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Abstract

In this study, conceptual and algebra-based physics students were engaged in scientific inquiry using Physics Education Technology (PhET) interactive simulations via semester-long group projects. The instructor and students used the Scientific Abilities Assessment Rubrics (SAAR) to evaluate project presentations and papers (formative assessment). The overall research project was evaluated using Lab Skills Self-Assessment (LSSA) survey (pre and post) and the post reflection survey. The Science Process Skills Inventory (SPSI) was used to analyze some of the students' responses to the reflection survey. Quantitative analysis of the LSSA survey showed a large effect size for both conceptual and algebra-based physics students (Cohen's $d > 0.8$, in both courses). Qualitative analysis of the reflection surveys supported this apparent huge gain in lab skills and revealed considerable positive students' experiences of the PhET simulations (88% of students indicated positive satisfaction).

Introduction

Science educators usually face several challenges in designing and implementing inquiry-based activities. Common challenges include limited apparatus and time constraints. Labs play various roles in science education including development of science process skills such as inquiry, investigative, organizational, and communicative skills. Thus, incorporating inquiry projects in the curriculum, early in students' academic careers, has the potential to teach students research skills. This is unlike traditional labs, whereby students follow stepwise procedures to complete labs, thereby inhibiting critical thinking in the process. Despite the importance of inquiry-based labs, there is some resistance among science educators in adopting inquiry labs such that traditional labs are prevalent in several institutions across the nation (Brickman et al., 2009). There are several challenges that prevent implementation of inquiry curricula in schools. These include limited class time for instructors to guide students through the inquiry process, lack of pedagogical skills, and lack of knowledge to deal with issues of safety on the part of students. Besides, there is also an issue of limited physical apparatus due to cost and space. It should also be mentioned that inquiry labs are generally demanding not only on the part of the instructor, but also students.

In an effort to deal with several of the above concerns, in this project, the researchers designed and assessed inquiry activities that involved students in exploration of physics ideas using Physics Education Technology (PhET) simulations, through semester long group projects that involved term paper writing and presentation of results to the entire class. The researchers thought that semester long projects would deal with the common concern of limited time during inquiry projects. With enough time, researchers were hopeful that students would have adequate time to carry out formative assessment (thereby assessing themselves on scientific skills attained) and develop positive attitudes towards the PhET inquiry projects. With enough time the researchers were also hopeful that students would also engage in regular physical labs apart from the virtual labs. Thus, project evaluation involved exploration of the impact of inquiry-based virtual labs on students' science skills and students' views of the group projects.

Theoretical Framework

Traditional physics labs follow a cookbook approach. According to Volkmann & Abell (2003), "traditional cookbook labs are organized around five familiar steps: purpose, procedure, data, analysis, and conclusion." (p. 38) In these labs, students are given a recipe to follow and prescribed questions to answer. Bloom's taxonomy's cognitive domain has six hierarchical components which faculty must aim to attain. These components comprise (1) knowledge or remembering, (2) comprehension or understanding, (3) application or applying, (4) analysis or analyzing, (5) evaluation or evaluating, and (6) synthesis or creating. Sadly, the traditional cookbook physics labs do not properly address the last three stages of Bloom's cognitive taxonomy. Analysis of a cookbook lab by Volkmann & Abell (2003, p. 38) found that students did not answer "scientifically oriented questions", did not "give priority to evidence", and did not "formulate evidence-based explanations." It is hard for students to attain higher order skills from the laboratory if they cannot address the skills mentioned by Volkmann & Abell (2003). According to Kastberg (2003), high level activities are characterized by analysis, evaluation, and synthesis.

Inquiry labs can address the shortfalls observed in the cookbook labs. According to National Research Council (NRC) (2000, p. 25), students in the inquiry labs are

- (1) Are engaged with scientifically oriented questions;
- (2) Give priority to evidence
- (3) Formulate evidence-based explanations;
- (4) Compare and evaluate the merit of explanations; and
- (5) Communicate and justify explanations.

In inquiry labs, students can develop meaning from the activities they are doing because they are given opportunities to behave like scientists. Scientists make observations, ask research questions, formulate a hypothesis, and design and carry out an experiment. These are the skills that physics labs must instill in our students. Labs which will ensure that students acquire these skills adhere to the constructivist theory according to Barrows (1998). In these types of labs, students will look at available information, identify a problem and go through the rest of steps of scientific inquiry. In this case, students enhance their understanding of the material because they (students) can construct meaning through engagement with the material. This aligns with Bodner's

(1986, p. 873) definition of constructivism where “knowledge is constructed in the mind of the learner.” Different variations of inquiry have been effectively utilized in the physics laboratory. These variations include project-based learning (Liu, 2014) experimentation inquiry (Smith et al., 2020), and inquiry labs (Sanders & Perez, 2014). These labs are mostly face to face where students are going to physically interact with physics instrumentation. However, physics instrumentation is not always available and time factors can also hinder the administration of inquiry physics labs. Indeed, community college students face a lot of challenges in their learning due to other engagements such as fulltime work and parenting among other challenges. Therefore, this project integrates PhET simulations to implement inquiry-based activities via semester-long group projects at a community college.

