EXPLORING THE INFLUENCE OF PHYSICAL AND DIGITAL HANDS-ON MODALITIES ON GRADE 9 STUDENTS' MASTERY OF SCIENCE CONCEPTS

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ABSTRACT

The integration of digital technologies in science education has accelerated post-COVID, prompting educators to reassess traditional laboratory methods. This study compares the effectiveness of physical and digital hands-on activities on Grade 9 students' science performance, focusing on knowledge acquisition and engagement. Using a quantitative quasi-experimental design, two groups of students (n=25) participated in lessons on Natural Selection and Extinction, followed by pre- and post-tests and engagement surveys. Results show both modalities support learning, with the physical group scoring slightly higher, though not significantly ($p > 0.05$). The findings suggest a blended approach may best support student outcomes. This study contributes to the limited research on blended science instruction at the Grade 9 level and recommends further exploration across broader populations and grade levels.

Keywords: *physical and digital hands-on activities, knowledge acquisition, engagement*

INTRODUCTION

It is fascinating how direct experiences, curiosity, and reflections shape knowledge and understanding. Experience has been at the heart of many educational philosophies and pedagogies, including John Dewey's Experiential Learning, Constructivism by Piaget and Vygotsky, and the Montessori Method by Maria Montessori. These learning models and philosophies, which have been adapted in schools worldwide, have one common goal – to make learning more meaningful by actively engaging in hands-on activities and experience, and move away from the conventional way of teaching where the teacher is the central source of information. Because of this shift, educators, curriculum developers, or anyone involved in designing and planning curricula and programs must utilize resources that can maximize learning experiences and highlight their exploratory nature.

The scientific theories, laws, and concepts that humans use to explain various phenomena are products of curious minds and a laborious inquiry and experimentation process, made only possible using tools. To this day, hands-on activities remain highly regarded as the most effective ways to explore, learn, and experience science. However, studying science has come a long way and evolved with the rise of digital tools and technologies. Yet, the role of teachers in schools and educational institutions, and the effectiveness in teaching basic to complex scientific concepts, are still being debated by curriculum experts and overlooked by many students and parents.

Globally, this evolution in science learning has been shaped not only by pedagogical change but also by rapid technological advancement. In Vietnam, similar trends have emerged as schools increasingly integrate educational technologies into classroom instruction. The Ministry of Education and Training (MOET) has encouraged the use of digital tools to support inquiry, competency development, and technological literacy in both public and private schools (MOET, 2018; MOET, 2021). As a result, many Vietnamese schools, especially bilingual institutions like The Dewey Schools, now combine traditional laboratory experiences with digital platforms to enhance science learning.

Following COVID-19, The Dewey Schools have incorporated digital citizenship as one of their core visions. An Educational Research and Pedagogy Council (ERPC) Specialist of Dewey shared that the school is among the first schools in Vietnam that has an official curriculum that includes digital citizenship through a dedicated subject and a framework of six core digital citizenship competencies (The Dewey Schools, 2025). Regardless of the addition of a digital citizenship vision and the use of digital tools daily at TDS, the facilities, laboratories, function rooms, and creative spaces are still highly utilized and well-equipped. This shows that despite the popularity of virtual and online materials, actual and physical hands-on activities remain irreplaceable and will always be an integral part of the experiential learning model.

The dichotomy between the two modes of hands-on activities — physical and digital — raises a significant debate in science education at various grade levels: which approach better facilitates knowledge acquisition and engagement in science? This study aims to compare them by providing quantitative evidence to support findings and recommending next steps based on the gathered data.

Although several studies have been conducted on the impact of different laboratory-based activities in science, comparative studies and published information about the learning impacts of physical and digital hands-on activities on Grade 9 students remain insufficiently addressed. Grade 9 is a critical stage where students begin to consider future career choices and explore their interests (Elroi Academy 2024). When lessons are carefully planned, content is well-taught, learning materials are effective in achieving the objectives, and students are properly guided, they initiate reflections and begin exploring the interesting aspects of the subject and its potential as a career path.

Hands-on activities in science have long been unlocking people’s capacity to learn and inspiring them to pursue careers in science-related fields. But which of those hands-on modalities strengthened their grasp of the science content that ultimately motivated them to study science? Should schools teach science primarily through physical hands-

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on activities, or should they start incorporating digital hands-on activities due to the increasing number of tools available to everyone?

This study addresses these questions by comparing the effects of physical and digital hands-on activities on Grade 9 students' knowledge acquisition and engagement within a Vietnamese bilingual school setting.

Background of the Study

The use of books and rote memorization illustrated the customary methods of instruction (Rudolph, 2019). He adds that "the shift away from book learning was readily apparent in the teaching of the natural sciences that had risen in prominence in schools over the nineteenth century." Modern science education has shifted this by using teaching methods that emphasize active student participation. According to Duban et al. (2019), science teachers think that laboratory applications are indispensable as they help students learn by doing, develop critical scientific thinking, and reinforce theoretical knowledge. But do these laboratory applications have to be done physically?

Hands-on learning has long been considered essential in science because scientific understanding develops through direct observation, experimentation, and variable manipulation. Many researchers argue that students gain a deeper and more durable understanding of science when they can test hypotheses, collect data, and observe outcomes firsthand (Kolodner et al., 2003). Beyond concept mastery, hands-on science activities strengthen students' ability to ask meaningful questions, design fair tests, and analyze evidence, skills that form the core of scientific literacy (Hofstein & Kind, 2012). These benefits help explain why laboratory experiences remain integral to science education worldwide and why teachers view hands-on work as fundamental to student learning.

Kapici et al. (2019) emphasize that while conventional hands-on laboratory experiments are still widely used in schools, the unique benefits of simulations and virtual laboratories offer have led some institutions to consider integrating them into their instructional practices. Darah et al. (2014) also emphasize that well-designed and educationally effective virtual laboratories can support or serve as alternatives to physical hands-on activities. These claims have been proven valid when schools worldwide had to shift toward online instruction during the pandemic and utilize available online resources.

Digital hands-on tools offer advantages that physical laboratories alone cannot always provide. Virtual simulations allow students to illustrate difficult scientific processes—like particle motion, energy transfer, and or molecular interactions—that cannot be directly seen through real-world observation. They also provide opportunities to repeat experiments multiple times, explore extreme values or unrealistic conditions safely, and access experiences that may be restricted by cost, time, or laboratory resources. These features make digital environments particularly valuable in supporting conceptual understanding and offering equitable learning opportunities.

The global conversation about the role of digital tools in science education has grown significantly in recent years. For many schools, the pandemic highlighted the need to evaluate which aspects of science learning require physical materials and which can be effectively supported through technology-enhanced tools. Some researchers argue

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that physical hands-on activities develop essential procedural and tactile skills, while simulations enhance visualization and cognitive processing (Smetana & Bell, 2012; Rutten et al., 2012). Because both approaches have strengths and limitations, their relative effectiveness has become an important topic for investigation. This debate is highly relevant for schools seeking to design modern science programs that meet the demands of 21st-century learning.

The Dewey Schools is classified as a bilingual institution that bridges traditional and modern educational methods. The school offers five (05) academic programs: the Explore, Discover, Adventure, Journey, and International Baccalaureate (IB) programs. The language of instruction varies depending on the program in which the students are enrolled, but all students are bilingual. The Adventure, Journey, and IB programs have the highest percentage of English language instruction, ranging from 60% to 90% English and 10% to 40% Vietnamese or Korean. Regardless of the mode of instruction, the science programs and other disciplines at TDS promote inquiry-based and experiential learning, where students engage in different hands-on (physical and technology-based) activities and experiments (The Dewey Schools, 2023b).

At The Dewey Schools, the experimental aspect of the scientific method is still predominantly conducted using physical laboratory materials. However, the use of digital platforms such as Amplify Science and PhET Simulations, and other prescribed digital tools, has provided flexibility in exploring alternative methods to deliver lessons, particularly in scenarios where safety, resources, and equipment accessibility are limited. The school has emphasized the use of different educational tools to support experiential and inquiry-based learning across all subjects. With this, teachers and curriculum designers have planned and designed instructions that are a blend of actual and virtual hands-on activities, combine the national and international standards, and use English and Vietnamese as languages of instruction across disciplines.

Despite the simultaneous use of physical and digital hands-on activities at The Dewey Schools, there is a clear gap in evaluating their relative effectiveness. To date, the school has not conducted any study that directly compares these two modalities under identical instructional conditions, that is, using the same science topic, taught by the same teacher, within the same duration, and aligned with the same learning objectives. Without such a controlled comparison, it is difficult for teachers, curriculum designers, and program heads to determine when physical hands-on activities are more advantageous, when digital tools offer comparable or superior benefits, or how the two can be combined strategically. This makes the comparison not only relevant but necessary, especially for Grade 9 students who are developing foundational scientific reasoning and preparing for upper-secondary pathways.

