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Development and Validation of Manipulatives for Home-based Physics Experiments

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Abstract.
The major intention of this study is to design and validate manipulatives for home-based physics experiments. The Covid-19 pandemic has caused tremendous and rapid amendments to educational systems worldwide, immediately shifting from traditional on-the-ground teaching to virtual classroom instruction or modular learning approach to name a few. Similarly, it has made laboratory experiments problematic. Demonstrations are limited just to the four corners of the electronic gadget's screen, while simulations can only do so much in terms of experiential learning; hence, the urgency of developing these low-cost laboratory kits for students' use at home. The laboratory activities and kits went through thorough examination for validation by 3 experts in the field of Physics, all of them holding Masters-degree. The setup was found to be valid (overall mean of 4.67 from a 5-point Likert scale validation tool). The effectiveness, in terms of the performance of learners, was established using quasi-experimental methods involving 30 students (15 males and 15 females) in the control group and 30 learners (15 males and 15 females) in the experimental group. The control group was exposed to customary lectures via online classes with virtual simulations. The students in the experimental group attended the same online lectures and were provided with the home-based manipulative kit. The analysis and interpretation of data collected from the pretest-posttest scores of the student participants revealed that the laboratory manipulative kits are effective and highly acceptable. The normalized gain of the experimental group (g = 0.82, high gain) was significantly higher than that of the control group (g = 0.45, medium gain).

Keywords: manipulatives, home-based physics

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1. INTRODUCTION

The declaration of the Enhanced Community Quarantine (ECQ) by the President of the Philippines on March 17, 2020 did more than just shock the entire country; it brought negative effects to the economy, to the workforce, to businesses, to national security, and to educational institutions as well. Schools had to shut down and in the Philippines it stretched to two years. The situation was not any better with the institution where the first author is a Physics faculty member. Given the situation, the Physics Department finally decided to begin implementing virtual classes in place of in-person instruction. However, those who have limited access or no access to the internet at all were provided

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with modules that were hurriedly developed. The arrangement was something both the educators and learners had to adjust to. Difficulties arose and problems started surfacing especially with regards to internet connectivity, the mental health condition of learners, and the economic decline within households. One of the struggles that came up from student surveys was the lack of visualization, comprehension, and verification of Physics concepts that on-the-ground laboratory experiments used to address. This prodded the researchers to come up with low-cost home-based manipulatives that can be sent to students with little or no access to virtual classes.

Science guides students to discover the world around us by uncovering theories and principles behind things and phenomena. Science laboratory experiments are intended to develop concepts, scientific processes, verify facts, theories, hypotheses and subsequently develop positive attitudes towards the subject. They are designed to allow learners to question, probe, investigate, collect data, and come up with conclusions.

Traditionally, students are given opportunities to become active learners through experimentations. Materials, housed and maintained well in laboratory rooms, are normally provided by institutions while the teacher supervises the class performance after the proper laboratory procedure and precautions have been discussed. This is the typical setup in a conventional laboratory class. A set of directions designed and validated by experts would have to be followed by the students in each group. Guide questions usually lead learners towards the drawing of generalization, the general insight learned in the experiment. Recently, however, experiments have evolved into a different approach. Some have been designed in such a manner where students are given the opportunity to make their own observations and are challenged to come up with their own questions according to the observations stated. Many science educators have endorsed the use of this inquiry-based laboratory work [1]. In the traditional practice, laboratory work comes after the concept is presented to the students in antecedent lectures. In the inquiry approach, the laboratory usually is the first step of instruction in order to generate data that leads to and supports a scientific concept. Discussion of the concept is different for the two approaches. Regardless of the design, the ultimate goal of laboratory activities is the appreciation and understanding of concepts. By conducting the experiments, students are able to practice inquiry skills such as asking questions, hypothesizing, and suggesting a question for further investigation. This experience immerses students more into the excitement of science [2]. Further, students are able to construct their knowledge by solving insightful problems during laboratory activities [3].

Experiments can vary widely depending on the age and grade level but the common objective is to increase understanding between theoretical models and the theory or concept the models are representing [4]. If the learners understand an experimental model and connect the generalizations obtained to established theories, then it may be inferred that the experimental setup or model chosen was appropriate.

