Higher Education Studies; Vol. 12, No. 1; 2022
ISSN 1925-4741 E-ISSN 1925-475X
Published by Canadian Center of Science and Education

Assessing Students‟ Approaches and Perceptions to Learning in Physics Experiments Based on Simulations and At-Home Lab Kits

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Received: December 10, 2021 Accepted: January 13, 2022 Online Published: January 15, 2022

doi:10.5539/hes.v12n1p96 URL: https://doi.org/10.5539/hes.v12n1p96

Abstract

Our study evaluates students‟ approaches to and perceptions of the use of hands-on at-home laboratory kits (HALK) experiments, open-source computer-based simulations (OSCBS), and their combination (OSCBS-HALK) in undergraduate introductory asynchronous online physics courses. Anonymous survey data from students who had completed online physics courses with labs based on simulations, at-home lab kits, or both were collected using a modified version of the Learn Questionnaire (MVLQ). Findings in this study indicate that among the six scales (interest and relevance; peer support; staff enthusiasm and support; teaching for understanding; alignment; and constructive feedback) used to measure students‟ perceptions of the teaching and learning environments, interest and relevance, peer support, and teaching for understanding had statistically significant different means across the three lab types. Post-hoc comparisons using the Tukey HSD test for the interest and relevance scale indicated that students viewed using a combination approach of OSCBS and HALK labs ($M = 3.98$, $SD = 0.61$) more significantly positive than using computer-simulated labs only ($M = 3.56$, $SD = 0.75$). Compared to other labs, computer-simulated labs were perceived to lead to a deep approach to learning. However, they had the lowest interest and relevance, peer support, and alignment ranking among the three lab groups. Thus, developing strategies to improve students‟ engagement and ability to translate the simulations into physical processes is recommended for OSCBS.

Keywords: hands-on experiments, learning approaches, computer simulations, students‟ perceptions, virtual physics labs

1. Introduction

1.1 The Need for Physics Experience

Laboratory activities form the fundamental experimental foundation and an inductive process through which students learn how to perform physics investigations. Based on the American Association of Physics Teachers (AAPT), six student learning outcomes are recommended for physics curricula (Kozminski et al., 2014): 1) constructing knowledge; 2) modeling; 3) developing technical and practical laboratory skills; 4) analyzing and visualizing data; 5) designing experiments, and 6) communicating physics. The primary goal of the laboratory experience is to reinforce class concepts assimilation through experimental observation. However, studies have shown that perceptions and approaches to learning are dependent on learning environments (Asikainen et al., 2014; Campbell et al., 2001; Entwistle et al., 1993; Entwistle et al., 2003; Herrmann et al., 2017; Struyven et al., 2005). The learning environment is fundamentally different between traditional face-to-face and OSCBS or HALK physics experiments.

Studies persistently show that students' perceptions and approaches to learning influence their understanding of course content (Al-Qahtani, 2015; Campbell et al., 2001; Lizzio et al., 2002; Richardson, 2005; Tudor et al., 2010). The learning environment also influences students‟ perceptions of and approaches to learning and the learning strategies used (Biggs, 1993; Entwistle et al., 1993; Entwistle et al., 2003). With the increasing demand for online education, computer-simulated and home-operated lab kits-based activities are increasingly being used to satisfy the laboratory component for undergraduate online physics courses. Computer simulations and home-delivered kits provide flexibility, bridge accessibility gaps associated with distance and online education, and help meet some of the learning outcomes discussed above.

