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An effect of technology-infused active inquiry learning in primary school science on students' conceptions of learning science

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Abstract
Digital technology has been proposed as a pedagogical tool capable of transforming traditional inquiry-based learning methods into innovative inquiry-based learning environments for school science. Researchers have reported that technology-enhanced learning environments have significant potential to shape students' conceptions of learning and their learning approaches. This study, therefore, introduces a technology-infused active inquiry learning approach aimed at transforming primary school students' conceptions of learning science. 11 fifth-grade students from a university-based primary school in the northeastern region of Thailand were selected to participate in a two-week intervention based on this approach. The results indicate a noticeable shift in the students' conceptions of technology-infused active inquiry learning following the intervention. However, it was observed that many students still exhibited a tendency towards passive learning due to the overall interaction with technology during science lessons. This highlights the ongoing challenge of effectively incorporating technology in the classroom to foster more advanced conceptions of learning.

Keywords: digital technology, inquiry-based learning, technology-enhanced learning, conception of learning, nature of scientific inquiry, learning gain

INTRODUCTION

Teaching attitude is a psychological tendency of teachers. Recent developments in digital technologies and instructional science necessitate a contemporary framework for crafting an effective pedagogical strategy in technology-enhanced learning environments during a period of profound global transformation. This framework is designed to address the educational challenges faced by today's digital-native learners. The capabilities of digital technology have the potential to revolutionize both teaching and learning practices, making the integration of digital technologies and inquiry-based pedagogy a pivotal concern in facilitating student learning, especially in the context of science education. Within the science education community, a diverse array of effective technological environments and applications are available to enhance science teaching and learning. Examples include animations, simulations, modeling tools, microcomputer-based laboratories, smartphone and mobile applications, intelligent tutoring systems, web resources, spreadsheets, scientific databases, and more. These tools are valuable resources for both students and educators. Notably, mobile game-based learning environments have shown promise in improving students' learning outcomes and fostering their enthusiasm for science (e.g., Komalawardhana et al., 2021; Srisawasdi & Panjaburee, 2019; Tapingkae et al., 2020). Holá (2007) has suggested that the use of microcomputer-based laboratories and computer simulations can enhance students' cognitive development and elicit positive responses, as these tools aid in the comprehension of

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Contribution to the literature

- Integrating interactive video technology and real-time student-response systems into inquiry-based science learning has been proposed as a technology-infused active inquiry learning approach.
- The transformation of primary school students' conceptions of technology-infused active inquiry learning was examined. Results suggested a noticeable shift in the students' conceptions of technology-infused active inquiry learning in science.
- The challenge of employing digital technology in science classrooms to cultivate more sophisticated conceptions toward learning is called.

scientific concepts. For instance, Sung and Hwang (2013) advocate for game-based learning through the utilization of grid-based mindtools, which allow students to organize and communicate information while engaging in educational games.

Diverse approaches to technology-enhanced science learning have emerged, including internet-assisted self-directed learning, context-aware ubiquitous inquiry learning, mobile-assisted citizen inquiry learning, and goal-oriented online education. Moreover, a body of research has underscored the efficacy of blending inquiry-based pedagogies with digital technology in enhancing students' comprehension of scientific concepts and bolstering their motivation and attitude toward science (Natnivong & Srisawasdi, 2016; Pondee et al., 2017; Premthaisong & Srisawasdi, 2020). The integration of technology-infused innovative practices is steadily becoming more ingrained in science teaching and learning, with a focus on enhancing the learning performance of digital-native students (Srisawasdi, 2018b). The infusion of digital technology into inquiry-based learning, often referred to as a technology-infused active inquiry learning approach, represents a promising avenue for science education in Thailand. This approach opens new possibilities for educators to facilitate the inquiry-based learning process among students. Key aspects of this innovative approach encompass engaging students in inquiry activities with the support of mobile technology, facilitated through bring your own device (BYOD) model. This approach simplifies the complexity of inquiry-based learning tasks and introduces a more flexible format for conducting inquiry-type investigations and practices. Consequently, students' perceptions of how technology can assist their learning include the acquisition of content information and the generation of innovative ideas (Tsai, 2009; Yang & Tsai, 2010). Examining these student perspectives empowers educators and researchers to gain deeper insights into student needs and preferences, which, in turn, informs the development of tailored teaching and learning strategies.

