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THE DEVELOPMENT OF TEACHER INTERNS' COMPETENCIES OF SCIENCE INSTRUCTIONAL DESIGN AND IMPLEMENTATION USING STEM ACTIVITY BASED ON DIY, TINKER AND MAKER FRAMEWORKS

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Abstract

The objective of this research was to examine the impact of STEM activity based on DIY, Tinker and Maker frameworks on developing teacher interns' competency in science instructional design and implementations. These activities involve the integration of science, technology, engineering, and mathematics principles, fostering self-regulated learning, creativity, and innovation among students. The research encompassed the design of five STEM activity modules, including a UVC Box Experiment, Digital pH Meter, Air Sensor, Startup & Rare Earth Board Game, and Motion Sensor activity, which were shared with teacher interns via Google Classroom using tutorial videos, slides, and additional materials to enhance their skills. An examination of 26 lesson plans from 13 teacher interns was carried out through content analysis, within a learning model guided by High Impact Practices (HIPs) spanning six domains: well-structured lessons, project-based learning, reflection, learning progression framework, student-centered approach, and Technological Pedagogical Content Knowledge (TPACK). The results showed that the application of the DIY, Tinker, and Maker framework through STEM activities effectively improves teacher interns' competencies in science instructional design and implementation. Particularly noteworthy was the gradual enhancement observed from the initial to the subsequent implementation across all HIPs domains, especially in showcasing TPACK. Nonetheless, the research also identified variations in competency levels, prompting contemplation among students. The importance of developing activities that stimulate student reflection emerged as a key point to consider. This indicates that STEM activities based on the concepts of DIY, Tinker, and Maker should emphasize such reflective practices. The insights obtained from this study could advance the enhancement of teacher interns' skills and encourage further exploration of the topics discussed.

***Keywords* –** Competencies of science instructional design and implementation, Teacher interns, DIY, Tinker and maker frameworks, STEM activities.

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1. Introduction

The foundation of the philosophy of science and science education lies in the principles of empiricism and pragmatism. These fundamental concepts place a strong emphasis on the acquisition of knowledge through the means of observation, experimentation, and practical application, underscoring the significance of collecting evidence to substantiate and affirm the knowledge that is being formulated. In the realm of science instruction and learning, there is a parallel adherence to the ideologies of empiricism and pragmatism, underscoring the significance of experiences, phenomena, and actions in the development of scientific knowledge. This method has long been utilized to guarantee that educational settings mirror the characteristics of scientific discipline and communicate the fundamental aspects of acquiring scientific knowledge, rather than solely the knowledge itself. (Bybee, 2009). It is also consistent with current learning theory, which suggests that people learn by creating meaning in their thoughts, connecting prior experiences to new ones (Reid, Richards & Willox, 2021) and engaging in social interactions (Rumjaun & Narod, 2020), and creating works. The process of accessing experience and creating knowledge involves explaining and giving meaning to the world around the learner. According to the concept of Seymour Papert, learning by inventing is based on the learning theory -Constructionism developed by Papert and Harel (1991). One of the key tenets of constructionism is that learners must engage in active, creative processes to construct their own knowledge (Ungerer & Hartmann, 2023).

Creativity is, therefore, a crucial component of this theory, as it allows learners to generate new ideas and concepts by connecting existing information in novel ways (Gómez-Chacón, Pérez-Rodríguez & Rubio, 2020; Liggett, Earnshaw & Townsley, 2023). As Steve Jobs famously observed, this kind of creativity is essential for pushing the boundaries of what is possible and for driving innovation forward (Yoffie & Cusumano, 2021). Steve Jobs famously described connecting data or information to create new meanings or concepts.

> *"New idea is nothing more than a new combination of old elements. The ability to make those new combinations depends on our ability to see relationships. That's what makes some people more creative. They are better at spotting those connections, better at recognizing possible relationship. They are able to do this because they've had more experiences, or thought more about those experiences, than other the people"* (Trott, 2016).

