6-30-2023

Inclusion of Gamification Elements in the Context of Virtual Lab Environments to Increase Educational Value

Forough Shadbad
Oregon State University, forough.shadbad@oregonstate.edu

Gabriel Bahr
Oklahoma State University, gabriel.bahr@okstate.edu

Andy Luse
Oklahoma State University, andyluse@okstate.edu

Bryan Hammer
University of Montana, bryan.hammer.phd@outlook.com

Follow this and additional works at: https://aisel.aisnet.org/thci

Recommended Citation
DOI: 10.17705/1thci.00189

This material is brought to you by the AIS Journals at AIS Electronic Library (AiSeL). It has been accepted for inclusion in AIS Transactions on Human-Computer Interaction by an authorized administrator of AIS Electronic Library (AiSeL). For more information, please contact elibrary@aisnet.org.
Inclusion of Gamification Elements in the Context of Virtual Lab Environments to Increase Educational Value

Forough Nasirpour Shadbad  
Oregon State University, forough.shadbad@oregonstate.edu

Gabriel Bahr  
Oklahoma State University, gabriel.bahr@okstate.edu

Andy Luse  
Oklahoma State University, andyluse@okstate.edu

Bryan Hammer  
University of Montana, bryan.hammer.phd@outlook.com

Follow this and additional works at: http://aisel.aisnet.org/thci/

Recommended Citation
DOI: 10.17705/1thci.00189
Available at http://aisel.aisnet.org/thci/vol15/iss2/4
Inclusion of Gamification Elements in the Context of Virtual Lab Environments to Increase Educational Value

Forough Nasirpour Shadbad  
Business Information Systems, Oregon State University

Gabriel Bahr  
Management Science and Information Systems, Oklahoma State University

Andy Luse  
Management Science and Information Systems, Oklahoma State University

Bryan Hammer  
Management Information Systems, University of Montana

Abstract:

Previous research on gamification and virtual laboratories has suggested that both produce successful educational outcomes, but few studies have looked at both gamification and virtual labs in tandem. Drawing on social cognitive theory, we investigate gamification in the virtual labs’ context to examine whether learners’ educational performance is enhanced. In particular, we employ leaderboards as a motivational gamification mechanism for more engagement and participation that can result in higher learning outcomes. Using a student sample, our results show that using gamification within a virtual lab environment results in higher student performance; specifically, it helps them complete more-complex tasks and increases their self-efficacy. Our findings show promising evidence that gamification in virtual lab learning environments positively influences learning.

Keywords: Gamification, Leaderboards, Virtual Labs, Social Cognitive Theory

Andreas Janson, Manuel Schmidt-Kraepelin, Sofia Schöbel, and Ali Sunyaev were the accepting senior editors for this paper.
1 Introduction

Technology discontinuance is a common problem (Saeed & Abdinnour, 2013) that often arises when people perceive fun, enjoyment, and engagement at low levels (Salemon et al., 2017). To increase users' satisfaction with technological applications, scholars have attempted to use game designs to enhance user motivations through gamification (Rigby & Ryan, 2011; Yee, 2006). In the education context, scholars have extensively investigated gamified systems' effect on learning outcomes through enhanced social interaction and engagement (Cheong et al., 2019). Research has shown gamified elements in educational settings to increase student participation, engagement, lecture attendance, assignment scores, and understanding (Betts et al., 2013; Gibson et al., 2015; Isabelle, 2020; Mehta et al., 2022).

In addition to educational gamification (i.e., using gamification in a teaching setting such as classrooms), researchers have also heavily investigated virtual laboratories in relation to improving the overall educational experience. Virtual laboratories provide a unique environment for providing “hands-on” learning on an online platform. With the proliferation of online and other non-co-located education, virtual laboratories provide a cost-effective method for teaching interactive content (Kahai et al., 2023; Li & Mohammed, 2008; Wolf, 2009). Virtual laboratories have shown usefulness in many areas such as networking (Ruiz-Martinez et al., 2013; Wolf, 2009) and computer security (Willems & Meinel, 2012; Xu et al., 2013). These virtual labs enable students to interact with computing components and devices to gain valuable insight into devices’ connectivity and interactivity without requiring personal hardware and software.

Both virtual labs and gamification use a common pedagogical technique called active interaction (either with systems or peers) to enhance learning objectives (Saleem et al., 2022; Soliman et al., 2021) and provide valuable contributions to education. Even though virtual labs have several advantages such as cost-efficiency, flexibility, system modifiability, and multiple user accessibility, Potkonjak et al. (2016) noted that they have at least one crucial drawback: students have different attitudes about their virtual lab experience compared to physical lab experiences. Virtual labs sometimes create a lack of seriousness, carefulness, and responsibility to study the course content (i.e., students may take it for granted), while, for IT-related majors, using virtual labs is essential as students mainly participate in experiential activities and hands-on experiences (typically using virtual labs) to learn computer concepts. Hence, students need to feel motivated and engaged and become interested in performing virtual tasks. Furthermore, IT major courses such as information security usually use virtual computer labs to provide hands-on activities to increase learning outcomes in information security. However, research has shown that even meaningful step-by-step hands-on activities are not sufficient as they focus on learning activities’ technical aspects rather than pedagogical potency (Konak et al., 2014). Thus, one way to enhance the user experience and overcome the issue with virtual labs that we mentioned above would involve using game elements in a virtual environment. Research has already suggested that one could operationalize virtual lab-based courses based on gamification in a way that incorporates game elements (Badillo et al., 2020).

