International Journal of Teaching and Learning (INJOTEL) e-ISSN: 3025-8308
Vol. 3 No. 1 2025, pages: 230~249

HANDS-ON LABORATORY ACTIVITIES FOR TEACHING CELL TRANSPORT MECHANISMS IN SENIOR HIGH SCHOOL BIOLOGY

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ABSTRACT

The research assessed the academic performance in General Biology 1 of the Grade 11 STEM students at a science high school in Bantayan Island, Cebu, using the developed hands-on laboratory activities for the following competencies: (a) explaining transport mechanisms in cells (diffusion, osmosis, facilitated transport, active transport) and (b) differentiating endocytosis and exocytosis. Results of the pretest showed 40% and 38% in the control and experimental groups, respectively; both did not meet expectations based on the national agency's grading system. However, the post-test results of the experimental group increased to 91%, which exceeded the Outstanding threshold. Statistical analysis using a t-test revealed the following findings: (a) the conventional setup produced significant mean increases across multiple competencies in the control group (i.e., diffusion-.001, osmosis-.001, facilitated transport-.021, and active transport-001 in competency one), but the minimal increase in knowledge in exocytosis and endocytosis at .620 (competency 2) did not approach statistical significance, (b) the experimental group produced statistically significant mean increases (all at .001) demonstrating how well the hands-on method improved students' comprehension of cellular transport systems. In the comparison between the mean gains of the two groups, there was a statistically significant difference, with the experimental group showing more considerable mean gains. Moreover, the five themes that emerged during interviews with selected students, supplemental and collaborative, developing practical skills and long-term memory, and time constraints, provided a foundation for the successful implementation of the study. Hence, hands-on laboratory activities for teaching cell transport mechanisms in senior high school Biology are recommended.

Keywords: Science Teaching; Biology Teaching; Hands-on Activities; Cell Transport Mechanisms; Senior High School

INTRODUCTION

Science education is vital in the advancement of technology and of a country. In a study by Ahmad et al., 2018, they defined science education as a field that bridges science experts' knowledge and methods shared with people not part of the scientific community. Science links to technology and industry, thus preserving our country's cultural heritage (SEI-DOST, 2011 & DepEd K to 12 Curriculum Guide, 2016). As a field, science has many branches. Biology is a branch of science and is a prerequisite for continuing in many fields of learning, such as agriculture, medicine, biotechnology, pharmacy, and other related fields. The study of biology in senior high school equips the students with the necessary skills and competencies to face challenges in pursuing their studies.

Over the years, biology has been known as the study of life. Concepts covering the minute cells to the widest biosphere have been covered in teaching the subject. In Nakano's (2017) study, biology is the science that deals with the recognizable characteristics of living things, including their movement, death, respiration, growth, excretion, irritability, reproduction, and nutrition. Chukunyerenmuwa (2013) emphasized that biology is one of the basic sciences known to be efficient and effective in teaching and learning universally if only undertaken simultaneously with the help of adequate instructional resources and facilities.

Biology is a subject that contains many complex concepts to study (Fauzi et al., 2021) due to its abstract concepts, especially at the molecular level of living organisms. Another study by Santos et al. (2021) stated that one common problem faced by science students is their low mastery of content knowledge in science, specifically biology. This is supported by the study of Großschedl et al. (2014), which stated that the most challenging part for educators is to assist learners in developing their knowledge of subjects such as biology. They cited that these difficulties are affected by different factors, such as students' background knowledge, intelligence, and motivation. Studies indicate that out of all science topics, learners enjoy and are highly interested in Biology (Awan et al., 2011; Baram & Yarden, 2005; Osborne & Collins, 2000; Prokop et al., 2007). However, despite the popularity of Biology among students, conceptual understanding and performance are still low (Çimer, 2004).

The United Nations Development Programme has determined 17 Sustainable Development Goals (SDGs), which serve as the universal call to action in addressing the most pressing problems that the world is experiencing (UNDP, 2023). It involves the concept of quality education. Delivering quality education to cater to learners' needs has long been a global challenge. The Philippines lags behind other countries in quality education, particularly in a science subject (Millanes et al., 2017; Rogayan et al., 2019). The Philippines ranked 70th out of 144 participating countries in terms of the quality of mathematics and science education, according to the World Economic Forum by Schwab and Sala-i-Martin (2016). The difficulty of learning Biology is not only experienced in the country. Results of studies from other countries, such as Indonesia (Fauzi et al., 2021), Turkey (Çimer, 2012; Gungor & Ozkan, 2017), and Nigeria (Etobro & Fabinu, 2017) have shown that students have difficulty learning the subject under the topics material cycle, endocrine system, aerobic respiration, cell division, gene and chromosomes which mainly falls in the broad concepts of physiology, genetics, and cytology. In the study of Müller et al. (2021), students of all ages have experienced difficulties in understanding cellular transport mechanisms, especially when it comes to processes on the molecular level, such as osmosis and diffusion.