Studying science in educational institutions often poses challenges as students may lack opportunities for authentic scientific engagement, such as independently formulating experiments without strict guidelines (Günter, Ahnesjö & Gullberg, 2023; Meier, 2021). Research highlights the importance of students' deeper involvement in scientific investigations, yet practical experiences typically do not involve genuine scientific endeavors (Bevan, 2017). This gap between traditional science education and authentic scientific practices underscores the need for innovative approaches to foster independent scientific inquiry among students. Implementing inclusive and community-oriented science education, as well as promoting engagement with socioscientific issues through various knowledge sources, can enhance students' attitudes and involvement in scientific exploration (Scheer & Orban, 2022; Klaver, Walma van der Molen, Sins & Guérin, 2022). By addressing barriers and enablers to authentic scientific experiences, educators can better prepare students for real-world scientific challenges and opportunities.

Furthermore, the media and educational resources in science classrooms may not always be accessible or adequately prepared, the allocation of funding per student persisted at a relatively low level in comparison to several countries that were chosen for comparison, amounting to 19.7% of the per capita Gross Domestic Product (Vandeweyer, Espinoza, Reznikova, Lee & Herabat, 2020). The allocation for educational materials is vital for enhancing the learning environment, as outlined by the Thai Office of the Basic Education Commission, Ministry of Education. These materials, including art supplies, safety scissors, paper, digital resources, and specialized items for students with disabilities, are essential for student development. The budget per student annually varies by educational level: pre-primary education is allocated approximately 290 baht ($9), primary education 440 baht ($13), and both lower and upper secondary, including vocational levels, receive 520 baht ($15) per year, with allocations made per semester for more detailed budgeting. This strategic funding aims to support and enhance educational quality for all students, demonstrating a commitment to inclusive and accessible learning experiences (Office of the Basic Education Commission, 2024). These challenges are interconnected with the enhancement of proficiencies in formulating and executing science education, particularly for practicing teachers and teacher trainees or novices with limited pedagogical exposure. In instances where educators encounter such obstacles, they may resort to conventional teaching methodologies, emphasizing the transmission of curriculum content over fostering scientific investigation (Valtonen, Leppänen, Hyypiä, Kokko, Manninen, Vartiainen et al., 2021). This constrains learners' chances to amass knowledge and obstructs the cultivation of vital competencies like problem-solving, innovation, and cooperation, crucial for tackling contemporary and future real-world challenges.

Addressing the deficiency in scientific learning equipment presents a complex challenge that cannot be easily resolved within the confines of the classroom or through policy interventions. This issue underscores a fundamental reliance on external entities for the selection of equipment used in learning activities, potentially leading to the reemergence of equipment shortages. The implications of these challenges are twofold: firstly, educators may lack the expertise required to independently design activities in alignment with predetermined benchmarks; and secondly, the insufficiency of materials and equipment may not align with the specific context of the educational institution, encompassing geographical location and socio-economic status. Consequently, educators may resort to conventional and expedient teaching methodologies, such as lecture-based instruction (Roche, Bell, Galvão, Golumbic, Kloetzer, Knoben et al., 2020).

One approach to address this issue involves the incorporation of do-it-yourself (DIY) activities, do-it-together (DIT) activities, as well as maker and tinker activities rooted in STEM, which can be linked to the neighboring communities of educational institutions. This strategy has the potential to enhance students' comprehension of scientific concepts by taking into consideration the spatial factors of the local community. Scholarly articles and evaluations underscore the significant influence of maker and tinker activities on students' knowledge and cognitive abilities, particularly at the secondary school level. Such activities are capable of nurturing innovation, problem-solving skills, and critical thinking among learners (Shi, Cheng & Wei, 2023; Soomro, Casakin, Nanjappan & Georgiev, 2023; Thompson, 2023; Balakrishnan, Kamarudin, Ma'rof & Hassan, 2023). The integration of maker education into academic curricula enriches the learning journey and encourages originality among pupils (Burdett & Ronfard, 2023). Educational environments like makerspaces, notably in STEM fields, have demonstrated a positive influence on students' creative and analytical capabilities. Moreover, tinkering, a prevalent aspect of STEAM education, enables learners to partake in nonlinear approaches to problem-solving, thereby fostering mathematical involvement and creativity. Furthermore, tasks involving open-ended innovation, coupled with tinkering, have proven to boost children's capacity for innovation by promoting exploration and multiple iterations in quest of solutions.