Although both physical and digital hands-on methods are available and encouraged at TDS, teachers still encounter instructional challenges that make the comparison between the two approaches highly relevant. Physical hands-on activities require material preparation, time management, and safety oversight, and the availability of equipment may limit the number of experiments that can be conducted. Conversely, digital simulations, while flexible and accessible, could be limited in reproducing the tactile and procedural aspects of actual experimentation. Additionally, in a bilingual learning environment, variations in students' English and Vietnamese proficiency can influence

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how effectively they follow lab procedures or navigate simulation interfaces. These realities highlight the importance of understanding how each modality functions in actual classroom settings.

In terms of conducting physical hands-on activities, the school has the grade-level appropriate laboratory equipment to conduct practical and traditional experiments safely and effectively. The stable school-wide internet connection, fully functioning IT laboratories, and the requirement of personal devices for academic use among all students allow them easy access to different online tools. These online tools became particularly valuable over physical hands-on activities during the COVID-19 pandemic, when schools worldwide — including The Dewey Schools — had to transition into remote and hybrid learning environments, and this shift demonstrated that both methods can complement each other.

To address this identified gap, this study is being conducted to provide empirical evidence or data on which of these two approaches is more effective in supporting scientific knowledge acquisition. The outcomes of this research may help the school, science teachers, curriculum developers, and other educational institutions make informed instructional decisions in the future and improve the implementation of science programs and teaching practices. By examining the influence of both modalities on Grade 9 students' performance and engagement, the study can guide teachers in capitalizing on the strengths of each method, addressing their shortcomings, and developing a holistic educational experience.

In summary, although both physical and digital hands-on activities are actively used at The Dewey Schools, there is no existing research that compares their impact under controlled and identical instructional conditions. Understanding which modality better supports student learning—and under what circumstances—is essential for guiding future instructional decisions and program development. The following Statement of the Problem presents the specific research questions that guide this study.

Vietnam's Education System

The Vietnamese education system has been heavily shaped by its historical influences, from Confucian traditions to the French colonial period, socialist ideologies, and the present pressures of globalization (Lattman n.d). After the August Revolution of 1945, more than 90 percent of the Vietnamese population could not read or write. This prompted the government to take action and launch nationwide literacy campaigns as one of its priorities (Vietnam.vn, 2025). The early reform efforts, which took place between 1945 and 1954, were guided by these principles: nationalism, scientification, and mass literacy. Aiming to deliver education in Vietnamese, move away from rote memorization, and make schooling more available to the public (Vietnam.vn, 2025). The Đổi Mới (Renovation) period in the late 1980s had shifted Vietnam's education model from state-subsidized to a more socialized one where community and participation were encouraged while promoting modernization and globalization (Vietnam.vn, 2025). These changes led to significant improvements in educational attainment at all levels. Currently, Vietnam boasts a 97% youth literacy rate, one of the highest in the Southeast Asian region, and nearly all Vietnamese children are enrolled in primary education (World Bank, 2020). With Vietnam's under-35 population comprising 70% of the total, it is well-positioned to

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leverage education to foster its future economic and technological growth (World Bank, 2020).

The Ministry of Education and Training (MoET) is the governing body of Vietnamese education. The ministry introduced the General Education Program 2018. MoET states that the reform is designed "theo hướng phát triển năng lực, phẩm chất học sinh" or "towards developing competencies and qualities", restructure curriculum to integrate disciplines, promote inquiry-based learning, and use of technology in classrooms (MoET, 2024; Nguyen, Thanh, and Toan, 2024). These reforms mark a clear shift away from instruction dominated by the teacher to a more active, competency-based model that hones higher-order thinking skills. This shift has become important for science and STEM education, where inquiry, experimentation, and hands-on engagement are essential to developing students' understanding of scientific knowledge and applying it beyond the classroom.

Science Education in Vietnam

According to Vietnam Journal of Educational Sciences (2023), many Vietnamese secondary schools are adopting "Natural Science" as an integrated subject at Grade 6 and use practical labs, digital tools, and collaborative projects in their science classes. This is driven by the 2018 General Education Programme or GEP curriculum reform and the policy before it, Resolution 29/NQ-TW (2013), which pushed schools to shift from traditional teaching toward competency-based, student-centered science learning (Nguyen, 2024). This lays the foundation for a modern system that focuses on inquiry, problem-solving, and real-world applications rather than merely memorizing facts and information. This shift goes along with the increasing use of English-medium instruction in science and other disciplines across Vietnam. Apart from The Dewey Schools, other schools like the British Vietnamese International School (BVIS) combine the English National Curriculum with Vietnam's national curriculum, delivering science lessons in both languages (BVIS Hanoi, n.d.).

To understand how Vietnam's science education evolved over time, we must look back on the Doi Mới era and into the early 2000s, when science teaching was mostly teacher-led, knowledge-focused, and exam-oriented. The government increasingly emphasized STEM education and efforts to enhance global competitiveness beginning in the mid-2010s. In a recent review, Nguyen (2024) describes how STEM was formally launched in Vietnam around 2015 and has been included in national policy, though often still confined to extracurricular activities rather than being a formal curriculum. A British Council report from 2017 found a strong desire for a curriculum change toward more active, hands-on STEM learning, but flagged the lack of laboratory infrastructure and necessary teacher preparation for the shift in many schools (British Council, 2017).

With this gradual evolution, Vietnam's science education is now creating more avenues for learners to carry out practical science tasks in both in-person and digital environments. On the physical side, instead of purely lecture-based formats, schools are encouraged to equip their labs, promote student-designed toys or projects, and include scientific investigations into lessons (Quang et al., 2015). On the digital side, virtual simulations and online experimentation tools are becoming more significant. This wider push toward blended learning came to light due to the disruptions of schooling during the

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COVID-19 pandemic. Nguyen (2024) asserts that these virtual tools make abstract phenomena (for example, adaptation and mass extinction) more observable and interactive, and they open new ways for inquiry-based science outside the traditional lab.

Despite these directions, science education in Vietnam still faces challenges that temper the optimism. Key issues include teacher professional development training in inquiry-based instruction, disparities in resources between rural and urban schools, rote learning traditions, and limited systematic STEM curriculum integration (Nguyen, 2024). Policy commentary also argues that if Vietnam wants to compete globally in STEM and boost science education quality, it needs more comprehensive strategies and policies (VietnamPlus, 2023).

These challenges help explain the mixed picture of international benchmarking. In the PISA 2022 assessment, 79% of Vietnamese students are at least level 2 in science proficiency, just above the OECD average of 76% (OECD, 2023). This means that Vietnam performed well relative to many countries. However, if you compare Vietnam with high-performing Asian systems like Singapore, Chinese Taipei, and Hong Kong, it is still well behind, as only 2% of students reached the top proficiency (Level 5 or 6) in science (Vietnam News, 2023). This suggests that the transition from sufficient to exemplary science learning remains a key frontier.

Overall, science education in Vietnam is at a turning point. The policies and reforms are already in place, and the move toward more hands-on and digital learning experiences is evident. However, for these efforts to be successful, the gap between policy and classroom practice, such as better teacher training, improving laboratories and digital facilities, ensuring equal access for all students, especially in rural areas, and aligning practical science experiences with curriculum goals and assessments, needs to be addressed.

Physical Hands-on Activities in Science

Hands-on activities are practical learning experiences such as observing, experimenting, constructing, and reflecting on the results, allowing students to engage directly with scientific concepts. Instead of passively receiving the information, learners interact with real materials to understand scientific concepts. Hofstein & Luneta (2004) state that these activities can take the form of experiments, model-building, or fieldwork, all designed to promote inquiry and other thinking skills such as problem-solving. Within science classrooms, hands-on learning has been linked to better comprehension of challenging concepts, strengthening retention, and stimulate curiosity by making science experiential and meaningful (Brunton & Coll, 2005).

Physical hands-on science education can be linked to the early 20th-century progressive education movement. Thinkers like John Dewey, who argued that authentic understanding arises from experience or “learning by doing” rather than rote memorization (Dewey, 1938). Constructivist theory by Jean Piaget and the discovery learning framework by Jerome Bruner both reinforced the idea that students actively build knowledge through manipulation and experimentation (Piaget, 1970; Bruner, 1961). Over time, these philosophies became the norms for science instruction, especially in laboratory-based courses where the focus of learning is inquiry and investigation.

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By the late 20th century, some international programs like the *Science – A Process Approach (SAPA)* in the United States and *Nuffield Science* in the UK had further shaped the modern view of hands-on learning. These programs mirrored the structured, inquiry-based laboratory experiences and methods that real scientists do (Hurd, 1969; Jenkins, 1979). It aimed to ensure that students gained more than just scientific facts but also an inquiry mindset and skills.

Studies show that students demonstrate stronger conceptual understanding and are more engaged when participating in laboratory and practical activities compared to those who were taught through teacher-lectures alone (Abrahams & Reiss, 2012). Additionally, hands-on activities help students develop the ability to apply scientific reasoning in everyday life (Millar, 2010). So, it is not surprising that in present-day education, hands-on learning remains the backbone of effective science education. One example of this is the Next Generation Science Standards (NGSS), a modern educational standard that highlights inquiry, modeling, and engineering practices as its core competencies, and many schools worldwide, including The Dewey Schools, have adopted this framework to strengthen experiential learning in sciences (The Dewey Schools n.d.).

