

Best of Both Worlds: The Inclusion of Gamification in Virtual Lab Environments to Increase Educational Value

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Abstract

Previous research investigating gamification and virtual laboratories has suggested that both are successful in educational outcomes, but few have looked at both gamification and virtual labs in tandem. This research explores the idea of investigating both contexts within one unified platform. We examine whether gamification within virtual labs is effective in enhancing learners' educational performance. Particularly, we employ leaderboards as a motivational gamification mechanism for more engagement and participation that can result in higher learning outcomes. Using a sample of students, our results show that utilization of gamification within a virtual lab environment causes students to exhibit higher performance in terms of more task accomplishments (specifically more complex tasks) and higher self-efficacy. The current findings show promising evidence on the positive influence of gamification within virtual lab learning environments.

Keywords: gamification, leaderboards, virtual labs.

1. Introduction

Technology discontinuance is a common problem (Saeed & Abdinnour, 2013), often due to low perceptions of fun, enjoyment, and engagement (Salimon et al., 2017). To increase users' satisfaction in technological applications, scholars have attempted to utilize the potential benefits of game designs in enhancing user motivations through gamification (Rigby & Ryan, 2011; Yee, 2006). In the context of education, scholars have extensively investigated the effect of gamified systems on learning outcomes in which gamification can be considered an effective tool to improve the learning environment due to enhanced social interaction and engagement (Cheong et al., 2019). The usefulness of gamified elements in educational settings has been shown in increased student participation, engagement, lecture attendance, assignment scores, and the understanding of concepts (Betts et al., 2013; Gibson et al., 2015; Isabelle, 2020).

In addition to educational gamification, virtual laboratories have also been heavily researched in relation to improving the overall educational experience. Virtual laboratories provide a unique environment for providing "hands-on" learning within 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 (Li & Mohammed, 2008; Wolf, 2009). Virtual laboratories have shown usefulness in many areas including 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 in order to gain valuable insight into the connectivity and interactivity of devices without the overhead of personal hardware and software. While both gamification and virtual labs provide valuable contributions to education, little research has investigated gamification within the context of virtual labs, leaving a gap where research should investigate the effect of these two in tandem. Since many institutions have moved to virtual education (especially after the pandemic), it is worth investigating how a combination of both could influence student performance (Dustman et al., 2021).

Although past research provided noteworthy contributions to the gamification literature, generally, the behavioral and psychological outcomes of gamification are assessed based on self-reported measures and quasi-experiments are utilized to observe short-term effects (Schöbel et al., 2020). Recently, IS scholars have put forth a research agenda for future gamification studies. In particular, Schöbel et al. (2020) call for studies on investigating the effect of specific game design elements on specific outcomes and designing longitudinal experiments to evaluate user behaviors objectively. Furthermore, Osatuyi et al. (2018) highlighted the existing research gap of gamification within education settings and invited researchers to study collaborative and interconnective effects of gamification within teams/groups in gamified learning environments. They also encourage researchers to examine how game elements contribute

to higher learning performance beyond the classroom. Therefore, our proposed research question asks: “How effective is the use of game elements (e.g., leaderboard) within virtual labs for collaborative groups to enhance learners’ educational performance?” To this end, we conduct a long-term experimental study that applies gamification within virtual labs using a sample of students from a networking course who work in dyadic teams. We use a leaderboard as a common game element and as a design principle of gamified educational applications (Landers et al., 2017; Zichermann & Cunningham, 2011). We use two proxies to measure students’ learning performance: an objective variable to measure the number of implemented services and a self-assessed measure of task-specific self-efficacy (Santhanam et al., 2013). Findings show that the leaderboard provides significant increases in both the number of services implemented and individual levels of self-efficacy. Further analysis shows that the leaderboard has significant impacts 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 the system (Deterding et al., 2011). Gamified systems follow incentive mechanisms to increase user interest and motivation to effective system use, exploration, and engagement (Bitrián et al., 2021; Faiella & Ricciardi, 2015). Incentives consist of game elements to 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) as well as utilitarian outcomes such as usefulness and/or work-related benefits (Liu et al., 2017). There is no consensus on a comprehensive list of game elements to ensure which motivational affordances make a system gamified. Affordance are the potential features of a system that utilize user motivations to gain experiential outcomes through interactions with systems (Deterding et al., 2011). The selection of game elements are relatively subjective (Sailer et al., 2017); however, decisions to select game elements should fulfill the criteria in creating enjoyable and playful activities (Werbach, 2014). The common motivational affordances used in

gamification literature are points, leaderboards, badges, levels, story, feedbacks, clear goals, rewards, progress, and challenge, where points and leaderboards are recognized to frequently be implemented in gamified contexts (Hamari et al., 2014). Points work as a rewarding measure in which users are compensated 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 are used to provide a competitive environment and a sense of eagerness to help users accomplish activities (Nah et al., 2014).

