JPII 15 (2) (2026) 238-248

Jurnal Pendidikan IPA Indonesia

https://journal.unnes.ac.id/journals/jpii

EFFECTS OF MICRO-LABORATORY DEMONSTRATION ACTIVITIES ON SCIENCE ENGAGEMENT AND MASTERY TOWARDS LEARNING FLOW

A. A. E. Panergayo*[1], C. N. Ate[2], C. F. Gregana[3]

[1,2,3]College of Teacher Education, Laguna State Polytechnic University, Philippines

DOI: 10.15294/jpii.v15i2.36125

Accepted: November 10th, 2025. Approved: June 29th, 2026. Published: June 29th, 2026

ABSTRACT

Science mastery and engagement remain a persistent challenge in Philippine public schools, often due to limited access to laboratory resources and passive instructional methods. In view of this, the study designed and implemented Micro-laboratory Demonstration Activities (MLDAs) that are cognitively enriching, emotionally immersive, and behaviorally engaging. The MLDAs aim to unlock learning flow through hands-on tasks with clear objectives, appropriate challenges, and immediate feedback. Using educational action research, five expert-validated activities were designed to promote science mastery and engagement, achieving a strong content validity (S-CVI > 0.90) and high reliability (α=0.89), were designed to promote science mastery and engagement (α=0.89). The researchers administered the designed MLDAs to a sample of Grade 8 struggling students (n=42). Paired-sample t-tests revealed statistically significant improvements across all cognitive domains of science mastery, with large effect sizes in remembering (d=0.83), applying (d=0.95), analyzing (d=1.03), and overall mastery (d=1.51), while understanding showed a medium effect (d=0.74). The survey, observational data, and student interviews confirmed sustained high student engagement. Thematic analysis identified five prominent themes in students' perspectives and experiences regarding MLDAs: hands-on learning, collaborative play, sensory appeal, conceptual clarity, and creative facilitation. These findings show that MLDAs are effective tools for fostering higher-order thinking, sustained engagement, and transformative science learning in resource-constrained classrooms.

Keywords: learning flow; micro-laboratory activity; science engagement; science mastery

INTRODUCTION

Active student involvement and participation are crucial components of effective science education, fostering deeper conceptual understanding, critical thinking skills, and intrinsic motivation among students. By shifting the focus from passive information reception to active engagement in hands-on activities, laboratory experiments, and collaborative problem-solving, students gain firsthand experience with scientific phenomena, thereby enhancing their comprehension and retention of scientific concepts. Active participation encourages students to ask questions, seek explanations, and connect theory and practice, fostering a more holistic understanding of scientific principles. Moreover, collaborative activities and peer interactions facilitate the development of essential skills, such as communication, collaboration, and problem-solving, which are invaluable in both scientific inquiry and everyday life. Additionally, active involvement in the learning process nurtures a sense of ownership and empowerment among students, fostering a lifelong appreciation for scientific inquiry and discovery.

In line with the United Nations Sustainable Development Goals (SDGs), specifically SDG

*Correspondence Address
E-mail: albertandry.panergayo@lspu.edu.ph

4: Quality Education, there is a pressing need to improve science instruction. The Philippine K-12 Curriculum is aligned to SDG 4 through the Basic Education Development Plan (BEDP) 2030. The K to 12 Science Education curriculum in the Philippines is designed as a student-centered, inquiry-based discipline, emphasizing students' active participation in their own learning process (Panergayo et al., 2022). Rooted in constructivist pedagogy, this approach places students at the center of the educational experience, encouraging them to explore scientific concepts through inquiry, experimentation, and discovery. Laboratory activities play a pivotal role in this curriculum, providing students with hands-on experiences that deepen their understanding of scientific principles and phenomena. By engaging in practical investigations and experiments, students not only acquire theoretical knowledge but also develop critical thinking, problem-solving abilities, and scientific inquiry skills. Laboratory activities catalyze active engagement and learning, allowing students to apply theoretical concepts in a real-world context and make meaningful connections between theory and practice. Moreover, the Learning Flow Theory (FT) posits that optimal learning occurs when students are fully immersed in challenging yet achievable tasks that match their skill level, with continuous feedback and opportunities for reflection (Csikszentmihalyi, 2014). Laboratory activities align with this theory by providing students with hands-on experiences that are both intellectually stimulating and personally rewarding, fostering a state of flow where students are fully absorbed and motivated to explore scientific concepts further. Thus, integrating laboratory activities into the K to 12 Science Education curriculum not only enhances instruction but also nurtures a genuine passion for scientific inquiry among students.

However, the current state of public schools in the Philippines underscores significant deficiencies in science laboratory equipment and facilities, as well as a shortage of essential learning materials. Despite efforts to improve educational infrastructure, many public schools across the country continue to grapple with inadequate resources for conducting hands-on science experiments and demonstrations. A study conducted by the Philippine Business for Education (PBEd) revealed that around 80% of public schools in the Philippines lack science laboratory facilities, severely hampering students' opportunities to engage in practical scientific inquiry (PBEd, 2017). According to UP Diliman's data (2023), of the 12,390 high schools in the Philippines, 4,520 have no access to a science laboratory, and even fewer to modern digital tools. Furthermore, the shortage of learning materials such as textbooks, laboratory supplies, and multimedia resources further exacerbates the challenges faced by both students and teachers in delivering quality science education (UNESCO, 2019). This dearth of essential resources not only hinders students' ability to grasp scientific concepts effectively but also undermines their overall learning experience and academic performance. As a result, addressing the disparities in access to science laboratory equipment and learning materials remains a critical priority in efforts to enhance the quality of science education in Philippine public schools. During the 2022 Program for International Student Assessment (PISA), the Philippines ranked 77th out of 81 countries in science, with an average science score of 356, which is significantly lower than the OECD average of 485. Comparing this to the 2018 PISA results for the same country, which scored 357, shows no significant improvement in mastery of science over the last 5 years. Only 23% of students have mastered basic science proficiency, and only 1 in 4 students can apply basic science knowledge to identify the correct explanation of a scientific phenomenon (OECD, 2023). Another report from the Second Congressional Commission on Education (EDCOM 2, 2024) found that the highest-achieving Filipino students are comparable to the average students in Vietnam and Malaysia. Given these concerns, improving science education in the country is crucial as students prepare to be globally competitive and face future challenges.