1.2 Problem Statement

With the demand for online education increased due to the COVID-19 outbreak, universities may continue with hybrid delivery models involving OSCBS and HALK labs. Thus, examining the impact of these lab activities on students‟ learning experiences remains a high priority. Struyven et al. (2005) identified two major approaches to learning that are pertinent to this study; 1) Surface approaches to learning - completing a task with insignificant personal engagement; and 2) Deep approaches to learning - active conceptual analysis leading to a deep level of understanding. In addition, Entwistle et al. (2003) identified organized effort as another student learning approach. An assessment of these approaches provides an understanding of the level of students‟ engagement and understanding of concepts in asynchronous OSCBS and HALK laboratory activities. Asikainen et al. (2014) suggested that developing the deep approach to learning at the undergraduate level requires activities that support students‟ knowledge construction, critical thinking, and problem-solving skills. While the relationship between students‟ perceptions of the teaching-learning environment and approaches to learning have been examined and found to be predominantly positive in the Business and Social Sciences programs (Herrmann et al., 2017), little attention has been given to emerging remote physics lab modalities. Sithole et al. (2020) noted that the delivery of remote non-traditional physics labs poses the most significant challenge to physics educators in asynchronous online courses. For non-traditional labs to meet the intended learning outcomes, it is essential to understand the association between them and approaches to learning and students‟ perceptions of them. This study seeks to contribute knowledge in the delivery of physics labs in line with the AAPT recommended student learning outcomes (Kozminski et al., 2014).

Laboratory experience is critical in cultivating the vital skills needed in today‟s technology-driven careers. While OSCBS and HALK labs have been integrated into online physics courses for some time now, resistance to their widespread use and concerns about their impact on student learning remain prevalent (Brinson, 2015). Understanding students‟ perceptions of learning and approaches to learning are essential for student recruitment (Loshbaugh & Claar, 2007), retention (Sithole et al., 2017), identity and learning (Tudor et al., 2010).

1.3 Aim of the Study

This study examines students‟ perceptions of and approaches to online learning using OSCBS and HALK physics lab kits in asynchronous online physics experiments. The study seeks to answer the following questions: 1) What are students‟ perceptions of computer-based simulations and home-delivered physics lab kits? and 2) Is there a relationship between approaches to learning and organized effort (studies and time management) and lab types?

2. Materials and Methods

2.1 Data Sources and Inclusion

Through SurveyGizimo (now called Alchemy) data acquisition platform, anonymous responses to the modified version of the Learn Questionnaire (MVLQ) were solicited from undergraduate students at selected colleges and universities in the United States (US) Midwest who had completed online physics courses utilizing OSCBS, HALK, or OSCBS-HALK as substantive lab components. The HALK activities involved using unsupervised at-home laboratory kits, while OSCBS experiments involved running open-source physics simulations on computers. In both cases, students had no direct supervision. Using an anonymous online questionnaire with a 5-point Likert scale (ranging from 1 „strongly disagree‟ to 5 „strongly agree‟), students responded to items on the perceptions of the teaching-learning environment and the approaches to learning. Responses for each of the constructs were scaled from one to five. A high score on every construct (e.g., 5) equated with a heightened perception of the teaching-learning environment and increased satisfaction with approaches to learning. Respondents who consented to the study but did not submit any response were excluded from further analysis. The study protocol and procedures were approved by the Institutional Review Boards.

2.2 Measures and Scale Generation

To measure students‟ perceptions of OSCBS and HALK labs, we developed the Modified Version of the Learn Questionnaire (MVLQ) based on the Learn Questionnaire (LQ) (Parpala & Lindblom-Ylänne, 2012) and validated by Herrmann et al. (2017). While the LQ is a robust, versatile, and reflective tool (Parpala & Lindblom-Ylänne, 2012) and has been used in various disciplines, modification of items in LQ was undertaken to suit physics laboratory procedures and to correctly measure the students‟ approaches to learning (SAL), perceptions to the learning environment (PLE) and teaching-learning environment (TLE) in physics remote labs. Further, the LQ was developed for an education system different from the US, underscoring the need for adjustments. The PLE, SAL, and TLE scales had 11, 12, and 22 items, respectively, on the MVLQ. In addition, four open-ended questions were included to understand some of the challenges students face when utilizing OSCBS, HALK, or OSCBS-HALK and their suggestions for improving these labs.

2.3 Statistical Analyses

For every student, a score for each construct in the teaching-learning environment and approaches to learning was calculated as the mean of all items contributing to the construct. Analyses of variance (ANOVA) were used to assess the effect of laboratory-type on the students‟ approaches and perceptions of learning. The reliability of each of the constructs was assessed using Cronbach alpha. All statistical analyses were conducted using IBM SPSS version 26, and a significance level of 0.05 was used.