Application of game elements in various information systems has provided promising findings in psychological and behavioral outcomes in different contexts including healthcare, marketing, task performance, social networking, and education (Dicheva et al., 2015; Hammedi et al., 2017; Huotari & Hamari, 2012; Mekler et al., 2017; Simões et al., 2013). Psychological outcomes include enjoyment, engagement, fun, satisfaction, and social motivation (Cheong et al., 2013; Guin et al., 2012; Li et al., 2012) while behavioral outcomes include participation, learning outcomes, task completion speed, user contribution amounts, time management, intention to use, and task productivity (Domínguez et al., 2013; Farzan et al., 2008; Hamari & Koivisto, 2013; Isabelle, 2020; Jung et al., 2010). Systematic literature reviews suggest that gamification research mostly focuses on behavioral outcomes rather than psychological outcomes. In particular, educational learning outcomes are the most common research objectives for the implementation of gamification (Hamari et al., 2014) since gamification can be successfully operationalized for effective instructional methods (Sailer & Homner, 2020; Saleem et al., 2022; Zainuddin et al., 2020).

2.2 Virtual Labs

Virtual laboratories have gained popularity in higher education as a mechanism for effectively teaching hands-on concepts. Traditional lab environments, while effective, can become cost prohibitive (Wolf, 2009) and are not conducive to the increasing number of online students (Li & Mohammed, 2008). Conversely, virtual labs provide a realistic learning environment that is both cost effective and more easily implementable for online students (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 mimicking the real-world (Rursch & Jacobson, 2013).

Specifically, in the area of networking, virtual laboratories have been utilized to enable effective learning of hands-on networking concepts (Luse & Rursch, 2021; Ruiz-Martinez et al., 2013; Wolf, 2009) as well as related areas such as network security (Willems & Meinel, 2012; Xu et al., 2013). Overall, virtual laboratories have shown to be a viable option for teaching computer network and security concepts.

While virtual laboratories have been utilized extensively for learning, little research has investigated the use of gamification within these virtual lab environments. One notable example is work by Luthon and Larroque (2014) using game-like training. Within their environment, students were able to remotely control physical robotic arms to build physical circuits for electrical engineering. Their environment provided a leaderboard for users as a gamified dimension. While very useful, their environment was centered around electrical engineering as opposed to computer networking and security. Furthermore, their lab was not completely virtual but involved a hybrid lab whereby physical elements were still utilized for the lab.

A few other studies also utilized 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 instead of a lecture. However, these studies lack using collaborative game elements such as leaderboards or points tracking to engage students in an online experience.

3. Hypothesis Development

Research on gamification has revealed that gamified systems have the potential to enhance the productivity of teaching and learning outcomes in many ways. First, gamification influences learning through enhanced instructional effectiveness by changing learners' behavior/attitudes (Landers, 2014). Second, due to the social dimensionality of gamified applications, learners perceive social credibility via recognition of their achievements (Faiella & Ricciardi, 2015). The positive emotions, in turn, may impact students' scores and performance (Kapp, 2012). Moreover, cooperation and competition as parts of gamified applications provide a challenging area for performance-comparison that make trainees compete with others to achieve better learning outcomes (Santhanam et al., 2016). Finally, motivation and engagement, as crucial elements of education, can be fulfilled by gamified learning applications (Hamari et al., 2016; Shin, 2006). Student engagement in learning

activities can be derived through behavioral involvement (participation and attention), cognitive involvement (to learn a subject), and affective involvement (interest to perform tasks) (Kahu, 2013).

Past research has examined the effect of gamification (i.e. gamified learning software, badged-based) on educational outcomes- both objective (e.g., number of participations in class activities, exam scores, and time of task completion) and self-assessed measures (e.g., engagement, enjoyment, 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 where one was exposed to a gamified system and the other a non-gamified tutorial system. They found the gamified group accomplished tasks faster and reported higher engagement.