Laboratory activities provide students with the opportunity to apply theoretical knowledge in a practical context, fostering a more holistic and experiential approach to learning science (Abdurakil et al., 2024). This study will be significant as it explores the efficacy of micro-laboratory demonstrations as an alternative to traditional classroom laboratory activities. However, previous literature revealed that most existing studies focus on well-equipped laboratories, virtual laboratories, or technology-driven simulations (Belisario & Paglinawan, 2025; Fajrin & Hakim, 2023; Pitiporntapin et al., 2024), with little empirical attention to MLDAs in resource-constrained classrooms in public schools, particularly catering to struggling students in science. These Micro-laboratory activities can also help promote SDG 12: Responsible Consumption by offering sustainable, cost-effective solutions that students can use to conduct hands-on activities with minimal material use.

In investigating the impact of micro-laboratory demonstrations on science engagement and mastery, this research aims to support and provide valuable insights into optimizing instructional methods and enhancing students' learning experiences in science education. This study aims to extend previous studies' findings to low-resource educational settings (Fajrin & Hakim, 2023) and potentially refute the assumption that effective laboratory learning requires complete laboratory facilities and high-cost equipment. This study will also serve as a baseline to inform pedagogical practices and curriculum development in K-12 Science Education, paving the way for innovative approaches that maximize student engagement and achievement in science.

METHODS

This study employed educational action research, drawing on both quantitative and qualitative evidence to address the research problems. This action research is framed by the Plan-Do-Study-Act (PDSA) model, a widely used systematic framework in educational research to guide iterative instructional enhancement (Crowfoot & Prasad, 2017). This research design is deemed appropriate as it involves a systematic approach to investigating and improving educational practices through a collaborative process of reflection, planning, action, and evaluation. The PDSA model was adopted and modified to form the action research cycle, aligning planning with diagnostic assessment, implementation with instructional action, evaluation with systematic study of outcomes, and reflection with instructional refinement. This study aimed to improve the implementation of laboratory activities in public schools through the lens of heightened students' mastery and engagement in science, which eventually leads to the state of learning flow. The concept of learning flow is anchored on Flow Theory (Csikszentmihalyi, 2014), which emphasizes optimal learning through sustained engagement, balance of challenge and skills, and intrinsic motivation.

The participants of this study are Grade 8 junior high school students from one public high school situated in the Division of San Pablo City, Laguna. These students are classified as struggling students, identified by their respective teachers at the research site. Struggling students are students who face challenges in academic performance or learning progress compared to their peers. The identification of struggling students was based on academic records, formative assessments, and teachers' professional judgment during the diagnostic stage. The study aims to implement an intervention to address low mastery and engagement in science. The intervention consisted of five modified low-cost laboratory activities (MLDAs) designed to address the identified learning gaps.

The research utilized an integrated framework encompassing Flow Theory (FT), Cognitive Load Theory (CLT), and Kagan's Cooperative Learning (CL) to develop MLDAs. Csikszentmihalyi (2014) developed the concept of flow theory (FT). It helped create immersive tasks that made students feel deeply focused and happy, or in a state of learning flow (Oliveira et al., 2021; dos Santos et al., 2018). Clear goals, difficult tasks, and new things kept people's attention and encouraged them to ask questions (Shernoff et al., 2003; Gyllenpalm, 2017; Mandhana & Caruso, 2023; Zhang & Qi, 2023).

CLT guided the design of laboratory activities to enhance cognitive processing by integrating intrinsic, extraneous, and germane load (Sweller, 2011; Lin et al., 2012; Bounajim et al., 2021). Stepwise scaffolding, visual aids, and structured instructions alleviated cognitive overload while facilitating conceptual comprehension (De Jong, 2009; Sweller, 2011; Kuldaş et al., 2014). This practice ensures that students can focus on applying what they have learned and improving their higher-order thinking skills without feeling overwhelmed (Skulmowski & Xu, 2021).

Kagan's CL stressed collaborative learning, encouraging participation, interaction, and shared responsibility (Clowes, 2011; Chong et al., 2019). MLDAs were carried out in a sequence that followed the integrated framework: sensory-rich demonstrations to activate prior knowledge (FT), guided hands-on experiments to build understanding (CLT), collaborative games to practice problem-solving (CL), and reflection with creative facilitation to keep the flow of learning sustained (Csikzentmihalyi, 2014; Van Ryzin et al., 2020; Dorji et al., 2021; Tran & Nguyen, 2023). This method encouraged participation, skill acquisition, and social-emotional growth.