Overall, the traditional or physical hands-on science education empowers students to learn through doing. It bridges theory and application, taps students' curiosity, and prepares them for a future where inquiry and innovation are essential.

Digital Hands-on Activities in Science

Science education has always valued the concept of learning through doing, but that concept has changed significantly in the 21st century. Traditionally, it referred to using tangible materials to conduct experiments. Today, it also includes computer-based or digital environments where students can simulate the experimental process. Ma and Nickerson (2006) stated that these digital hands-on activities, including virtual labs, remote experiments, and interactive simulations, have redefined how learners experience inquiry and experimentation. These tools do not replace physical labs but extend scientific learning beyond the classroom. They allow students to explore complex or hazardous phenomena safely and repeatedly.

The early framework of Ma and Nickerson (2006) described the three forms of laboratory experience — hands-on, simulated, and remote — which illustrate the gradual integration of technology into science. Kapici, Akçay, and de Jong (2019) also noted that physical experiments remain valued in schools; however, digital simulations offer unique advantages such as accessibility and visualization. Following the same idea, Darrah et al. (2014) found that well-designed virtual labs can be an effective alternative for traditional setups, especially when safety conditions and resources are limited.

There is no doubt that the use of digital tools in science classes has expanded alongside the advances in technology and the changing demands of education. Studies by Santos and Prudente (2021) and Lancer Santos and Prudente (2022) demonstrate that virtual laboratories are now mainstream instructional tools, producing learning progress across different science disciplines. Their meta-analyses show that these tools are no longer complementary but integral components of science education in many

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countries, such as The Dewey Schools in Vietnam and other schools that follow NGSS and other frameworks and curricula that highlight inquiry and experiential learning.

The COVID-19 pandemic accelerated this transformation worldwide when schools needed to shift to online learning. The digital hands-on tools, activities, and laboratories became crucial in maintaining the experimental aspect of science courses. Ray et al. (2020) reported that during lockdowns, virtual labs served as vital alternatives to physical experiments; they ensured that students could still participate in scientific investigations. Chirikov et al. (2020) observed an increase in online science platform usage during the periods of remote learning, platforms like PhET Interactive Simulations and Labster. These studies show that inquiry-based learning could continue beyond the laboratory's walls.

Since then, virtual and blended laboratories have become a permanent part of science education rather than a temporary solution. Reviews done recently, like Rosli & Ishak (2024), show that these platforms are now intentionally designed to substitute face-to-face experimental activities through blended setups, and the meta-analysis conducted by Frontiers in Education (2023) comparing physical and digital investigations concluded similar achievement gains in learning the concepts, provided that activities are guided clearly. Therefore, the rise of digital labs and hands-on activities reflects a wider redefinition of how students engage in the scientific inquiry process.

Benefits and Challenges of Physical Hands-on Activities and Experiments

In science, learning starts with observation — touching, seeing, and testing ideas with actual objects. These interactions make scientific concepts tangible. Burkett (2011) stated that students develop a stronger understanding of abstract theories and concepts when they are allowed to handle real materials and variables. This tells you the difference between memorizing facts and making sense of them.

Toma and Greca (2018) found that students who took part in practical investigations in mechanics understood Newton's laws more deeply than those who only listened to lectures. Their results echo what teachers often notice during laboratory sessions: once students can experiment and test their assumptions, misconceptions start to fade. The physical setting of an experiment—where things can go wrong or surprise them—pushes learners to think critically rather than rely on rehearsed answers.

Hands-on science also shapes how students feel about learning itself. Kirilmazkaya and Dal (2022) observed that even low-cost experiments in classroom settings improve motivation and attitudes toward science. This highlights the idea that when students are given a chance and space to manipulate materials and see direct outcomes, science becomes more personal and less abstract. Trnova (2015) also pointed out that hands-on experiments keep students involved because they are no longer passive observers. Instead, they become active participants in constructing knowledge.

The laboratory has long been a place where students discover not only scientific content but also the discipline of inquiry. As described by Williams, Briggs, and Williams (1988), the laboratory is where students question and make predictions and decisions based on their observations, making it the natural ground for discovery-based learning. This process helps students move from concrete observation to more abstract reasoning,

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allowing them to think like scientists (Flick, 1993). In these moments, the lab becomes a training ground for independent thinking and not just a place to “complete an activity”.

Yet, the benefits of physical hands-on learning often meet real-world barriers. Zacharia and Olympiou (2011) explained that experiments require time, preparation, and careful safety management. Schools without sufficient resources or funding may find it difficult to provide every student with enough opportunities for actual laboratory work. Rutten, van Joolingen, and van der Veen (2012) also added that limited equipment and large class sizes often lead to experiments being demonstrated rather than conducted by the students themselves. In many classrooms, compromises like shortening or removing activities need to be done due to the unavailability of materials, and teachers are balancing the need for practical work with time constraints, safety issues, and curriculum demands. Although understandable, these can reduce the hands-on engagement that makes science meaningful in the first place.

Despite the challenging aspects of physical experiments, teachers continue to value them because of their authenticity. The feel of handling lab equipment, observing real chemical reactions, and collecting live data are experiences that no simulation can completely replace. However, not all schools have the same access to laboratories or materials, and this has encouraged educators to look for alternative approaches. Zacharia and Olympiou (2011) and Rutten et al. (2012) mentioned that many schools now combine traditional and digital methods, using simulations or virtual environments to support or extend what happens in the physical lab. This blended approach allows science to remain interactive even when resources are limited.

Hands-on learning in its physical form remains central to science education. It shapes how students think, question, and understand the world around them. The challenge now is finding ways to address issues of time, safety, and equity — ensuring that every learner, regardless of context, has the chance to experience the excitement of scientific discovery firsthand.

Benefits and Challenges of Digital Hands-on Activities and Virtual Laboratories

Digital tools and programs such as PhET Interactive Simulations, Labster, Amplify Science, Tinkercard, etc., have made experiments that are impractical to do in person doable. These experiences started as an alternative for schools with limited equipment, but over time, they have become a regular part of science instruction. Tatli and Ayas (2013) observed that simulations give students the opportunity to engage with scientific processes that are challenging to visualize when resources are scarce. A study by Kapici et al. (2019) discovered that students gained a deeper understanding when physical activities were complemented with virtual experiments, showing that both approaches work best together.

Aside from virtual laboratories, many classrooms now use other digital tools to make science learning accessible and interactive. Ardhita and Khanafi (2024) found that integrating online platforms and interactive software into lessons has improved students’ engagement and understanding in science. Similarly, Zhao (2025) showed that smartphone-based laboratories, where students need to use mobile sensors and an analysis app, have developed data processing skills even when lab setups are limited. In the university context, a study by Lahme et al. (2023) showed that digital experiments

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these days can take any form as instructors increasingly rely on tablets and maker-tech kits to connect hands-on work with digital competencies. These studies suggest that digital hands-on activities and tools offer distinct benefits and a place in science education.

The flexibility and accessibility that digital and virtual tools have made them popular. They allow for repeated experimentation and exploration of inquiry questions and "what if" scenarios that might be impossible or costly in a traditional lab setup. As emphasized by Darah et al. (2014), digital platforms let students safely try risky and costly experiments, while Lin et al. (2020) added that these tools allow students to grasp abstract or microscopic processes — from chemical bonding to molecular motion — as they offer a level of representation that books alone cannot provide.

Apart from convenience, this flexibility also gives a sense of control over students' own learning. de Jong, Linn, and Zacharia (2013) found that virtual laboratories encourage learners to take initiative in setting up their experiments, manipulating variables, and testing different conditions at their own pace. And because they get real-time feedback, students can refine their understanding immediately, making the learning process personal and reflective. However, this liberty requires structure and clear guidance, as the open-ended nature of digital tools can be overwhelming to students.

Despite all the convenience, flexibility, and accessibility, the digital environment has its downsides and cannot be considered a cure-all approach. As Rutten, van Joolingen, and van der Veen (2012) pointed out, sometimes students treat simulations as video games rather than experiments if not properly guided. Pyatt and Sims (2012) also highlighted that determining how effective virtual labs can be depends on self-discipline and digital fluency. With these, teacher scaffolding is crucial, as students may prioritize the final results over the learning process.

As previously mentioned, access and equity remain major concerns in digital science learning. As Deriba et al. (2024) assert, poor internet access and uneven access to technology resources limit some students' participation in virtual labs. And even when they are available, engagement sometimes depends on the quality of their devices and software. These gaps remind us that technology is useful, but can also deepen inequalities if not supported with the right digital infrastructure.

Still, few teachers today see digital labs as mere substitutes. They view them as companions to physical inquiry and hands-on activities. As Burkett (2016) described, digital experimentation has become an extension of modern science learning—one that invites curiosity, encourages mistakes, and opens new ways to explore. The task for educators now is not to choose between physical and digital experiences, but to blend them thoughtfully so that students can develop both the mind and the hands of a scientist.