Scholars have uncovered that students' perceptions of the learning process play a pivotal role in shaping their academic journeys and ultimate achievements. Notably, students' motivational beliefs and the learning strategies and approaches they employ can exhibit variation contingent upon their individual conceptions of learning (Dart et al., 2000; Huang et al., 2018; Lee et al., 2008; Lin et al., 2019; Soltani & Askarizadeh, 2021; Tan et al., 2021; Wang et al., 2017). While researchers have extensively examined students' conceptions of science learning, there has been a noticeable gap in the exploration of students' perceptions regarding the role of digital technology in facilitating science learning (e.g., Chang & Tsai, 2023; Hsieh and Tsai, 2017; Yeh et al., 2019).

BACKGROUND

Technology-Infused Active Inquiry Learning in Science

Researchers reported that students taught in active learning classrooms do better than those taught in traditional classes (Yimer, 2020). Inquiry-based learning is a common active learning technique used to teach science in general. Active inquiry learning spans several decades and promotes students' engagement and proactive involvement in generating scientific knowledge and comprehending scientific practices via inquiry-type investigation, such as conventional science experimentations. The 21st century is commonly considered a technological era. (Srisawasdi, 2012). In the 21st century, digital technologies have ushered in a transformation in the methods employed by both learners and educators in the field of science education. The creation of active, engaging, and coherent learning environments within science classrooms has emerged as a pivotal development capturing the attention of science educators, educational researchers, and curriculum developers. Over recent years, a flood of digital educational resources specifically designed for science education has emerged, encompassing probe ware, interactive videos, animations and simulations, digital games, mobile applications, augmented and virtual reality tools, as well as web-based platforms. These Technological resources have been utilized in a multitude of ways to help both learners and educators throughout the learning and teaching process (Srisawasdi, 2018a). In contrast to the aforementioned active inquiry learning, technology-infused active inquiry learning represents a distinct pedagogical approach within the realm of technology-enhanced inquiry-based learning in science. This approach involves the seamless integration of technological tools and resources into the active inquiry-based learning process. Within this context, the utilization of digital technology offers learners the opportunity to access extensive information resources, engage in virtual experiments and simulations, collaborate with peers, and efficiently communicate their discoveries. It is essential to note that the efficacy of digital technologies in the learning process is intricately linked to the pedagogical strategies employed, such as inquiry-based learning (Flick & Bell, 2000).

Accordingly, numerous researchers have attempted to implement multiple digital technologies in science classrooms. For example, Srisawasdi and Sornkhatha (2014) presented computer simulations incorporated with dual-situated learning for conceptual learning of Newton's laws of motion as part of technology-integrated inquiry learning in physics. At a microscopic level, Nachairit and Srisawasdi (2015) created an augmented reality (AR) for the chemistry learning of acid-base titration to support students' science learning abilities. Lokayut and Srisawasdi (2014) designed a computer game for students with low or high motivation in the science classroom to positively learn about the biology of human circulatory system. In addition, incorporating interactive videos into school science curricula offers a unique opportunity to engage students through active inquiry learning strategies to address the quantity and complexity of the science content taught. For example, Sinnayah et al. (2021) used H5P digital content technology to create interactive learning content, such as interactive videos and branching scenarios, to promote self-paced and self-directed learning in science, and the technology could be innovatively incorporated into science-based lessons to support learning pedagogy via active learning. In addition, a technology-facilitated formative assessment tool, such as Nearpod, is regarded as one of the solutions that can enhance student interaction, encourage classroom participation, and support learning resources during active inquiry learning in order to provide students with more opportunities to collaborate and be actively engaged in the learning process. To promote a technology-infused active learning, Feri and Zulherman (2021) developed a Nearpod-based science learning module to enhance the academic achievement of elementary school students.

Conceptions of Learning Science in Technology-Enhanced Environments

Scholars have delved into the factors influencing the acquisition of scientific knowledge and have established that students' conceptions of learning science (COLS) are impacted by variables such as grade level, school type, and teaching methodologies employed by educators (Sadi & Cevik, 2016). These conceptions of learning pertain to the beliefs and perceptions held by students about their learning experiences and their preferred approaches to learning (Liang & Tsai, 2010). The term "COLS" encompasses what students know, as well as how they comprehend and perceive the learning process, particularly in the domain of science (Lee et al., 2008; Tsai, 2017). Furthermore, research has demonstrated a strong correlation between students' conceptions of learning and their self-efficacy and motivation in the learning context (Dart et al., 2000; Tsai, 2017). To investigate students' conceptions of learning within science classrooms, COLS questionnaire was developed, building on previous research aimed at understanding how students contemplate the purposes, tasks, strategies, and activities inherent to their learning experiences (Lee et al., 2008; Tsai, 2004; Vermunt & Vermetten, 2004).