Related Literature

Virtual labs refer to simulation-based labs, in which students manipulate objects and variables to conduct experiments on computers (Chen et al., 2014). Such labs are more safe, cost-efficient, clean, flexible, and time efficient than physical experiments (Papadouris & Constantinou, 2009; Triona & Klahr, 2003). Virtual simulations are particularly useful during a pandemic where several schools are compelled to deliver lessons online. NSTA (2007) asserts that virtual experimentations provide an enhancement (and not a replacement) to hands-on (physical) experimentation. Physics Education Technology (PhET), a product of University of Colorado Boulder, was developed with the help of funds from many donations so that it can be accessed for free. The simulations can be accessed at <http://www.phet.colorado.edu>. PhET simulations provide students with an invaluable opportunity to visualize physics ideas without buying expensive physical apparatus. The simulations are designed in such a way that students can explore a physical law such as Newton’s second law or apply a principle such as conservation of energy to design devices of interest. It should be noted that PhET is not just for physics anymore; it has expanded to other STEM fields such as chemistry and biology.

Previous research has shown that virtual experiments may yield equal if not greater learning gains compared to physical experimentation (Jaakkola et al., 2011; Zacharia & Anderson, 2003). Efforts to make the particle nature of radioactive material and radiation visible to students through computer simulations have demonstrated improved student differentiation between radiation and radioactive material (e.g., (Johnson & Hafele, 2010)). The study by Pyatt & Sims (2012) found that virtual labs can be effective alternatives to physical labs in terms of students’ cognitive and affective performance. Some researchers (e.g., Chen et al., 2014) have argued that virtual labs can be as effective as physical labs but have cautioned educators that virtual labs may lead learners to mindlessly plan and conduct experiments. Chen et al., (2014) also found that physical lab students expressed slightly better attitudes toward laboratories than virtual lab students. In that project, students cited that virtual labs did not provide a lasting impression compared to physical labs, and that virtual labs were not as much fun as physical labs.

Some researchers, e.g., Zacharia & Olympiou (2011) have found that a blended combination of physical and virtual labs enhances students’ conceptual understanding more than the use of physical or virtual experimentations alone. Likewise, Erdosne et al., (2009) found that a blended version of the two environments

(virtual and physical labs) are effective in students learning. Particularly, results showed a strong preference by students for the virtual work preceding the hands-on laboratory. Zhou et al. (2011) explored the impact of a virtual lab against the traditional problem-solving approach on improving conceptual understanding of circular motion. The study indicated that virtual lab students had statistically significant gains in their understanding of related concepts. The study also revealed that students preferred the interactive virtual experiment over the traditional approach.

Batuyong & Antonio, (2018), found that there was a significant improvement of the Physics academic performance of the students when they (students) studied electromagnetism using PhET. Additionally, students expressed positive views of the approach (e.g., students expressed that physics is fun and easy). However, Yunzal, Jr. & Casinillo, (2020), found that teaching electrodynamics using PhET simulations did not significantly improve students' learning, although students showed interest in playing with the simulations. A study that seems closer to the current study is the one conducted by Astutik & Prahani, (2018) who engaged junior high school students in collaborative groups using PhET simulations and assessed students' scientific creativity after going through a natural science lesson. This study showed a significant increase in students' scientific creativity. At a higher education level, creative thinking (triggered by the use of PhET simulations) was assessed with results showing a considerable increase in creative thinking skills (Habibi et al., 2020).

Another closely related study by Sulisworo et al., (2019) investigated the impact of hypothetical-deductive strategy (using PhET simulations) on 10th-grade students' critical thinking levels. Using pre and post test essay scores, the study indicated a significant increase in critical thinking. Yuliati et al., (2018) integrated inquiry-based activities with PhET simulations (involving direct current) in a class intended for prospective physics teachers and assessed the impact of the instructional design on students' learning gains (content and problem-solving skills). This study concluded that a few students improved their problem-solving skills after going through the instruction. A related study by Ceberiol et al., (2016) found that simulation-based materials not only improved students' problem solving skills and scores, but also resulted in students' development of favorable attitudes towards the instructional approach. Faour et al., (2018), investigated the effect of using virtual labs on grade 10 students' learning and attitudes towards physics. Results indicated that students in the experimental group had a significant gain in conceptual understanding. However, there was no significant difference in students' attitudes towards physics between the experimental and control groups. Ramadhan (2017), using literature review, determined that virtual labs enhance "students' problem solving, critical thinking, creativity, conceptual understanding, science process skills, lab skills, motivation, interest, perception, and learning outcomes." (p. 494).