3. Results

3.1 Participant Characteristics

A total of 108 students were included in the final sample for analysis. Most of the students who participated were male (56%), had a GPA of more than 3.5 (51.9%), were from the Engineering degree program (50%), or doing their physics labs using computer simulations (49.1%). The descriptive statistics of the participants are presented in Table 1.

Table 1. Characteristics of students who participated in the study

Characteristics	N (%)
Gender	
Male	60 (55.6%)
Female	48 (44.4%)
Level of education	
Freshman	8 (7.4%)
Junior	34 (31.5%)
Senior	32 (29.6%)
Sophomore	34 (31.5%)
GPA (4.0 scale)	
Less or equal to 3.5	52 (48.1%)
More than 3.5	56 (51.9)
Degree Program Area	
Engineering	54 (50.0%)
Life Sciences	37 (34.3%)
Other	17 (15.7%)
Tutor Assistance	
Yes	24 (22.2%)
No	77 (71.3%)
No answer	7 (6.5%)
Physics Lab Types	
Computer simulations	53 (49.1%)
Physics home-based experiments	6 (5.6%)
Both computer-simulated & home based	42 (38.9%)
No answer	7 (6.5%)

3.2 Students' Perceptions of the Teaching-Learning Environment

All the items regarding students‟ perception of the teaching-learning environment were grouped to measure student perception towards the learning environment. Then, a mean score for each construct was calculated. For interpretation purposes, the mean score was divided into three primary levels: a) 0.00–2.00 = low level of agreement; b) 2.01–3.00 = moderate level of agreement; and c) 3.01–5.00 = high level of agreement. Table 2 shows the main descriptive statistics of the six scales assessing the students‟ perceptions of the teaching-learning environment and internal reliability. All six constructs of the teaching-learning environment showed high agreement across the six scales, irrespective of the lab type. Mean scores of peer support and alignment were highly rated, indicating that students favorably perceived the two compared to other teaching and learning environment scales. The Cronbach‟s alpha values, used to assess the instrument‟s internal reliability, were consistently in the good range (0.76 to 0.87) for four of the six scales. Peer support, Interest, and Relevance showed potential problems concerning internal reliability (alpha < 0.70).

Table 2. Descriptive statistics for scales reflecting students‟‟perceptions of the teaching-learning environment

Measure	Items	Mean	Std. Deviation	Skewness	Kurtosis	Alpha
Interest and relevance	TLE (4,9,13)	3.75	0.7	-0.11	-0.3	0.58
Peer support	TLE (8,11,15)	3.84	0.76	-0.46	-0.13	0.64
Staff enthusiasm and support	TLE (10,12,14,16)	3.62	0.83	-0.1	-0.54	0.77
Teaching for understanding	TLE (5,6,7)	3.68	0.83	-0.14	-0.57	0.83
Alignment	TLE (1,3,18,19)	3.85	0.71	-0.48	-0.12	0.76
Constructive feedback	TLE (17,20,21,22)	3.59	0.92	-0.49	-0.15	0.87

3.3 Students' Approaches to Learning

Among the three compound scales used to assess the students‟‟approaches to learning, the *deep approach* and *surface approach* to learning indicated good internal consistency. At the same time, the organized effort had an α < 0.70 (Table 3). The results also showed that students agreed (Mean = 3.04, SD = 0.93) that the different labs and their combination supported a deep approach to learning. On the other hand, students had a moderate agreement that the labs supported a surface approach and an organized effort to learn. Overall, this shows that the labs enabled students to engage in conceptual analysis, resulting in a deep understanding level.

Table 3. Descriptive statistics for scales reflecting students‟‟approaches to learning

Measure	Item	Mean	Std. Deviation	Skewness	Kurtosis	Alpha
Deep Approach	SAL (5,6,11,12)	3.04	0.93	-0.85	-0.21	0.79
Surface Approach	SAL (1,3,7,9)	2.48	0.74	-0.12	-0.15	0.71
Organized Effort	SAL (2,4,8,10)	2.88	0.91	-0.62	-0.48	0.63

We also assessed the distribution of the mean scores grouped by lab type (OSCBS, HALK, OSCBS-HALK). The mean scores and the associated standard deviation for each of the scales reflecting perceptions of the teaching-learning environment and grouped by lab type are presented in Table 4. The mean scores for computer-simulated (OSCBS), home-based (HALK), and both labs (OSCBS-HALK) showed a high level of agreement (mean > 3.40) on all the six constructs. A one-way analysis of variance (ANOVA) between-subjects was conducted to compare the effect of lab-type on the perception of the teaching and learning environment as measured by the six scales (Table 4).