Regarding the conceptions of learning in technology-enhanced environments, Tsai (2017) indicated that there were four distinct approaches that students adopted to pursue knowledge in their learning process. First is the *surface motive*. In this approach, students viewed their studies through the lens of short-term goals, often driven by the looming presence of examinations. Their primary focus was on preparing for these tests, and they considered the results as direct indicators of their learning outcomes and overall efficiency. Secondly, it is the *surface strategy*. Students following this path employed rather simplistic and mechanical methods in their studies. They relied on memorization techniques to retain important points from their textbooks or devoted their efforts solely to practicing calculations to pass their examinations. The goal was not to truly comprehend the subject matter but to fulfill the requirements to clear the exams. Thirdly, it is the *deep motive*, where students find themselves contented with their learning experiences and are eager to continue the pursuit of knowledge beyond the boundaries of the classroom. Driven by genuine curiosity and a thirst for understanding, they ventured into uncharted territories, exploring additional related knowledge independently. Their motivation extended far beyond the confines of grades and exams. Finally, it is a realm of *deep strategy*. Here, students could connect new knowledge with the broader framework of the subject and sometimes even beyond it. They exhibited initiative in applying their learnings to tackle unfamiliar problems, showcasing comprehension, and critical thinking that went beyond the surface level. Their approach was characterized by a genuine desire to grasp the subject matter holistically and use their knowledge meaningfully. As we conclude our narrative, we realize that each approach represents a unique perspective on learning. The Surface motive and strategy, driven by short-term goals and simplistic methods, catered to immediate needs. On the other hand, the deep motive and strategy reflected a profound appreciation for knowledge, extending far beyond examinations and embracing a lifelong commitment to

Table 1. Course topic & contents of this study

Lesson	Time	Topic	Content	Technology
1	50 min.	Why do salmons have to swim upstream?	-Scientific investigations all begin with a question & do not necessarily test a hypothesis. -Inquiry procedures are guided by question asked.	-H5P interactive video -Nearpod student-response system
2	50 min.	How to restore salmon population?	-There is no single set or sequence of steps followed in all investigations (there is no single scientific method). -All scientists performing the same procedures may not get the same results.	-H5P interactive video -Nearpod student-response system
3	50 min.	How do salmon know where their home is when they return from ocean?	-Inquiry procedures can influence results. -Research conclusions must be consistent with the data collected. -Scientific data are not the same as scientific evidence. -Explanations are developed from a combination of collected data and what is already known.	-H5P interactive video -Nearpod student-response system

learning and exploration. These different approaches showcased the diverse paths students could choose on their educational journeys, ultimately shaping their growth, understanding, and future endeavors.

In the assessment of conceptions related to learning science, the conventional instrument employed is COLS scale, initially developed by Tsai (2004) and subsequently utilized in various studies to gauge students' perspectives on science learning (Chiou & Liang, 2012; Lee et al., 2008; Tsai et al., 2011). This scale categorizes students' COLS into seven distinct domains, encompassing memorization, testing, calculation, acquisition, application, comprehension, and innovative perception. As per the information presented, it is evident that students' COLS assume a pivotal role in shaping their science education experiences.

RESEARCH METHODOLOGY

Context & Sample Description

The study was conducted at a demonstration primary education school situated in the northeastern region of Thailand. The study involved the participation of 11 fifth-grade students and aimed to explore their COLS within the context of technology-enhanced active inquiry learning in science. The study was approved by the Khon Kaen University Ethics Committee, No. HE663111, and informed consent was obtained from all individual participants.

The educational setting followed the guidelines of the basic education core curriculum of Thailand, specifically in the domain of general science.

The research methodology encompassed the administration of a pre-questionnaire on COLS, with a duration of 50 minutes. Subsequently, the students engaged in a series of technology-infused science lessons that revolved around the scientific inquiry scenario of how spawning fish navigate back to the stream of their birth, a phenomenon exemplified by salmon swimming upstream for reproduction. These lessons spanned three sessions held over a period of three days within a two-week timeframe, totaling 150 minutes.