None of the articles reviewed considered the effect of implementing inquiry labs using PhET simulations via semester-long group projects for community college students who oftentimes struggle to participate in science due to work and family/parenting obligations. (In the USA, community colleges are open-admission two-year institutions of higher education often referred to as "junior colleges".) In general, previous research has focused on the impact of the virtual labs on content understanding and specific lab skills such as control of variables and experimental design. This project extends assessment of lab skills to include communication skills (ability to

write reports and present findings). Previous studies have either focused on high schools or four-year colleges but rarely on community college students and the issue of limited time has not been properly addressed. Therefore, this study explores the impact of collaborative inquiry-based PhET projects (over a semester) on scientific skills and perceptions of these labs among community college students.

Research Objectives

Considering previous research, in this study, the authors designed an instructional approach to allow students to interact with PhET simulations, design their own experiments, and communicate their findings. Consequently, the researchers addressed the following research objectives: (1) explored the gain in students' scientific skills, and (3) investigated the students' perceptions of using PhET simulations.

Methodology

Research Design

This study employed mixed methods design (Creswell, 2007) whereby both quantitative and qualitative data were used to meet the research objectives. Quantitative data involved a Likert-scale questionnaire to assess perceived lab skills before and after the instructional approach, while qualitative data was obtained using a reflection survey which was administered post instruction.

The Participants and Sampling Procedure

The project was carried out at a North-Eastern urban community college in USA in Spring and Fall 2019 semesters. Two groups of lower-level physics students (conceptual and algebra-based physics students) participated in the project. About a third of students in the conceptual course were elementary education majors, and the rest were liberal arts and STEM majors. The algebra-based physics course is an introductory two-semester algebra (and trigonometry) based course for engineering technology majors. Only students who were taking the first semester of the course were involved in the study. In this case, our project sample was a convenient one.

The Instruments and the Reflection Survey

Before we designed the instrument, we thought about the goals of physics laboratory. According to American Physics Teachers Association (1998), physics students must be able to design their own experiment; they must be able to put the data they collect into a form that can be easily understood. Furthermore, they must understand the knowledge the physics lab intends to teach them. Lastly, students must be able to collaborate with peers as they carry out their research. Further, Kozminski et al., (2014) recommend that students in physics labs must be able to "design experiment, develop technical and practical laboratory skills, analyze and visualize data, and communicate in physics" (p. 2-3). Our instrument was developed with these skills in mind. We have items that deal with identifying a problem, asking research questions, collaborating with peers, analyzing and interpreting

data, and students' confidence in designing and carrying out an experiment.

In terms of visualizing data, Kozminski et al., (2014) assert that physics labs should enable students to represent their data in a way that is easily understandable and be able to make interpretations. Kozminski et al., (2014) further indicate that physics students must have skills to present their laboratory results in authentic formats such as journal style, and conference style presentations. Therefore, our instrument has items that address students' confidence in these types of skills. In addition, students must also be able to make connections between physics lecture content and the lab skills they are gaining. This has also been addressed in the instrument.

To answer the first research objective, we developed an instrument called "Lab Skills Self-Assessment" (LSSA) Survey (See Appendix A) based on the literature review that describes what skills and knowledge students must learn (e.g., Etkina et. al. 2006; Kozminski et al., 2014). This questionnaire consists of statements indicating several scientific skills, and students were asked to rate the extent to which they were confident with each statement (once at the beginning and once towards the end of the semester. We also examined other evaluation surveys like Science Process Skills Inventory (SPSI) created by (Bourdeau, & Arnold, 2009) and Undergraduate Research Student Self-Assessment (URSSA) created by (Weston & Laursen, 2015). Although the SPSI has relevant items for our study it does not explicitly include some lab skills relevant to our study, especially those related to group work and presentation skills.

The URSAA survey happens to be too general for our study and purpose, focusing on thinking and working like a scientist. For our purpose, and to expand on the existing studies, we decided to create a survey that is neither too short nor too long. Our middle ground, considering an inquiry lab, and the project's purpose was the "Lab Skills Self-Assessment" (LSSA) Survey". This set of general skills can also be found in the Scientific Ability Rubrics developed by Etkina et. al. (2006). Thus, the 'Lab Skills Self-Assessment' instrument, was designed in consideration of lower-level lab classes. The lab skills are not limited to 'designing experiment and organizing data' but also include students' 'ability to interact with peers and to communicate findings through term paper and presentation to peers.'