Table 4. Descriptive statistics for scales reflecting perceptions of the teaching-learning environment grouped by lab type

Measure	Items	OSCBS Mean (SD)	HALK Mean (SD)	OSCBS-HALK Mean (SD)	p-value
Interest and relevance	TLE (4,9,13)	3.56 (0.75)	4.00 (0.47)	3.98 (0.61)	0.024*
Peer support	TLE (8,11,15)	3.68 (0.82)	3.94 (0.57)	4.13 (0.63)	0.018*
Staff enthusiasm and support	TLE (10,12,14,16)	3.42 (0.82)	3.96 (0.70)	3.80 (0.82)	0.121
Teaching for understanding	TLE (5,6,7)	4.06 (0.44)	3.48 (0.84)	3.92 (0.75)	0.033*
Alignment	TLE (1,3,18,19)	3.71 (0.72)	4.08 (0.72)	4.03 (0.68)	0.095
Constructive feedback	TLE (17,20,21,22)	3.45 (0.86)	4.08 (0.75)	3.74 (0.93)	0.094

SD – standard deviation

Results from ANOVA showed that the effect of lab-type was statistically significantly different on interest & relevance [F (2,91) = 3.88, p=.024]; peer support [F (2,91) = 4.23, p=.018]; and teaching for understanding [F (2,91) = 3.54, p= .033]. Post hoc comparisons using the Tukey HSD test for the interest and relevance scale indicated that the mean score for computer-simulated (M = 3.56, SD = 0.75) was significantly different from the mean score for students using both labs (M = 3.98, SD = 0.61). However, the home-based labs (M = 4.00, SD = 0.47) did not differ significantly from computer simulated and both labs. The same pattern was observed for peer support and for teaching for understanding.

Table 5. Descriptive statistics for scales reflecting Students‟ approaches to learning grouped by lab type

Measure	Items	OSCBS Mean (SD)	HALK Mean (SD)	OSCBS-HALK Mean (SD)	p-value
Deep Approach	SAL (5,6,11,12)	3.14 (0.86)	2.79 (1.01)	2.95 (1.01)	0.532
Surface Approach	SAL (1,3,7,9)	2.57 (0.64)	2.54 (0.58)	2.36 (0.86)	0.424
Organized Effort	SAL (2,4,8,10)	3.04 (0.75)	2.58 (1.06)	2.72 (1.05)	0.189

SD – standard deviation

Table 5 shows the distribution of the mean scores across the three different lab types for each measure of the students‟ perceptions of approaches to learning. Students in the simulated computer group (OSCBS) showed a high agreement with the deep approach and organized effort to learning but demonstrated a moderate agreement with the surface approach. Our results show a moderate agreement with the deep approach, surface approach, and organized effort for the students in the home-based group. However, a one-way ANOVA did not show any statistical differences across the three lab types.

3.4 Subscale Intercorrelations

Estimations of effect size are based upon Cohen‟s (1992) criteria from the magnitude of correlation coefficients: Values less than 0.1 are regarded as insubstantial, values from 0.1 to 0.3 as small, values of 0.3 to 0.5 as moderate; and values greater than 0.5 as large. The effect size could be described as small or moderate. Table 6 shows a summary of the results. The six teaching-learning environment constructs were moderately correlated with each other. On the other hand, the same six teaching-learning environment scales were negatively correlated with the three learning scales (deep approach, surface approach, and organized effort). The deep approach and organized effort to the learning scale were negatively related to learning and learning environment perceptions. There was no correlation between deep approach and teaching for understanding and between surface approach and peer support, staff enthusiasm, or constructive feedback.