Due to the abstract nature of the comprehension of these concepts, innovations have been developed by experts and educators to increase the learners understanding. Researchers Barjis, Smith, and Samarrai (2010) developed modeling and simulation of cellular transport mechanism using Second Life as a modeling tool and platform to model, simulate, and create a semi-permeable cell membrane that would enable students to select a molecule they want to be and find a way how to enter the cell. Another study (Müller et al., 2021) addresses the problem through a virtual reality-based application that allows students to freely explore molecular transport mechanisms across the membrane by interacting with the environment and manipulating the molecule concentration or initiating transport mechanisms by actively moving molecules. Ibarra and Foresto (2021) designed a simple and inexpensive laboratory exercise to evaluate osmosis and tonicity on white blood cells by flow cytometry for biomedical physiology students.

Thus, this study is presented to enhance the academic performance of the senior high school Grade 11 STEM students regarding cell transport mechanisms in General Biology 1 by incorporating hands-on laboratory activities.

Using hands-on laboratory activities is believed to be a step toward realizing DepEd's and the UNDP's SDGs' vision of quality education and producing globally competitive and holistically developed learners.

This study assumed hands-on laboratory activities enhance cell transport mechanisms in Senior High School General Biology 1.

The most basic theory the study is anchored to is the constructivist model of human cognition (Savery & Duffy, 1994), precisely the learning-by-doing principle developed by the philosopher John Dewey (1959). Learning by doing engages the students in reliving real-life experiences in which they can manipulate materials for learning. It emphasizes student engagement and the fact that students learn along the process when they are engaged.

The learning-by-doing principle pertains to learning from experiences directly related to one’s actions (Miller, 2022). This hands-on approach concludes that people must interact with their environment to adapt and learn.

It is further motivated by experiential learning theory, in which students undergo science experimentation to increase their academic performance in the most essential learning competencies. Experiential learning theory (ELT) is also rooted in the learning-by-doing principle (Western Governors University, 2020). It states, “Experiential learning focuses on the idea that the best way to learn things is through experiences. Those experiences stick out and help you retain information and remember facts.”

The pioneer of ELT, who also created a model with four stages for this theory, was David Allen Kolb in 1939 (Varas et al., 2023). The four stages include concrete learning, reflective observation, abstract conceptualization, and active experimentation.

In activity theory (Jonassen & Rohrer-Murphy, 1999), learning is firmly rooted in its ability to perform voluntary skilled movements. The theory argues that conscious learning emerges from activity rather than the one that comes before it.

In a study conducted by Penn and Ramnarain in 2019, they stated that “laboratory experimentation in the context of school science is a widely advocated teaching strategy for the simplification of several abstract scientific concepts.”

Furthermore, the study is connected to the concept of guided theory. In an article by Sachs (2023), he pointed out the active participation of students in guided discovery, where they discover the knowledge, create and add to their scaffolding knowledge, and, thus, progress in creating their knowledge.

In a study by McKnight (1993), she quotes that misconceptions are prevalent in science (Lavoie, 1089) partly due to the abstract nature of concepts to be learned (Simpson & Marek, 1988) in combination with the concrete reasoning ability of most students. Like the Western Australian Ministry of Education (Secondary Education Authority, 1991), the Philippines Department of Education acknowledges the significance of transport mechanisms as a significant concept in science through their inclusion in the most essential learning competencies (DepEd K to 12 MELC, 2020).

An article by Nagarjuna G. (2021) elaborates on examples of some misconceptions around diffusion and osmosis. She stated that misconceptions about diffusion and osmosis arise when teachers ignore physics while teaching biology. For instance, students often answer that the lungs filter when probing about taking in oxygen and releasing carbon dioxide. Lungs cannot select this kind since no such selection ability exists at the respiratory surface. Additionally, teachers often rely on defining terms independent of a theoretical model. Misconceptions also arise from the terms used. The misconceptions associated with diffusion and osmosis arise not only from the definitions of the terms “diffusion” and “osmosis” but also from “solution,” “solvent,” “solute,” and popularly drawn distinctions regarding the mixtures and compounds on one hand and physical and chemical changes on the other. Students develop mental models by learning each of these concepts independently. In another article by A-level Biology Tutor (2016), common mistakes and misconceptions within cells and membranes include the concepts that "facilitated diffusion uses only channel proteins," "active transport uses only carrier proteins," and "exocytosis is the same as active transport."