Comparative Studies: Physical and Digital Hands-on Activities

After reviewing the studies and literature on the benefits and challenges of physical and digital hands-on activities, it is imperative to conduct comparative studies of both modalities to gain a better understanding of their effectiveness in science education, globally, regionally, and locally.

Globally, several studies have found that both physical and digital hands-on activities can lead to comparable outcomes when lessons are structured to encourage

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active engagement. Zacharia and Olympiou (2011) supported this after finding out that students achieved similar conceptual understanding in both lab environments, provided that instruction was thoughtfully planned. Similarly, a study of Pyatt and Simms (2012) found that chemistry students performed equally well whether the experiments they conducted were simulated or real, showing that reflection and the quality of interaction mattered more than the medium itself. These findings support Chi and Wylie's (2014) ICAP (Interactive, Constructive, Active, and Passive) framework, which suggests that as students move from being passive to more active and constructive engagement, regardless of the learning environment, learning deepens. More recent meta-analytic and systematic reviews confirm this pattern, showing that virtual laboratories can produce learning gains comparable to physical labs when activities are guided clearly (Santos & Prudente, 2022; Ojetunde, 2025; Sellberg, Nazari, & Solberg, 2024).

At the Southeast Asian region level, studies have echoed these findings while emphasizing the value of blended learning. A study by Dizon (2018) reported that Filipino high school students who used virtual labs demonstrated greater engagement and retention of learning, particularly when guided by structured inquiry. Another study done in the Philippines by Santos and Herrera (2020) observed that combining physical experiments and digital simulations produced stronger academic outcomes, and students' ability to connect theory with practice has improved. In Vietnam, Nguyen and Pham (2021) showed that comprehension and motivation have improved when interactive simulations are integrated in science instruction, while Le and Tran (2022) found that students became more confident in physical experimentation after practicing through virtual platforms. Students who used augmented-reality-based simulations showed higher understanding and engagement compared to those taught using traditional instruction (Pham Ngoc Son et al., 2025). Vu Thi Thu Hoai et al. (2024) also reported that teachers acknowledge the potential of augmented reality (AR) and virtual reality (VR) to improve interest in science, but infrastructure and training barriers still limit full integration of them. All these studies show that digital tools cannot fully replace the sensory experience of physical labs, but they can effectively complement them.

Supporting this balance are the findings of Tokatlidis et al. (2024), showing that while students who engage in virtual labs excelled in knowledge tests, those who participated in physical labs developed stronger procedural and measurement skills. Similarly, Bazie et al. (2024) and Alhashem & Alfailakawi (2023) report that virtual labs are highly effective for conceptual understanding but must be paired with physical experiences to develop hands-on skills. This suggests that the two approaches are equally valuable as they foster different aspects of science learning.

These comparative studies point to a shared conclusion: in modern education, both physical and digital hands-on activities are essential, and it seems like the key is not to decide if one is better than the other, but to understand how each can strengthen the other.

Theoretical Framework

This study is anchored in John Dewey's Experiential Learning Theory, often summed up as "learning by doing." Dewey (1938) believed that students learn best when they are not just listening to information, but actively involved in experiences that require

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exploration, thinking, and reflection. Instead of being passive recipients, students develop a deeper understanding by engaging with their surroundings, making sense of their observations, and applying new ideas in meaningful ways.

In science education, Dewey's ideas suggest that students should be encouraged to experiment, observe, and reflect, rather than simply reading about scientific theories. Whether through physical hands-on activities or digital simulations, the heart of learning remains the same: students build knowledge most effectively when they are actively participating.

Modern research continues to support this approach. Hofstein and Lunetta (2004) emphasized that traditional laboratory work not only strengthens inquiry skills and conceptual understanding but also boosts students' confidence in studying science. Similarly, Zacharia and Olympiou (2011) showed that well-designed virtual tools can offer learning experiences that are just as meaningful as physical activities in science. These findings highlight that it is not the medium – physical or digital – that matters most, but the quality of student engagement.

In line with Dewey's principles, this study uses experiential learning as a foundation for comparing these hands-on activities. Both methods are designed to give students opportunities to actively explore scientific ideas, reflect on their experiences, and apply their learning. By assessing how Grade 9 students perform using each method, the study aims to explore which type of experiential approach better supports the development of scientific knowledge.

In addition to Dewey's Experiential Learning Theory, this study is also guided by the ICAP Framework (Chi & Wylie, 2014), which classifies engagement into four modes: Passive, Active, Constructive, and Interactive. According to ICAP, when students move toward more cognitively demanding forms of participation, learning gains increase. This framework best fits the engagement aspect of this study because the Likert-scale survey items align with these categories by measuring how students interact with the learning materials. Integrating ICAP strengthens the theoretical grounding of the study because it highlights the quality of engagement across hands-on modalities, along with John Dewey's learning by doing.

Research Questions

This study primarily seeks to analyze and compare the effects of learning science using physical and digital hands-on activities on the acquisition of knowledge by Grade 9 science students. The study aims to address these research questions:

1. What are the pre-test scores of students who engaged in physical and digital hands-on activities?
2. What are the post-test scores of students who engaged in physical and digital hands-on activities?
3. What are the pre- and post-engagement levels of students who engaged in physical and digital hands-on activities?
4. Is there a significant difference in post-test scores between students who participated in physical hands-on activities and those who participated in digital hands-on activities?

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5. Is there a significant difference in pre-test and post-test scores between students who participated in the physical and digital hands-on activities?
6. Based on the findings, which type of hands-on activity – physical or digital – can be proposed to enhance Grade 9 students' science performance and engagement?

Hypothesis 1 (H_{01}):

There is no significant difference between the post-test scores in scientific knowledge of both groups.

Hypothesis 2 (H_{02}):

There is a significant difference between the pre-test and post-test results in the scientific knowledge of both groups.

Scope and Delimitations

This study centers on Grade 9 science instruction, with emphasis placed on comparing two hands-on activities – digital and physical – in science lessons. It specifically compares knowledge acquisition and engagement levels when participating in digital or physical hands-on activities. The study is limited to two topics covered in the Grade 9 science curriculum: Natural Selection and Evolution, and Fossils and Extinction.

This study was conducted within the science classrooms of The Dewey Schools, where both physical materials and internet access are available. Students from two grade 9 classes participated in the study: one class engaged in physical hands-on activities, and the other class used digital simulations and activities.

The comparison focused on two specific learning outcomes:

- **Scientific knowledge acquisition** (measured through pre- and post-tests)
- **Engagement levels** (measured through a Likert Scale)

To provide a well-rounded and fair comparison between instructional methods, the study included two lessons under the broader topic of evolution:

Lesson 1 – Natural Selection

- **Physical Hands-on Group**: Students simulated predator-prey interactions using black and red rubber bands on contrasting backgrounds to model camouflage and how environmental changes affected survival and reproduction.
- **Digital Hands-on Group:** Students used the Peppered Moth simulation to observe how camouflage and environmental changes affected survival and reproduction.

Lesson 2 – Fossils and Extinction

- **Physical Hands-on Group:** Students uncovered clay layers with embedded fossil tokens to investigate fossil evidence, extinction events, and understand the "*Law of Superposition*".
- **Digital Hands-on Group:** Students used the "Layers of Time" interactive game to sequence fossils in rock layers, identified mass extinction events, and understand the "*Law of Superposition*".

Class Structure and Timing

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Each lesson was taught within an 80-minute class period following a consistent structure:

- 40 minutes – Teacher-guided instruction and concept explanation
- 40 minutes – Group-based activities (hands-on or digital)

A 40-minute pre-test with embedded survey items was administered before Lesson 1 to determine baseline knowledge and initial engagement levels. After Lesson 2, a 40-minute post-test with the same survey items was given to assess both knowledge acquisition and changes in engagement.

METHODOLOGY

Research Design

The study adopted quantitative quasi-experimental design employing non-equivalent groups with pre-test and post-test. It aimed to compare the effectiveness of two physical and digital hands-on activities and whether there is a significant difference in knowledge acquisition and engagement levels. And because science classes at The Dewey Schools, Tay Ho Tay, campus combine the use of both hands-on activities, this study did not have control and experimental groups, but it still allowed manipulation of an independent variable (the type of hands-on activity) and dependent variables (knowledge acquisition through post-test scores and post-instruction engagement survey results).

Due to the study's quasi-experimental design, two Grade 9 classes at The Dewey Schools Bilingual Program were chosen as the study's participants. One class consisted of fifteen (15) students, while the other had sixteen (16) students. Both classes were chosen based on their comparable academic schedules and the coverage of their English-Science curriculum.

A quantitative quasi-experimental comparative design is appropriate because it allows for a direct comparison between two instructional modes – physical and digital hands-on activities – in similar learning conditions. To ensure consistency and reliability of the design, the lesson content, teaching time, and the teacher were kept the same for both classes.