With the pandemic situation and consequently the shift to virtual classrooms, performing laboratory experiments and developing laboratory skills among students have become problematic [5]. The various restrictions the nation had to go through prevented students from manipulating the laboratory tools and equipment hands-on. The science educators with laboratory loads had to resort to a virtual demonstration of activities and interactive online simulations. In online experiment demonstrations, the teacher performs each of the steps of the experiment before a camera as students watch their screens in a virtual conference or meeting. Then, the teacher asks the students to tabulate the data and answer the necessary guide questions and eventually draw conclusions. Literature says non-traditional laboratory experiments such as this, lean towards outcome in content knowledge [6], incur low operating and maintenance costs, are easily replicated, are accessible in multiple opportunities and supports safety protocols of the government. What is lacking are the tangible results with sensory feedback and student-teacher interaction. In simple terms, experiential learning is not evident.

Experiential learning is a process wherein students learn by ‘doing’ and reflecting on the learning experience. This component is crucial in any science education journey [7]. Learning is considered experiential if there are elements of reflection, critical analysis, and synthesis. The students must be given opportunities to make decisions, take initiatives and be made accountable for the results. Kolb’s Cycle of Learning [8] is an integration of knowledge, activity, and reflection.

Experiential learning is considered as an integral part of any science subject. The experiences can come from various forms like laboratory sessions, field trips, internships [9]. For the past two pandemic years, students have been deprived of practically all modes of experiential learning. They experience little or none in terms of the use of their senses in learning the science concepts.

Experiences are carefully chosen by the educators to provide opportunities to encounter new and unpredictable situations that may support emergent learning in the study of natural phenomena. While the process of learning is going on, the students may pose questions, investigate, experiment, solve problems, construct meaning or take initiative. Their mistakes and victories in the process are likewise opportunities

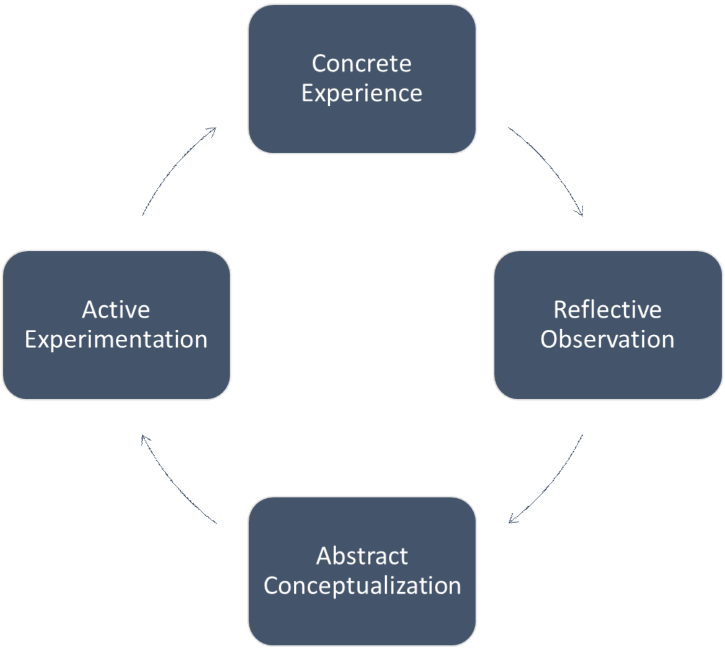
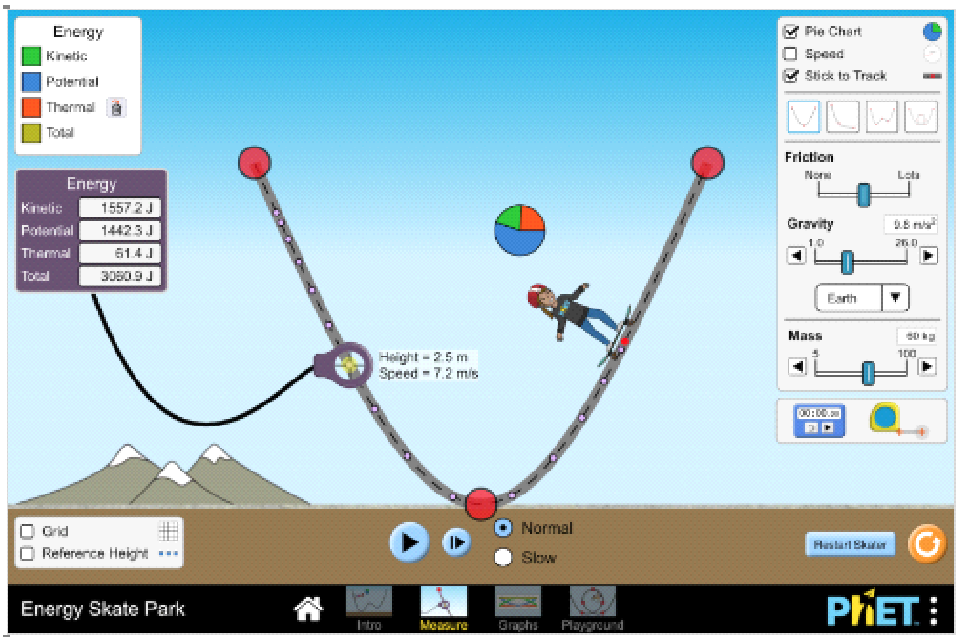