Misconceptions possessed by learners can be obtained from the learning outcomes at the previous level of education (Hala et al., 2018). Research studies have innovated ways for teachers to deepen students' understanding of cell transport. Halpin & Golapan (2021) used the flipped teaching method and dramatization of teaching membrane transport concepts, and the results show increased students' understanding, engagement, and confidence levels. Barjis et al. (2010) incorporated modeling and simulation of cellular transport mechanisms as a game that enabled students to select a molecule they wanted to be and find how to enter the cell. Müller et al. (2021) designed a virtual reality-based application that allowed students to freely explore molecular transport mechanisms across the cell membrane by interacting with the environment and manipulating the molecule concentration or initiating transport mechanisms by actively moving molecules.

This research ascertained the effectiveness of hands-on laboratory activities for teaching Cell Transport Mechanisms in General Biology 1 subject of the Senior High School – STEM Grade 11 students. Specifically, it sought to answer the following sub-problems:

1. What is the pretest performance of the two groups of students (i.e., control and experimental) in the following most essential learning competencies:
   1.1 explaining transport mechanisms in cells (diffusion, osmosis, facilitated transport, active transport) and
   1.2 differentiating endocytosis and exocytosis?
2. How can the instructional material with hands-on laboratory activities be developed and implemented to enhance students' performance in cell transport mechanisms?
3. What is the posttest performance of the two groups of students (i.e., control and experimental) in the abovementioned most essential learning competencies?
4. Is there a significant difference in the pretest and posttest performances of the control and experimental groups?
5. Is there a significant difference in the mean gain between the control and experimental groups?
6. What are the experiences of the students and teachers with the hands-on laboratory activities?

RESEARCH METHODOLOGY

The study used a concurrent mixed (quantitative-qualitative) research method. The quantitative method was the quasi-experimental research design used to determine the effectiveness of implementing hands-on laboratory activities.

In this study, two groups of the two Grade 11 sections of a science high school were randomly assigned as control and experimental groups, respectively. The conventional teaching strategy (CTS) was used in the control group to deliver the concepts on the target learning competencies on cell transport mechanisms. Consequently, the experimental group received hands-on laboratory activities.

The study's qualitative method was an individual interview with selected students. Based on the writings of Braun & Clarke (2022) and Caulfield (2023), a thematic analysis of responses was made.

The instrument used in the study was a set of adopted and revised questionnaires from the General Biology 1 textbook for data gathering of this study. It consisted of the profile of the respondents with their gender, the pretest questions, the teaching strategies involved using CTS and the use of hands-on laboratory activities, and the posttest questions. It should be noted, however, that gender was not a variable in the study. It was used only for demographic profiling of the respondents. Science experts evaluated the questionnaire and hands-on laboratory activities before implementation and were pilot tested to the section not included in the study. The Cronbach's alpha is 0.718, meaning the tool is reliable for data gathering. Independent samples' T-tests were utilized to determine the pre-and post-test results of the student's performance, and dependent samples' T-tests were utilized to determine whether there was a significant difference in the pre-and post-test performances of the students. Themes were used to analyze the responses of the students during the interview.

RESULTS AND ANALYSIS

Pretest Performance of the Students in General Biology 1

The students' performances in General Biology before the pedagogical interventions were implemented are presented in Table 1.

The pretest results in Table 2 shed essential light on students' foundational knowledge in General Biology 1, with a particular emphasis on several cellular transport mechanism domains. The control group has lower mean scores than the minimum expected 75% for all competencies relevant to cellular transport systems, including Diffusion, Osmosis, Facilitated Transport, Active Transport, and Endocytosis/Exocytosis. The mean score for Diffusion is 1.90 (SD = 1.06), or 47.50%, indicating a performance that fell short of expectations. For Osmosis (mean = 0.97, SD = 0.93, equiv. % = 24.25), Facilitated Transport (mean = 1.57, SD = 0.94, equiv. % = 39.25), Active Transport (mean = 1.83, SD = 0.91, equiv. % = 45.75), and Endocytosis/Exocytosis (mean = 1.93, SD = 0.91, equiv. % = 48.25), the same tendency is seen throughout all four processes. The control group received an overall mean score of 8.20 (SD = 2.87), or 41.00%, which is below expectations overall. This suggests that, on average, the control group's students fell short of the required proficiency in these areas. Students' mastery of how molecules move across a cell membrane is foundational knowledge before acquiring broader and more advanced concepts. Moreover, abstract biological processes at the submicroscopic level are inherently complex for the students to conceptualize (Reinke et al., 2021).