One of the researchers developed the instrument and sent it to the co-researchers to make suggestions. The instrument was then later sent to two science educators for face validity. Then we used the instrument to collect data from 61 participants in two semesters. The IRB approved the project to make sure that all ethical considerations were considered. After collecting the data, we investigated how variables within the instrument related to the constructs that we sought using confirmatory factor analysis. The analysis came up with two factors that we named, (1) Technical Lab Skills (TLS), and (2) Group Work & Presentation Skills (GWPS). We used varimax rotation for loading because we wanted to maximize the variance of the loadings (i.e., making high loadings higher and low loadings lower) (Abdi, 2003). Using the Varimax rotation, 12 items out of nineteen loaded on factor 1, and seven items loaded on factor 2. Table 1 shows the factor loadings.

Table 1. Confirmatory Factor Analysis

Item#	Factor 1	Factor 2
1		0.620
2	0.525	
3		0.514
4	0.616	
5	0.654	
6	0.587	
7	0.717	
8	0.732	
9	0.722	
10	0.628	
11	0.604	
12		0.853
13		0.527
14	0.678	
15	0.737	
16		0.894
17	0.595	
18		0.713
19		0.526
Factor Alpha	0.91	0.86
Instrument Alpha		0.94

We also tested the reliability of the instrument and found a Cronbach's α of 0.94. Further tests of each factor resulted in the alpha value of 0.91 for factor 1, and 0.86 for factor 2, all of which are acceptable (Abdi, 2003). We further tested the items using a split-half correlation with Spearman-Brown Correction. The correlation coefficient between even and odd items was 0.91. After the Spearman-Brown correction, the correlation coefficient changed to 0.96, which is high. This shows that the instrument strongly measures what it is intended for.

For the qualitative data collection, all the researchers brainstormed to come up with a reflection survey (Appendix B). The aim of the reflection survey was to determine the students' views of the online simulation projects in physics. The questions focused on how the students view the whole online project activity, what strengths they observed from the project, and what they have learned from it. We felt that the qualitative aspect would strengthen our data from the quantitative survey. After brainstorming, the first author put the questions together and sent them to the two researchers for comments. The two researchers added their comments to improve the questions. The first author made those corrections and all the authors discussed and approved the final questions as indicated in Appendix B.

Intervention and Data Collection

In the first week of the semester, students were given the LSSA as pre-test. Immediately, students were given different topics from which to select for their semester-long project. They were then asked to select colleagues to work with on the project. The students were given a handout containing the assignment. During the first week, the instructor set aside some time to discuss the handout and discuss with the students how to go through the different steps of scientific inquiry as they conducted their project. Students were encouraged to ask questions concerning the project at any time throughout the semester. The first author was the instructor for all the lab sections in this study.

Students worked in groups of two to three. Each group was asked to pick one physics simulation from the following list: (1) Generator, (2) Gas Properties, (3) Buoyancy, and (4) Hooke's Law. (It should be noted that this PhET term project was incorporated in a regular physical traditional lab, without any addition to lab time. For this reason, and for some selected physical traditional labs, no formal reports were required. Students only submitted data, calculations, and responses to some questions. This created some time for students to handle the PhET project.) These topics are rarely covered in lectures and the rationale was for students to research more about related concepts without considerable prior knowledge to appreciate the process of science. These simulations were downloaded from <https://PhET.colorado.edu/> and then uploaded on lab computers.

Students were also asked to access the simulations on their own on the website using library or their own computers/smart phones. Each group was asked to (i) explore the simulation, (ii) make notes about the simulation, (iii) predict relationship between pairs of variables (make hypotheses), (iv) design experiments to test their predictions, (v) think about how to present data, and (vi) decide how to communicate data as a scientific paper and oral presentation (PowerPoint). Each week, every group was given about 5 to 10 minutes to update the entire class on their project. Groups were required to keep a "research" notebook to document progress.

In the middle of the semester, students were asked to submit the research design for feedback. No grade was assigned at this point, but students used the feedback from the instructor and classmates to improve their project. Formative assessment was facilitated using the Scientific Abilities Assessment Rubrics (SAAR). This enabled both students and the instructor to formatively evaluate project papers and presentations.

The completed draft paper was submitted twice: towards end of semester (two weeks away from final day of lab meeting), and then resubmitted on the last day for final grade. This way students had a chance to improve their paper for better learning and grade. For the final day of the class, students presented their project findings to the class. Presentations were required but not graded (to minimize stress). This entails that students' final paper was graded only if they presented their results. The format for the project paper was the same format they used to write their lab report except that this time students were required to be more detailed. Grading rubric of the project write-up resembled that of the regular lab report as well. In the last week of the semester, students were given the LSSA again as post-test. They were also given a reflection survey during the same period.

Results and Discussions

Having crafted an instructional approach that allowed students to interact with PhET simulations, design their own experiments, and communicate their findings, the researchers explored the gain in students' scientific skills, and investigated the students' perceptions of using PhET simulations. Results are presented in this section starting with gain in scientific skills followed by student's perceptions of the instructional approach.