Gamification research established the effectiveness of using a set of game elements where points, progress bars, levels, badges, leaderboards, and avatars are the most commonly used elements (Dicheva et al., 2015). These elements usually are used together to provide an engaging environment for active learners to enhance the level of content understanding using both traditional and flipped classroom (Giannetto et al., 2013; Mitchell et al., 2013; O'Donovan et al., 2013). Additionally, a virtual learning environment using game-based feedback and award points had a positive influence on students' perceptions of their academic standing (Charles et al., 2011). In the context of information security training, 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 make users acquire more knowledge and demonstrate higher satisfaction.

The leaderboard is a common element used in gamifying systems to increase the effectiveness of various outcomes (Landers et al., 2017; Silva, 2010); however, it is rarely employed exclusively in designing gamified research. 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, or number of edits. In the context of education, research by Domínguez et al. (2013) showed that using a leaderboard can have positive effects on learners' performance finding that students who experienced gamified education had higher scores in practical assignments.

Virtual labs have also been shown to impact objective measures of performance for students utilizing these systems. Online laboratories integrating learning management systems for general engineering topics have been shown to impact student scores on

the understanding of the implemented topics (Ruano et al., 2016). LaboREM, a hybrid physical/online laboratory for remotely interacting with electronics, has also been shown to impact student scores and completion times (Luthon & Larroque, 2014). Further work in hybrid physical/online laboratories has also been shown to impact student scores (Bochicchio & Longo, 2009). In the area of network security, online laboratories have been shown to allow students to achieve scores that are on par with traditional physical labs (Luse et al., 2021). Given the research on both gamification and virtual labs demonstrates the ability to impact student performance, we hypothesize these combined elements will increase student performance related to networking concepts.

Hypothesis 1: *Individuals using a leaderboard within a virtual lab environment will successfully implement a greater number of network services as compared to those not using a leaderboard.*

As mentioned above, one important self-assessed educational outcome is self-efficacy (Santhanam et al., 2016). Self-efficacy is defined as a person's perceptions of his/her capabilities to perform required actions to gain a certain achievement (Bandura, 1986). Gamified systems, using social comparison elements, provide an environment for users to improve their self-efficacy beliefs in order to outperform others and exhibit higher levels of learning outcomes (Santhanam et al., 2016). Game mechanics such as leaderboard rankings can be used as a goal to enhance user performance in terms of self-efficacy (Hamari, 2017; Yang et al., 2016). Furthermore, rewarding points and giving feedback are positively related to self-efficacy (Feng et al., 2018). There is evidence that suggests gamification-based education increases user performance and self-efficacy (Banfield & Wilkerson, 2014; Bonde et al., 2014; Su & Cheng, 2016).

Virtual labs have also been shown to increase student self-assessments of their abilities (Wolf, 2009). Virtual world learning environments for STEM education have been shown to increase self-efficacy in the engineering sciences (August et al., 2015). Hybrid virtual/physical engineering labs have also been shown to increase self-efficacy (Cooper & Ferreira, 2009). Specifically, in the area of computer and network security, virtual laboratories have been shown to increase student self-efficacy (Kongcharoen et al., 2017) as well as task specific self-efficacy in the area of networking (Luse et al., 2014; Rursch et al., 2009). Given the advantages of both gamified elements and virtual laboratories for increasing student self-assessments of their abilities, we hypothesize these

combined elements will provide improvements in self-efficacy related to networking concepts.

Hypothesis 2: *Individuals using a leaderboard within a virtual lab environment will have a greater level of task-specific self-efficacy as compared to those not using a leaderboard.*

4. Methodology

4.1 Sample and Design

To investigate the hypotheses, a longitudinal experiment was designed using two groups of students engaged in gamified and non-gamified class activities. Subjects for this research were students from five sections of a networking course across five separate semesters at a large Midwestern university. The course was required of all IS majors but was the first course in the area of networking. Each section had around 40 students, with all students completing the same exact project using the same exact environment. The project was completed 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). Students were given new modules each week for each of the services to build towards a complete corporate environment. While much of the work could be done in class, the students also had access to the system anytime outside of class.