To the best of our knowledge, little research has investigated gamification in a virtual lab context, which means we lack knowledge about the topic. It would be interesting to understand how students learn when they experience two environments simultaneously (i.e., gamified virtual labs). Osatuyi et al. (2018) highlighted that we lack research on gamification in education settings and invited researchers to study collaborative and interconnective effects of gamification on teams/groups in gamified learning environments beyond the classroom. Also, since many institutions have moved to virtual education (especially after the pandemic), researchers are investigating how gamification and virtual labs in combination could influence student performance (Dustman et al., 2021). Therefore, we address the following research question (RQ):

**RQ:** How effectively do game elements (e.g., leaderboard) in virtual labs for collaborative groups enhance learners’ educational performance?

To address our research question, we rely on social cognitive theory (SCT) (Bandura, 1986). SCT theorizes that individuals’ self-efficacy enhances the extent to which they believe their skills are adequate to accomplish a task (Bandura, 1986; Compeau & Higgins, 1995). Through persuasion, experience, observation, and physiological states, individuals increase their task-specific self-efficacy. We theorize that leaderboards provide a medium to “persuade” students in an “experience”-driven virtual lab environment that leads to increases in self-efficacy and influences subsequent task performance. Prior information systems (IS) research has used SCT as a mechanism and self-efficacy (Liu et al., 2017;
Santhanam et al., 2016) in various contexts such as pedagogical research (Janson et al., 2017; Lee et al., 2019; Theriault et al., 2021) and health wearables (Huang et al., 2018).

To investigate this proposed idea, we conducted a long-term experimental study in which we applied gamification in virtual labs using a student sample from a networking course who worked in dyadic teams. We limited gamification in the virtual lab environment to a leaderboard, which we did for three reasons. First, leaderboards represent a common game element, and gamified educational applications use them as a design principle (Landers et al., 2017; Zichermann & Cunningham, 2011). Second, IS scholars have put forth a research agenda for future gamification studies. In particular, Schöbel et al. (2020) called for studies to investigate the isolation effect that specific individual game elements have on specific outcomes as well as longitudinal experiments to evaluate user behaviors more objectively. Third, due to our study experiment’s nature (i.e., implementing security networks) and based on Barber et al.’s (2021) suggestion that game elements should align with the problem and user needs, we found leaderboards a relevant and appropriate element to gamify the virtual lab.

Although past research provides noteworthy contributions to the gamification literature, it has generally assessed gamification’s behavioral and psychological outcomes based on self-reported measures and quasi-experiments are utilized to observe short-term effects (Schöbel et al., 2020). We used two proxies to measure students’ learning performance: 1) an objective variable to measure how many services subjects implemented and 2) a self-assessed measure to determine their task-specific self-efficacy (Santhanam et al., 2013). We found that the leaderboard resulted in a significant increase in both how many services subjects implemented and their self-efficacy. Furthermore, we found that the leaderboard had a significant impact on more complicated service implementations. Our findings provide insights into designing effective systems implementing gamification elements in tandem with virtual laboratory environments.

2 Related Work

2.1 Gamification

Gamification refers to applying game elements in designing utilitarian systems or non-game contexts to enhance user motivation to use systems (Deterding et al., 2011). Gamified systems follow incentive mechanisms to increase user interest and motivation to effectively use, explore, and engage with a system (Bitrián et al., 2021; Faiella & Ricciardi, 2015). Game elements work as incentives that induce user-system interactions such as exploration, collaboration, competition, and challenge (Blohm & Leimeister, 2013). As a result, users experience meaningful engagement to obtain experiential outcomes (e.g., joy, flow, satisfaction) and utilitarian outcomes such as usefulness and/or work-related benefits (Liu et al., 2017). The literature lacks consensus on providing a comprehensive list of elements that make a system gamified. Researchers have taken a relatively subjective approach to selecting game elements when designing gamified systems (Sailer et al., 2017); however, the decision should consider whether the game elements result in enjoyable and playful activities (Werbach, 2014) and that align with organizational needs (Barber et al., 2021). Commonly used motivational affordances in the gamification literature include points, leaderboards, badges, levels, stories, feedback, goals, rewards, progress, and challenges, though researchers have implemented points and leaderboards the most frequently in gamified contexts (Hamari et al., 2014). Points work as a rewarding measure in which users receive compensation for accomplishing a certain activity (Werbach & Hunter, 2015). Leaderboards display players’ rank and relative success according to their performance in a certain activity (Costa et al., 2013). Both features provide a competitive environment and a sense of eagerness to help users accomplish activities (Keith et al., 2018; Nah et al., 2014).

In applying game elements in various information systems, researchers have provided promising findings in psychological and behavioral outcomes in different contexts such as healthcare, marketing, task performance, social networking, and education (Dicheva et al., 2015; Hammadi et al., 2017; Huotari & Hamari, 2012; Mekler et al., 2017; Simões et al., 2013). Psychological outcomes include enjoyment, engagement, fun, satisfaction, and social motivation (Barber et al., 2021; Cheong et al., 2013; Guin et al., 2012; Li et al., 2012; Wiethof et al., 2021), while behavioral outcomes include participation, learning outcomes, task completion speed, user-contribution amount, time management, intention to use, task productivity, brand loyalty, and health-behavior change (Domínguez et al., 2013; Farzan et al., 2008; Hamari & Koivisto, 2013; Isabelle, 2020; Jung et al., 2010; Kankanhalli et al., 2021; Mattke & Maier, 2021). Systematic literature reviews suggest that gamification research mostly focuses on behavioral
outcomes rather than psychological outcomes. In particular, researchers have investigated educational learning outcomes the most frequently when implementing gamification (Hamari et al., 2014) since one can operationalize gamification for effective instructional methods (Sailer & Hommer, 2020; Saleem et al., 2022; Zainuddin et al., 2020).