Gains in Scientific Skills

Statistical comparisons between the pre- and post-tests were conducted to gauge the students' gains in scientific skills. Table 2 shows the results of the Lab Skills Self-Assessment (LSSA) survey analysis.

Table 2. Comparison of Mean Score between Pre-test and Post-test for Both Groups

Class	n	Pre-Test Score (SD)	Post-Test Score (SD)	% Gain	Cohen's d effect size	Hake's g Effect-Size
PH101	36	3.62 (0.62)	4.39 (0.40)	22	1.48	0.59
PH201	25	3.69 (0.68)	4.27 (0.57)	16	0.92	0.42

As noted in Table 2, the effect size using Cohen's d was large indicating that the gain in confidence levels regarding doing science was statistically significant. Further, Hake's g shows medium effect size for both physics courses indicating that the implemented collaborative PhET inquiry activities helped students acquire science process skills/scientific abilities.

Student's Perceptions of the Instructional Approach

For the second research objective, a reflection survey was created to explore students' experiences and perceptions of the PhET project (see appendix B). Qualitative analysis of written responses involved coding and categorization of relevant data (Creswell, 2007). The first part of the qualitative analysis involved scrutinizing the spread of various scientific skills as depicted by students. Here, we used the Science Process Skills Inventory (SPSI) (Bourdeau, & Arnold, 2009) for a priori coding of responses from question six of the reflection survey. Thus, we had pre-established categories.

The first author conducted initial data exploration and coding and then shared the preliminary results with the other two authors. The other two authors then provided suggestions on refinement of allocation of codes to various categories. This process went back and forth until the final categorization was reached by consensus. Note that our aim was to see the spread of the various scientific skills as given by students. We were not interested in whether students know what scientific ability is or not. For that reason, unclear responses (such as 'I learned about gas properties') were eliminated from the analysis and that the emphasis was on codes and not

students. Figure 1 shows the results of this analysis.

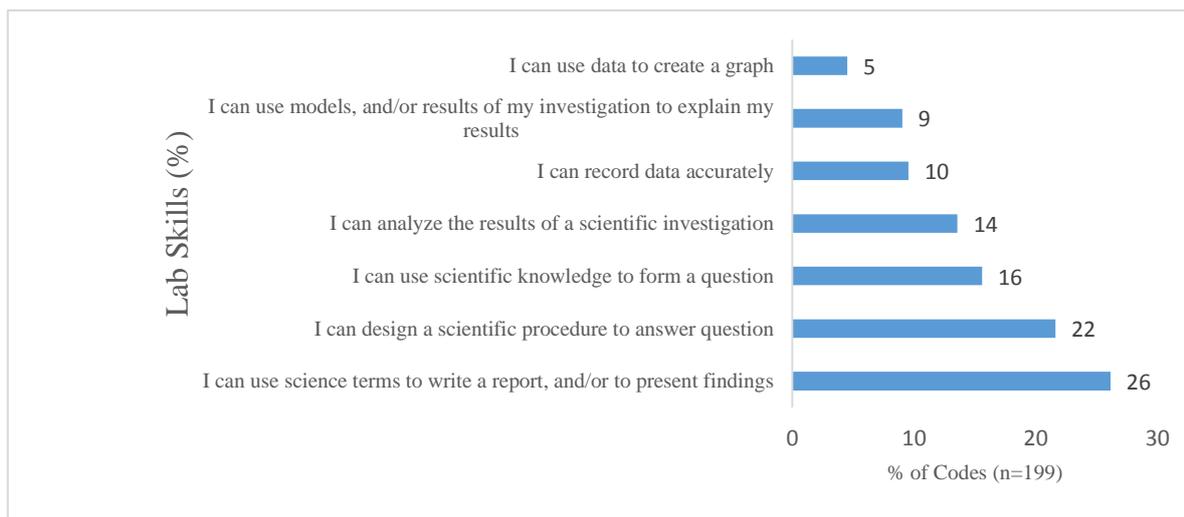


Figure 1. The Spread of the Various Scientific Skills

Scientific communication (term paper writing and presentation) as well as experimental design stood up as first two most common skills. Creating graphs happened to be the least common feature reported among students. Questions 3 and 5 on the reflection survey were analyzed to gauge the positive and negative aspects of the PhET simulation project as perceived by students. Here positive aspects refer to what students thought were either the likable parts or easiest parts of the project. On the other hand, negative aspects refer to unlikable parts of the PhET simulation projects that were conceived to be difficult. Responses to questions 3 and 5 were analyzed by coding and categorization, and frequency of codes were categorized, with the final coding reached by consensus among the three authors. The focus of the analysis was on the frequency of the codes (and not number of students) across the entire pool of responses. Figure 2 presents the positive aspects of the project and Figure 3 the negative aspects.