Stage 1: Plan

The plan stage is composed of diagnostic assessment and instructional planning. The data sources were obtained from the learning assessment, interviews, and observation protocols. During the Plan stage, baseline data were collected to assess students' conceptual mastery and engagement in science. To gauge students' mastery of science, a researcher-developed conceptual understanding test was designed based on the learning competencies identified in the science curriculum. The questions highlighted an understanding of the basic concepts and principles of the topic at hand. The test consisted of 20 multiple-choice items, which were expert- validated and pilot-tested to ensure validity and reliability. Content validity was established through expert review, while reliability was ensured through pilot testing and internal consistency analysis.

For science engagement, the Engagement in Science Learning Activities was developed by Chung et al. (2016). This survey is intended for use with 10–14-year-old respondents immediately after a science activity. It comprises 14 items to assess the students' behavioral, cognitive, and affective engagement. Survey results suggest specific engagement dimensions that need improvement, guiding targeted revisions in activity structure, pacing, and student participation. Behavioral engagement findings informed increased hands-on manipulation, while cognitive engagement data guided scaffolding through guiding questions. Affective engagement results influenced contextualization, relevance, and motivational elements embedded during the planning phase of MLDAs.

The designed MLDAs are structured learning tasks that aim to unlock the learning flow of struggling students by being enjoyable, cognitively enriching, and emotionally immersive. Anchored on Kagan's cooperative learning, CLT, and Csikszentmihalyi's FT (2014), these activities feature clear objectives, appropriate challenges, and immediate feedback. They promote hands-on investigation, peer collaboration, and conceptual clarity. The five laboratory activities were expert-validated by five science education specialists and obtained commendable S-CVIS of above 0.90. Reliability was also confirmed through a pilot test with Cronbach's alpha of 0.89, indicating high internal consistency. These results imply strong content validity and reliability, ensuring consistent, meaningful engagement and conceptual learning outcomes.

Stage 2: Do

This stage involves implementing planned instructional strategies in authentic classroom settings. For data collection, the study uses action research with a pretest-posttest design. The purposively selected group was used during the experimental stage. The experimental group was taught using the five designed MLDAs based on the Science education curriculum for Grade 8 students. The groups were subjected to a pretest to assess students' baseline understanding of the selected science topic. The test scores were collected and recorded individually. The teacher ensured that the students were properly oriented and received the instructional materials and resources appropriate for each designed instruction. The teacher would use the observation protocol to collect relevant information during actual laboratory demonstrations to document the teaching and learning process. Table 1 shows the study's flow.

Table 1. Schedule of Implementation of MLDAs

Session	Activities
1	Orientation of the Program
2	Pre-assessment
3	Laboratory Activity 1: *Transverse Wave Model*
4	Laboratory Activity 2: *Characteristics of a Wave*
5	Laboratory Activity 3. *String Telephone, Straw Pan Flute*
6	Laboratory Activity 4. *Mirror, Mirror on the Bowl*
7	Laboratory Activity 5. *Rainbow in a Glass*
8	Post-Assessment and Reflection
10	Semi-structured Interview

Stage 3: Study

The Study stage constitutes observation, monitoring, and data analysis. Observation sheets were also used to document interactions during the intervention. The observation will highlight how the intervention affects students' mastery and engagement in science. The observation protocol focused on behavioral indicators such as participation, persistence, and collaboration, as well as on-task behavior, consistent with engagement and flow-related constructs.

Thereafter, the group was administered a post-test to measure changes in students' mastery of science. Moreover, the students were asked to respond to the engagement after every laboratory demonstration to minimize memory biases or inferences based on beliefs students have about themselves or the learning context. Thus, the students answered the survey five times. The test scores and responses were tallied and recorded using spreadsheets. The teacher also led a focus group discussion to explore and verify students' experiences with the designed intervention.

The data were analyzed using appropriate statistical and qualitative methods. For the quantitative data, descriptive statistics, such as mean and standard deviation, were used to describe students' mastery and engagement in science before and after the designed intervention. Assuming the data were normally distributed, t-tests for dependent samples were administered to determine whether there was a significant improvement in students' mastery and engagement in science before and after instruction in both groups.

Stage 4: Act

This stage focused on reflective evaluation, informing possible refinements, scaling, or redesign of the intervention for subsequent action research cycles, consistent with the interactive nature of the PDSA model. Semi-structured interviews and learning logs were also implemented to allow the students to record their learning experience during the experiment. This stage further allowed us to gauge the other effects of the designed intervention, not only focusing on science mastery and engagement but also on other variables. This stage also helped explain the mechanism by which the designed intervention improves conceptual understanding.

For the qualitative data, the observation and FGD transcripts were transcribed verbatim. The qualitative data were coded and analyzed using thematic analysis to identify patterns and similarities across the observation notes and students' responses. The qualitative data analysis emphasized the learning affordances and constraints of implementing the designed MLDAs, which are critical to achieving learning flow.

RESULTS AND DISCUSSION

Figure 1 presents the mean performance on the science mastery test for participants before and after using the MLDAs.