Researchers have commonly used a leaderboard to gamify systems and increase the effectiveness of various outcomes (Landers et al., 2017; Silva, 2010); however, research on gamification has rarely used leaderboards exclusively. For example, Landers and Landers (2014) examined leaderboards on a gamified online wiki-based project. Those users exposed to the leaderboard performed better in time on task (i.e., number of edits). In the education context, Domínguez et al. (2013) showed that using a leaderboard can have positive effects on learners’ performance and that students who experienced gamified education had higher scores in practical assignments.

### 2.2 Social Cognitive Theory

Social cognitive theory (Bandura, 1986) is a widely accepted and empirically validated model for explaining individual behavior. According to this model, a mutual relationship exists among environmental influences (e.g., virtual labs and social pressures through leaderboards), personal influences (e.g., personality and demographic characteristics), and behavioral outcomes (e.g., task performance and task-specific self-efficacy). These three factors are either affected by or affect the other two factors. Bandura (1977) asserts that self-efficacy plays a central role in behavioral changes and, thus, that it represents an important construct for the theory. Self-efficacy “highlights the self-beliefs of individuals about their ability and competency to accomplish a task” (Mensah et al., 2023). Thus, self-efficacy does not directly measure one’s real skills and abilities but rather one’s beliefs to perform a task. Bandura (1977) posits four types of self-efficacy: mastery experience, vicarious experience, persuasion, and physiological and affective states. Mastery experience represents the way in which individuals interpret their past successes and failures and current active experiences on given tasks. If people obtain success through their own personal skills, then they are much more likely to be confident about future success in the area.

Vicarious experience refers to when one observes a friend or peer accomplishing a task. If a student observes other students in the same class succeed in a task, that student will make judgments about their own capability to accomplish the task. Vicarious experience self-efficacy is less stable than mastery experience. For example, if a student fails a task after observing other students accomplish the task, that student will immediately have lower self-efficacy than a student who fails a task after having previous mastery experience. It may take several task failures to see mastery experience self-efficacy decrease.

Persuasion refers to the ability to make someone believe something through relative information. Persuasion can have either a positive or negative effect on self-efficacy. For example, if someone tells someone else that “they can do it” or “they can’t do it,” these comments will affect that person’s self-efficacy in either a positive or negative way. In our study, leaderboards enact persuasion effects in students because a leaderboard has rankings and values for its members to compare against. In Santhanam et al.’s (2016) study, trainees who faced lower-skilled competitors reported higher self-efficacy beliefs and a better learning outcome than trainees who faced higher-skilled competitors.

Finally, physiological states refer to bodily cues that express affective states such as anxiety. Examples could include sweaty hands, an increased heart rate, panic, and trembling. People can interpret these signs as nervousness and, thus, believe they cannot succeed in a task. However, people can interpret feeling relaxed and comfortable as confidence and, thus, have higher self-efficacy. Physiological states represent the weakest type of self-efficacy.

### 2.3 Contextualization (Virtual Labs)

Context plays an important role in theory development. Researchers test and apply theories in different contexts to assess their boundaries. In studying context in theory development, Hong et al. (2014) revealed how context-specific factors better explain behavioral intentions in a decomposed technology acceptance model (TAM). In our study, we used virtual labs as the context to extend prior research using social cognitive theory and gamification.

Virtual labs are one type of online laboratory where students perform tasks with simulated or virtual equipment (De Jong et al., 2014). Unlike physical laboratories (a room to run experiments with tools and
equipment), virtual labs allow students to work remotely via the Internet to replicate physical labs by manipulating the physical environment into an online environment (Reeves & Crippen, 2021).

Virtual laboratories have gained popularity in higher education as a mechanism for effectively teaching hands-on concepts such as the Internet of Things (IoT), network security (Luse & Shadbad, 2023; Luse et al., 2021b), and organizational cloud integration (Krieger & Luse, 2022). Traditional lab environments, while effective, can become cost-prohibitive (Wolf, 2009) and cannot support the increasing number of online students (Li & Mohammed, 2008). Conversely, virtual labs provide a realistic, cost-effective, and easily implementable learning environment (August et al., 2015; Ruiz-Martinez et al., 2013). These labs can range from virtual learning spaces mirroring the classroom (Halvorson et al., 2011; Wyss et al., 2014) to environments that mimic the real world (Rursch & Jacobson, 2013). Specifically, in the networking area, researchers have used virtual laboratories to help students effectively learn hands-on networking concepts (Luse & Rursch, 2021; Ruiz-Martinez et al., 2013; Wolf, 2009) and related areas such as network security (Willems & Meinel, 2012; Xu et al., 2013).

Overall, research has shown virtual laboratories to be a viable option for teaching computer network and security concepts. As a notable example, Luthon and Larroque (2014) used game-like training. In their environment, students could remotely control physical robotic arms to build physical circuits for electrical engineering. Their environment provided a leaderboard for users as a gamified dimension. However, while useful, their environment focused on electrical engineering as opposed to computer networking and security. Furthermore, they did not use a completely virtual lab but a hybrid lab that still used physical elements.

A few other studies also used gamification techniques to run virtual experiments for mechanical engineering and microbiology students (Dustman et al., 2021; Schnieder et al., 2021). Their gamified instructional method involved a game narrative or a PowerPoint-based platform to provide step-by-step instruction for a given exercise rather than a lecture. However, these studies did not use game elements that require collaborations (or competitions) with others such as leaderboards or points (as opposed to game narrative) tracking to engage students in an online experience.