In this study, the independent variable was the mode of instruction or type of hands-on activities, and the dependent variables were:

• Students' knowledge acquisition. This was assessed through a 40-minute post-test administered after the completion of both learning modes. The post-test consisted of 15 multiple-choice questions designed to evaluate students' understanding of Natural Selection and Mass Extinction topics.

• Students' engagement levels. This was measured using a Likert-scale survey that was distributed along with the post-test questionnaires. This survey collected data on students' emotional, cognitive, and behavioral engagement during tasks.

To control the confounding variables, the two Grade 9 classes received the same lesson content, sequence, and duration. Neither class had prior experience with the digital activities used – the peppered moth simulation and layers of time gamified extinction model. The physical activities were also unfamiliar to the students. Although a few students had background knowledge from earlier lessons in the unit, none had previously explored the tasks used in the study, meaning prior exposure couldn't be attributed to

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their performance. The researcher was the teacher who delivered both lessons using the same slides, worksheets, explanation and exploration time, questioning techniques, and feedback. Teacher bias was further reduced by following the structured guide and avoiding additional guidance that was beyond what was written in the procedure. The only intentional difference was the activity format. That means any measured variation in knowledge gain or engagement could only be attributed to the modality rather than instructional differences.

Locale of the Study

This study was conducted at The Dewey Schools Tay Ho Tay campus, a private bilingual school located in Hanoi, Vietnam. The school houses the largest student population among the three campuses of The Dewey Schools, ranging from 1,200 to 1,500 students annually, and employs approximately eighty (80) foreign teaching staff. These teachers teach English and other English-medium subjects such as science and mathematics.

As mentioned previously, the school was a suitable environment for this study as it featured modern science classrooms and laboratories with essential equipment and safety tools for hands-on activities, along with a strong digital infrastructure that includes access to the internet, IT labs, and an IT support team. Students own personal digital devices – provided by the school in some cases – to facilitate the use of various virtual learning platforms.

The school's commitment to student-centered and experiential learning by utilizing both traditional and technology-enhanced science education makes it a highly appropriate site for this research.

Participants of the Study

The participants of this study were the Grade 9 students from the Bilingual Program at The Dewey Schools, Tay Ho Tay Campus. No random reassignment was done, as the school required that existing class groupings be maintained. So, two intact classes took part in the research, each following a different instructional approach: one class engaged in physical hands-on activities, and the other participated in digital hands-on activities.

One class consisted of fifteen (15) students, and the other had sixteen (16) students. However, not all of them provided informed consent to participate. Only twelve (12) students in the digital hands-on group submitted parent consent and student assent forms, and thirteen (13) in the physical hands-on group. In total, 25 students participated in the study. However, the limited number of participants means the findings cannot be generalized to all Grade 9 students or other school contexts. The results should be viewed as exploratory, offering localized insight into how both modalities influence student performance within a small-class environment.

Participation was voluntary, and written consent was secured from both students and their parents before the data collection. Students who chose not to take part in the study remained in class and engaged in the lessons when they were conducted, but were excluded from the data collection process. All identifying information was kept confidential, and participation had no impact on their grades or standing in class.

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Instruments of the Study

Two primary tools were employed in this investigation: the results from the pre- and post- assessments to gauge students' knowledge gains, and the engagement survey administered at both time points. The knowledge assessment included fifteen (15) multiple-choice questions aligned with the learning objectives of the lessons. Because the testing period was limited to a 40-minute Get Things Done (GTD) time block, the assessment was intentionally designed to be concise while still capturing essential concepts.

Before its administration, a pilot test was conducted with another Grade 9 class not included in the study. The pilot helped assess the clarity of the questions, the level of difficulty, and whether any items needed revision. Feedback showed that a few items needed some adjustments in wording, which were revised before the actual implementation.

For engagement survey questions, a Likert scale was used to measure students' self-reported engagement levels before and after the lessons. The survey included items designed to assess cognitive, behavioral, and emotional aspects of engagement in relation to their learning experience.

The research instruments, the 15-item knowledge test and the student engagement survey were expert-validated before implementation. Two validators reviewed the instruments: (1) a middle school English-Science teacher who also serves as the English-Science Department Lead, and (2) a Biology and Science Curriculum Expert from The Dewey Schools. Using the school's quantitative validation rubric, the evaluators examined the instruments based on clarity of instructions, appropriateness of language, alignment with target constructs, content comprehensiveness, and ease of use for respondents.

Both experts rated the instruments as "High" to "Very High" across all criteria. Their written feedback indicated that the instruments were *well-designed, clearly aligned with the lesson objectives, comprehensive, and easy to administer.* Specific comments noted that the items effectively measured the intended constructs and that the structure and wording were appropriate for Grade 9 learners. Minor suggestions for clarity led to revisions that were incorporated before the pilot testing phase.

To further establish reliability, Cronbach's Alpha was computed for the engagement survey.

Table 1. Cronbach's Alpha Results of Pre and Post-Engagement Levels of Students in Digital and Physical Hands-On Groups

Group		Cronbach Alpha
Digital Group	Pre-test	0.740
	Post-test	0.876
Physical	Pre-test	0.844
	Post-test	0.933

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Table 1, the Cronbach's Alpha values for the engagement surveys ranged from 0.740 to 0.933, showing that the instrument was reliable for both physical and digital hands-on groups. All four scores fall within the acceptable (≥0.70) to excellent range, indicating that students responded consistently across the engagement indicators. The reliability results increased in the post-test for both groups, especially for the physical group, which reached an excellent level (0.933). This confirms that the survey items reliably captured students' cognitive, emotional, and behavioral engagement.

Data Gathering Procedure

The data collection process was carried out for several weeks and included the following phases: preparation, instructional delivery, post-experiment assessment, and data processing.

1. **Preparation Phase**

Before data collection, the researcher finalized all research materials, which included the following:

- Approvals signed by the Head of the English Program, Science Lead, and the School Executive Director, and research instrument validation by the experts.
- Two lesson plans aligned with the Grade 9 science curriculum, with interdisciplinary links to Humanities, as agreed by the researcher and school administrators.
- Pre- and post-experiment test questionnaires and post-engagement surveys.
- Informed consent letters for parents and guardians, and student assent.

The copies of these research materials can be found in the Appendix of this paper.

2. **Preparation Phase**

During this phase, students had to take a 40-minute pre-test and a Likert-scale engagement survey to establish a baseline. They were administered to both classes before the first instructional session began. These were conducted during their Get-Things-Done (GTD) time – a 40-minute block after lunch, allotted for independent work and completing schoolwork to avoid using additional class time. This arrangement ensured minimal class disruption to their regular class schedule while maintaining standardized test conditions for both groups.

3. **Instructional Implementation Phase**

The instructional component was delivered across two science lessons, with equal duration and identical learning objectives. The lesson contents also remained consistent across both groups – physical and digital – hands-on groups. The physical hands-on group engaged in tactile learning experiences using real materials for physical simulation to conduct a mini-investigation, modeling, and worksheet copies. On the other hand, the digital hands-on group used various online platforms, like a virtual simulation, a gamified application to model a scientific phenomenon, and digital worksheets and Google Forms. Each group followed a lesson plan structure – Hook, I Do (Teacher-Led Instruction), We Do (Class Activity/Discussion), You Do (Individual or Group Exploration), and Wrap-up (Exit Tickets and Reflections) – ensuring that the difference in learning outcomes could only be attributed to the type of hands-on activity the classes engaged in.

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4. **Post-Assessment Phase**

Following the instructional sessions, both groups completed a 40-minute post-test to measure knowledge acquisition and post-instruction engagement levels. The post-test was also administered during the GTD period, ensuring uniform timing and environment across both groups. Conducting the post assessment for each group the day after they finished the instructional phase helped reduce recall bias and ensured the credibility of the gathered data.

Data Analysis

All pre- and post-test results, along with survey responses, were collected, reviewed, and encoded into a digital spreadsheet for data and statistical treatment. To maintain confidentiality, students' names were replaced with coded identifiers (e.g., S1, S2, S3…S13) before conducting any data analysis. The researcher ensured that data from both hands-on groups were recorded with consistency to maintain comparability.

Descriptive and inferential statistical methods were used to process the verified data, see the Data Analysis Tools section. These analyses were conducted to identify patterns, determine differences, and answer the research questions. The summarized results and syntheses are presented in detail in Chapter IV.

To address the study's research questions 1 and 2 and examine whether the two groups differed in their learning outcomes—specifically knowledge gains and engagement—both the test results and engagement survey data were processed using descriptive and inferential statistical techniques in IBM SPSS Statistics.

For research question 3, the mean scores, standard deviations, and frequency distributions were used to summarize students' test performance and engagement levels. These descriptive measures provided an overview of the central tendency and variability of post-test scores, highlighting patterns and differences between the groups.