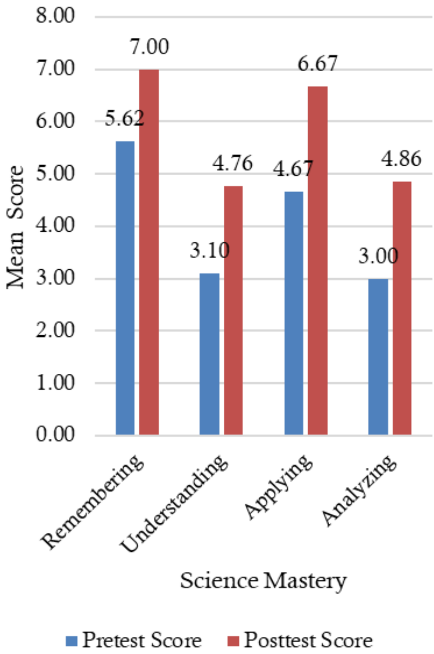

Figure 1. Pretest and Post-test Mean Scores on Science Mastery Test

Figure 1 shows the mean performances in all domains of science mastery before and after exposure to MLDAs. Students' post-test scores increased in remembering, understanding, applying, and analyzing, suggesting that MLDAs may have helped make abstract concepts more concrete through hands-on experiences. These demonstrations may have enhanced struggling students' engagement, supported better retention, and fostered active participation. The students demonstrated a willingness to participate during MLDAs, despite prior records of reluctance to participate in science classes. It is also evident that they can perform experimental tasks independently with minimal teacher guidance.

The paired-samples t-test results, presented in Table 2, revealed a significant improvement in all science mastery domains after the intervention using MLDAs. Each dimension, remembering (t= -5.369, p <.001), understanding (t= -4.780, p <.001), applying (t= -6.186, p <.001), and analyzing (t= -6.679, p <.001), shows a negative mean difference, indicating higher post-test scores. The p-values across all pairs are below the 0.05 significance level, confirming that the gains are statistically significant. Overall, students' total science mastery increased substantially (t = -9.773, p <.001).

Table 2. Effect Size of Science Mastery

Science Mastery	t-value	N	Cohen's d	Interpretation
Remembering	-5.36	42	0.83	Large
Understanding	-4.78	42	0.74	Medium
Applying	-6.18	42	0.95	Large
Analyzing	-6.67	42	1.03	Large
Overall	-9.77	42	1.51	Large

Table 2 further shows significant improvements in science mastery across cognitive domains after exposure to MLDAs. Large effect sizes were found in remembering (d=0.83), applying (d=0.95), analyzing (d=1.03), and overall mastery (d=1.51), while understanding showed a medium effect (d=0.74). This finding suggests that the designed MLDAs effectively enhance the students' higher-order thinking and overall science performance. This implies that integrating such activities into the curriculum can foster deeper engagement and sustained mastery in science. These results address the research gap in providing domain-specific empirical evidence on how micro-laboratory demonstrations influence higher-order thinking processes, which have been underexamined in resource-limited educational contexts (Hofstein, 2016). Moreover, the large effect sizes observed challenge prior assumptions that substantial gains in analysis and application require fully equipped laboratory environments, thereby extending current knowledge of scalable and low-cost science instructional strategies.

Recent studies affirm the value of hands-on, flow-oriented science activities in enhancing student performance. Tindan & Anabs (2024) argued that hands-on tasks in science classrooms significantly improve academic success and conceptual understanding by reducing cognitive overload and increasing engagement. Similarly, Balaoro (2024) found that active learning strategies with a collaborative structure foster the development of scientific skills and sustain attention in laboratory settings. Panergayo & Prudente (2024) also reported significant gains in science mastery among STEM students exposed to structured lab activities. These findings reinforce the present results and validate the characteristics of the designed laboratory approach. In particular, the structured sequencing and scaffolding embedded in the activities supported students' progression towards deeper conceptual understanding (Zeng et al., 2024). The observed increases in engagement indicate that the activities successfully balanced task challenge and student capability, a key condition of learning flow (Kiili et al., 2012). Thus, the present findings align with literature emphasizing experiential, student-centered laboratory designs as effective mechanisms for improving science mastery.

Table 3. Students' Level of Engagement on MLDAs

Laboratory Activity	Mean	SD	Interpretation
1	3.72	1.09	Highly Engaged
2	3.75	0.98	Highly Engaged
3	3.83	0.96	Highly Engaged
4	3.88	1.04	Highly Engaged
5	3.83	0.92	Highly Engaged

Table 3 shows the mean engagement scores of the students across five MLDAs, ranging from 3.72 to 3.88. These measures consistently indicate a high level of engagement. This is consistent with Figure 2, which shows consistently high engagement among struggling students across all designed MLDAs, with mean scores ranging from 3.72 to 3.88. This visual trend suggests that students found each activity stimulating and effective. The slight variation in mean score reflected personal preferences for the activities, possibly linked to sensory appeal or conceptual clarity. Overall, the figure highlights the success of the activities in fostering curiosity and keeping students engaged, thereby unlocking learning flow. Based on observation, students showed deep focus, curiosity, and enjoyment, indicating immersive flow during hands-on science investigation.

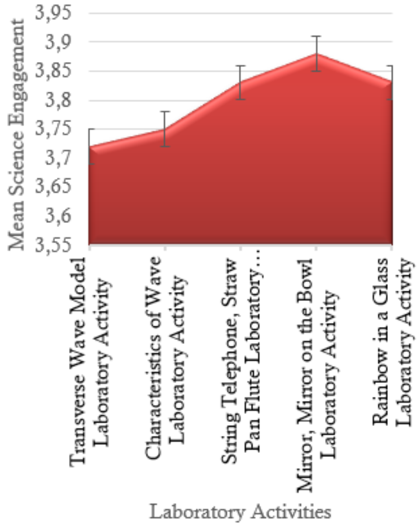

Figure 2. Visual Representation of Students' Level of Engagement on MLDAs

Student engagement in science learning is multidimensional, encompassing behavioral, participation, emotional investment, and cognitive effort. Behavioral engagement is evident in the students' active participation during games and group tasks, aligning with the emphasis on the role of structured collaboration in sustaining attention and effort. Emotional engagement, as reflected in students' enjoyment and curiosity, aligns with Wang et al. (2025), who found that an emotionally positive environment enhances motivation and persistence. Cognitive engagement, as evidenced in students' conceptual development, aligns with Kuhail et al. (2022), which linked deep thinking to immersive, well-scaffolded tasks. These layers of engagement collectively explain the high mean scores and observed learning flow in the MLDAs.