Table 1. Pretest performance of the students in General Biology 1

Group	Competency	Mean (SD)	Equiv. %	Description [a]
Control	C1- Diffusion	1.90 (1.06)	47.50	DNME
	C1- Osmosis	0.97 (0.93)	24.25	DNME
	C1- Facilitated transport	1.57 (0.94)	39.25	DNME
	C1- Active transport	1.83 (0.91)	45.75	DNME
	C2- Endocytosis, Exocytosis	1.93 (0.91)	48.25	DNME
	Total	***8.20 (2.87)***	***41.00***	***DNME***
Experimental	C1- Diffusion	1.80 (1.03)	45.00	DNME
	C1- Osmosis	1.70 (1.06)	42.50	DNME
	C1- Facilitated transport	1.40 (0.97)	35.00	DNME
	C1- Active transport	1.60 (0.93)	40.00	DNME
	C2- Endocytosis, Exocytosis	1.10 (0.89)	27.50	DNME
	Total	***7.60 (2.44)***	***38.00***	***DNME***

[a] Based on DepEd's grading system: Below 75 (DNME - Did not meet expectations), 75-79 (FS - Fairly satisfactory), 80-84 (S - Satisfactory), 85-89 (VS - Very satisfactory), 90 and above (O - Outstanding)

A similar pattern can be seen in the experimental group, where the mean scores for each skill are below the 75% cutoff. In particular, scores below the expected level are shown by Diffusion (mean = 1.80, SD = 1.03, equiv. % = 45.00), Osmosis (mean = 1.70, SD = 1.06, equiv. % = 42.50), Facilitated Transport (mean = 1.40, SD = 0.97, equiv. % = 35.00), Active Transport (mean = 1.60, SD = 0.93, equiv. % = 40.00), and Endocytosis/Exocytosis (mean = 1.10, SD = 0.89, equiv. % = 27.50). The experimental group's overall mean score is 7.60 (SD = 2.44), or 38.00%. The results justify Harrison's (2018) study about demonstrating the diffusion of molecules using role-playing activities, a topic that can be difficult for students to differentiate and remember. This further justifies the study of Fauzi et al. (2021) that students need higher foundational knowledge of these transport topics due to these abstract concepts.

Based on their pretest results, both groups need to improve their knowledge of cellular transport systems. Even if the experimental group's mean scores are somewhat lower than the control group's, they are still below the predicted competency level. These results emphasize the necessity of focused interventions to improve students' understanding of these ideas. To meet the unique learning demands of each group, personalized and differentiated teaching methodologies could also be considered. Many studies have presented and analyzed the effects of specific teaching methods on changes in students' conception of cell transport mechanisms. Some of them are modeling and simulation (Barjis et al., 2010), virtual reality-based applications (Müller et al., 2021), and simple and inexpensive laboratory exercises (Ibarra & Foresto, 2021). Thus, these hands-on laboratory activities for Senior High School students have been developed.

Development and Implementation of the Instructional Material with Hands-on Laboratory Activities

The development of hands-on laboratory activities was rooted in the Department of Education's localization and contextualization concept in response to RA 10533 IRR Section 10.2, where this curriculum feature is emphasized, most importantly, on learning by doing. Also, due to the abstractness of the concepts of cell transport mechanisms, these learning competencies have been regarded as among the least learned in the subject. As a result of the quarterly audit of implemented learning competencies, these competencies of cell transport mechanisms have been one of the least learned by students. With this, the researcher thought of ways to devise strategies for successful implementation and increased academic achievement.

After reading various literature on the topic and other related sources, the researcher conceived the idea of crafting contextualized and localized hands-on activities for passive, active, and bulk transport mechanisms for effective learning and using the materials found in the locality and at home, such as eggs, food coloring, potato, marble, yarn, and those that can be used to explicitly show how these activities will help learners understand how these mechanisms work in the body.

Each hands-on laboratory activity has two parts: the Laboratory Activity Number and the Laboratory Report Sheet. The Laboratory Activity has four parts: Introduction – which has a short overview of the transport mechanisms indicated; Objectives – which gives the target of the activity; Materials – listing of all the needed materials and equipment; and Procedure – containing the step-by-step instructions on the activity. Then, the Laboratory Report Sheet serves as the answer sheet where learners write their observations, illustrations, or simply their answers to the given guide questions, and lastly, the conclusion of the learners on the activity.

The first laboratory activity was about passive transport mechanisms. It includes the processes of diffusion and osmosis, with the objectives of 1) exhibiting the phenomenon of diffusion and 2) distinguishing the different tonicities of cells in varied osmolarity. The materials used in the activity were meticulously chosen so that students could simulate the cellular process. The diffusion activity involved food coloring, beakers, and water samples (lukewarm, hot, and cold). The laboratory report sheet for this activity includes illustrating the outcome and writing their observations, as well as taking note of measurements by following the given procedure thoroughly. Guide questions were also included to be answered. After this, they will conclude the whole process of the transport mechanism.