For research question 4, descriptive statistics were also applied to analyze students' engagement levels based on their responses to the Likert-scale survey administered during both the pre- and post-assessment sessions. The degree of engagement was interpreted using categorical ranges. The following intervals guided the interpretation: 1.00-1.80 (Not Engaged), 1.81-2.60 (Minimally Engaged), 2.61-3.40 (Somewhat Engaged), 3.41-4.20 (Engaged), and 4.21-5.00 (Fully Engaged). The data were analyzed descriptively and were not subjected to inferential testing due to the nature of the data being self-reported attitudes rather than achievements.

For research question 5, Inferential Statistics was utilized**.** An *Independent Samples t-test* was conducted in SPSS to examine whether the two groups differed significantly in their performance, specifically by comparing the post-test results of the physical and digital hands-on cohorts. Although the number of participants was modest ($n = 25$), the test remained suitable because both groups experienced comparable instructional conditions, and the dataset satisfied the assumptions required for this procedure. This analysis enabled the researcher to determine whether the contrast in mean scores between the two groups reached statistical significance.

A *Paired Samples t-test* was also carried out to evaluate changes between the pre-test and post-test scores within each group. In alignment with common practice in educational research, the significance threshold was set at $\alpha = 0.05$.

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The post-test scores were also interpreted using a defined scoring rubric: *13-15 (Excellent), 9-12 (Proficient), 6-8 (Needs Improvement),* and *1-5 (Unsatisfactory).* This system provided a clear framework for classifying student performance and a standardized comparison between the two groups.

The use of these data analysis tools provided a balanced and systematic treatment of data. Descriptive measures showed a detailed summary of performance and engagement, while the inferential measures provided statistical evidence regarding the significance of the differences between hands-on activities. Together, these tools enabled the researcher to evaluate the comparative effectiveness of physical and digital hands-on activities objectively.

Ethical Considerations

Before the study began, approval was obtained from the school's leadership to confirm that the procedures followed institutional guidelines and policies. This step was crucial because the research involved students in a school environment.

Parental consent and student assent were obtained through written forms that clearly outlined the aim of the research and the period of participation. To ensure full communication, a message was also sent through the school's messaging system (ssm.edufit.vn). A Google Form link was attached to the message to provide an alternative means of giving electronic consent in case the student misplaced the printed copy of the parent consent letter.

Those forms emphasized that participation was entirely voluntary. Students and their guardians were also informed that they could withdraw from the study at any time without any consequences.

Additionally, no names, class codes, or any personal and identifying details appeared in the final report to protect the privacy and confidentiality of participants. All data was used only for this academic research and was handled responsibly. Any files containing student responses or results were stored securely to prevent unauthorized access.

Throughout the study, students were fully informed of their rights to ensure they feel safe and respected. The researcher also took into account the developmental level of the students (Grade 9) and ensured that clear communication and age-appropriate instructions were used. The participants also had the option to ask questions or express concerns at any point during the process. The aim was to create a transparent and supportive environment and experience for everyone involved.

RESULTS

Pre-Test Performance of Students in Physical and Digital Hands-On Groups

Table 2 presents the descriptive statistics of the pre-test scores for both groups. The digital hands-on group obtained a mean of 7.83 (SD = 2.44), while the physical hands-on group obtained a mean of 7.31 (SD = 2.69). Both means fall within the Needs Improvement range.

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Table 2. Descriptive Statistics of Pre-Test Scores

Groups	Sample	Mean	Standard Deviation
Digital Hands-on	12	7.83	2.44
Physical Hands-on	13	7.31	2.69

Post-Test Performance of Students in Physical and Digital Hands-On Groups

Table 3 shows the descriptive statistics for post-test scores. The digital hands-on group obtained a mean of 11.67 (SD = 1.78), while the physical hands-on group obtained a mean of 12.77 (SD = 1.36). Both means fall within the Proficient range.

Table 3. Descriptive Statistics of Post-Test Scores

Groups	Sample	Mean	Standard Deviation
Digital Hands-on	12	11.67	1.78
Physical Hands-on	13	12.77	1.36

Pre-Engagement Levels

Tables 4 and 5 summarize the pre-engagement scores for both groups. The physical hands-on group reported an overall mean of 3.58 (SD = 0.80), while the digital hands-on group reported an overall mean of 3.87 (SD = 0.79). Both means fall within the Engaged range.

Table 4. Descriptive Statistics of Pre-Engagement Levels of Students in the Physical Hands-On Group

Questions	Mean	St. Dev	Level
1. Digital hands-on activities keep my attention in science lessons.	3.85	0.80	Engaged
2. Physical hands-on activities keep my attention in science lessons.	3.38	0.96	Engaged
3. Digital hands-on activities are enjoyable.	3.77	0.73	Engaged
4. Physical hands-on activities are enjoyable.	3.54	0.97	Engaged
5. Digital hands-on activities help me understand science topics.	3.46	0.66	Engaged
6. Physical hands-on activities help me understand science topics.	3.77	0.73	Engaged

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7. Digital hands-on activities make science lessons feel meaningful.	3.46	0.88	Engaged
8. Physical hands-on activities make science lessons feel meaningful.	3.54	0.78	Engaged
9. I actively participate in digital hands-on activities.	3.62	0.77	Engaged
10. I actively participate in physical hands-on activities.	3.69	0.85	Engaged
11. I feel confident when I do digital hands-on activities.	3.54	0.78	Engaged
12. I feel confident when I do physical hands-on activities.	3.38	0.87	Engaged
Overall	**3.58**	**0.80**	**Engaged**

Note: For Interpretation, the following remarks apply to the mean interval: 1.00-1.80 for Not Engaged, 1.80 - 2.60 for Minimally Engaged, 2.61 - 3.40 for Somewhat Engaged, 3.41 -4.20 for Engaged, and 4.21 - 5.00 for Fully Engaged

Table 5. Descriptive Statistics of Pre-Engagement Levels of Students in the Digital Hands-On Group

Questions	Mean	St. Dev	Level
1. Digital hands-on activities keep my attention in science lessons.	3.92	1.00	Engaged
2. Physical hands-on activities keep my attention in science lessons.	3.58	0.90	Engaged
3. Digital hands-on activities are enjoyable.	3.75	0.87	Engaged
4. Physical hands-on activities are enjoyable.	3.83	1.03	Engaged
5. Digital hands-on activities help me understand science topics.	4.00	0.60	Engaged
6. Physical hands-on activities help me understand science topics.	3.83	0.72	Engaged
7. Digital hands-on activities make science lessons feel meaningful.	3.75	0.75	Engaged
8. Physical hands-on activities make science lessons feel meaningful.	3.67	0.65	Engaged
9. I actively participate in digital hands-on activities.	3.92	0.79	Engaged
10. I actively participate in physical hands-on activities.	3.92	0.79	Engaged
11. I feel confident when I do digital hands-on activities.	4.08	0.67	Engaged
12. I feel confident when I do physical hands-on activities.	4.17	0.72	Engaged
Overall	**3.87**	**0.79**	**Engaged**

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Note: For Interpretation, the following remarks apply to the mean interval: 1.00-1.80 for Not Engaged, 1.80 - 2.60 for Minimally Engaged, 2.61 - 3.40 for Somewhat Engaged, 3.41 -4.20 for Engaged, and 4.21 - 5.00 for Fully Engaged

Post-Engagement Levels

Tables 6 and 7 summarize the post-engagement scores. The physical group recorded an overall mean of 4.02 (SD = 0.68), while the digital group recorded an overall mean of 3.94 (SD = 1.06). Both results fall within the Engaged range.

Table 6. Descriptive Statistics of Post-Engagement Levels of Students in the Physical Hands-On Group

Questions	Mean	St. Dev	Level
1. Digital hands-on activities keep my attention in science lessons.	3.85	0.55	Engaged
2. Physical hands-on activities keep my attention in science lessons.	4.23	0.73	Fully Engaged
3. Digital hands-on activities are enjoyable.	3.92	0.49	Engaged
4. Physical hands-on activities are enjoyable.	4.15	0.80	Engaged
5. Digital hands-on activities help me understand science topics.	3.77	0.60	Engaged
6. Physical hands-on activities help me understand science topics.	4.08	0.76	Engaged
7. Digital hands-on activities make science lessons feel meaningful.	3.77	0.60	Engaged
8. Physical hands-on activities make science lessons feel meaningful.	4.15	0.69	Engaged
9. I actively participate in digital hands-on activities.	4.08	0.64	Engaged
10. I actively participate in physical hands-on activities.	4.23	0.73	Fully Engaged
11. I feel confident when I do digital hands-on activities.	3.92	0.76	Engaged
12. I feel confident when I do physical hands-on activities.	4.08	0.76	Engaged
Overall	**4.02**	**0.68**	**Engaged**

Note: For Interpretation, the following remarks apply to the mean interval: 1.00-1.80 for Not Engaged, 1.80 - 2.60 for Minimally Engaged, 2.61 - 3.40 for Somewhat Engaged, 3.41 -4.20 for Engaged, and 4.21 - 5.00 for Fully Engaged

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Table 7. Descriptive Statistics of Post-Engagement Levels of Students in the Digital Hands-On Group