In total, 120 dyads from five separate semesters were included as part of the study, with 63 of the pairs not utilizing the leaderboard and the remaining 57 utilizing the leaderboard display. Previous research looking at pre and posttest scores of task-specific self-efficacy within the context of virtual labs found that a sample size of 35 is needed to provide necessary power to find results (Luse et al., 2020). Given the field experiment nature of the study, sample size was taken from those actually taking the course and not balanced as in a lab experiment. Student groups were tasked with implementing all the required services just as a corporate network would provide these services to their users. Table 1 presents descriptive statistics of our sample. These descriptive statistics show that most of the students had none (1) to little (2) networking experience prior to the course, most thought they would use some (3) of the concepts in the course in their future job, and the students had on average more than 3 IS courses prior to the course. Males and US Citizens accounted for the majority of the samples.

4.2 Procedure and Learning measures

	Leaderboard	Non-Leaderboard
net courses	1.7 (none/little)	1.93 (none/little)
future job	2.47(little/some)	3.25 (some/quite a bit)
IS courses	4.5	3.23
males	88%	82%
US Citizen	91%	94%

Table 1. Sample descriptive statistics.

We utilized the ISEAGE virtual internet environment. The environment provides a virtualized “internet” experience whereby users are given public IPs, DNS names, and other functionality that is available on the outside internet. The virtual lab then provides routing functionality to allow students to setup corporate environments, including web, file sharing, email, etc., as well as access other students’ corporate environments. The ISEAGE environment has been utilized for cyber defense competitions (Luse et al., 2014; Rursch et al., 2009) and more recently, for traditional courses on networking and security (Luse et al., 2021). For this research, the students were each given 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, a student would be given an IP range of 123.45.67.0/24 with a DNS name of corp1.com. The student was then in charge of setting up a webpage at www.corp1.com, file transfer at ftp.corp1.com, email at webmail.copr1.com, RDP access at rdp.corp1.com, as well as DHCP service for internal clients and DNS service so all the services were available using the URL’s indicated.

A gamified leaderboard was setup for the experimental manipulation consisting of a webpage displaying the status of each of the services listed (a green “up” or red “down”). This webpage ran a script every 20 minutes to check the status of each of the services. The script would programmatically act as a “typical user” by connecting to each service to gauge functionality. For example, the script would connect to each student webpage; if the webpage was accessible, then the service would be categorized as “up”, otherwise the service would be categorized as “down.” The students have the entire duration of the project to get as many services as possible up and working and can try anything from within the course or their collective knowledge to get these services up and running. This leaderboard provided a unique link between the virtual environment and the public world by providing a publicly accessible leaderboard for users showing an evaluation of services in the virtual environment. Each student pair is presented on the leaderboard as one entity where the status of each

service is presented for the group as a whole. Students are able to see which students have more services up and running to enable them to gauge their progress as compared to others in the course.

An experiment was designed in order to test the impact of the leaderboard. Three semesters of the course completed the entire project without the use of the leaderboard while two semesters completed the course with the leaderboard. An objective measure of service functionality was used to evaluate the two conditions by analyzing the functionality of six different services implemented for the project: domain name service (DNS), dynamic host configuration protocol (DHCP), web (HTTP), file transfer protocol (FTP), remote desktop protocol (RDP), and email.

Of note is that over two-thirds of those utilizing the leaderboard did so during the initial semester impacted by the COVID-19 virus 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.

Learning differences were also evaluated using longitudinally, self-assessed measures of learning efficacy. Self-efficacy (Bandura, 1986) provides a measure of self-beliefs about personal ability which, in tandem with the objective skills measure provides a more robust overall assessment (Scheibe et al., 2007). Task self-efficacy has been shown to provide a valid mechanism for evaluating self-efficacy in a specific area (Marakas et al., 2007). Given this, a measure of task-specific self-efficacy in the area of network/infrastructure was utilized from previous research (Davazdahemami et al., 2018) with the questions provided in Appendix A. A pretest-posttest longitudinal design was implemented as advised in previous literature (Heppner et al., 2008). The students in all sections were asked the same set of nine questions both before the project and after the project at the end of the semester.

5. Results

5.1 Services

Services were first analyzed to assess the overall implementation of the deliverables for the project. First, the total number of services correctly implemented was tallied using a single number from zero to six that identified the total number of services implemented. A two-sample t-test was run to evaluate the total number of services implemented by those sections where the leaderboard was not present vs. present. Results showed a significant difference in the

number of services implemented ($t_{(117)} = -1.74$, $p = 0.04$) where those without the leaderboard implemented 4.5 services whereas those with the leaderboard implemented over 5, supporting H1.