Table 6. Correlations (Pearson‟s r) across all scales of perception to teaching-learning and approaches to learning

	1	2	3	4	5	6	7	8	9
1.Interest and relevance									
2. Peer support	.496**								
3. Staff enthusiasm & support	.584**	.624**							
4. Teaching for understanding	.567**	.217*	.266**						
5. Alignment	.669**	.561**	.738**	.325**					
6. Constructive feedback	.592**	.633**	.739**	.358**	.754**				
7. Deep Approach	-.364**	-.367**	-.419**	-.203	-.291**	-.296**			
8. Surface Approach	-.295**	-.174	-0.162	-.417**	-.327**	-.150	.346**		
9. Organized Effort	-.402**	-.231*	-.293**	-.274**	-.308**	-.295**	.684**	.346**	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

4. Discussion

Innovations in educational delivery mechanisms have expanded educational opportunities, especially in some courses requiring laboratory experience to reinforce assimilation through experimental observations. We evaluated the perceptions of the teaching-learning and approaches to learning for undergraduate physics students using open-source computer-based simulations (OSCBS), hands-on at-home laboratory kits (HALK), or their combination (OSCBS-HALK) to fulfill the lab component of their course. Our findings indicated that OSCBS promotes a deep approach and organized effort to learning when compared to other lab types. However, students ranked OSCBS lowest regarding interest and relevance, peer support, and alignment. This may be because, as pointed by Gamage et al. (2020), students taking OSCBS lack hands-on experience using the equipment and analyzing and interpreting incorrect or uncharacteristic data.

Peer support and alignment were highly rated regarding students‟ perceptions of the teaching-learning environment using different lab types. Also, the students had a high level of agreement that the different labs and their combinations supported a deep approach to learning. Students using OSCBS labs were less motivated by the lab activities than the other two lab groups. Our results align with Hargis and Chun (2020), who found that

HALK labs kept students engaged, motivated and persistent in online courses. Still, students‟ inadequate technological capacity was a significant distraction. Thus, OSCBS may require developing strategies to improve student engagement and translate the simulations into physical processes. While software overcomes some of the problems identified above, the use of open-source software may also present technical challenges to some students in cases where simulations are not compatible with computer settings operating systems.

Among the three scales measuring student approaches to learning, the surface approach recorded the lowest mean, 2.48 (SD = 0.74). This pattern is consistent with and comparable to findings from Herrmann et al. (2017). However, Cronbach‟s alpha for the organized effort scale did not support the assumption of internal reliability. While the items that affect the reliability of latent factors are commonly removed from the constructs, the noted difference can be due to the uniqueness of the learning environments compared to the face-to-face settings. The means of the six factors measuring students‟ perceptions of the teaching-learning environment ranged from 3.59 to 3.85 on a scale of 1-5. Although peer support and interest and relevance did not seem to fit our data, our findings on peer support agree with results reported by Herrmann et al. (2017). Contrary to Parpala et al. (2013), our findings showed that the deep approach and organized effort to learning scales were negatively related to teaching and learning environment perceptions.

While constructing meaning and developing understanding remain central in the learning process, the influence of student motivation to learn cannot be overemphasized. McTighe and O'Connor (2005) identified task clarity, relevance, and potential for success as the main ingredients of student motivation. In the current study, computer-simulated labs were rated higher than home-based experiments when assessing the students‟ understanding of teaching. This may be supported because OSCBS lab experiments can be performed multiple times, are easy to install and run, produce the same results, and do not require putting physical components together. Also, when using OSCBS, students can re-do the simulations, allowing for deep understanding, which reduces the student‟s frustrations, which could result from unsuccessful lab constructions using HALK. However, hands-on at-home experiments would require students to complete the physical lab settings, and quite often, the results will not be the same when measurements are taken repeatedly. The experimental procedure and the students‟ ability to visualize the laboratory instructions in hands-on settings constrained the HALK laboratory activities. As noted in their responses, these differences are likely to skew the students‟ views of these lab types. For instance, when students were asked about the problems they encountered when completing OSCBS labs, most responses pointed to the need to provide a clear and succinct introductory description of the concepts to be learned, practical relevance, and matching up the lab activity to lecture material "around the same time frame." In addition, video demonstrations on how to navigate the software and explain the relationships between variables experimented were suggested as improvements to the labs. Similar sentiments were echoed for HALK kits, as one student participant highlighted "I would appreciate a clearer conversation with the lecturer on what is the expectation of the lab and how we can apply our findings to the material we are expected to learn in class." Thus, the use of either OCBS, HALK, or their combination requires substantial interaction between the students and the course instructor. However, Campari et al. (2021) argued that when students work in isolation at home, they are forced "to think about what they were doing more carefully and deeply than they usually do in the lab." Still, they miss the "opportunities, advantages, and fun of working in small groups," as in traditional physical face-to-face laboratory settings.