3 Hypothesis Development

SCT’s model for individual behavior applies to both task performance and task-specific self-efficacy and has pertinence in gamification (Schöbel et al., 2021; Treiblmaier et al., 2018). In this study, we see gamification as an environmental influence that impacts both task-specific self-efficacy and task performance.

SCT posits that self-efficacy and observations of environmental cues influence task-based outcomes. Recently, research has shown that task-specific self-efficacy measures offer greater predictive power and overall reliability and validity as compared to general measures (Davazdahemami et al., 2018). Task-specific self-efficacy measures self-efficacy that pertains to a specific task as opposed to general measures that cover a wider area (Marakas et al., 2007). Gamified systems, using social comparison elements, provide an environment for users to improve their self-efficacy beliefs in order to outperform others and exhibit better learning outcomes (Santhanam et al., 2016). One can use game mechanics such as leaderboard rankings as a goal to enhance user performance in terms of self-efficacy (Hamari, 2017; Yang et al., 2016). Furthermore, rewarding points and giving feedback positively relate to self-efficacy (Feng et al., 2018). Some evidence suggests gamification-based education increases user performance and self-efficacy (Banfield & Wilkerson, 2014; Bonde et al., 2014; Su & Cheng, 2016).

For example, past research has examined the effect that gamification (i.e., badge-based gamified learning software) has on both task performance outcomes (e.g., number of participations in class activities, exam scores, and time of task completion) and self-assessed measures (e.g., engagement, enjoyment, and self-efficacy) (Cheong et al., 2013; Denny, 2013; Denny et al., 2018). In one study, Li et al. (2012) implemented a gamified tutorial tool, GamiCAD, and experimentally examined two groups (one exposed to a gamified system and the other to a non-gamified tutorial system). They found the gamified group accomplished tasks faster and reported higher engagement. In the information security training context, Baxter et al. (2016) used a gamified training system called TrueOffice, which included game elements such as story, goal settings, and progress elements. They found that gamified systems helped users acquire more knowledge and demonstrate higher satisfaction.
In this study, we also see virtual labs as an environmental influence that impacts both task performance and task-specific self-efficacy. Research has shown virtual labs to impact objective performance measures for students who use these systems. Research has shown online laboratories that integrate learning management systems for general engineering topics to impact student scores on understanding the implemented topics (Ruano et al., 2016). It has also shown LaboREM, a hybrid physical/online laboratory for remotely interacting with electronics, to impact student scores and completion times (Luthon & Larroque, 2014). Further, it has been shown that hybrid physical/online laboratories impact student scores as well (Bochicchio & Longo, 2009). In the network security area, research has shown that online laboratories allow students to achieve scores on par with traditional physical labs (Luse et al., 2021a).

Research has also shown virtual labs increase how well students self-assess their abilities (Wolf, 2009). It has been shown that virtual world learning environments for science, technology, engineering, and mathematics (STEM) education can help to increase self-efficacy of students in engineering sciences (August et al., 2015). It has been shown that hybrid virtual/physical engineering labs have to increase self-efficacy (Cooper & Ferreira, 2009). Specifically, in the computer and network security area, research has shown virtual laboratories to increase student self-efficacy (Kongcharoen et al., 2017) and task specific self-efficacy in networking area (Luse et al., 2014; Rursch et al., 2009). Given the advantages that both gamified elements and virtual laboratories have for increasing how well students self-assess their abilities, we hypothesize that these combined elements will provide improvements in self-efficacy related to networking concepts.

We argue that the mastery experience's self-efficacy mechanism will influence performance via leaderboards in a virtual lab environment. Mastery experience refers to a self-efficacy belief in which past and active experiences increase confidence about whether one will succeed in future outcomes. We theorize that, as individuals' standing on a leaderboard increases (due to their continually increasing achievements), their self-efficacy will increase. Mastery leads to increases in motivation, involvement, and engagement, which represent crucial education elements that gamified learning applications fulfill (Hamari et al., 2016; Shin, 2006). One can derive student engagement in learning activities through behavioral involvement (participation and attention), cognitive involvement (to learn a subject), and affective involvement (interest in performing tasks) (Kahu, 2013).

Persuasion self-efficacy refers to a belief based on the net cumulative effects of encouraging or discouraging messages. We theorize that individuals will rely on the leaderboard as a way to compare their performance and any gains or losses observed act to persuade the individual. Prior research supports this idea: trainees who faced lower-skilled competitors reported higher self-efficacy beliefs and a better learning outcome than trainees who faced higher-skilled competitors (Santhanam et al., 2016). Thus, the leaderboard operates as a constant comparator that provides encouraging (or discouraging) messages. Due to gamified applications' social dimensionality, learners perceive social credibility when others recognize their achievements (Faiella & Ricciardi, 2015). The positive emotions that students experience may, in turn, impact their scores and performance (Kapp, 2012). Moreover, cooperation and competition as parts of gamified applications provide a challenging area for performance comparisons that makes trainees compete with others to achieve better learning outcomes (Santhanam et al., 2016). In our study, we also paired students together in dyadic groups. Students who cooperate together persuade each other in competitive contexts.

Based on what we argue about how gamification and virtual labs impact student learning outcomes and given that we used a leaderboard to enable both mastery experience and self-efficacy's persuasion mechanics, we hypothesize that a leaderboard in a virtual lab environment will increase task-specific self-efficacy and student performance related to networking concepts.