Figure 1: Kolb's experiential learning cycle.

for learning. Reflection on the learning that transpired will lead students to analysis, synthesis, and critical thinking. Because the learners are engaged intellectually, emotionally, socially, and physically, the learning becomes authentic. The fruits and benefits of experiential learning are lacking in virtual laboratory classes. The practical objective of acquiring laboratory skills is unmet. Hence, home-based manipulatives were conceptualized and developed by the researcher in the hope of bridging this gap.


Energy
Kinetic 1557.2 J
Potential 1442.3 J
Thermal 61.4 J
Total 3060.9 J

Height = 2.5 m
Speed = 7.2 m/s

☑ Pie Chart
☐ Speed
☑ Stick to Track

Gravity 9.8 m/s²
Earth
Mass 60 kg

☐ Grid
☐ Reference Height
● Normal
○ Slow

Figure 2: Sample virtual simulation from https://phet.colorado.edu/.

2. RESEARCH method

The study employed the descriptive-developmental research design in determining the validity of Home-based Manipulatives. Particularly, the researchers utilized the Analysis, Design, Development. Implement, Evaluate (ADDIE) model [10].

Figure 3: Development and content validation process.

The research began with the development of home-based manipulatives that can be utilized by students enrolled in a Physics class who have limited to no internet connection at home for their performance of the experiments. The home-based kits were intended to be used for the 2nd quarter of the school year 2021-2022. The topics that are included in the scope of the grading period are Newton’s Laws of Motion and Projectile Motion. These had corresponding experiments for which home-based manipulatives were made. Activity 1 was about the Law of Acceleration while Activity 2 was focused on Projectile Motion. Figure 3 summarizes the steps taken in the development and validation of the kits.

The first step is the designing of the experiments. The customary approach of laboratory experiment was employed in the crafting of the experiment. First, the main objectives were stated, followed by the materials needed in the experiment. Then, the procedure states each step the learner has to take in order to investigate the Law of Acceleration and Projectile Motion. This was the experiment to be given to the 30 participants in Group A (Traditional Group). The 30 students in the Experimental Group (Group B) were given two (2) sets of experiments that contained identical objectives, procedure, and guide questions given in Group A. The major difference is that the experiment of Group B contains materials not found in Group A. These are the low-cost materials that were carefully selected by the researcher to replace the originally required materials. These manipulative materials were designed to be functional, student-friendly, and operationally similar to the Physics instruments available in the laboratory. Group A on the other hand used the virtual simulation version of the experiments.

The content expert validators ensured the validity of the materials used as a substitute for the original material required in the experiments based on their appropriateness, cost-effectiveness, and safety. The researcher provided each of the three experts with an *Expert Evaluation Checklist*, a 5-point Likert scale researcher-made evaluation tool.

The results of the first evaluation were very satisfactory (4.3 out of a highest score of 5) but some revisions were recommended.

Figure 4: Packaged home-based manipulatives.

The contents of the kit were sent over to the experts again for the second phase of evaluation and the result turned out to be 4.67. The revisions sent were approved so the entire contents of the kit were packed in each of the 30 boxes. Figure 3 displays pictures of the packaged manipulatives.

The home-based manipulatives were sent individually to the 30 students comprising the Experimental Group (Group B). The researcher gave a virtual orientation to both groups, explaining that there is no difference between the manner they will be graded (assessment). The same set of assessment tasks will be received by both as well as the process of grading. Before allowing the students to start with their experiments, they were provided with a 30-item pre-test covering the topics for the quarter. After five weeks of implementation of both traditional online laboratory experiments and home-based experiment with manipulatives, the participants were administered a 30-item post-test containing questions that are parallel with what was given during the pretest.