Alignment, which measures students‟ perception of learning to the course objectives and outcomes, was rated higher in HALK and OSCBS-HALK groups than in OSCBS labs. The results showed that students taking HALK and OSCBS-HALK could easily see the connection between the lab activities and learning objectives in the course. A higher level of perception of alignment for HALK and OSCBS-HALK showed that these lab modalities have a higher likelihood of achieving the AAPT recommended learning outcomes (Kozminski et al., 2014). Across the three-factor scales (deep approach; surface approach; organized effort), measuring students‟ approaches to learning grouped by lab type, no statistically significant differences in the means were observed. However, OSCBS were consistently rated higher than both HALK and a combination of both lab groups. The inter-scale correlations mainly were statistically significant except between the deep approach and teaching for understanding and between the surface approach and constructive feedback. The deep approach, surface approach, and organized effort were mainly inversely correlated with other scales. These findings are consistent with Herrmann et al. (2017), who reported negative correlations between the surface approach scale and organized effort and deep approach scale. The same observations were reported by Richardson (2005). Thus, students‟ views indicated that the surface approach to learning, which may involve memorizing and reproducing the learning material without understanding (Lindblom-Ylänne et al., 2019), did not support mastery of concepts in all lab types. However, according to Gamage et al. (2020), the significant aims of laboratory work are to teach students to acquire experimental, problem-solving, data-recording and analysis, practical, collaboration, communication, and technical skills, among others. Using computer-based simulations, the authors noted that learning equipment operation techniques and practical skills are hard to achieve. Even when HALK labs are used, the potential for limited hands-on interaction with experimental apparatus is real (Fox et al., 2020). Nevertheless, other researchers (Fox et al., 2020; Sauter et al., 2013; Sithole at al., 2020), argue that the key to a successful remote laboratory learning experience lies in the design of the lab activities. Automatically adapting the traditional laboratory exercises directly to the online environment poses challenges to both the students and the instructor. For instance, the design of remote labs should factor in the availability of tools needed and software limitations. In the case of OSCBS, the software update is a significant challenge for remote learning (Sithole et al., 2020). A further challenge to the use of OSCBS is that open-source lab software is subject to change over time, which may require periodic updating of experimental procedures.

4.1 Limitations of the Study

The data used in this study were collected only from US Midwestern universities and colleges with different levels of student classroom support. Thus, the findings may not be generalizable to students at other institutions with varying support mechanisms.

5. Conclusion

With the demand for online learning increasing, remote labs bridge accessibility gaps between distance and online education and may help meet learning outcomes. Overall, we found strong support for the deep approach and moderate levels of support for surface and organized effort approaches to learning. In our study, the surface approach to learning was negatively correlated to a deep approach to learning and peer support. Although OSCBS labs promoted a deep approach to learning compared to HALK activities, students" perceptions of alignment, motivation, and peer support were relatively low. Thus, alignment, motivation, and peer support need to be addressed when computer simulations are in place of physical laboratory activities. OSCBS-HALK labs rated higher for peer support and alignment than those who took single lab types. Based on students" perceptions in this study, lab types with emphasis on surface approach to learning are less likely to lead to mastery of skills than those that provide peer support and mechanisms for developing laboratory skills. In addition, there is a need to increase organized effort, interest, and relevance in OSCBS experiments. OSCBS, HALK labs, or combination may be used in various circumstances depending on the course learning outcomes. While the sample size and the location constrained the study, the findings in this study provide an insight into the students" perceptions and approaches to the use of OSCBS and HALK lab activities in asynchronous online physics courses and provide direction on areas that required new strategies to improve students" laboratory learning experiences.

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