Moreover, the convergence of these engagement dimensions suggests that MLDAs create a learning environment in which students regulate their own learning and interact meaningfully with peers and content (Li & Lajoie, 2021; Alam & Mohanty, 2024). Sustained behavioral involvement supports emotional safety, allowing students to take intellectual risks and persist through challenging tasks (Cents-Boonstra et al., 2020). In turn, positive emotion reinforces cognitive effort, enabling students to connect prior knowledge with new concepts and apply ideas flexibly (Monta & Perdio, 2025). Teacher facilitation and timely feedback further strengthen this process by guiding inquiry with diminishing autonomy (Obenieta et al., 2025). Consequently, engagement is not episodic but sustained across activities, assessments, and reflections, fostering transferable skills, deeper understanding, and consistent participation that extends beyond the immediate instructional contexts. This combination cultivates collaboration and scientific curiosity among students.

The following results from the thematic analysis present students' perspectives on how the designed MLDAs promoted science mastery and engagement, which, in turn, activated learning flow. Drawing from individual interviews and classroom observation notes, five core themes emerged. These themes reveal that students found the activities enjoyable, cognitively enriching, and emotionally immersive. Demonstrations clarified misconceptions, encouraged teamwork, and sustained attention through sensory-rich, well-facilitated experiences.

Hands-on Learning

Students consistently emphasized how laboratory demonstrations helped them understand abstract concepts through direct experience. Students 5 shared, *"Sa demonstrations ginawang mas naiintindihan ko ang lesson* [The demonstrations made the lesson easier to understand]", showing how hands-on tasks clarified wave behavior. Students 4 added, "*Akala ko dati iisa ang kulay na yellow* [I used to think yellow was a single color]," revealing conceptual shifts through experimentation. Students seemed to notice that the lesson was structured: it started with a demonstration and then moved to the activities, which helped them understand the steps. These insights affirm that MLDAs foster mastery by transforming passive learning into active discovery.

Collaborative Game

Games and groupwork were repeatedly cited as sources of enjoyment and learning. Student 1 said, "*Sa mga pa games po, nakaka-enjoy at nasusubok kung paano naming maiintindihan*, [The games are enjoyable and test how well we understood]," while Student 3 noted, *"Groupings po kase nade-develop ang pakikisama* [groupings helped us develop camaraderie]. Students reflected that the games were timed after the demonstration, allowing them to discuss and apply what they learned with peers, which made learning fun yet purposeful. These activities balance challenge and fun, promoting engagement through peer interaction and playful inquiry. The collaborative format encourages teamwork, communication, and shared problem-solving. These are essential to sustain attention and emotional investment.

Sensory Appeal

Sensory-rich activities, especially those involving light and colors, captivated students. Student 2 expressed, "*Yung mga colors ng light. Nag-enjoy po talaga ako* [The colors of light, I really enjoyed them], and Student 6 discovered, "*Magka-iba ang primary colors sa Science at MAPEH* [The primary colors in Science and MAPEH are different]. Students commented that these activities were placed at the start of the lesson, helping them to see and experience concepts before learning the explanation, which made the ideas more memorable. These responses show how visual stimuli enhance curiosity and retention. Demonstrations like "Rainbow in a Glass" made abstract optics tangible, allowing students to connect scientific ideas with vivid, memorable experiences.

Conceptual Clarity

Several students reflected on how the activities corrected earlier misunderstandings. Student 3 shared, "*Knowledge sa characteristics ng red nagkakabaliktad dun sa reflection of colors* [My understanding of red's characteristics was reversed in color reflection], and later affirmed by Student 8, "*Mas maiintindihan naming ano ang ni-reflect ng visible light* [We now better understand what visible light reflects]." Students realized that the lessons challenged what they thought they knew first, then guided them to the correct understanding, showing how MLDAs encouraged them to rethink prior ideas. These statements revealed how MLDAs serve as cognitive interventions, helping students reconstruct prior knowledge and reinforce accurate scientific reasoning.

Creative Facilitation

Learning flow was unlocked through dynamic teaching and creative delivery. Student 3 recalled, "*Jokes na related sa lesson, creative pictures…* [Lesson-related jokes and creative pictures], while Student 6 noted, "*Creative lahat ang activities ni teacher* [All the activities of our teacher were creative]. Student 4 emphasized, "*Madaming energy si teacher, they really caught my attention* [The teacher has a lot of energy, and it catches my attention]," linking enthusiasm to engagement. Students also notice that the teacher's energy and creative approach guided them through the lesson, keeping them engaged from start to finish and reflecting the planned flow of the MDL sequence. These responses show that flow emerges when students are emotionally and cognitively immersed in a motivating, resonant learning environment.

The study's findings indicate that the designed MLDAs effectively enhanced struggling students' mastery of science across multiple domains. Students showed marked improvement in recalling information, applying concepts, and analyzing scientific ideas, suggesting that the demonstrations' inquiry-based approach supported both foundational and higher-order thinking skills (Antonio & Prudente, 2024). While conceptual understanding also improved, it appeared less beneficial in other domains, suggesting the need for additional strategies to deepen comprehension. These outcomes affirm the MLDAs' capacity to strengthen cognitive performance in science education (Parappilly et al., 2013).