**H1:** Individuals who use a leaderboard experience an increase in performance as compared to individuals who do not.

**H2:** Individuals who use a leaderboard experience an increase in task-specific self-efficacy as compared to individuals who do not.
4  Methodology

4.1  Sample and Design

To investigate the hypotheses, we designed a longitudinal experiment using two student groups engaged in gamified and non-gamified class activities. Specifically, our subjects comprised students from five sections of a networking course across five separate semesters at a large Midwestern university in the United States. The university required all IS majors to take the course. Each section had around 40 students with all students completing the same exact project in the same exact environment. They completed the project in a “flipped” lab environment for 1.5 hours each week starting the third week of the semester and continuing until two weeks before finals (11 weeks total). We gave the students new modules each week for each service to build towards a complete corporate environment. While students could complete much of their work in class, they also had access to the system anytime outside of class.

In total, 120 dyads from five separate semesters took part in the study: 63 pairs did not use the leaderboard, while the remaining 57 pairs did. We used pairs in the study to allow students to individually study the material outside of class (for the flipped format) but then have some help from a partner during the class sessions to allow each student to have another student to help them understand and implement the material. Previous research that has examined pre- and post-test scores for task-specific self-efficacy in a virtual lab context has found that one needs a sample with 35 or more participants to provide the necessary power to find results (Luse et al., 2021a). Since we conducted a field experiment, we took sample size from students who actually took the course, which meant it lacked the balance that a lab experiment would exhibit. We tasked student groups with implementing all the required services just as a corporate network would provide these services to its users. Table 1 presents descriptive statistics for our sample. Additionally, we evaluated the differences in these descriptive statistics to verify that these variables did not have any differential effect across groups in the hope that they exhibited balance with regard to subjects. These descriptive statistics show that most students thought they would use some concepts in the course in their future job (t = -0.90, p = 0.37) and that they had completed, on average, more than four IS courses prior to the course (t = -1.80, p = 0.05). Also, males (χ2(1) = 0.41, p = 0.52) and U.S. citizens (χ2(1) = 0.06, p = 0.81) accounted for most samples in both groups.

### Table 1. Sample Descriptive Statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Leaderboard</th>
<th>Non-Leaderboard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of concepts in future job</td>
<td>2.47 (little/some)</td>
<td>2.26 (little/some)</td>
</tr>
<tr>
<td># of IS courses completed</td>
<td>5.84</td>
<td>4.17</td>
</tr>
<tr>
<td>Males</td>
<td>88%</td>
<td>78%</td>
</tr>
<tr>
<td>U.S. citizen</td>
<td>91%</td>
<td>85%</td>
</tr>
</tbody>
</table>

4.2  Procedure and Learning Measures

We used the ISEAGE virtual Internet environment for the study. The environment provides a virtualized “Internet” experience that gives users public Internet protocol addresses (IPs), domain name system (DNS) names, and other functionality that the public Internet provides. The virtual lab then provides routing functionality to allow students to set up corporate environments (e.g., websites, file sharing, email, etc.) and access other students’ corporate environments. Researchers have used the ISEAGE environment for cyber defense competitions (Luse et al., 2014; Rursch et al., 2009) and, more recently, for traditional courses on networking and security (Luse, Brown, et al., 2021; Luse & Rursch, 2021). For our study, we gave each student several machines connected by a switch through a router to the ISEAGE environment. The machines included a Windows server, a Linux server, a Windows client, and a router. The students oversaw setting up various services on their network that other students could access. For example, we would give a student the IP range 123.45.67.0/24 with the DNS name corp1.com and the student had to set up a webpage at www.corp1.com, file transfer at ftp.corp1.com, email at webmail.corp1.com, RDP access at rdp.corp1.com, DHCP service for internal clients, and DNS service so all the services worked using the indicated URLs. Figure 1 shows a logical diagram of the ISEAGE environment, while Figure 2 shows sample virtual machines that students used in the environment.
We set up a gamified leaderboard for the experimental manipulation that comprised a webpage that displayed each service’s status (a green “up” or red “down”). This webpage ran a script every 20 minutes to check each service’s status. The script programmatically acted as a “typical user” by connecting to each service to gauge functionality. For example, the script connected to each student’s webpage; if it could access the webpage, then it categorized the service as “up”; otherwise, it categorized it as “down”. Students could try to get as many services as possible up and working over the project’s duration and could try anything from the course or their collective knowledge to do so. The leaderboard provided a
unique link between the virtual environment and the public world by providing a publicly accessible leaderboard that evaluated services in the virtual environment. The leaderboard presented each student pair as one entity and each service’s status to the group as a whole with groups listed numerically by “corp” number. Students could see which students had more services up and running to enable them to gauge their progress as compared to others in the course. Figure 3 shows a live leaderboard snapshot.

![Figure 3. Leaderboard](image)

We designed an experiment in order to test the leaderboard’s impact on learning outcomes. Three student cohorts completed the course and the entire project in three separate semesters without using the leaderboard, while two student cohorts completed the course with the leaderboard. We used an objective service functionality measure to evaluate the two conditions by analyzing whether students had implemented the six different services in the project: domain name service (DNS), dynamic host configuration protocol (DHCP), web (HTTP), file transfer protocol (FTP), remote desktop protocol (RDP), and email.

We also evaluated learning differences using longitudinally self-assessed learning efficacy measures. Self-efficacy (Bandura, 1986) measures self-beliefs about personal ability which, in tandem with the objective skills measure, provides a more robust overall assessment (Scheibe et al., 2007). Research has shown task self-efficacy to provide a valid mechanism for evaluating self-efficacy in a specific area (Marakas et al., 2007). Thus, we used a task-specific self-efficacy measure in the network/infrastructure area from previous research (Davazdahemami et al., 2018) (see Appendix A for the questions). We implemented a pre-test/post-test longitudinal design as previous literature has advised (Heppner et al., 2008). We asked the students in all sections the same nine questions both before the project and after the project at the end of the semester.

