playful learning experiences. Additionally, memorization-based gamification like Kahoot has limited applicability due to the complexity of power system problems and their longer solution times.

Finally, on RQ3, developing a pathway for gamification in power engineering education, the authors found that concepts from multiple fields could be adapted to the specific needs of power engineering education. Synthesizing this work includes:

- **Simulation-based Gamification**: Developing simplified versions of tools like PowerWorld, or building environments in tools like AnyLogic, that encourage experimentation.
- **Course Structuring**: Incorporating game elements at the course level, such as optional challenges, team-based goals, and reward systems for extra credit.
- **Bridging Education and Industry**: Gamifying continuing education and professional training to close the gap between academia and industry.
- **Design Science Research Approaches**: Applying these approaches to ensure practical and engaging gamified experiences for students.

Conclusions

Power system education could likely benefit from the implementation of gamification. It would likely improve engagement, reduce stress, and provide an easier way for students to remember the concepts it relies on. The broad concepts problems that do not share the same broad structure commonly make the subject more difficult to implement gamification on the level of assignments and labs. Despite this, changes to the general structure of the course or access to additional classwork that can be completed as part of a gamified system would likely be effective. Implementing a game or simulation as a method of teaching power systems would be impractical for teaching the general concepts.

Gamification has found widespread use in education for a variety of subjects. Physics, programming, and math are subjects that experience gamification before college. In college, medicine, programming, and engineering experience widespread implementation through gamification. Power system education currently exists through interactive playful games as found with physics, and gamification at the class level. Further implementation can likely be developed, and already has several viable paths.

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