Students remained consistently high throughout the implementation of the five MLDAs. Students actively participated, expressed interest, and sustained focus during each session, reflecting a learning environment conducive to flow experience (Dalimunthe et al., 2024; Zou & Ren, 2024). This level of involvement likely contributed to the observed mastery, reinforcing the idea that engagement is a critical component of academic success (Jinmin & Qi, 2023). The MLDAs' hands-on, contextual nature appears to have fostered curiosity and motivation, aligning with student-centered pedagogies that emphasize active exploration.

These results resonate with the existing literature in inquiry-based and experiential science instructions (Antonio & Prudente, 2024; Ellwood & Abrams, 2017; Zulfiani et al., 2025). Prior studies have shown that laboratory demonstrations, when designed with cognitive and affective goals in mind, can promote deeper learning and retention (Panergayo & Prudente, 2024; Cleaver et al., 2025; Winn et al., 2019; Yanee et al., 2025). The improvements observed in application and analysis echo findings from the literature, which emphasized the role of practical investigation in developing scientific reasoning (Shana & Abulibdeh, 2020; Oliveira & Bonito, 2023). The relatively modest gain in understanding suggests that pairing demonstrations with reflective dialogue or concept mapping may enhance conceptual depths. In addition, structured reflection allows students to articulate underlying principles and confront misconceptions that may not surface during hands-on activities alone (Mann, 2016). Integrating guided questioning and peer explanation can further scaffold meaning making, strengthening the link between experience and theory (Haley, 2019; Cents-Boonstra et al., 2020). Such strategies align with constructivist perspectives, highlighting the importance of metacognitive engagement in transforming activity-based learning into robust conceptual understanding.

While the intervention was generally effective, several challenges emerged during implementation. Teachers observed that some students initially hesitated to engage in group tasks, especially when roles are unclear or when dominant voices overshadowed quiet peers. One teacher noted, "*May grupo na hindi agad nagkaayos kung sino ang gagawa ng alin, kaya natagalan magsimula* [Some groups could not immediately agree on who would do what, so they took a while to get started]." Additionally, a few students expressed confusion about how to connect hands-on activities to the lesson objectives, as Student 4 shared. "*Masaya po siya, pero minsan hindi ko agad naiintindihan kung paano siya konektado sa topic* [It's fun, but sometimes I don't immediately understand how it connects to the topic]." These responses suggest the need for clear task structuring and more explicit conceptual bridging during debriefing sessions. The study confirms that designed MLDAs positively influence both science mastery and students' engagement. Their integration into the curriculum is recommended to sustain and amplify these benefits. Educators may consider adapting demonstrations to include metacognitive prompts or structured collaborative tasks to support understanding further. This addition can encourage the students to reflect on their thinking processes and articulate their reasoning and arguments during experiments. Structured collaborative tasks can also help students encounter diverse perspectives and strategies during problem-solving and reasoning.

CONCLUSION

This study concludes that designed MLDAs meaningfully improved science mastery and engagement among struggling junior high school students. The integration of hands-on tasks with structured collaboration created a supportive environment where students could actively participate, reflect, and gradually build confidence in their scientific thinking. These conditions fostered a flow state, allowing students to experience deep focus and motivation despite initial challenges. The research underscores the potential of cognitively and emotionally immersive approaches to transform science classrooms into inclusive spaces for struggling students' mastery and engagement. This study addresses a research gap in the limited effectiveness data on MLDAs as an alternative to traditional laboratory instruction. The findings demonstrate that meaningful gains in both engagement and mastery can be achieved even in the absence of fully equipped laboratory facilities, thereby challenging prevailing assumptions in the literature. Reflecting on these findings, teachers are encouraged to continuously improve their professional practice by designing learning experiences that balance cognitive challenge with emotional support. The success of the intervention underscores the importance of responsive facilitation, cooperative structures, and reflective scaffolds that meet students where they are. Evidence-informed strategies and student feedback are critical for educators to cultivate classrooms that not only deliver content but also nurture students' curiosity, resilience, and science identity. For the next action research cycle, it is recommended to integrate structured metacognitive routines such as reflection journals or guided questioning to strengthen conceptual understanding. Additionally, classroom observations and students' feedback should be systematically collected to refine cooperative learning roles and ensure equitable participation among struggling students.

REFERENCES

Abdurakil, J. D., Evalle, F. S. P., Kiram, A. J., Lintasan, A. M., Madjid, A. A., Sabbaha, N. A., & Sasapan, F. R. U. (2024). Effect of laboratory activities on the science performance of STEM students in Mindanao State University-Sulu. *Ignatian International Journal for Multidisciplinary Research*, *2*(5), 2351-2361.

Alam, A., & Mohanty, A. (2024). Framework of Self-Regulated Cognitive Engagement (FSRCE) for sustainable pedagogy: a model that integrates SRL and cognitive engagement for holistic development of students. *Cogent Education*, *11*(1).

Antonio, R. P., & Prudente, M. S. (2024). Effects of Inquiry-Based Approaches on Students' Higher-Order Thinking Skills in Science: A Meta-Analysis. *International Journal of Education in Mathematics, Science and Technology*, *12*(1), 251-281.

Asma, H., & Sarnou, D. (2020). Cognitive Load Theory and its Relation to Instructional Design: Perspectives of Some Algerian University Teachers of English. *Arab World English Journal*, *11*(4), 110–127.

Balaoro, M. J. B. (2024). Enhancing Scientific Skills among Students Through Engaging in Active Learning Activities. *United International Journal for Research & Technology, 5*(7), 242-251.