The instructional module was crafted to foster a collective understanding of the nature of scientific inquiry (NOSI), which pertains to the methods and motivations guiding scientists in their work, as outlined in previous work by Lederman et al. (2014, 2019, 2020, 2021). Upon completion of the lessons, the students underwent post-questionnaires to assess any changes in their COLS, with a similar duration of 50 minutes.

Implementation of Technology-Infused Active Inquiry Learning Approach

A two-week science lesson, "salmon migration", on how salmon find their way back home, was carried out based on technology-enhanced active inquiry learning in science. The science lesson on salmon migration mainly adopts a process-oriented inquiry learning strategy and integrates interactive video, by H5P platform and a student-response system, by Nearpod, to deliver as an approach.

The themed course expands on students' understanding of NOSI. The technology-infused active inquiry learning module was divided into three thematic lessons, as shown in **Table 1**.

This study consists of three topics focused on NOSI and the history of science. Each topic follows three stages, including the pre-investigation stage, the self-investigation stage, and the collaborative investigation stage.

Figure 1 depicts the learning process of technology-infused active inquiry learning in science proposed in this study. In the science class, the teacher engaged the students with an inquiry question to perform the inquiry via BYOD method, as displayed in part A in **Figure 1**. Then, the students were allowed to interact with a self-directed interactive video using tablets, as displayed in part B in **Figure 1**. At the end of class, a class communication has been organized to discuss the main idea to reconstruct new mental sets addressing the inquiry question, as shown in part C in **Figure 1**.

The first topic was an inquiry-based lesson to investigate why salmons have to swim upstream. During the pre-investigation stage, teachers introduced

Figure 1. Technology-infused active inquiry learning in science class: teacher introduced into a science topic with essential inquiry question (A), students interacted with H5P interactive video (B), & teacher & students discussed scientific main ideas by Nearpod platform (C) (Source: Authors' own illustration)

the phenomenon of salmon migration with a common question, “Have you ever observed any unusual animal behavior situations before?” to stimulate brainstorming and gather their opinions. Subsequently, students were assigned to watch a video of grizzly bears catching salmon and engage them in a see-think-wonder task to promote a personal learning process. In second stage of self-investigation, all students interacted independently with a video related to salmon swimming upstream via H5P interactive video, which lasted for 20 minutes. Afterward, during the collaborative investigation stage, teachers and students discussed what they observed in H5P interactive video, focusing on NOSI, via Nearpod platform. Then, the teacher communicated two main ideas about NOSI, which are “scientific investigations all begin with a question and do not necessarily test a hypothesis” and “inquiry procedures are guided by the question asked” and conclude with empirical information obtained from interaction with H5P interactive video and collaborative discussion with Nearpod platform.

The second topic covered in this study is the restoration of salmon populations. Initially, the teacher reviewed what they learned from the last topic and gave feedback on students’ queries regarding the first topic, obtained from Nearpod platform. Similar to the first activity, all students viewed a video on salmon reproduction and participated in a brainstorming session regarding discovering that only 10% of salmon can return home. A procedural knowledge question, “How do we increase the salmon population?” has been posted to the class. This activity lasted roughly 15 minutes. Students actively engaged with and responded to prescriptive questions and prompting in an interactive H5P video that focused on how scientists can increase the salmon population through research and restoration partnerships, hatchery innovations, or dam removal. In concluding phase, two main ideas about NOSI were presented and then communicated to the whole class. These ideas included “There is no single set or sequence of steps followed in all investigations” and “All scientists performing the same procedures may not get the same results.”

The last lesson was an inquiry-based lesson to investigate a scientific phenomenon of how salmon know, where their home is when they return from the ocean. To begin, students watched a video showcasing salmon swimming underwater in the river. Following this, students engaged with an interactive H5P video that presented various hypotheses about how salmon can find their way back home. This activity immersed students in different scenarios related to salmon’s homing behavior, and they were required to answer questions about these situations. In the final stage, the teacher summarized the findings from the video and connected them to examples of salmon homing research from journal papers. This discussion induced four main ideas about NOSI, as follows: “Inquiry procedures can influence results”; “research conclusions must be consistent with the data collected”; “scientific data are not the same as scientific evidence”; and “explanations are developed from a combination of collected data and what is already known.” Subsequently, students participated in a formative assessment of the four main ideas and then engaged in group discussions through Nearpod platform. These discussions lasted approximately 15 minutes and allowed students to share their perspectives and insights on the topic.