In light of the evident beneficial outcomes stemming from maker and tinker activities for learners, this study embraces and adjusts the DIY-Tinker-Maker Concepts, underscoring self-sufficiency in formulating and executing science education for aspiring educators during their practical training as teacher Interns. The sequence of activities in the Maker concepts typically progresses from do-it-yourself (DIY) with existing processes or adaptations to tinkering and inventing things (Bevan, 2017; Lee & Song, 2022). Maker activities involve hands-on creation, experimentation, and problem-solving, fostering creativity and innovation (Laywood, 2022). The Maker movement offers significant opportunities for students, especially those in disadvantaged conditions, by engaging them in activities that positively impact attitudes towards STEM subjects (Jones, Cohen, Schad, Caratachea & Smith, 2020). Maker education plays a crucial role in addressing the evolving demands of contemporary society by emphasizing creativity, design, and engineering processes in educational settings (Lin, Yin, Tang, Hadad & Zhai, 2020). Understanding the complexity of learning situations in makerspaces contributes to discussions about interdisciplinary learning, creativity, and the integration of informal making practices into formal educational settings. By embracing this methodology, it becomes feasible to transition the educational program away from conventional essentialism towards pragmatism and empiricism, fundamental pillars of scientific inquiry that can facilitate enhanced ingenuity and originality among educators and students.

This approach has been found to have numerous benefits for both students and teachers, it nurtures interdisciplinary skills such as computational thinking abilities and stimulates enthusiasm, involvement, and innovation among students (Spieler, Schifferle & Dahinden, 2022). Educators participating in makerspace undertakings have recognized advantages such as links to STEM educational goals, student drive, cooperation, and creativity. Nevertheless, obstacles such as evaluating projects, deficiency in digital skills, and sophisticated equipment impede the smooth assimilation of makerspace ethos into conventional educational environments (Winters, Farnsworth, Berry, Ellard, Glazewski & Brush, 2021). Makerspaces have been commended for empowering learners of diverse ages and proficiencies, endorsing experimentation, and promoting community establishment (Walan & Gericke, 2022).

This investigation seeks to improve the competence of science teacher interns in formulating and executing science education via STEM activities grounded in the DIY, Tinker, and Maker theoretical framework. The research findings consist of five collections of STEM activities crafted utilizing the DIY, Tinker, and Maker frameworks, along with information on the proficiency of the research subjects in formulating and executing science education. Furthermore, the initiative will facilitate the organization of science education encounters for volunteers engaged in the research, which can be applied to professional development for teachers. The DIY, Tinker, and Maker theoretical framework will be merged into practical applications and future investigations within the science education scholarly community. This strategy will not only elevate the capabilities of science teacher interns but also foster STEM education growth by motivating students to actively engage in their educational journey.

2. Methodology

This study utilizes a mixed-method approach, incorporating qualitative and quantitative methodologies to investigate the potential of the DIY, Tinker, and Maker conceptual framework in enriching STEM education. The primary aim of this study was to assess the efficacy of a framework centered on DIY, Tinker, and Maker ideologies in fostering the competency of teacher interns in design and implement science activities. This was achieved through the development and assessment of five specific STEM activities aligned with the principles of DIY, Tinker, and Maker.

2.1. Participants

The study included 13 teacher interns specializing in science disciplines (Physics, Chemistry, Biology) in the academic year 2020. The selection of participants followed purposive and volunteer sampling methods, and recruitment procedures were in accordance with the guidelines established by the Office of the Ethics Committee on Human Research at Chiang Mai University.

2.2. DIY Tinker Maker Activities

The researchers have devised five STEM undertakings grounded on the DIY, Tinker, and Maker conceptual framework. These tasks entail the creation or alteration of apparatuses through manual manipulation, rather than reliance on a pre-existing product. The tasks are crafted to encompass scientific principles from a range of fields such as physics, chemistry, biology, earth and space science, utilizing readily accessible and cost-efficient tools. The quintet of STEM activities formulated in alignment with the DIY, Tinker, and Maker concept are delineated below:

Unit 1: Experiment on UVC Box

Unit 2: Implementation of Digital pH Meter

Unit 3: Carbon dioxide Detector (Air Sensor)

Unit 4: Commencement & Unique Earth Board Game

Unit 5: Detection of Motion

The outcomes of the creation and execution of the five units are expounded upon in the findings and discourse part.