Questions	Mean	St. Dev	Level
1. Digital hands-on activities keep my attention in science lessons.	4.17	0.83	Engaged
2. Physical hands-on activities keep my attention in science lessons.	3.17	1.19	Somewhat Engaged
3. Digital hands-on activities are enjoyable.	4.33	0.89	Fully Engaged
4. Physical hands-on activities are enjoyable.	3.50	1.09	Engaged
5. Digital hands-on activities help me understand science topics.	4.33	0.78	Fully Engaged
6. Physical hands-on activities help me understand science topics.	3.42	1.00	Engaged
7. Digital hands-on activities make science lessons feel meaningful.	4.33	0.98	Fully Engaged
8. Physical hands-on activities make science lessons feel meaningful.	3.58	1.08	Engaged
9. I actively participate in digital hands-on activities.	4.42	0.79	Fully Engaged
10. I actively participate in physical hands-on activities.	3.67	1.30	Engaged
11. I feel confident when I do digital hands-on activities.	4.75	0.45	Fully Engaged
12. I feel confident when I do physical hands-on activities.	3.58	1.08	Engaged
Overall	**3.94**	**1.06**	**Engaged**

Note: For Interpretation, the following remarks apply to the mean interval: 1.00-1.80 for Not Engaged, 1.80 - 2.60 for Minimally Engaged, 2.61 - 3.40 for Somewhat Engaged, 3.41 -4.20 for Engaged, and 4.21 - 5.00 for Fully Engaged

Independent Samples t-Test for Pre-Test Scores

Table 8 shows no statistically significant difference in pre-test scores between the physical and digital hands-on groups ($t = 0.510$, $p = 0.615$).

Table 8. Independent Samples t-Test for Pre-Test Scores

Groups	Mean	Standard Deviation	t-value	df	p-value	Remarks
Digital Hands-on	7.83	2.44	0.510	23	0.615	NS
Physical Hands-on	7.31	2.69				

Note: NS – No Significant Difference ($p > 0.05$)

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Independent Samples t-Test for Post-Test Scores

Table 9 shows no significant difference in post-test scores (t = –1.750, p = 0.093) between groups.

Table 9. Independent Samples t-Test for Post-Test Scores of Physical and Digital Hands-On Groups

Groups	Mean	Standard Deviation	t-value	df	p-value	Remarks
Digital Hands-on	11.67	1.78	-1.750	23	0.093	NS
Physical Hands-on	12.77	1.36				

Note: NS – No Significant Difference (*p > 0.05*)

Paired Samples t-Test for Pre- and Post-Test Scores

Table 10 shows significant increases from pre-test to post-test in both groups. The physical hands-on group recorded a significant improvement (t = –3.074, p = 0.002), and the digital hands-on group also recorded significant gains (t = –3.189, p = 0.001).

Table 10. Paired Sample T-Test Results for Pre- and Post-Test Scores of Physical and Digital Hands-On Groups

Activities	Calculated value	p-value	Remarks
Physical Hands-on	-3.074	0.002	S
Digital Hands-on	-3.189	0.001	S

Note: S – With Significant Difference (*p > 0.05*)

DISCUSSION

The purpose of this study was to compare the effectiveness of physical and digital hands-on activities on Grade 9 students' science performance and engagement. The results provide several insights that address the research questions and clarify how each instructional modality contributed to student learning.

RQ1: What are the pre-test scores of students who engaged in physical and digital hands-on activities?

Based on the results, both groups showed comparable baseline knowledge before the intervention. The mean score of the digital hands-on group was 7.83, while the physical hands-on group scored 7.31. This supports the findings by Zacharia & Olympiou (2011) and Pyatt & Sims (2012), who also observed no significant difference in baseline knowledge when students were randomly assigned to physical or virtual lab conditions, indicating that differences in learning outcomes cannot be attributed to prior knowledge.

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RQ2: What are the post-test scores of students who engaged in physical and digital hands-on activities?

After the implementation of the lessons, both groups showed improvement. The digital hands-on group achieved a mean of 11.67, while the physical hands-on group reached 12.77. Although the latter group scored slightly higher, the difference between the two groups' independent samples t-test revealed no significant difference ($t = -1.750$, $p = 0.093$) in post-test scores between them. This supports international and Southeast Asian studies, such as Pyatt and Sims (2012); Santos & Herrera (2020); Dizon (2018), which found that both modalities often lead to comparable academic performance when instruction is clear and inquiry-based. This is also consistent with the meta-analysis from Frontiers in Education (2023), which concluded that both experiments lead to equal learning gains when learners are guided by meaningful activity structures.

RQ3: What are the pre- and post-engagement levels of students who engaged in physical and digital hands-on activities?

The engagement survey results show that both groups were generally engaged before the lessons, as shown in their pre-engagement survey results, with a mean score of 3.58 (physical) and 3.87 (digital). Their post-engagement levels slightly increased but still within the engaged category, with a mean score of 4.02 (physical) and 3.94 (digital). These results reflect studies by Kirilmazkaya & Dal (2022); Trnova (2015), showing that physical experiments foster active involvement and curiosity, while digital environments provide interactivity and motivational appeal according to the studies of Nguyen & Pham (2021); Rosli & Ishak (2024).

RQ4: Is there a significant difference in post-test scores between students who participated in physical hands-on activities and those who participated in digital hands-on activities?

The difference between the two groups' independent samples t-test revealed no significant difference ($t = -1.750$, $p = 0.093$) in post-test scores between them. This means that while the physical hands-on group scored slightly higher, the difference was not statistically significant. The results failed to reject the null hypothesis.

RQ5: Is there a significant difference in pre-test and post-test scores between students who participated in the physical and digital hands-on activities?

The paired t-test results with the p-values at 0.002 and 0.001 for physical and digital hands-on groups, respectively, show a significant difference between the pre- and post-test scores in both groups. The ICAP of Chi and Wylie (2014) supports this, which argues that active and constructive learning environments – whether physical or digital – produce stronger cognitive gains than passive instruction.

RQ6: Based on the findings, which type of hands-on activity – physical or digital – can be proposed to enhance Grade 9 students’ science performance and engagement?

Based on the findings, the type of hands-on activity – physical or digital – can be proposed to enhance Grade 9 students’ science performance and engagement.

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The question was not tested statistically, but derived from comparative interpretation and analysis of data. The physical hands-on group showed a higher mean in post-test performance, while the digital hands-on group displayed a slight increase in engagement. Therefore, a blended approach integrating both methods is recommended to maximize learning performance in science, and below is the recommended 6-week Blended Inquiry Skills Training Program for Teachers.

Table 11. Proposed 6-Week Blended Inquiry Skills Training Program for Science Teachers

Program Component	Specific Training Activities	Duration and Facilitator	Expected Outcome and Evidence
Session 1: Orientation Physical and Digital Approaches	- Overview of the purpose and features of physical and digital hands-on activities. - Short demonstration of both modalities using samples of grade 9 tasks. - Teachers analyze a sample lesson and identify which components benefit from physical and digital tools. - Quick classification activity: Sorting sample tasks into “best for physical”, “best for digital”, or “works for both” with rationale.	**Week 1** (1-1.5 hours) **Facilitator**: Head of the Science Department	- Exit card mentioning where physical is more appropriate and one where digital is more effective.
Session 2: Workshop on Designing Blended Science Lessons	- Step-by-step guided creation of a blended lesson plan using the school’s prescribed template. - Teachers choose any topic from the current Grade 9 curriculum (e.g., atoms, forces, evolution, etc.) - Identify clear inquiry questions, hands-on tasks, and physical and digital scaffolding opportunities. - Evaluate an existing lesson and modify it into a blended version. - Peer-review of draft lesson plans using a rubric.	**Week 2** (2 hours) **Facilitator**: Curriculum Designer / Head of the Science Department	- Completed blended lesson plan per teacher pair. - Peer-review rubric results. - Uploaded lesson draft to shared drive.
Session 3: Digital Tools Training	- Guided navigation through key platforms (PhET phet.colorado.edu, Gizmos gizmos.explorelearning.com , American Museum of Natural History or amnh.org,	**Week 3** (2 hours) **Facilitator**: ICT Coordinator / Edtech Specialist	- One digital worksheet is ready for classroom use. - Quick performance

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	askabiologist.asu.edu, or school-approved and subscribed digital tools). - Common troubleshooting workshop: loading errors, browser issues, and student device compatibility. - Create a digital worksheet that includes: inquiry and discussion questions, data tables, analysis prompts, and reflection.		check (e.g., running a simulation, taking and exporting a screenshot)
Session 4: Physical Lab Setup and Management Workshop	- Demonstration of setting up simple investigation or model activities using low-cost materials found in Vietnamese schools (paper models, markers, measuring tools). - Training on timing, transitions, material distribution, safety reminders, and effective grouping. - Brainstorm a physical hands-on activity or experiment based on the chosen topic and how to prepare it using available materials.	**Week 4** (1.5 hours) **Facilitator**: Lab Technician/ Senior Science Teacher or Lead Teacher	- Completed safety and materials checklist. - Sample student data sheet created. - Quick evaluation checklist.
Session 5: Classroom Pilot Implementation	- Teachers teach the blended lesson they designed (physical + digital) - Use an observation checklist on engagement and inquiry behaviors. - Collect exit tickets, physical and digital outputs/worksheets. - After-lesson short reflection on challenges and successes.	**Week 5** (1 hour or 1 lesson period) **Facilitator**: Science Coordinator or Curriculum Designer (observers)	- Folder containing: student work samples, exit tickets, and observation notes. - Short teacher's pilot reflection.
Session 6: Reflection, Revision, and Sharing	- Roundtable session where teachers share what worked and what needs improvement. - Facilitators highlight common patterns and effective supports. - Group creates a school "Best Practices List for Blended Hands-on Science" including practical tips and examples.	**Week 6** (1 hour) **Facilitator**: Head of the Science Program/ Academic Head	- Individual teacher reflection write-up about the 6-week training. - Completed Best Practices document for school use.