This novel approach integrated the use of H5P interactive video and Nearpod formative assessment technology within the framework of inquiry-based learning. It involved a sequence of events designed to engage students, including:

(1) Initiating the learning process by kindling curiosity and interest through a scientific inquiry task and essential inquiry questions. This was followed by providing foundational background information and assigning inquiry-based tasks, all of which were guided and facilitated by teacher.

(2) Creating opportunities for students to actively engage in the inquiry process with the assistance of H5P interactive video, where they could interact within predetermined learning conditions and parameters.

(3) Promoting classroom discourse and collaboration centered around the visualization of scientific phenomena. This stage leveraged Nearpod student-response system to facilitate group discussions on the core concept, offering guidance on how to draw conclusions based on investigative evidence. Students were encouraged to navigate this process both independently and collaboratively, fostering the development of new cognitive frameworks, as depicted in **Figure 2**.

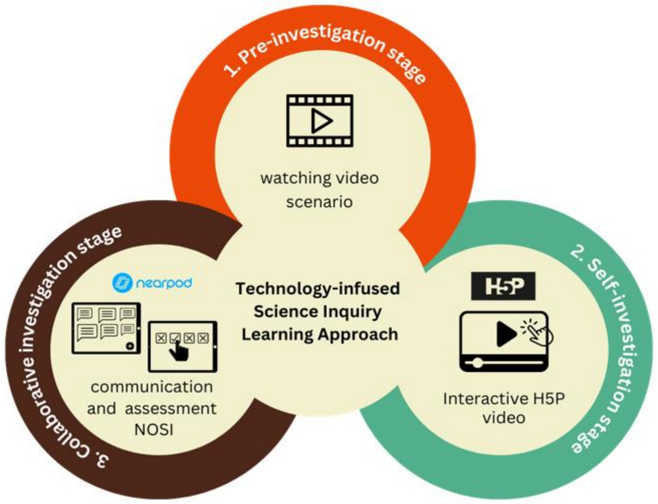

Figure 2. A conceptual model of technology-infused active inquiry learning approach in science (Source: Authors' own illustration)

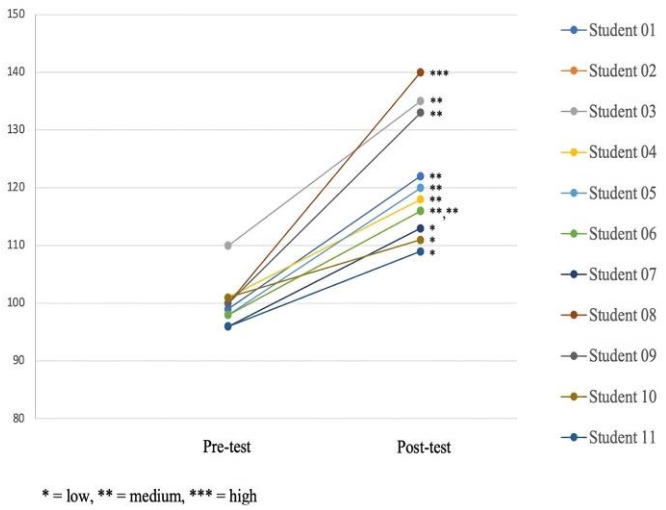

Figure 3. A conception of learning science pre- & post-test of 11 primary students (Source: Authors' own illustration)

Research Instrument

To assess students' COLS before and after their participation in the educational activities, pre- and post-conceptions questionnaires were administered. COLS questionnaire, adapted from Lee et al. (2008), comprised a total of 31 items, each rated on a five-point Likert scale, ranging from one (strongly disagree) to five (strongly agree). For instance, one of the questionnaire items inquired, "Learning science enables me to view natural phenomena and nature-related topics in new ways in terms of understanding and perception." The questionnaire was designed to evaluate students across six distinct dimensions:

(1) memorization,

(2) assessment,

(3) calculation and practice,

(4) knowledge expansion,

(5) application, and

(6) understanding and new perspectives.

As per Lee et al. (2008), these dimensions demonstrated substantial internal consistency, with Cronbach's alpha values of 0.85, 0.91, 0.89, 0.90, 0.84, and 0.91, respectively. The overall alpha coefficient for the entire questionnaire was 0.91, indicating a high level of reliability. This robust reliability suggests that these variables were highly dependable for investigating students' perceptions of science learning.