2.3. Data Collection

The assessment criteria for proficiency in crafting and executing science instruction are firmly rooted in the analysis of lesson plans and classroom observations. The assessment process consists of the subsequent stages:

1. Conducting a thorough examination of documents and literature to pinpoint fundamental aspects of the lesson plan according to the High-Impact Practices (HIPs) framework.
2. Developing a rubric-based assessment instrument for lesson plans that includes components of High-Impact Practices (HIPs), drawing from the framework introduced by Chamrat, Apichatyotin and Puakanokhirun (2018).
3. Presenting the rubric-based assessment tool to three specialists for their assessment and input.
4. Editing the rubric-based assessment tool based on feedback from experts.
5. Examining the lesson plans against actual teaching practices via in-person or online classroom observations, utilizing the triangulation approach and inter-rater reliability to ensure consistent assessment.
6. Collecting data by compiling lesson plans through the Google Classroom platform as illustrated in Figure 1.

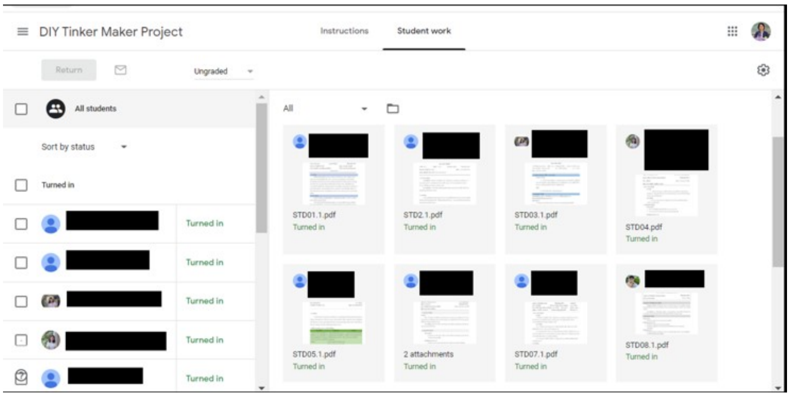

Figure 1. Collection of lesson plans via Google Classroom system

2.4. Data Analysis

The data for this research were gathered from the lesson plans and learning records of teacher interns during their internship periods. This collection included 26 of initial and revised lesson plans (along with associated learning materials) from a cohort of 13 teacher interns. The content of these documents was systematically analyzed employing both descriptive statistics and content analysis techniques, as outlined by Neuendorf (2017). The content analysis procedure encompassed several steps: identifying underlying theories with a focus on High Impact Practices (HIPs) frameworks, constructing a conceptual framework, organizing analytical workshops, formulating a preliminary code and coding scheme, choosing exemplar content for detailed examination, ensuring the reliability of coding through verification, and performing the final data analysis using the established coding scheme. A minimum of two analysts were involved in the coding activity to ensure accuracy, with their findings being inter-rated for agreement. The outcomes of this analysis were then depicted through tables, figures, and quantitative data to illustrate the findings comprehensively.

Table 1 offers a succinct summary of the High Impact Practices (HIPs) along with concise explanations for each. The objective of this study is to evaluate the degree to which teacher interns applied these six dimensions in the creation and execution of their science lessons across two distinct instances, pinpointing the key attributes of successful lesson planning. Moreover, the research delineates the variation in the application intensity of each HIP component, providing insights into the prevalence of their use among teacher interns.

HIPs Aspect	Details
Well-Designed Lesson	Emphasizes lesson structure and preparation of learning intentions and objectives, advocating for lessons that are meticulously planned to align with student learning processes.
Cognitive Demand Variation (Learning Progression)	Concentrates on the development of learning pathways throughout a lesson, ensuring a scaffolded increase in cognitive demands and academic challenges.
Student-Centered Approach	Prioritizes student levels and prior knowledge at the lesson's onset, encouraging teachers to minimize lecturing in favor of active learning opportunities for students.
Reflective Opportunities for Students	Highlights the importance of student reflection on learning, enhanced by teacher feedback. Encourages diverse forms of formative evaluation, such as discussions, drawings, and writings, to deepen student understanding.
Project-Based Learning Assignments	Targets challenges that require higher-order thinking and collaborative efforts, showcasing the effectiveness of Project-Based Learning in engaging students in complex problem-solving and project completion.
TPACK Reflection in Lessons	Focuses on the transformation of teacher knowledge into practical lesson design and delivery. Stresses that content knowledge, integrated with technological and pedagogical insights, is crucial for effective teaching and student success.