Secondly, the next laboratory activity was about active transport mechanisms. It included activities to 1) arrange events chronologically in the primary active transport mechanism and 2) complete statements about the secondary active transport mechanism. Materials used in the activity comprised photos/illustrations about the processes under this mechanism. Moreover, the guide questions were to be answered, and the conclusion was to be given.

Finally, the third laboratory activity was about bulk transport mechanisms, which include endocytosis and exocytosis. The simulation aimed to 1) describe the process of endocytosis and 2) explain the process of exocytosis. The materials given were readily available in the locality and households, like cord/yarn and marble. The procedure was stated in an understandable manner. The laboratory report sheet included parts for students to illustrate the before and after following the procedure stated. Then, guide questions were answered, and a conclusion was given.

Two (2) experts validated the developed hands-on laboratory activities for Cell Transport Mechanisms together with the pre- and post-test questionnaires with an S-CVI Average of 1. If two experts validate the questionnaire, the acceptable CVI value is at least 0.80 (Davis, 1992). Hence, the questionnaire and the developed hands-on laboratory activities are satisfactory.

After conducting the pretest, the teacher-researcher taught the conventional teaching method to the students in the control group in the classroom. Meanwhile, hands-on laboratory activities were distributed to the students in the experimental group in the Science Laboratory.

Posttest Performance of the Students in General Biology 1

The students' performances in General Biology after the pedagogical interventions were implemented are presented in Table 2.

The posttest results in Table 2 give a thorough picture of how instructional interventions—especially practical laboratory exercises—affect students' performance in General Biology 1. Different patterns in posttest scores across skills are seen between the experimental group, which participated in hands-on laboratory activities, and the control group, which was exposed to the traditional setup.

Table 2. Posttest performance of the students in General Biology 1

Group	Competency	Mean (SD)	Equiv. %	Description [a]
Control	C1- Diffusion	3.53 (0.63)	88.25	VS
	C1- Osmosis	2.43 (0.94)	60.75	DNME.
	C1- Facilitated transport	2.20 (1.10)	55.00	DNME
	C1- Active transport	2.70 (0.60)	67.50	DNME
	C2- Endocytosis, Exocytosis	2.07 (1.08)	51.75	DNME
	Total	***12.90 (2.86)***	***64.50***	***DNME***
Experimental	C1- Diffusion	3.87 (0.43)	96.75	O
	C1- Osmosis	3.73 (0.64)	93.25	O
	C1- Facilitated transport	3.50 (1.01)	87.50	VS
	C1- Active transport	3.57 (0.77)	89.25	VS
	C2- Endocytosis, Exocytosis	3.57 (0.68)	89.25	VS
	Total	***18.20 (3.10)***	***91.00***	***O***

[a] Based on DepEd's grading system: Below 75 (DNME - Did not meet expectations), 75-79 (FS - Fairly satisfactory), 80-84 (S - Satisfactory), 85-89 (VS - Very satisfactory), 90 and above (O - Outstanding)

The control group's posttest scores indicate a significant improvement over the pretest. The mean score for Diffusion (C1) climbed to 3.53 (SD = 0.63), which is equal to 88.25% and reaches a "Very Satisfactory" rating. The results, however, continued to fall short of the predicted level of proficiency in Osmosis (mean = 2.43, SD = 0.94, equiv. % = 60.75), Facilitated Transport (mean = 2.20, SD = 1.10, equiv. % = 55.00), Active Transport (mean = 2.70, SD = 0.60, equiv. % = 67.50), and Endocytosis/Exocytosis (mean = 2.07, SD = 1.08, equiv. % = 51.75). The control group's overall mean score is 12.90 (SD = 2.86), or 64.50%, below the "satisfactory" threshold. Based on the article from EuroSchool (2023), there is an efficient transmission of information from teacher to student, especially in covering a substantial amount of content. This is why, after its implementation in the control group, there was an increase in the students' performances, but it was low since it was below the satisfactory level.

On the other hand, the experimental group showed notable gains in every competency due to their participation in practical laboratory activities. The results exceeded the "Outstanding" threshold for Diffusion (mean = 3.87, SD = 0.43, equiv. % = 96.75), Osmosis (mean = 3.73, SD = 0.64, equiv. % = 93.25), Facilitated Transport (mean = 3.50, SD = 1.01, equiv. % = 87.50), Active Transport (mean = 3.57, SD = 0.77, equiv. % = 89.25), and Endocytosis/Exocytosis (mean = 3.57, SD = 0.68, equiv. % = 89.25). The experimental group's overall mean score is 18.20 (SD = 3.10), or 91.00%, which is an exceptional performance level. This result showed the same results as other studies comparing traditional teaching methods with other modern teaching methods, such as web-based and cooperative learning (Ashoori, 2014), constructivist teaching in college biology (Lord, 1997), and interactive teaching (Miles, 2019), among others.