Belisario, J. M., & Paglinawan, J. L. (2025). The Relationship between Instructional Materials Availability and Student Engagement in Science. *International Journal of Research and Innovation in Applied Science*, *X*(V), 263–270.

Bergström, T., Gunnarsson, G., & Olteanu, C. (2021). The importance of flow for secondary school students' experiences in geometry. *International Journal of Mathematical Education in Science and Technology*, *54*(6), 1067–1091.

Bounajim, D., Rachmatullah, A., Hinckle, M., Mott, B., Lester, J., Smith, A., ... & Wiebe, E. (2021, September). Applying cognitive load theory to examine STEM undergraduate students' experiences in an adaptive learning environment: a mixed-methods study. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 65, No. 1, pp. 556-560). Sage CA: Los Angeles, CA: SAGE Publications.

Cents-Boonstra, M., Lichtwarck-Aschoff, A., Denessen, E., Aelterman, N., & Haerens, L. (2020). Fostering student engagement with motivating teaching: an observation study of teacher and student behaviours. *Research Papers in Education*, *36*(6), 754–779.

Chong, X. T., & Yunus, M. M. (2019). The Effects of Kagan Cooperative Learning Structures in Teaching Subject–Verb Agreement among Rural Sarawak Learners. *Arab World English Journal*, *10*(2), 151–164.

Chung, J., Cannady, M. A., Schunn, C., Dorph, R., & Bathgate, M. (2016). Measures technical brief: Engagement in science learning activities. *Activation Lab*.

Cleaver, A., Crean, L., & Howitt, S. (2025). Student perceptions of cognitive, Psychomotor and affective learning in the undergraduate laboratory. *Biochemistry and Molecular Biology Education*.

Clowes, G. (2011). *The essential 5: A starting point for Kagan cooperative learning*. San Clemente.

Crowfoot, D., & Prasad, V. (2017). Using the plan–do–study–act (PDSA) cycle to make change in general practice. *InnovAiT Education and Inspiration for General Practice*, *10*(7), 425–430.

Csíkszentmihályi, M. (2014). Flow and education. In *Springer eBooks* (pp. 129–151).

Dalimunthe, H. A., Dewi, I. K., Yunita, Y., Faadhil, F., & Lubis, D. M. G. S. (2024). Building a supportive learning environment: The role of psychology in increasing student motivation and engagement. *OPSearch American Journal of Open Research*, *3*(4), 934–939.

De Jong, T. (2009). Cognitive load theory, educational research, and instructional design: some food for thought. *Instructional Science*, *38*(2), 105–134.

Dorji, P., Yangzom, & Tenzin, J. (2021). Application of Kagan's cooperative learning structures to maximize student engagement: An action research. *Journal of Education, Society and Behavioural Science*, 54–64.

dos Santos, W. O., Bittencourt, I. I., Isotani, S., Dermeval, D., Marques, L. B., & Silveira, I. F. (2018). Flow theory to promote learning in educational systems: Is it really relevant?. *Revista Brasileira de Informática na Educação*, *26*(02), 29.

Ellwood, R. B., & Abrams, E. (2017). Student's social interaction in inquiry-based science education: how experiences of flow can increase motivation and achievement. *Cultural Studies of Science Education*, *13*(2), 395–427.

Fajrin, S., & Hakim, D. L. (2023). Implementation of Low-Cost Laboratory in Education: A Systematic Literature review. *Jurnal Ilmiah Pendidikan Teknik Dan Kejuruan*, *16*(2), 163.

Gyllenpalm, J. (2017). Inquiry and flow in science education. *Cultural Studies of Science Education*, *13*(2), 429–435.

Haley, C. M. (2019). The Benefits of Structured Reflection in Team-Based Learning (TBL). *Medical Science Educator*, *29*(4), 1171–1172.

Hofstein, A. (2016). The role of laboratory in science teaching and learning. In *Science Education* (pp. 357–368).

Jinmin, Z., & Qi, F. (2023). Relationship between learning flow and academic performance among students: a systematic evaluation and meta-analysis. *Frontiers in Psychology*, *14*, 1270642.

Kiili, K., De Freitas, S., Arnab, S., & Lainema, T. (2012). The design principles for flow experience in educational games. *Procedia Computer Science*, *15*, 78–91.

Kuhail, M. A., ElSayary, A., Farooq, S., & Alghamdi, A. (2022). Exploring Immersive Learning Experiences: a survey. *Informatics*, *9*(4), 75.

Kuldaş, S., Satyen, L., Ismail, H. N., & Hashim, S. (2014). Greater Cognitive Effort for Better Learning: Tailoring an Instructional Design for Learners with Different Levels of Knowledge and Motivation *Psychologica Belgica*, *54*(4), 350–373.

Li, S., & Lajoie, S. P. (2021). Cognitive engagement in self-regulated learning: an integrative model. *European Journal of Psychology of Education*, *37*(3), 833–852.

Lin, Y. C., Liu, B. Y., & Liu, C. J. (2012). A study of applying cognitive load theory to science education websites. *International Journal of Science and Engineering*, *2*(3), 53-58.

Mandhana, D. M., & Caruso, V. (2023). Inducing flow in class activities to promote student engagement. *Communication Education*, *72*(4), 348–366.

Mann, K. V. (2016). Reflection's role in learning: increasing engagement and deepening participation. *Perspectives on Medical Education*, *5*(5), 259–261.

Monta, E. R., & Perdio, A. C. (2025). Laboratory-based science instruction in public schools: insights from teachers' experiences and implications for contextualized interventions in Bataan, Philippines. *EPRA International Journal of Research & Development (IJRD)*, 322–328.