Table 1. Key Aspects of High-Impact Pedagogical Practices (HIPs)

2.5. Human research ethics

This research complies with the principles of human research ethics, in accordance with the Belmont Report (Beauchamp, 2008). The report outlines three foundational principles: (1) respect for persons, (2) beneficence, ensuring no harm and maximizing benefits, and (3) justice. The project, code COE 63/255, has been approved by the Chiang Mai University Research Ethics Committee and has received a Certificate of Exemption.

The research methodology employed in this study is illustrated through the research process diagram depicted in Figure 2.

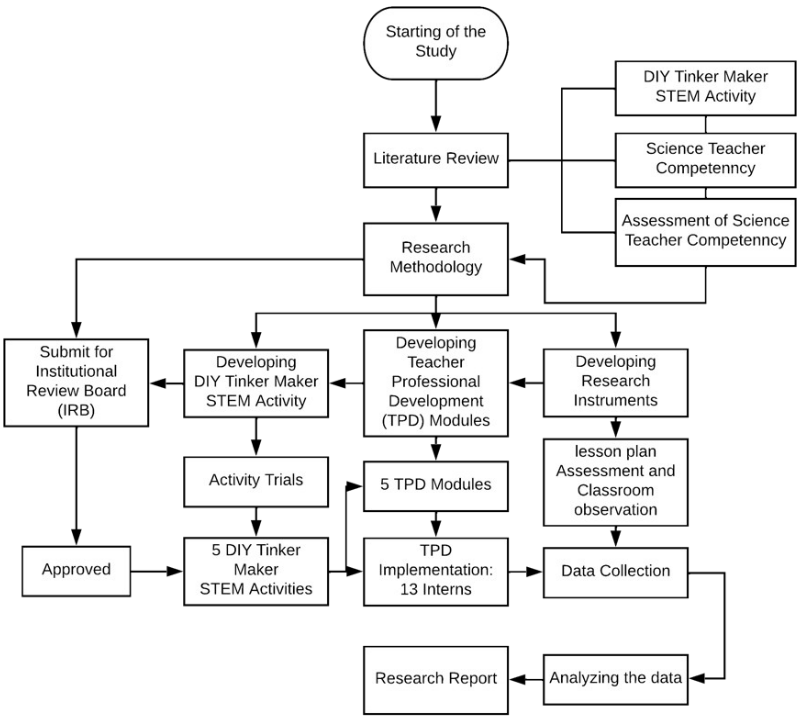

Figure 2. Research process diagram

3. Results and Discussion

This section is divided into two main parts for a structured discussion of the findings. Part 3.1 focuses on STEM activities that are based on DIY, Tinker, and Maker frameworks, exploring how these methodologies influence learning and engagement. Part 3.2 examines the development of teacher interns' competencies, specifically their skills in designing and implementing effective science instruction.

3.1. STEM Activity Based on DIY, Tinker, and Maker Frameworks

This section outlines the development of five STEM activities based on the DIY, Tinker, and Maker conceptual frameworks. These modules were designed to engage teacher interns in experiential learning, thereby enhancing creativity and problem-solving skills within STEM disciplines. The objective was to explore the potential of these activities to strengthen STEM skills and understanding, and to evaluate their effectiveness in enhancing the competencies of teacher interns in designing and implementing science instruction. Below, an overview of each module's initial ideas, key concepts, and practical applications is provided.

3.1.1. Activity Module 1 UVC Box Experiment

During the COVID-19 pandemic, an activity box using ultraviolet light with a wavelength called UVC became widely used. This device emits electromagnetic waves in the wavelength range of approximately 100-280 nm (UVC Band), which can be applied in various experimental activities related to ultraviolet waves at these wavelengths. This set of activities serves as an example for students to gain practical experience in science and is suitable for use by science teachers. The activity box consists of a shoebox, foil, essential stationery such as a cutter, scissors, a ruler, and a tube that emits UVC light. It can be purchased online for about 130 baht (4$). Materials and final artifacts are shown in Figures 3 and 4.