Data Analysis

All 11 primary school students took pre- and post-test, and descriptive statistics of students' learning gain were calculated for categorical and continuous variables. Individual actual gains Gi (where Gi is post-test score pre-test score) were tabulated to determine percent absolute gain (where average Gi/maximum score possible) and percent relative gain, expressed as a percentage (where C is average Gi/pre-test score) for the class. The class average normalized gain g was calculated to measure the lesson effectiveness. G is the actual gain, %post-, and %pre- are the final (post-) and initial (pre-) class averages, and <g> is the average actual gain divided by the maximum potential gain. In addition, a normalized gain is a valuable tool for analyzing pre- and post-survey scores to determine the efficacy of an intervention (Coletta & Steinert, 2020). A group-average normalized gain of 30% was used to determine the efficacy of the educational intervention because prior research suggests that a normalized gain of 0.30 (30%) is the lower limit of what would be regarded as an effective intervention (Hake, 1998; Khapre et al., 2021).

RESULTS

The results of the study, based on quantitative data analysis using individual normalized learning gain, indicate an improvement in students' COLS following the implementation of technology-enhanced learning in science lessons. Pre- and post-lesson assessments were administered to measure students' COLS, and the data revealed a substantial increase in individual normalized learning gain across the three lessons, as shown in **Figure 3**. **Figure 3** shows the ranking of the single-student normalized gains from 0.19 (19%) to 0.73 (73%), with ranking of their size effects from low to high levels.

Mean test scores of students' COLS improved from 64.34% (99.73/155±3.82) to 78.18% (121.18/155±10.34). The absolute gain was 13.84% (21.45/155±8.71), and the relative gain was 21.47%. The class average normalized gain <g> was 39.27% (part A in **Figure 4**). In addition, absolute gains were noted in all six elements of COLS: memorizing (10.42%), testing (35.45%), calculating and practicing (8.73%), increasing one's knowledge (9.46%),

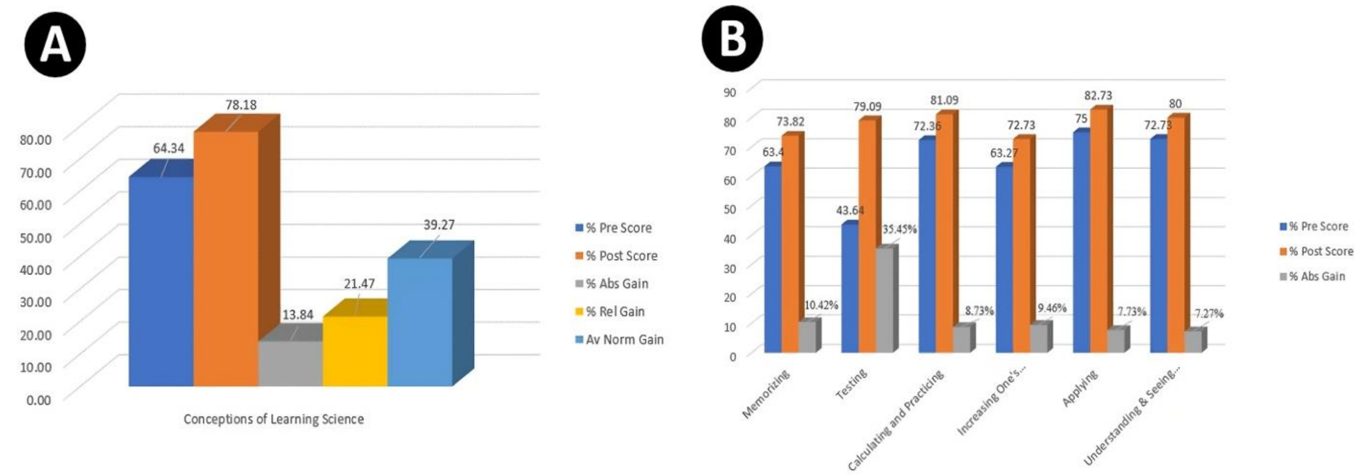

Figure 4. A comparison of students' conception of learning science for pre- & post-test measurement & learning gain (Source: Authors' own illustration)

applying (7.73%), and understanding and seeing in a new way (7.27%) (part B in **Figure 4**).

In addition, the average gain in COLS from pre- to post-test COLS was 0.35. The highest gain of students' conceptions of technology-infused active inquiry learning in science is on testing (<g>=.62), calculating and practicing (<g>=.34), applying (<g>=.33), understanding and seeing in a new way (<g>=.31), memorizing (<g>=.27), and increasing One's knowledge (<g>=.25), respectively.