5 Results

5.1 Services (Objective Outcome Assessment)

We first analyzed services to assess how well students implemented the deliverables for the project overall. First, we tallied how many services the student pairs correctly implemented using a single number from zero to six. We ran a two-sample t-test to evaluate the total number of services in sections with the leaderboard versus sections without the leaderboard. Results showed a significant difference in how many services the students implemented (t(117) = -1.74, p = 0.04): students without the leaderboard implemented 4.5 services, whereas those with the leaderboard implemented over 5, which supports H1.
To differentiate the task complexity level, we analyzed each service independently with a dichotomous outcome variable (0: not implemented; 1: implemented). Using a Fisher’s exact proportional test, we analyzed how many student pairs implemented each service between the two groups. We found that, while DNS, DHCP, HTTP, and RDP did not show significant differences, both FTP ($\chi^2(1) = 5.01, p = 0.01$) and email ($\chi^2(1) = 2.05, p = 0.08$) showed significant to marginally significant differences in that a larger proportion of students in the leaderboard group implemented FTP and email (0.89 and 0.68, respectively) compared to the non-leaderboard group (0.71 and 0.54, respectively). Looking at these two services compared to the others, DNS, DHCP, web, and RDP involve a one-way interaction to connect, whereas FTP and email involve further interaction beyond the initial connection, such as uploading/downloading files and sending/receiving messages. Thus, our results imply that the leaderboard proved beneficial for services with more complex user-interaction requirements.

We note that over two-thirds of students who used the leaderboard did so during the initial semester that the coronavirus disease of 2019 (COVID-19) impacted whereby the students transitioned and completed the last seven weeks of the course online as compared to the first part of the course being in person. Conversely, all other students completed the project during a semester with a traditional co-located course.

One might expect that the disruption from COVID-19 would have adversely impacted the course; however, we still saw a significant increase in the leaderboard group. To assess this impact, we removed the COVID-19-impacted students from the sample and reran the test (total sample: 36). Results showed that the leaderboard ($t(77) = -5.39, p < 0.001$) had a highly significant impact in that students without the leaderboard implemented 4.5 services and students with it implemented 5.8. Furthermore, proportional analyses showed a greater proportion of successfully implemented DHCP ($\chi^2(1) = 3.41, p = 0.03$), FTP ($\chi^2(1) = 5.06, p = 0.01$), RDP ($\chi^2(1) = 4.63, p = 0.02$), and email ($\chi^2(1) = 3.90, p = 0.02$) when using a leaderboard. This finding provides even greater credence to the positive impact that the leaderboard in a virtual lab environment has on student learning. Cramer’s V effect sizes also showed a medium effect size for all significant tests (Cohen, 1992).

We also assessed whether the leaderboard actually constituted the distinguishing factor between the two groups. To do so, we ran a post hoc analysis to calculate how much the students actually used the leaderboard. We analyzed Apache logs from the system that hosted the leaderboard to assess how often they used the system during one course semester. We found that, over a one-week period two weeks before the project’s due date, students accessed the leaderboard 6,005 times in total or around 858 times per student. Figure 4 shows that each student accessed the leaderboard from 3 to 38 times per day and that, on average, they accessed it 18 times each day.

<table>
<thead>
<tr>
<th>Service</th>
<th>$\chi^2(1)$</th>
<th>V</th>
<th>No leaderboard</th>
<th>Leaderboard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total sample</td>
<td>DNS</td>
<td>0.97</td>
<td>0.09</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>DHCP</td>
<td>0.17</td>
<td>0.04</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>Web</td>
<td>0.00</td>
<td>0.00</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>FTP</td>
<td>5.01**</td>
<td>0.22</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>RDP</td>
<td>1.60</td>
<td>0.12</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>Email</td>
<td>2.05†</td>
<td>0.15</td>
<td>0.54</td>
</tr>
<tr>
<td>Pre-COVID</td>
<td>DNS</td>
<td>1.63</td>
<td>0.21</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>DHCP</td>
<td>3.41*</td>
<td>0.31</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>Web</td>
<td>0.23</td>
<td>0.08</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>FTP</td>
<td>5.06**</td>
<td>0.37</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>RDP</td>
<td>4.63*</td>
<td>0.36</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>Email</td>
<td>3.90*</td>
<td>0.33</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Table 2. Prop Results ($t p < 0.1, * p < 0.05, ** p < 0.01$)
Inclusion of Gamification Elements in the Context of Virtual Lab Environments to Increase Educational Value

Figure 4. Daily Accesses of the Leaderboard System

This log analysis provides some credence to the assertion that students actually used our manipulation (the leaderboard) in the classes. Specifically, we found that, as expected, students used the system more towards the middle and end of the week. However, students accessed the leaderboard more than 10 times each on Saturday and more than five times per day on Sunday. Thus, we can see that students seemed to find the leaderboard useful not only during class periods but also during non-class days such as on the weekend.