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Summary of Findings

This study examined the effects of two types of hands-on activities on Grade 9 students' science performance and engagement at The Dewey Schools, Tay Ho Campus in Hanoi, Vietnam. One group performed physical hands-on activities on Natural Selection and Extinction, while the other group engaged in digital simulations of the same lesson or topics. Findings are presented according to the research questions.

1. **Pre-Test Scores of Students in the Physical and Digital Hands-on Groups**
   - Both groups took a 15-item multiple-choice pre-test (40 minutes) prior to the intervention, interpreted using the rubric: 13-15 (Excellent), 9-12 (Proficient), 6-8 (Needs Improvement), and 1-5 (Unsatisfactory).
   - The mean scores of the digital and physical hands-on groups were 7.83 (SD=2.44) and 7.31 (2.69), respectively.
   - This indicates that both groups started with limited initial understanding and comparable baseline knowledge of Natural Selection and Extinction.
2. **Post-Test Scores of Students in the Physical and Digital Hands-on Groups**
   - After the intervention, both groups completed the same 15-item post-test to compare learning gains.
   - The physical hands-on group scored 12.77 (SD=1.36), while the digital group scored 11.67 (SD=1.78).
   - Both groups' mean scores moved into the Proficient range, indicating improved performance in both modalities.
3. **Pre- and Post-Engagement Levels of Students Before and After the Intervention**
   - Before the lessons, both groups reported being "Engaged" with overall means of 3.58 (physical) and 3.87 (digital).
   - After the intervention, engagement increased slightly for both groups: 4.02 for the physical group and 3.94 for the digital group.
   - These results indicate that both learning modalities positively and equally supported students' engagement.
4. **Statistical Analysis of Post-Test Scores Between Physical and Digital Hands-on Groups**
   - An independent sample t-test showed no significant difference in post-test scores between the physical and digital hands-on groups ($t = 1.750$, $p = 0.093$).
   - This means that both instructional modalities resulted in comparable learning gains.
5. **Statistical Analysis of Pre and Post-Test Scores Between Physical and Digital Hands-on Groups**
   - Paired samples t-test showed significant improvement from pre- to post-test in both groups: physical ($t = 3.074$, $p = 0.002$) and digital ($t = -3.189$, $p = 0.001$).
   - Both groups' post-test scores increased significantly compared to their pre-test scores.
   - This indicates that both physical and digital hands-on activities effectively improved students' science performance.

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6. **Proposed Instructional Enhancement Activities Based on Findings**
   - With no significant difference in post-test scores and both groups showing significant improvement, both modalities were found to be effective.
   - A blended approach integrating physical and digital hands-on activities is recommended to maximize learning and engagement.

Overall, the findings show that both instructional methods are beneficial to students' learning and engagement. These findings form the basis for the conclusion and recommendations.

Conclusions

Based on the findings, the following conclusions were drawn:

1. Both the physical and digital hands-on groups began with limited and comparable baseline knowledge of Natural Selection and Extinction. This similarity in pre-test performance establishes that subsequent learning outcomes can be attributed to the instructional interventions rather than prior differences in content understanding.
2. Although the physical hands-on group achieved a slightly higher mean score in the post-test, the gains in both groups placed them within the *Proficient* range. The moderate increase from pre-test to post-test suggests that students in both modalities gained conceptual understanding, although not to the extent originally anticipated. This modest improvement may be attributed to the inherent difficulty of evolutionary concepts, which often require extended instructional time for deeper learning and retention.
3. Both groups reported being "*Engaged*" before and after the intervention, with slight increases in their post-engagement levels. The results indicate that physical hands-on activities fostered enjoyment, collaboration, and active participation, while digital simulations supported confidence, visualization of complex ideas, and accessibility for bilingual learners. These findings show that each modality engages students in different but complementary ways.
4. The absence of a statistically significant difference between the post-test scores of the two groups indicates that neither instructional method was superior. This finding aligns with previous research demonstrating that thoughtfully implemented digital simulations can be as effective as traditional laboratory setups in supporting science learning. The comparable outcomes affirm that both approaches can produce meaningful learning gains.
5. The significant improvement within each group from pre-test to post-test confirms that both physical and digital hands-on interventions effectively enhanced student learning. The gains, although moderate, demonstrate that hands-on learning, whether physical or digital, plays an important role in supporting conceptual understanding in challenging topics such as evolution.
6. Based on the collective findings, this study concludes that both physical and digital hands-on activities are equally effective in supporting Grade 9

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students' science performance and engagement. Although the physical group achieved slightly higher mean scores and engagement ratings, the absence of a statistically significant difference indicates that both modalities promote meaningful learning when implemented purposefully. Each approach offers distinct advantages: physical hands-on activities foster collaboration, curiosity, and tactile inquiry, while digital simulations support visualization of abstract concepts, accessibility for bilingual learners, and ease of preparation in settings with limited laboratory equipment. In line with these findings, this study proposes a 6-week Blended Inquiry Skills Training Program for Science Teachers (Table 11) designed to strengthen teachers' capacity to integrate both physical and digital hands-on approaches in science instruction. The enhancement program includes structured professional learning sessions on blended lesson design, digital tool navigation, physical lab setup using low-cost materials, and classroom pilot implementation, culminating in collaborative reflection and the establishment of school-wide best practices. By supporting teachers with appropriate training and resources to apply blended hands-on strategies, the program aims to help students capitalize on the strengths that each approach provides

Overall, the results of this study reinforce the value of combining both instructional modes, and the proposed training program provides a practical, research-based pathway for improving science teaching and learning at The Dewey Schools.

Recommendations

The comparative analysis of physical and digital hands-on activities reveals that both modalities effectively enhance Grade 9 students' scientific knowledge and engagement. While the physical group showed marginally higher post-test scores, the difference was not statistically significant. Engagement levels improved in both groups, with digital activities offering unique benefits through interactivity and gamification. Hence, these recommendations are proposed:

For Science Teachers and Curriculum Designers

a. Adopt flexible and multimodal instructional strategies by providing opportunities for students to engage in both physical and digital hands-on activities. This aligns with evidence showing that both methods can effectively support learning and engagement outcomes.

b. Use consistent lesson structure – clear instructions, guided exploration time, and structured activity sheets – to help students organize data, apply concepts, and reflect on their learning after engaging in hands-on activities.

c. Allocate enough lesson time for abstract and complex topics such as natural selection and extinction, especially in bilingual classrooms

d. Monitor students' work during hands-on activities and offer timely feedback during exploration to deepen understanding and address misconceptions.

e. Where possible, design units that intentionally sequence both physical and digital hands-on activities rather than relying only on one format.

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f. Implement the 6-Week Blended Inquiry Skills Training Program developed in this study to strengthen teacher capacity in designing and integrating multimodal hands-on lessons.

For Schools and Administrators

a. Continue investing in accessible and student-friendly digital tools and platforms to supplement high-risk laboratory activities or when resources are limited.

b. Strengthen the internet infrastructure and equip the science laboratory spaces with basic materials needed for simple hands-on activities related to evolution and other science topics.

c. Provide professional development training for teachers on how to effectively integrate digital and physical laboratory tools and resources into science instruction.

For Students

a. Engage actively in both physical and digital hands-on activities by asking questions, participating in class discussions, and using the provided tools and simulations properly.

b. Take responsibility for organizing and analyzing data collected during hands-on activities, as this strengthens science reasoning skills and improves comprehension.

c. Leverage digital tools, such as simulations, replay features, and data visualization to review challenging concepts.

For Future Research

a. Larger sample size and more diverse samples across different grade levels, schools, or science programs and curricula to strengthen generalizability.

b. Longer instructional periods would provide a clearer picture of how each method supports learning over time.

c. Test a blended approach, where physical and digital hands-on activities are intentionally combined within the same lesson or unit, to see whether this strengthens students' performance.

d. Qualitative data, such as student reflections, interviews, or in-class observations, tto explore more thoroughly into students' experiences, choices, and challenges with each method.

e. Explore the role of bilingual instruction, specifically how the types of hands-on activities support multilingual classrooms.

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