Figure 3. Materials used in the fabrication of the UVC sterilization box

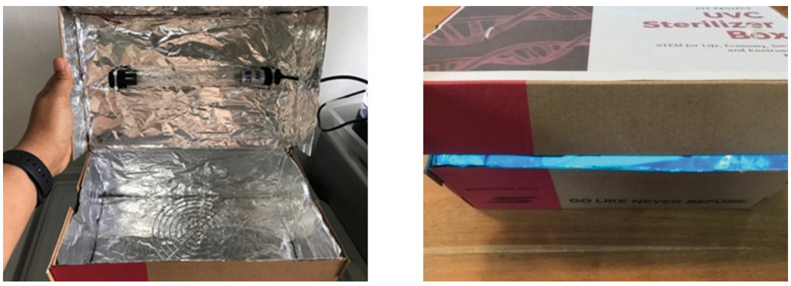

Figure 4. Ready-to-use UVC sterilization box

The primary purpose of using this lamp is to eliminate algae in aquariums. However, the DIY Tinker Maker concept can be adapted to create a UVC box for various experiments, such as testing the mold growth on bread exposed to UVC light for different durations, as shown in Figures 5 and 6.

Figure 5. Breads in Ziplock Bags Prepared for UV-C Exposure at
Different Durations Ranging from 0-5 and 10 Minutes

Figure 6. Bread Mold (e.g., Rhizopus Stolonifer) Appears in slices of bread
without Disinfection or with Insufficient UV-C Exposure

The UVC box is the first example of the DIY and Tinker concepts. It demonstrates how available materials can be repurposed for STEM-based activities in the classroom, known as Hacking. In the module, science teacher interns were challenged to create their own DIY equipment or experimental sets using items found in their environment. This approach promotes creativity and resourcefulness and encourages a hands-on learning experience that can be easily adapted to various educational settings.

3.1.2. Activity Module 2 Digital pH Meter

Laboratory experiments are crucial in the teaching and learning of chemistry. However, some schools, especially small ones or those not yet fully equipped, may not have the necessary equipment for these experiments, such as a pH meter. This lack of equipment can hinder the effectiveness of science learning and prevent students from reaching the expected learning outcomes. In recent years, computing science has been added as a new subject to the Thai science and technology curriculum to develop students' computational thinking, technology literacy, media literacy, and digital technology. One such device that can be used in computational science experiments is the microcontroller, which can be used to measure scientific quantities with sensors. These devices are affordable and widely available.

In this module, the researchers proposed the following objectives: (1) to invent a microcontroller-controlled digital pH meter and (2) to compare the performance of the digital pH meter with a standard laboratory pH meter and a pH meter in the Vernier LabQuest kit. The digital pH meter developed in this study is low-cost and easy to assemble, using available materials from online platforms. It performs similarly to the standard pH meter used in the laboratory and can be used as a replacement for it. This digital pH meter can be used in chemistry learning and incorporated into integrated STEM lessons. In fabricating a digital pH meter, the following equipment is used: a pH controller electrode probe with a BNC connector, a sensor module with a monitoring control board, an LCD screen with a 16 × 2 LED display and LED backlighting, and an Arduino UNO R3 microcontroller. The steps for creating the digital pH meter include:

- Studying concepts and researching the acid-base theory and the integration of computational science in chemistry content.
- Studying the relevant code and modifying it using the Arduino IDE program.

Experimenting with connecting various devices while checking and editing the code. The digital pH meter has a connection circuit as shown in Figure 7, with the Arduino microcontroller and sensor connection board shown in Figure 8.