The validation tool provided to the experts consisted of 4 categories. The experts were instructed to give corresponding points to each category depending on their evaluation of the manipulatives. The scales are as follows: 5 – Totally Evident, 4 – Somewhat Evident, 3 – Undecided, 2 – Somewhat Lacking, and 1 – Totally Lacking. The mean score was obtained for each expert validator and the overall average was calculated after the evaluations of the three validators were turned in. The acceptability or effectiveness of the manipulatives was established using an independent t-test for two samples done to the pre-test and post-test scores of the participants.

3. result and discussion

The evaluations of the three experts were tabulated per category as seen in Table 1.

Table 1: Results of the validation by experts.

Criteria	**Expert 1**	**Expert 2**	**Expert 3**
Availability	5	5	5
Congruence to Original Materials	4	5	5
Cost-effectiveness	4	4	4
Safety	5	5	5
Average	4.5	4.75	4.75

Results show that the manipulatives passed the evaluation of the experts. They were assessed to be readily available in the market, safe, and cost-effective. Ultimately, the materials composing the manipulatives are serving the same purpose as the materials the experiment originally requires from the science laboratory. An overall mean of 4.67 shows high validity of the home-based manipulatives. The Fleiss' Kappa value obtained showed high inter-rater agreement.

Paired sample t-test was administered for the pre-test and post-test scores of the students in the Experimental Home-based Manipulatives Group. This was done to check whether there was a significant difference in the performance of students when the manipulatives were sent out to them. The results of the t-test showed that the mean difference of 19.1 points (post-test minus pre-test) is statistically significant.

Further, the normalized gains of the two groups were determined using the Hake gain formula [11]. The normalized gains of the two groups were compared and it was revealed that the Experimental Home-based Manipulatives Group got higher learning gains (g = 0.82, high gain) compared to the Traditional Demonstration Group (g = 0.45, medium gain). The study of Arabeta [12] where she integrated gamification elements in the teaching of Physics also revealed a significant improvement in motivation, performance, and perception of students towards learning physics.

4. CONCLUSION

Anna Carmela Bonifacio wishes to thank the PSHS Main Campus Director Dr. Lawrence Madriaga and the members of the Management Committee for their all-out support of this study about Home-Based Manipulatives; the Physics Unit members and its head, Lieza Crisostomo for all the numerous permissions, documents and materials for this study; Science Research Assistants Reynaldo Gonzales and Estela Ayunon for their meticulous preparation of necessary apparatus; Delfin Angeles for the production of the modified manipulative devices in his workshop.

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References

[1] Abd-El-Khalick F, Boujaoude S, Duschl R, Lederman NG, Mamlok-Naaman R, Hofstein A, et al. Inquiry in science education: international perspectives. Sci Educ. 2004;88(3):397–419.

[2] Hofstein A, Lunetta VN. The laboratory in science education: foundations for the twenty-first century. Sci Educ. 2004;88(1):28–54.

[3] Clough MP. “Using the laboratory to enhance student learning.,” Learning science and the science of learning. pp. 85–94, 2002.

[4] Feisel LD, Rosa AJ. The role of the laboratory in undergraduate engineering education. J Eng Educ. 2005;94(1):121–30.

[5] Fox MF, Hoehn JR, Werth A, Lewandowski HJ. Lab instruction during the COVID-19 pandemic: effects on student views about experimental physics in comparison with

previous years. Phys Rev Phys Educ Res. 2021;17(1):010148.

[6] Brinson JR. Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research. Comput Educ. 2015;87:218–37.

[7] Abdulwahed M, Nagy ZK. Applying Kolb's experiential learning cycle for laboratory education. J Eng Educ. 2009;98(3):283–94.

[8] Kolb DA. Experience as the source of learning and development., 1984.

[9] Bhute VJ, Inguva P, Shah U, Brechtelsbauer C. Transforming traditional teaching laboratories for effective remote delivery—A review. Educ Chem Engineers. 2021;35:96–104.

[10] Molenda M. "Designing instructional systems.," Training and development handbook. p. 1996.

[11] Hake RR. Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. Am J Phys. 1998;66(1):64–74.

[12] Arabeta HH. "Integration of gamification in teaching grade 10 physics: Its effect on students motivation and performance.," p. 2018.