The significant improvement observed in the experimental group indicates that practical laboratory activities substantially enhance students' comprehension and application of cellular transport mechanisms. The exceptional scores are probably a result of a greater understanding of the topics brought about by the immersive character of these activities. The traditional teaching method may have helped the control group's Diffusion score, but overall performance is lacking, highlighting the potential benefits of experiential learning.

These posttest findings highlight the effectiveness of including practical laboratory exercises in General Biology 1 classrooms since they produce excellent results in various competencies. The results highlight how interactive and immersive learning approaches can improve biology students' performance and understanding.

Comparison between the Pretest and Posttest Performances in General Biology 1

The students' pretest and posttest performances were subjected to t-tests to compare whether there were significant improvements across the different competencies for the control and experimental groups. The results are gleaned in Table 3.

Table 3. Statistical comparison between the pretest and posttest performances

Group	Competency	Mean Gain	t (p-value)	Interpretation*
Control	C1- Diffusion	1.63	6.89 (.001)	Significant
	C1- Osmosis	1.47	6.15 (.001)	Significant
	C1- Facilitated transport	0.63	2.43 (.021)	Significant
	C1- Active transport	0.87	4.56 (.001)	Significant
	C2- Endocytosis, Exocytosis	0.13	0.50 (.620)	Not significant
	Total	***4.73***	***6.73 (.001)***	***Significant***
Experimental	C1- Diffusion	2.07	9.65 (.001)	Significant
	C1- Osmosis	2.03	9.86 (.001)	Significant
	C1- Facilitated transport	2.10	8.38 (.001)	Significant
	C1- Active transport	1.97	10.78 (.001)	Significant
	C2- Endocytosis, Exocytosis	2.47	15.02 (.001)	Significant
	Total	***10.63***	***16.89 (.001)***	***Significant***

*Significant at α=.05

The statistical analysis of the pretest and posttest results in Table 5 sheds light on how instructional interventions affected the control and experimental groups' students' comprehension of cellular transport systems.

The conventional setup produced significant mean increases across multiple competencies in the control group. The understanding of Diffusion (C1), Osmosis (C1), Facilitated Transport (C1), and Active Transport (C1) was notably improved. High t-values and low p-values, which show statistical significance, indicated these benefits. However, the minimal mean increase in knowledge of exocytosis and endocytosis (C2) did not approach statistical significance. Despite this, the control group's overall mean gain was statistically significant, indicating a general improvement in the pupils' performance. This significance emphasizes the importance of the traditional method in teaching since it allows teachers to deliver the topics ought to be delivered to students as planned. Students must take detailed notes while instructing lectures (Kelly, 2019).

Conversely, the experimental group showed notable and statistically significant mean increases in all abilities after exposure to practical laboratory activities. There were notable improvements in all processes: diffusion (C1), osmosis (C1), facilitated transport (C1), active transport (C1), endocytosis, and exocytosis (C2). The experimental group's overall mean gain was noticeably higher, demonstrating how well the hands-on method improved students' comprehension of cellular transport systems. Learning by doing has dramatically improved the students' performances through the conduct of the activity. Drapa (2019) cited that scientific concepts are deeply understood and better scored by students once they have first-hand experience of the activities.

When mean gains between the two groups were compared, the experimental group continuously outperformed the control group, suggesting that hands-on laboratory activities more significantly impacted students' learning outcomes. The experimental group's notable improvements imply that the experiential learning strategy offered a more thorough comprehension of the material. The results showed the contributions of experiential learning to improve the value of education, which centers on developing students' abilities and experiences (Kong, 2021), thus increasing their performances after the post-test.

These results show the significance of instructional strategies in biology education. Even though it produced advances, the hands-on laboratory activities proved more effective than the standard teaching technique. The two groups' statistically significant gains highlight the possibility of improving student comprehension with focused educational interventions. The practical method, in particular, allows students to interact with the content immediately and reinforces theoretical knowledge with real-world experiences, which aligns with the concepts of active learning and application.

Comparison between the Mean Gains of the Two Groups in General Biology 1

The mean gains of the control and experimental groups were compared using the t-test for independent samples. The statistical result is shown in Table 5.

Table 5. Statistical comparison between the mean gains

Group	Mean Gain	Difference	t (p-value)	Interpretation*
Control	4.73	5.90	6.25 (.001)	Significant
Experimental	10.63			

*Significant at α=.05

There is a statistically significant difference between the mean gains of the experimental and control groups, with the experimental group showing more significant mean gains. The experimental group's mean gain was much higher at 10.63 than the control group's 4.73. The t-test results for independent samples showed a statistically significant difference in the mean gains between the two groups, with a t-value of 6.25 ($p = .001$). Compared to the typical instructional arrangement in the control group, the experimental group's more significant mean gains indicate that the instructional material with practical laboratory activities was more helpful in fostering an understanding of cellular transport systems. The observed variances can be attributed to several reasons.