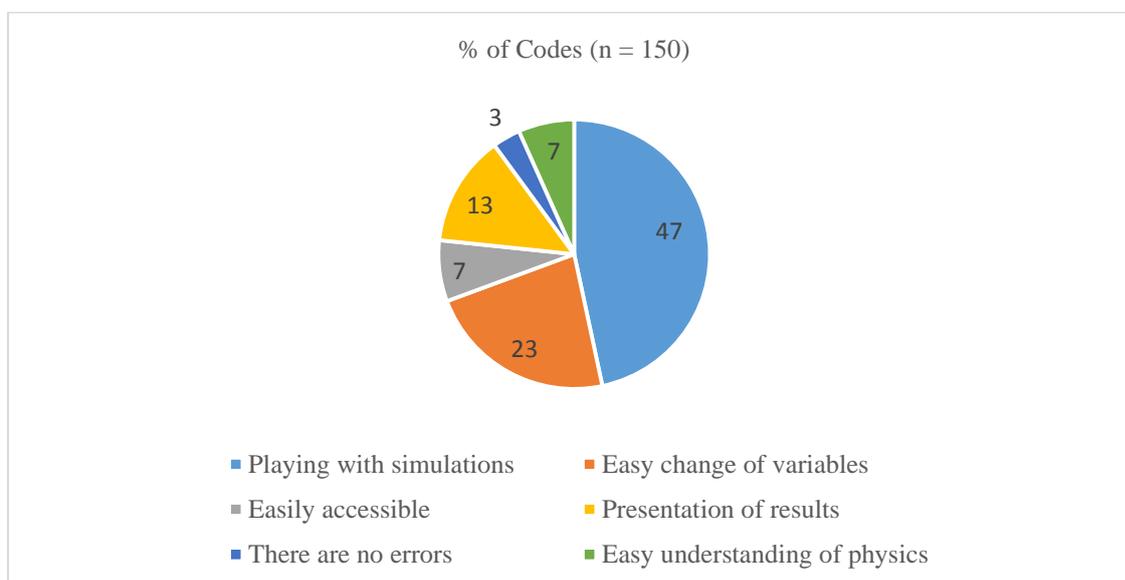


Figure 2. Positive Aspects of the PhET Simulations

Figure 2 indicates that playing with the simulations and seeing how a change in one variable affects the other are the first two most common aspects that showed up in the analysis. This is not strange as virtual simulations are generally safe and students feel comfortable to manipulate variables. A few students seem to have noticed that virtual simulations are inexpensive and can easily eliminate issues such as friction and gravity.

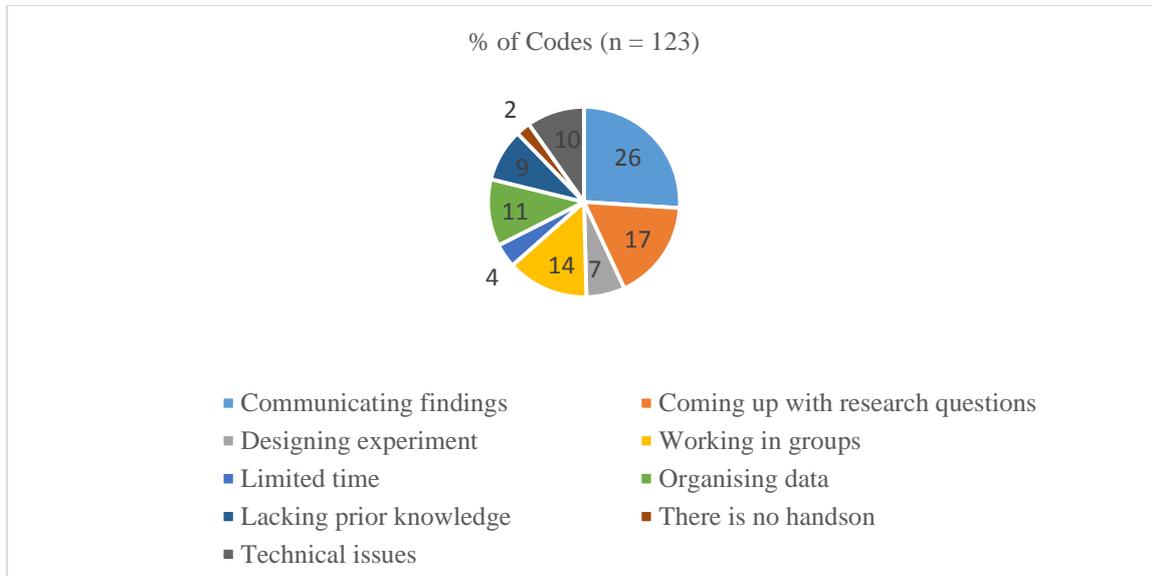


Figure 3. Negative Aspects of the PhET Simulations

As for the negative aspects, communicating findings and coming up with research questions showed up the most. While students enjoy playing with and exploring simulations, they also acknowledged that coming up with research questions, final paper, and oral presentations, are some of the challenging aspects. Issues like working in groups, report writing, and getting started or coming up with research paper appeared to be some of the other problems students experienced. Question 7 on the reflection survey sought to learn from students whether they would encourage other professors to use the simulations to teach or use the simulations in the lab. Responses to these questions were coded and categorized; this time, the focus of the analysis was on students and not code frequency.