5.2 Self-efficacy (Subjective Outcome Assessment)

We also examined subjects’ task self-efficacy reports to gauge the leaderboard system’s learning effectiveness. For the questionnaire items, we assessed normality using the Jarque-Bera normality test and found that the data did not significantly differ from normal ($\chi^2(2) = 6.12, p = 0.05$). Also, to examine the measure’s reliability, we evaluated Cronbach’s alpha internal consistency for the nine self-efficacy items and found good internal consistency for both the pre-test ($\alpha = 0.94$) and post-test ($\alpha = 0.96$) items. We also ran a confirmatory factor analysis measurement model for the TSE construct with the model fitting well ($\chi^2(25) = 31.61, p = 0.17$, RMSEA = 0.051, CFI = 0.99, SRMR = 0.026). We also calculated composite reliability and found it to be very high for both the pre ($\alpha = 0.95$) and post ($\alpha = 0.96$) constructs. We also found validity to be high with AVE values above 0.5 for both the pre (0.66) and post (0.72) constructs. In addition, individual indicator validity was high with all standardized item loadings for both the pretest and posttest items above 0.7. All the obtained values satisfied recommended thresholds (Chin, 1998; Fornell & Larcker, 1981; Gefen et al., 2000). We then combined the items using a mean score to produce a single pre-test and post-test self-efficacy score. We used analysis of covariance to assess the impact that the leaderboard had. By covarying out the pre-test scores, we obtained a residualized change score to help account for the non-random subject assignment to groups in this experiment (Heppner et al., 2008). Results showed a significant difference in post-test self-efficacy scores ($F(1,97) = 4.232, p = 0.042$, eta-squared = 0.13) in that subjects who lacked exposure to a leaderboard reported a mean self-efficacy of 5.57, whereas subjects who used a leaderboard reported a significantly higher mean self-efficacy of 6.01, which supports H2.

6 Discussion

In this study, we investigate how gamification in a virtual lab environment impacts students’ learning performance. We used multiple methods to evaluate the impact that gamification and virtual labs have on students’ objective and self-assessed performance measures in a networking course. Specifically, we...
used a leaderboard to gamify our system. We posited that students in a gamified virtual lab environment have greater self-efficacy and increased task performance compared to students in a non-gamified environment. We found support for both hypotheses.

First, we used self-efficacy to assess student learning with the gamified virtual lab system. Results showed a significant difference in task-specific self-efficacy scores in the virtual lab environment for students who used the gamified system as compared to students who did not use it. Previous research has shown that gamified elements help to increase self-reported self-efficacy, specifically leaderboard and point elements (Banfield & Wilkerson, 2014; Bonde et al., 2014; Feng et al., 2018; Hamari, 2017; Santhanam et al., 2016; Su & Cheng, 2016; Yang et al., 2016). Furthermore, research has also shown virtual lab environments to have a positive effect on self-efficacy (August et al., 2015; Cooper & Ferreira, 2009; Kongcharoen et al., 2017; Luse et al., 2014; Rursch et al., 2009). Given the positive effect that self-efficacy beliefs have on success in a particular area (Bandura, 1986), the ability of the system that we examined in this research provides promise for increasing individual learning.

Second, using an objective performance measure, we found that students’ task performance increased as they successfully implemented a greater number of services in the virtual lab with the leaderboard as compared to without it. Further analysis showed significant differences in the gamified group for implementing FTP and email services but not for the other four services, which we believe resulted from how much effort students needed to expend to set up FTP and email services. DNS, DHCP, HTTP, and RDP involve only a one-way interaction, while FTP and email services involve more complex uploading/downloading files and sending/receiving messages in addition to the initial connection. Previous research has shown that gamification has a significant impact on cognitive load with regard to tasks (Turan et al., 2016). Cognitive load theory postulates that individuals have limitations in their current working memory to allow for effective learning and instruction (Sweller, 1988). The two more complex tasks to set up FTP and email involve two other steps beyond the initial connection with an “up” or “down” displayed for each task on the leaderboard. Previous research has shown that visualizing network events provides a method to lessen individuals’ cognitive load and, thereby, enable them to better process information and increase performance (Luse et al., 2014). Given that we found students who used the leaderboard for more complex tasks had better performance than students who did not, cognitive load explains this differentiation (August et al., 2015; Bandura, 1986; Banfield & Wilkerson, 2014; Bonde et al., 2014; Cooper & Ferreira, 2009; Feng et al., 2018; Hamari, 2017; Kongcharoen et al., 2017; Luse et al., 2014; Rursch et al., 2009; Santhanam et al., 2016; Su & Cheng, 2016; Yang et al., 2016).

Finally, one critical finding concerns how well the gamified group performed even during the COVID-19 outbreak. We expected poorer task performance and self-efficacy results during a semester that abruptly became completely virtual mid-semester. On the contrary, the gamified virtual lab group still significantly outperformed the non-gamified virtual lab group. This finding provides even greater credence to the positive impact that the gamified virtual lab system had on learning for both a purely online course and the system’s ability to show improvements even during a highly volatile and unique learning semester.

7 Contributions

Conceptually, with this study, we contribute to the SCT literature by using both virtual labs and leaderboards as environmental influences that impact mastery experience and persuasion self-efficacy beliefs in addition to task performance. The leaderboard acts as a way for students to reflect on their continuous achievements in an assignment and, thereby, increase their mastery-experience self-efficacy. The leaderboard also acts as a tool for comparison. Students constantly search for social credibility through achievement recognition, cooperation, and competition. Task-specific self-efficacy beliefs are often associated with task performance, as we found in our virtual lab study.

This study contributes to the gamification literature by extending it to the education context in a virtual lab environment. Although researchers have extensively studied the positive effects of gamification and virtual lab teaching techniques in isolation, we found that gamification and a virtual lab environment in combination have a promising and significant impact on student learning outcomes. Not only do students’ self-beliefs in their capabilities to perform specific tasks increase, but they could also outperform by accomplishing more tasks. Teaching professionals should consider implementing gamified systems in a virtual lab setting to improve student learning and performance.