First, the students could interact with the material naturally and physically by giving the experimental group direct, immersive experiences through hands-on laboratory activities. Because they could watch, interact with, and experiment with the biological processes involved in cellular transport, students' active participation contributed to their greater comprehension of the ideas. Students' involvement means being active and engaged in teaching-learning (Bergmark & Westman, 2018). This gives them the privilege of interacting with their groupmates. Thus, they have been able to exchange ideas and have first-hand experience of the activity.

Second, the hands-on method encouraged a comprehensive learning experience by integrating academic knowledge with real-world applications. As a result of learning the concepts and understanding how they apply to real-world situations, this combination is believed to improve retention and comprehension. The experimental group's exposure to concrete examples during lab exercises helped them to understand the subject matter more thoroughly. In a study by Mahmud et al. (2018), the comprehensive learning theories involve cognitivism, constructivism, and behaviorism, which would explain the active engagement of the students (behavior displayed) in the hands-on laboratory activities (cognitive tool) provided a schema (constructivism) for them to understand deeper the concepts of the activities implemented to them.

Furthermore, involvement and engagement are encouraged by the interactive and collaborative nature of hands-on activities, which can enhance learning results. During laboratory sessions, peer interactions, conversations, and shared problem-solving experiences helped students in the experimental group, fostering a dynamic learning environment. In an article by School Specialty (2022), a dynamic learning environment allows learners to harness their 21st-century skills. These skills include communication, collaboration, innovation, critical thinking, and creativity, which could support the learners' academic performances.

Conversely, the control group saw improvements but did not gain from the same degree of direct contact with the material or active participation. Even though they are helpful, traditional teaching techniques occasionally need more experience and practical elements essential for understanding complicated biological ideas. This goes down to the disadvantages of the conventional teaching strategy, which includes generalized learning, passive learners, and teacher-centered education (Salim, 2019).

Overall, the experimental group's higher mean gains indicate that the hands-on laboratory activities in the educational material contributed to students' increased comprehension of cellular transport systems. The two groups observed statistically significant differences in mean gains. They were attributed to the hands-on approach's unique and immersive learning experience, which combined active involvement, collaborative learning, and practical application. This emphasizes how effective practical laboratory exercises are as a teaching tool for raising student achievement in biology classes. Enhancement of students' understanding of concepts in science; scientific practical skills and problem-solving abilities; scientific 'habit of minds'; understanding of how science and scientists' work; interest and motivation (Hamidu, 2014).

Experiences of the Students and Teachers with the Hands-on Laboratory Activities

Data was collected through an interview, and five (5) themes emerged as patterns from their responses to the six (6) questions.

These are the following: supplemental and collaborative – on how they find the laboratory activity; developing practical skills and long-term memory – on how it helped them increase their academic performance in the topic; on their description of their learning experience for the whole duration of the activity; and on how well they learned in the Cell Transport Mechanism topics as well as the advantages; and time constraints – on the disadvantages.

Supplemental and Collaborative

The themes are supplemental and collaborative. The activities helped the students better understand the concepts of different transport mechanisms. Cooperation and teamwork (i.e., working hand-in-hand with all the group members) have been one of the foundations for accomplishing the activities designed, thus making them exciting and fun.

Supplemental Instruction (SI) is a co-curricular academic approach that encourages collaboration with peers to attain the learning objectives for the concepts to be learned. In a study by Allen et al. (2021), the assessment of SI effectiveness revolves around student ability, achievement, motivation, and demographic characteristics and is frequently limited by available resources. It fosters collaboration, which is essential in developing the 21st-century skills of the learners.

Developing Practical Skills and Long-Term Memory

The emerging themes include developing practical skills and long-term memory. Through hands-on experience, the students enhanced their observation skills, essential for a thorough understanding of the topics involved. Due to their experiences in the hands-on laboratory activities, students could recall concepts and be able to remember them for a long time.

Under practical skills, sub-themes like level of difficulty (Question 3) and first-hand experiences (Question 5) were also developed during the hands-on laboratory activities. Regarding the number of activities, the students have experienced challenges and exhaustion upon receiving, yet they have surpassed them through collaborative efforts with their group mates. The students were able to immerse themselves in the activities, and they were very much involved. Thus, they discovered the resulting outcomes and took notes through first-hand experiences.

Moreover, sub-themes like visualization and active recall (Question 4) were also emphasized in the long-term memory part. The students grasped how these activities represented cell transport mechanisms in organisms and retrieved that information from their brains.