Obenieta, G. D., Satojito, J. P., & Martir, E. M. (2025). Teachers' use of Inquiry-Based approach, science laboratory learning environment and learners' performance. *International Journal of Science and Management Studies (IJSMS)*, 219–242.

Oliveira, H., & Bonito, J. (2023). Practical work in science education: a systematic literature review. *Frontiers in Education*, *8*.

Oliveira, W., Tenório, K., Hamari, J., Pastushenko, O., & Isotani, S. (2021). Predicting students' flow experience through behavior data in gamified educational systems. *Smart Learning Environments*, *8*(1).

Organization for Economic Co-operation and Development (OECD), (2023). PISA 2022 Results (Volume I): The State of Learning and Equity in Education. *OECD Publishing, Paris.*

Panergayo, A. A. E., & Prudente, M. S. (2024). Effectiveness of design-based learning in enhancing scientific creativity in STEM Education: A Meta-analysis. *International Journal of Education in Mathematics Science and Technology*, *12*(5), 1182–1196.

Panergayo, A. A. E., Gregana, C. F., & Panoy, J. F. D. (2022). Investigating the factors affecting the teaching efficacy of Filipino science teachers: A correlational study. *Jurnal Pendidikan Progresif*, *12*(1), 33–44.

Parappilly, M. B., Siddiqui, S., Zadnik, M. G., Shapter, J., & Schmidt, L. (2013). An Inquiry-Based Approach to Laboratory Experiences: Investigating students' ways of active learning. *eSpace (Curtin University)*, *21*(5), 42–53. http://hdl.handle.net/20.500.11937/3448

Pitiporntapin, S., Butkatanyoo, O., Piyapimonsit, C., Thanarachataphoom, T., Chotitham, S., & Lalitpasan, U. (2024). The influence of outdoor STEM activities on students' STEM literacy: a study of elective subject, extracurricular activities, and student club. *Jurnal Pendidikan IPA Indonesia*, *13*(2).

Second Congressional Commission on Education (EDCOM 2). (2024). Miseducation: The Failed System of the Philippine Education (Year One Report). Republic of the Philippines. https://edcom2.gov.ph/publications

Shana, Z., & Abulibdeh, E. S. (2020). Science practical work and its impact on students' science achievement. *Journal of Technology and Science Education*, *10*(2), 199.

Shernoff, D. J., Csíkszentmihályi, M., Schneider, B., & Shernoff, E. S. (2003). Student engagement in high school classrooms from the perspective of flow theory. *School Psychology Quarterly*, *18*(2), 158–176.

Skulmowski, A., & Xu, M. (2021). Understanding Cognitive Load in Digital and Online Learning: a New Perspective on Extraneous Cognitive Load. *Educational Psychology Review*, *34*(1), 171–196.

Sweller, J. (2011). Cognitive Load Theory. In *Psychology of Learning and Motivation* (pp. 37– 76).

Tindan, T. P., & Anaba, C. A. (2024). Scientific hands-on activities and its impact on academic success of students: A systematic Literature Review. *IOSR Journal of Research & Method in Education, 6*(14), 39-47.

Tran, Y., & Nguyen, T. H. (2023). Applying Spencer Kagan's cooperative learning approach to enhance Non-English majored students' engagement in English classroom. In *Advances in social science, education and humanities research* (pp. 254–269).

University of the Philippines Diliman. (2023). College of Science. https://upd.edu.ph

Van Ryzin, M. J., Roseth, C. J., & McClure, H. H. (2020). The effects of cooperative learning on peer relations, academic support, and engagement in learning among students of color. *The Journal of Educational Research*, *113*(4), 283–291.

Wang, X., Jaafar, W. M. W., & Sulong, R. M. (2025). Building better learners: exploring positive emotions and life satisfaction as keys to academic engagement. *Frontiers in Education*, *10*.

Winn, A. S., DelSignore, L., Marcus, C., Chiel, L., Freiman, E., Stafford, D., & Newman, L. (2019). Applying cognitive learning strategies to enhance learning and retention in clinical teaching settings. *MedEdPORTAL*, *15*, 10850.

Yanee, W. S. W. A., Hamidi, N. N., Khan, A. A. Y. F., Jianlei, C., Said, H. M., & Aris, S. R. S. (2025). Laboratory Safety Knowledge, Attitudes, Practices, and Compliance among Secondary School Pre-service Science Teachers: A Pilot Study. *Jurnal Pendidikan IPA Indonesia*, *14*(4).

Zeng, J., Zhang, P., Zhou, J., Shang, J., & Black, J. B. (2024). The impact of embodied scaffolding sequences on STEM conceptual learning. *Educational Technology Research and Development*, *73*(2), 767–792.

Zhang, J., & Qi, F. (2023). Relationship between learning flow and academic performance among students: a systematic evaluation and meta-analysis. *Frontiers in Psychology*, *14*.

Zou, M., & Ren, B. (2024). Exploring the flow experience of EFL learners in Technology-Enhanced Self-Regulated Language Learning using the experience Sampling method. *Journal for the Psychology of Language Learning*, *6*(2).

Zulfiani, Z., Suwarna, I. P., Fadlilah, D. R., Sari, I. J., El Islami, R. A. Z., & Mnguni, L. (2025). DigitalWIV-S: Enhancing Students' Inquiry Skills and Digital Literacy in PCR and Electrophoresis for Sustainable Education. *Jurnal Pendidikan IPA Indonesia*, *14*(3).