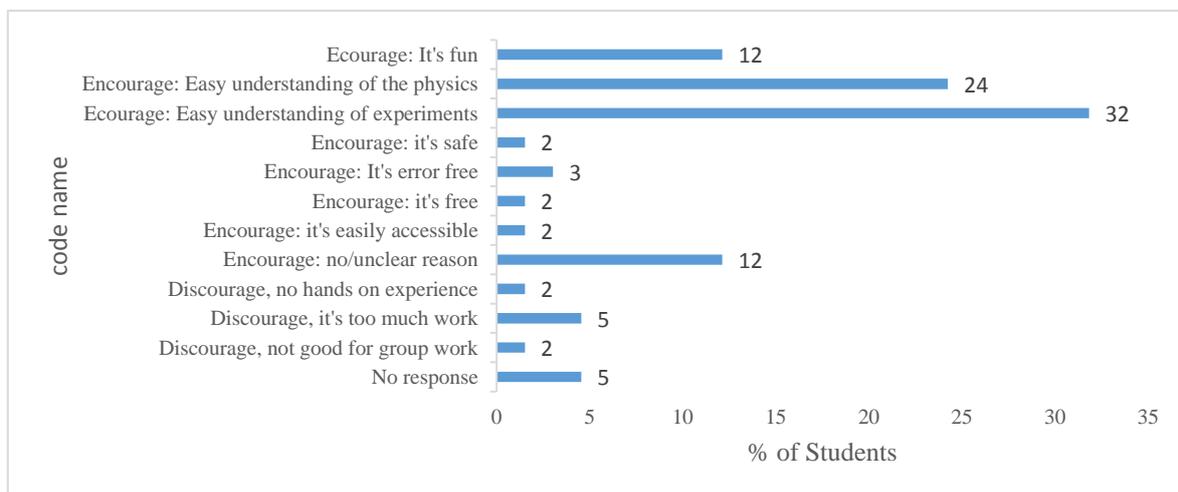


Figure 4. Students' Overall Perceptions of the PhET Project

Eighty-eight percent of students said they would encourage the use of PhET simulations. Students agreed that the simulations were helpful in their learning both for the content (physics (24%)) and process (doing experiments (32%)). The few students who discouraged the simulations mentioned that it involved too much work and did not work well for group activities.

Learners generally acknowledge that experiencing the complexity and frustrations faced by practicing scientists is challenging (Brickman et al., 2009), leading to their resistance to inquiry labs. However, inquiry labs have the potential to instill lab skills and, consequently, research skills. It is therefore important to carefully consider ways and means of delivering lab skills to lower-level physics students. Challenges facing implementation of inquiry include limited time and resources. Oftentimes, educators try to implement inquiry labs within a period of two hours (typical length of a physical inquiry lab). This is often met with frustrations both on the part of educators and students. This project provided an opportunity for students to engage in inquiry-based labs through virtual PhET simulations over a semester. The target was to minimize the common issues of time and resources (equipment) that are associated with physical inquiry labs. In this project, the issue of time was dealt with by assigning one project to students throughout the semester. Here students had enough time to go through the scientific inquiry process and communicate findings. Inquiry instruction is usually frustrating when students are only given one lab class to go through the process.

Regarding equipment, the PhET simulations provided safe and readily available experiments that would be difficult to arrange with physical labs. Consequently, the project (i) yielded huge gains in confidence associated with doing science (Cohen's $d > 0.8$, both courses), and (ii) positive experiences and attitudes towards the PhET simulations (88%). A similar result was obtained by Pyatt & Sims (2012) who found that high school chemistry students favored virtual labs more than physical labs. This confidence can be related to the skills that the PhET lab instilled in the students. According to (Wilcox & Lewandowski, 2017, p. 7), courses that focus primarily on developing lab skills demonstrate 'greater success with respect to fostering expert like beliefs about the nature and importance of experimental physics as well as their affect and confidence when doing physics experiments.