To gain greater insight into the impact of the leaderboard, each of the six services was analyzed independently with a dichotomous outcome variable of not implemented (0) or implemented (1). Using a Fisher's exact proportional test, the number who implemented each service was analyzed for differences between the two groups. Findings show 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 where the proportion of those who implemented FTP and email were greater in the leaderboard group (0.89 and 0.68, respectively) as 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 one-way interaction of connecting to the service, whereas FTP and email involve further interaction beyond initial connection, including uploading/downloading files and sending/receiving messages. This implies the leaderboard is beneficial for those services that are more complex in their user interaction requirements.

It would be expected that the disruption of COVID would adversely impact the course, yet given that we are still seeing a significant increase in the leaderboard group is even more compelling. To assess this impact, the COVID-19 impacted students were removed from the sample and the test rerun (with a total sample of 36). Results showed a highly significant impact of the leaderboard $t_{(77)} = -5.39$, $p < 0.001$ where those without the leaderboard implemented 4.5 services, and those with the leaderboard implemented 5.8. Furthermore, proportional analyses showed a greater proportion 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 utilizing a leaderboard. This provides even greater credence to the positive impact of the leaderboard in a virtual lab environment. Cramer's V effect sizes also show a medium effect size for all significant tests (Cohen, 1992). Table 2 shows the proportional results.

5.2 Self-efficacy

Subject reports of task self-efficacy were also examined to gauge the learning effectiveness of the leaderboard system. For the questionnaire items, we assessed normality using the Jarque-Bera normality test and found that the data is not significantly

different from normal ($\chi^2_{(2)} = 6.12$, $p = 0.05$). Also, to examine the reliability of the measure, Cronbach's alpha internal consistency was evaluated for the nine self-efficacy items, finding good internal consistency for both the pretest ($\alpha = 0.94$) and posttest ($\alpha = 0.96$) items. A confirmatory factor analysis measurement model was also run 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). From this we calculated composite reliability and found it to also be very high for both the pre (0.95) and post (0.96) constructs. Validity was also found to be high with AVE values above 0.5 for both pre (0.66) and post (0.72). In addition, individual indicator validity was high with all standardized item loadings for both the pretest and posttest items being above 0.7. All the obtained values satisfied recommended thresholds (Chin, 1998; Fornell & Larcker, 1981; Gefen et al., 2000). The items were then combined using a mean score to produce a single pretest and posttest self-efficacy score. Analysis of covariance was used to assess the impact of the leaderboard. By covarying out the pretest scores, this provides a residualized change score to help account for the non-random assignment of subjects to groups in this experiment (Heppner et al., 2008). Results found a significant difference in posttest self-efficacy scores ($F_{(1,97)} = 4.232$, $p = 0.042$, eta-squared = 0.13) where those not exposed to a leaderboard reported a mean self-efficacy of 5.57 whereas those utilizing a leaderboard reported a significantly higher mean self-efficacy of 6.01, supporting H2.

	Service	$\chi^2_{(1)}$	Proportion		
			V	No leaderboard	Leader-board
Total sample	DNS	0.97	0.09	0.86	0.93
	DHCP	0.17	0.04	0.78	0.82
	web	0.00	0.00	0.94	0.93
	FTP	5.01**	0.22	0.71	0.89
	RDP	1.60	0.12	0.73	0.84
	email	2.05 †	0.15	0.54	0.68
Pre-Covid	DNS	1.63	0.21	0.88	1
	DHCP	3.41 *	0.31	0.78	1
	web	0.23	0.08	0.94	1
	FTP	5.06**	0.37	0.71	1
	RDP	4.63*	0.36	0.73	1
	email	3.90*	0.33	0.54	0.83

Table 2. Prop results († $p < 0.1$, * $p < 0.05$, ** $p < 0.01$).

6. Discussion, Contributions, Limitations

The objective of this study was to investigate how gamification within a virtual lab environment impacts students' learning performance. Multiple methods

were utilized to evaluate the impact of the effect of gamification and virtual labs on students' objective and self-assessed performance measures within a networking course. Specifically, we used a leaderboard to gamify our system. We posited that students within a gamified virtual lab environment have an increased task performance measure and greater self-efficacy compared to students who are in the non-gamified environment, with both supported.