Process skills are foundational knowledge in science (Jack, 2013). These skills include practical skills that could help students accomplish the ascending difficulty level through direct first-hand experiences.

Long-term memory, on the other hand, could be strengthened, enhancing the students' visualization skills and active recall. Active recall is a process of retrieving information based on the learning experiences encountered by the students from the topics presented instead of just listening and reading information.

Time Constraints

The theme that emerged among the students' disadvantages was time constraints. The hands-on laboratory activities were designed for a week after the teacher discussed the topics on transport mechanisms in the subject. Indeed, it is time to complete the activity since, aside from the concept of transport mechanisms that the students will learn, the different scientific skills will also be enhanced.

Time constraints have been a disadvantage since a series of activities have been given to the respondents. In the eggshell reaction with the vinegar, it took them 3 days to soak the eggs and rub off the softened eggshell to view the membrane, which separates its inside from the outside environment.

Moreover, the teachers' comments during the evaluation of the hands-on laboratory activities were that they were well-crafted.

CONCLUSION

The results of the study showed that on the pretest performances of the students, the control group had lower mean scores than the minimum expected of 75% for all competencies relevant to cellular transport systems with their mean scores, including Diffusion (C1) (μ=1.90; SD=1.06; %=47.50), Osmosis (C1) (μ=0.97; SD=0.93; %=24.25), Facilitated Transport (C1) (μ=1.57; SD=0.94; %=39.25), Active Transport (C1) (μ=1.83; SD=0.91; %=45.75), and Endocytosis/Exocytosis (C2) (μ=1.93;

SD=0.91; %=48.25). The control group had an overall mean score of 8.20 (SD=2.87) or 41.00%, below expectations. The same pattern can be traced on the experimental group, where mean scores for each skill are below the 75% cutoff with their mean scores: Diffusion (C1) (μ=1.80; SD=1.03; %=45.00), Osmosis (C1) (μ=1.70; SD=1.06; %=42.50), Facilitated Transport (C1) (μ=1.40; SD=0.97; %=35.05), Active Transport (C1) (μ=1.60; SD=0.93; %=40.00), and Endocytosis/Exocytosis (C2) (μ=1.10; SD=0.89; %=27.50) with an overall mean score of 7.60 (SD=2.44) or 38.00%.

Moreover, the control group's posttest performances indicate a significant improvement over the pretest. The mean score for Diffusion (C1) increased to 3.53 (SD=0.63), which is equal to 88.25%. The results continued to fall short of the predicted level of proficiency in Osmosis (C1) (μ=2.43; SD=0.94; %=60.75), Facilitated Transport (C1) (μ=2.20; SD=1.10; %=55.00), Active Transport (C1) (μ=2.70; SD=0.60; %=67.50), and Endocytosis/Exocytosis (C2) (μ=2.07; SD=1.08; %=51.75). The control group's overall mean score has been 12.90 (SD=2.86), or 64.50%, below the Satisfactory threshold. On the other hand, notable gains can be seen in the results of the experimental group, Diffusion (C1) (μ=3.87; SD=0.43; %=96.75), Osmosis (C1) (μ=3.73; SD=0.64; %=93.25), Facilitated Transport (C1) (μ=3.50; SD=1.01; %=87.50), Active Transport (C1) (μ=3.57; SD=0.77; %=89.25), and Endocytosis/Exocytosis (C2) (μ=3.57; SD=0.68; %=89.25). The experimental group's overall mean score is 18.20 (SD=3.10) or 91.00% which is an exceptional performance level.

Moreover, comparing the pretest and post-test performances using a t-test, the conventional setup produced significant mean increases across multiple competencies in the control group, such as Diffusion, Osmosis, Facilitated Transport, and Active Transport in competency 1. However, the minimal increase in knowledge of Exocytosis and Endocytosis, which is in competency 2, did not approach statistical significance. In general, the control group's overall mean gain was statistically significant. Conversely, statistically significant mean increases can be noted in the experimental group after exposure to practical laboratory activities. The experimental group's overall mean gain was noticeably higher, demonstrating how well the hands-on method improved students' comprehension of cellular transport systems.

In the comparison between the mean gains of the two groups, there was a statistically significant difference, with the experimental group showing more considerable mean gains. The experimental group's mean gain was much higher at 10.63 than the control group's 4.73 with a t-value of 6.25 (p=.001).

It has also been found that on the experiences of the students and teachers with the developed hands-on laboratory activities, the following themes have emerged: supplemental, collaborative, developing practical skills, developing long-term memory, and time constraints.

Based on the study's findings, it is indicated that the instructional material with practical laboratory activities was more helpful in fostering an understanding of cellular transport systems. It is therefore concluded that hands-on laboratory activities are effective in teaching Cell Transport Mechanisms in Senior High School Biology.

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