The project was successful most likely because it employed the Scientific Abilities Assessment Rubrics (SAAR) developed by Etkina et al., (2006) to serve as a checklist for students and the instructor to assess projects, papers, and presentations. This made it easy for the students to grasp the purpose of the project (formative assessment). Indeed, integration of formative assessment into simulation-based inquiry activities has been shown to produce a better progression of scientific understanding (Srisawasdi & Panjaburee, 2015). Students' attitudes towards the PhET projects were also positive (88%) because they did not only experience virtual labs but also regular physical labs. Consequently, our project concurs with NSTA (2007), which asserts that virtual experimentations provide an enhancement, and not a replacement, to hands-on physical experimentation. Some students in virtual labs usually worry about lack of hands on experience compared with physical labs (Chen et al., 2014). The problem seems to be that of over-emphasis of these virtual labs or complete avoidance of physical labs. In this project, students experienced both virtual and physical labs such that few students expressed concern over lack of experience in physical hands-on labs. Blended versions have been shown to improve conceptual understand as well (Toth et al., 2014; Z. C. Zacharia & Olympiou, 2011).

One of the interesting aspects of this project is its view of ‘what constitutes scientific skills. Oftentimes, scientific skills are associated with the ability to design an experiment, display data, and make conclusions. In this project we looked at scientific skills broadly, by placing importance on the role of scientific communication among student groups, term paper writing, and presentations. The latter can be justified by looking at our overall project design (intervention), lab skills self-assessment survey, and the resulting factor analysis (Table 1). While our focus was on scientific skills, it was also interesting to learn that the PhET simulations also helped students learn the physics (Figure 4). This is in agreement with several previous studies (e.g., Jaakkola et al., 2011; Johnson & Hafele, 2010) which have documented the importance of simulations in improving conceptual understanding. Physics labs help students attain physics concepts, acquire lab skills, and develop interest towards physics. Instructors who focus on skills development oftentimes prefer inquiry-based labs while those who focus on concepts are more likely to employ verification labs (Wilcox & Lewandowski, 2017).

Conclusions

This project developed and assessed an instructional approach that involved the use of PHET simulations in an inquiry fashion throughout the semester among community college students. Students interacted with the simulations and designed their own experiments to explore laws or physics principles. Towards the end of the semester, students shared findings in terms of project papers and oral presentations. Project assessment involved assessment of skills gained and student’s perceptions of the instructional design. The project indicated that using PhET semester-long group projects, inquiry labs can be facilitated thereby enabling students to acquire the necessary scientific skills and to develop positive attitudes towards physics both of which are strong foundations for successful undergraduate research skills.

Suggestions for Future Study

Future studies may further explore the lab skills through skills test either through observation of students doing the experiments or assessing students’ reports and presentations using already available assessment rubrics.

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Appendix A. Lab Skills Self-Assessment Survey

Name _____

Date _____

Please read all the questions and rate them on a scale of 1 to 5 as follows:

Least confident 1, 2, 3, 4, 5 Very confident

No	Statement	Score
1	I can write a statement of a problem in form of a question.	
2	I can identify independent and dependent variables in my investigation.	
3	I can make a prediction on how changing one variable affects the other variables.	
4	I can easily work with PhET simulations.	
5	I can easily relate classroom work to the lab activities.	
6	I can write conclusions based on the data I have collected.	
7	I can easily organize data in various forms such as tables, figures etc.	
8	I can easily judge if the data I have collected is valuable.	
9	I can easily write a report from my lab activities.	
10	I can easily use various sources to explain the data I have collected.	
11	I can easily summarize the lab activities.	
12	I can easily work with colleagues on lab activities.	
13	I can easily write an independent report after working with colleagues although we have the same data.	
14	I can easily translate laboratory equations in my lab work calculations to obtain results.	
15	I can easily construct and interpret graphs from my data.	
16	I can easily communicate with colleagues in the lab.	
17	I can easily apply the principles of physics to solve problems.	
18	I can easily lead a portion of a lab activity in my group.	
19	I can easily present my findings to the peers in my lab class.	

Appendix B. Reflection Survey

We would like to learn your views regarding the research project you carried out in this lab. This section will not be graded but your responses will help in improving the activities and hence the teaching of the lab course. You are kindly requested to provide as much feedback as possible.

(Reasonable spaces were provided for student responses)

1. In your own opinion, what was the main purpose of the PhET projects?
2. Do you think you can apply what you learned from the project in everyday life? Please explain.
3. What aspects of the PhET project did you like best and what aspects didn't you like?
4. Share your thoughts regarding your involvement in group work to complete the research. Did that help or hinder your understanding of project objectives?
5. Starting from the beginning of the project to the end, what part(s) did you find to be the easiest to complete? What part(s) was/were the toughest to complete?
6. What scientific skills have you learned from this activity? What other skills have you learned from the project?
7. Would you encourage or discourage professors from using these types of simulations to teach classes? Please explain

END OF THE SURVEY: THANK YOU FOR YOR FEEDBACK