First, using an objective measure of performance, we found that student's task performance increased, whereby students successfully implemented a greater number of services in the virtual lab when gamification was present as compared to not present. Further analysis showed significant differences within the gamified group for implementing FTP and email services, but not for the other four services. We believe this is due to the level of involvement required to setup FTP and email services. DNS, DHCP, HTTP, and RDP only involve a one-way interaction instead of the more complex uploading/downloading of files and sending/receiving messages in addition to the initial connection. Previous research has shown significant impacts of gamification on cognitive load with regard to tasks (Turan et al., 2016). Cognitive load theory postulates that there are limitations placed on current working memory to allow for effective learning and instruction (Sweller, 1988). The two more complex tasks of FTP and email involve two other steps beyond initial connection, with an "up" or "down" displayed for each of these tasks on the leaderboard visualization. Previous research has shown that visualization of network events provide a method to lessen cognitive load of individuals and thereby enable those individuals to better process information and increase performance (Luse et al., 2014). Given the increased performance of those using the gamified leaderboard visualization for more complex tasks, cognitive load explains this differentiation.

Second, self-efficacy was used 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 those who used the gamified system as compared to those 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, virtual lab environments have also been shown 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 of self-efficacy beliefs on success in a

particular area (Bandura, 1986), the ability of the system used in this research provides promise for increasing individual learning.

Finally, one critical finding was 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 went completely virtual in the middle of the semester. On the contrary, the gamified virtual lab group still significantly outperformed the non-gamified virtual lab group. This provides even greater credence to the positive impact on learning of the gamified virtual lab system for both a purely online course as well as the ability of the system to show improvements even during a highly volatile and unique learning semester.

This study contributes to the literature by extending gamification to the context of education within a virtual lab environment. Although the positive effects of gamification and virtual lab teaching techniques have been extensively studied *in isolation*, the results of this study revealed that a *joint* effect of gamification and a virtual lab environment is promising, and together they can provide a significant impact on student learning outcomes. Students can outperform in terms of the number of task accomplishments and beliefs in their capabilities to execute specific tasks. Teaching professionals should consider the implementation of gamified systems within 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 of the behavioral educational research employs only self-assessed measures, while in this study, we used objective data of learners' actual performance instead of only relying on self-assessed evaluations. This increases the validity of our findings as common method bias is not a concern in this study due to respondents' perceptions.

Furthermore, this study demonstrated the power of a specific game element: *leaderboard*. The majority of gamification research implements a set of game elements together, and a specific element like a leaderboard is not isolated in the research design (Landers et al., 2017). While the leaderboard is a common element used in educational gamifying systems (Landers et al., 2017; Silva, 2010), it is rarely employed exclusively in designing gamified research such as work by Landers and Landers (2014). Our findings extend the literature and validate the use of leaderboards in a virtual lab environment for both utility and psychological learning outcomes. This can provide valuable insights for practitioners and game designers. Educational software applications can be designed by applying leaderboards to enhance

learners' performance by increasing user engagement. However, we acknowledge that application of only one element might not be practical as it inherently relates to other elements such as points.

Although our study contributes to a better understanding of the combined role of gamification and virtual labs in education, it has some limitations. First, the results of this study may depend on the course and the virtual lab for which the gamified system was implemented. Here, we used a networking course. Future research may replicate (or re-examine) the analyses using a different course using a virtual lab to generalize our findings. Another limitation is that 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 that students can see others' performance, those students who are competitive may engage more in the assigned project activities and implement more services (higher task accomplishments). Another area for future research could capture other objective measures like students' speed in performing tasks or time of task completion.

7. Conclusion

Past research has highlighted the importance of both virtual labs and the gamification in improving learners' performance, but these two items have only been investigated in isolation. To investigate the combined effect, we utilized gamification within a virtual lab environment. Results found that a gamified leaderboard causes students to accomplish more tasks, specifically those tasks that are more complex in nature. Furthermore, students also exhibited higher self-efficacy in executing a specific task. The findings show promise for the use of gamified systems within a virtual lab environment that can be utilized by educators to increase student learning. Additionally, future research could benefit from structural model or path analysis to examine the effectiveness of gamification on learning outcomes.

8. References

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9. Appendix A

Likert from 1 (Strongly Disagree) to 7 (Strongly Agree).

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