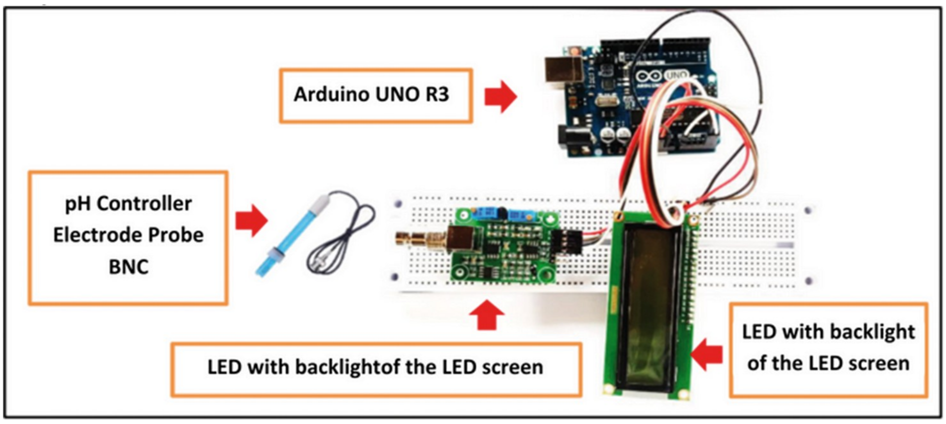

Figure 7. Digital pH meter device circuit connection

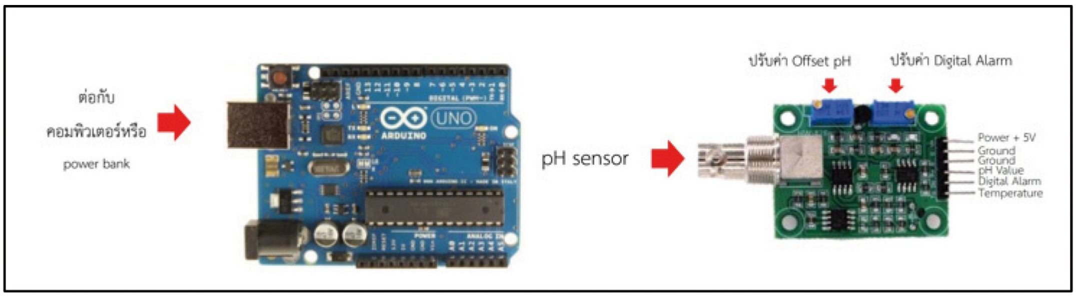

Figure 8. Arduino microcontroller and sensor connection board

3.1.3. Activity Module 3 Air Sensor (Carbon Dioxide Detector)

This activity was designed to explore the impact of greenhouse gases, particularly those produced by burning fossil fuels, on global climate change. Specialized tools, such as a vehicle inspection station, are often used to measure the amount of Carbon dioxide in the atmosphere, but these can be expensive. For example, such a station must have a tool to measure the fuel efficiency of cars, indicating whether the car burns fuel efficiently and the percentage of emissions it contributes to greenhouse gases. The impact of small particulate matter (PM 2.5) has heightened and is the leading cause of both short- and long-term illnesses. The work area includes a safe room, but over time, the lack of airflow from the outside results in a buildup of Carbon dioxide concentration, which can negatively affect health, especially the respiratory system. As such, this module focuses on developing low-cost DIY Carbon dioxide sensors.

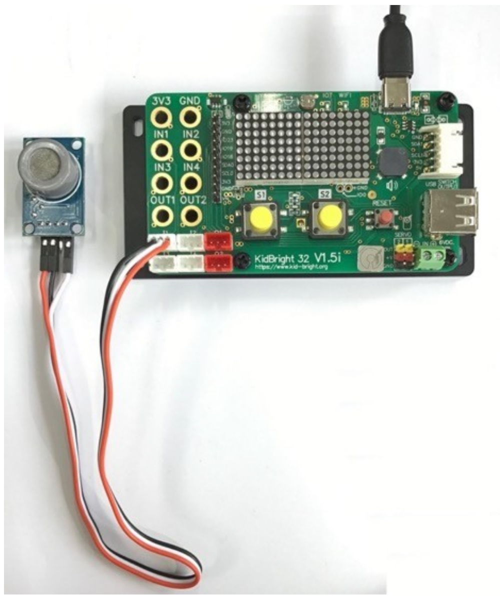

Figure 9. The Carbon dioxide sensor module with KidBright32i board

In addition, the researchers had configured the report to the Line Notification to use the Internet of Things (IoT) principle in this activity.

To read the analog input voltage of the KidBright32i board to use with the Carbon dioxide Sensor Module MQ-7 (Figure 9), which the board can receive the analog DC voltage from various sensors, all 4 channels are Pin I1, I2, I3 and I4, the researchers found that there is a precaution, that is, do not connect to the wrong polarity is strictly prohibited. And the DC voltage applied to the analog input must not exceed 3.3 V, which will damage the board.

3.1.4. Activity Module 4 Startup & Rare Earth Board Game

Another DIY activity that emphasizes gamification principles is the creation of board games, which are popular in teaching and learning, particularly in science education (Chen, Tsai, Liu & Chang, 2021) such as earth science (Eisenack, 2013), physics (Cardinot & Fairfield, 2022), chemistry (Triboni & Weber, 2018), and biology (Anyanwu, 2014). In this research, the board game concept was used as an example for students in the teaching profession to develop ideas for use in their classrooms. The design of board games is the fourth module of this research. The researchers have designed activities based on the startup concept, including the role of rare earth elements (REEs) in technology and innovation. This board game (Figure 10) design activity can be used to teach students about these topics in a fun and engaging way.