Also, to assess student educational performance, we used both objective and self-assessed measures. Much behavioral educational research has employed only self-assessed measures, while we used...
objective data to determine learners’ actual performance rather than relying only on self-assessed evaluations. In doing so, we increase our findings’ validity and avoid common method bias concerns that arise when researchers rely only on respondents’ perceptions.

Furthermore, we demonstrated the power of a specific game element: the leaderboard. Most gamification research has implemented game elements in a set and, thus, not isolated specific elements such as leaderboards (Landers et al., 2017). While many educational gamifying systems use leaderboards (Landers et al., 2017; Silva, 2010), researchers have rarely employed it exclusively in designing gamified research (e.g., Landers & Landers, 2014). Our findings extend the literature and validate that leaderboards in a virtual lab environment have both utility and psychological learning outcomes.

Finally, our research provides valuable insights for practitioners and game designers. Our findings suggest that they can design educational software applications by applying leaderboards to enhance learners’ performance by increasing user engagement. In particular, the advent of new technologies and the transformation to online education require instructors and educational institutions to implement new techniques that advance students’ online learning experiences. Since virtual labs appear commonly in many fields such as science, engineering, and IT, finding innovations such as gamification would effectively enhance students learning performance. As we found in this study, leaderboards represent a valuable solution to enhance engagement and improve task performance. Instructors can benefit from using leaderboards when providing experiential learning such as hands-on activities.

8 Limitations and Future Research

Although our study contributes to better explaining the combined role that gamification and virtual labs play in education, it has some limitations. First, our results may depend on the course (a networking course) and the virtual lab for which we implemented the gamified system. Future research may replicate (or re-examine) the analyses using a different course in a virtual lab to generalize our findings. Another limitation concerns personalization in gamification (Passalacqua et al., 2021); specifically, we did not control for individual differences in terms of IT familiarity (or IT innovativeness) or personality in competition-based participation and group activities. Since leaderboards provide such an environment where students can see others’ performance, competitive students may engage more in the assigned project activities and implement more services (higher task accomplishments), while others may not enjoy competition, which means gamification may result in negative outcomes for the latter (e.g., ethical and wellbeing issues) (Benner et al., 2022). Future research could also capture other objective measures such as students’ speed in performing tasks or time to complete tasks. Furthermore, future research could investigate not only whether participants completed a task but how well they did so. We also acknowledge that applying only one element might not be practical as it inherently relates to other elements such as points. Additionally, future research could benefit from structural models or path analyses to examine gamification’s effect on learning outcomes.

9 Conclusion

Past research has highlighted the importance of both virtual labs and gamification in improving learners’ performance but has investigated these two items only in isolation. To investigate the combined effect, we used gamification in a virtual lab environment and found that a gamified leaderboard caused students to accomplish more tasks and, in particular, more complex ones. Furthermore, students also exhibited higher self-efficacy in executing a specific task. The findings show promise for using gamified systems in a virtual lab environment that educators can use to increase student learning.
References


Appendix A

Likert scale from strongly disagree (1) to strongly agree (7).

- I can set up DNS for a network.
- I can set up a web server for individuals to view webpages.
- I can set up DHCP to dynamically configure IP settings for client machines.
- I can set up an email server to send and receive email for a domain.
- I can set up Active Directory to allow network-wide management.
- I can set up FTP to allow for file sharing on my network.
- I can set up a machine to provide routing of traffic between the outside world and my network.
- I can set up a network to allow the machines to connect with each other.
- I can install and setup a server.
About the Authors

Forough Nasirpouri Shadbad is an Assistant Professor at Oregon State University, College of Business. Her research interests include intentional/unintentional insider threats, technostress, gamification, and information privacy in social networking sites. She has published in European Journal of Information Systems, Information Technology & People, Journal of Computer Information Systems, Communications of the Association for Information Systems, and in the proceedings of the Americas Conference on Information Systems, the Hawaii International Conference on Systems Sciences, and other proceedings.

Gabriel Bahr is a Visiting Professor at Oklahoma State University, Spears School of Business. He has published in the proceedings of the Hawaii International Conference on System Sciences and the Institute for Operations Research and Management Sciences. He enjoys researching and writing about topics on information and communication technology for development, international technology diffusion, gamification, and country-level analysis.

Andy Luse is a William S. Spears Chair in Business and Associate Professor of Management Science and Information Systems in the Spears School of Business at Oklahoma State University. He received a BA degree in Computer Science from Simpson College, MS degrees in Information Assurance, Computer Engineering, Business Administration, and Psychology, and PhD degrees in Human Computer Interaction, Computer Engineering, and Information Systems from Iowa State University. He has been published in the Journal of Management Information Systems, Journal of the Association for Information Systems, Journal of Business Research, Communications of the Association for Information Systems, Decision Support Systems, Computers in Human Behavior, and many other outlets.

Bryan Iwata Hammer is an assistant professor at the University of Montana. He received a PhD in Business Administration from the University of Arkansas. His research interests include interpersonal trust and privacy in virtual work groups, heuristics and their psychophysiological basis in online information disclosure, technology's impact on individuals with intellectual and developmental disabilities, and text-based deception detection. His research has appeared in outlets such as MIS Quarterly, Journal of the Association for Information Systems, Information Systems Journal, Journal of Strategic Information Systems, Communications of the Association for Information Systems, the International Conference on Information Systems, International Journal of People-Oriented Programming, and Proceedings of the NeuroIS Gmunden Retreat.