However, additional study is still needed into the interaction and influence between technology-infused active inquiry learning approaches and conceptions of learning in science. An important issue of why students highly perceived the learning approach situating into unfruitful COLS, such as memorizing, testing, and calculating, will be discussed in the next.

DISCUSSION & CONCLUSIONS

This study evaluated the efficacy of a technology-infused active inquiry learning approach on COLS of fifth-grade primary school students to learn science, specifically on the topic of NOSI. This study's primary objective is to compare students' conceptions of technology-infused active inquiry learning before and after the instructional intervention in their typical school science setting. In other words, the study determines whether the technology-infused active inquiry learning approach contributed to their COLS. It was discovered that their conceptions of technology-infused active inquiry learning in science at the post-test were higher than the pre-test scores. In other words, the characteristics of the technology-infused active inquiry learning approach assisted students in constructing their COLS. The findings of this study demonstrate that the technology-infused active inquiry learning approach may function as a valuable cognitive tool for improving students' COLS in primary school science courses. According to features of the technology-infused active inquiry learning approach proposed in this study, the enhanced precision of learning interaction with science content enabled by interactive video technology and student-response formative assessment technology encourages primary school students to investigate a topic more deeply. The results comply with the view expressed by Cai et al. (2022) that primary school students generally had positive COLS when they learned science in an autonomous learning environment and advanced educational technologies, which helped them to be able to have better exploration in science. In addition, the digital learning environment allowed them more opportunities for independent exploration to avoid providing too much learning information and to give them the opportunities to develop their imagination in science. Particularly, students will acquire deeper notions and more comprehensive approaches to learning when technology is used to facilitate learning (Tsai, 2017). Therefore, students' actual learning experiences with a technology-pedagogy orchestration of H5P interactive video and Nearpod student-response formative assessment system embedded in inquiry-based science learning, named as a technology-enhanced active inquiry learning approach in this study, impacted a transformation of COLS for primary school students.

Nevertheless, it was discovered that most students who participated in this study tended to remain passive receivers of instruction and viewed memorizing, testing, calculating and practicing as short-term objectives for their studies. In other words, the students' conceptions of learning and approaches to learning activities became less sophisticated. This finding was contrasted with Tsai (2017) that students would develop deeper approaches when interacting with a technology-assisted learning environment. Based on our study, this might happen when teachers employ quiz-like technology-infused learning environments, both H5P interactive video and Nearpod student-response system in the class. In addition, this study found that the "testing" conception of learning science had a markedly higher gain (35.45%

absolute gain) compared to others. This finding was consistent with Tsai (2004) that testing is one of the particular COLS discovered in Taiwan characterized by the norm of school education.

Therefore, students may conceptualize learning science simply as preparing for tests (Tsai, 2004). The potential causes of this discovery may be attributed to the educational contexts and the inherent characteristics of school science education in Thailand. To date, various kinds of learning assessment in primary school science remain significant in assessing and evaluating students' academic achievement. Furthermore, there is a significant correlation between the acquisition of scientific knowledge and the performance on assessments, which frequently exhibit unacceptable results among numerous students in the Thai culture. These findings were also consistent with Marton et al. (1997) assertion that students' conceptions of learning could be characterized in terms of similar overall structure across cultures. Thus, there were a few shared characteristics, but additional features were emphasized in certain cultures.

Although the experimental outcomes suggest the positive impact of the technology-infused active inquiry learning approach on students' transformation of their conceptions of science learning, it is important to note that these results are based on data collected from a single school and a relatively small sample of primary school students. Consequently, it is imperative that further experiments within technology-infused learning environments be conducted to validate and replicate these findings in subsequent research endeavors. Furthermore, the current study underscores the considerable potential inherent in technology-enhanced learning environments for nurturing primary school students' conceptions of learning and their approaches to learning. However, it is essential to acknowledge that challenges persist in leveraging digital technology to enhance effective science learning. This includes addressing questions surrounding the integration of technology within the classroom to foster more advanced conceptions and deeper learning approaches. Further research and exploration in this area will be invaluable for addressing these challenges and advancing the field of science education.

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Ethical statement: The authors stated that the study was approved by the institutional ethics committee of Khon Kaen University, Thailand, IRB No. is HE663111. Informed consent was assured with participants.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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