Startup & Rare Earth is a board game that uses the mechanics of Monopoly but focuses on the theme of rare earth elements and business development. Designed for 4-6 players, the game aims to encourage players to become the wealthiest by strategically utilizing their knowledge of rare earth elements in buying businesses, collecting resources, and developing their ventures according to the world situation in each round.

In this game, players move around the board, like Monopoly, by rolling two six-sided dice, landing on various spaces that allow them to buy businesses, collect rare earth resources, or respond to the world's changing economic and political landscape. Instead of streets, railroads, and utilities, the board contains businesses, mines, and processing facilities related to rare earth elements, which can be bought and developed to increase their value and generate income. Chance and Community Chest cards are replaced with cards related to rare earth elements and global events, which can either benefit or penalize players. Players can trade resources, negotiate deals, and form alliances with other players to gain a strategic advantage.

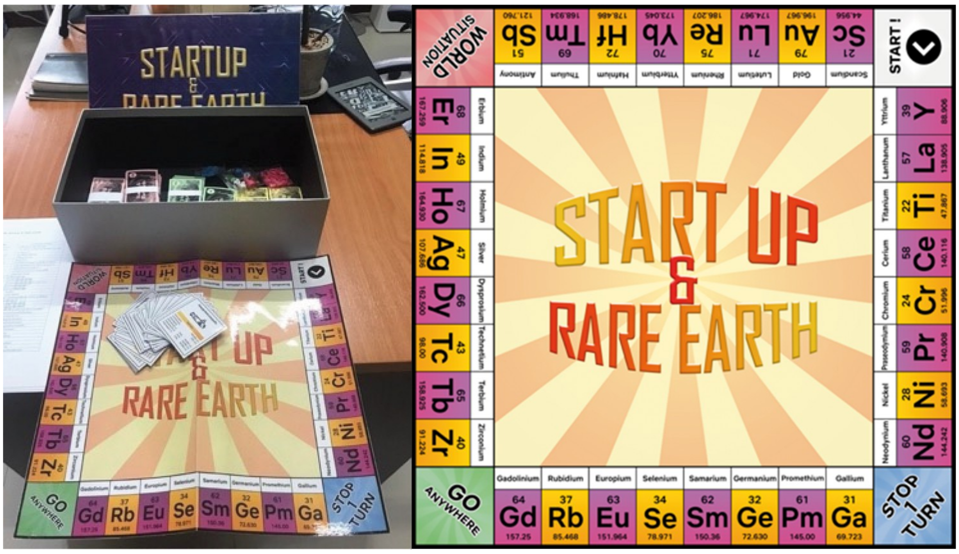

Figure 10. A set of board games developed by the researchers

The game emphasizes the importance of understanding the rare earth industry, market trends, and global politics to make informed decisions and build a successful business empire. The game ends when all players but one is bankrupt, and the remaining player is declared the winner. Startup & Rare Earth provides entertainment and an educational tool, raising awareness about the rare earth elements industry and its role in modern technology and global markets. Startup & Rare Earth also incorporates an exciting and educational element of startups and pitching activities during the game. Throughout the gameplay, players have opportunities to pitch their business ideas related to the rare earth industry, shown in Figure 11 to attract investments from other players or secure in-game funding.

When a player lands on a designated pitching space or draws a pitching card, they must present a brief business pitch to the other players, outlining their concept, the potential benefits and value it brings to the rare earth industry, and the resources required for successful execution. The pitch should highlight how the proposed venture will contribute to the player's overall strategy, offering unique advantages in the game. After hearing the pitch, other players have the option to invest in the proposed business, negotiate partnerships, or offer resources in exchange for a stake in the venture. These collaborative efforts can help players achieve a strategic advantage in the game and expedite their path to becoming the wealthiest player. The inclusion of startup pitching activities in Startup & Rare Earth adds an extra layer of depth and realism to the gameplay, teaching players about the importance of communication, negotiation, and collaboration in the business world. It also emphasizes the role of innovation and entrepreneurship in the rare earth industry, encouraging players to think creatively and develop novel solutions to real-world challenges.

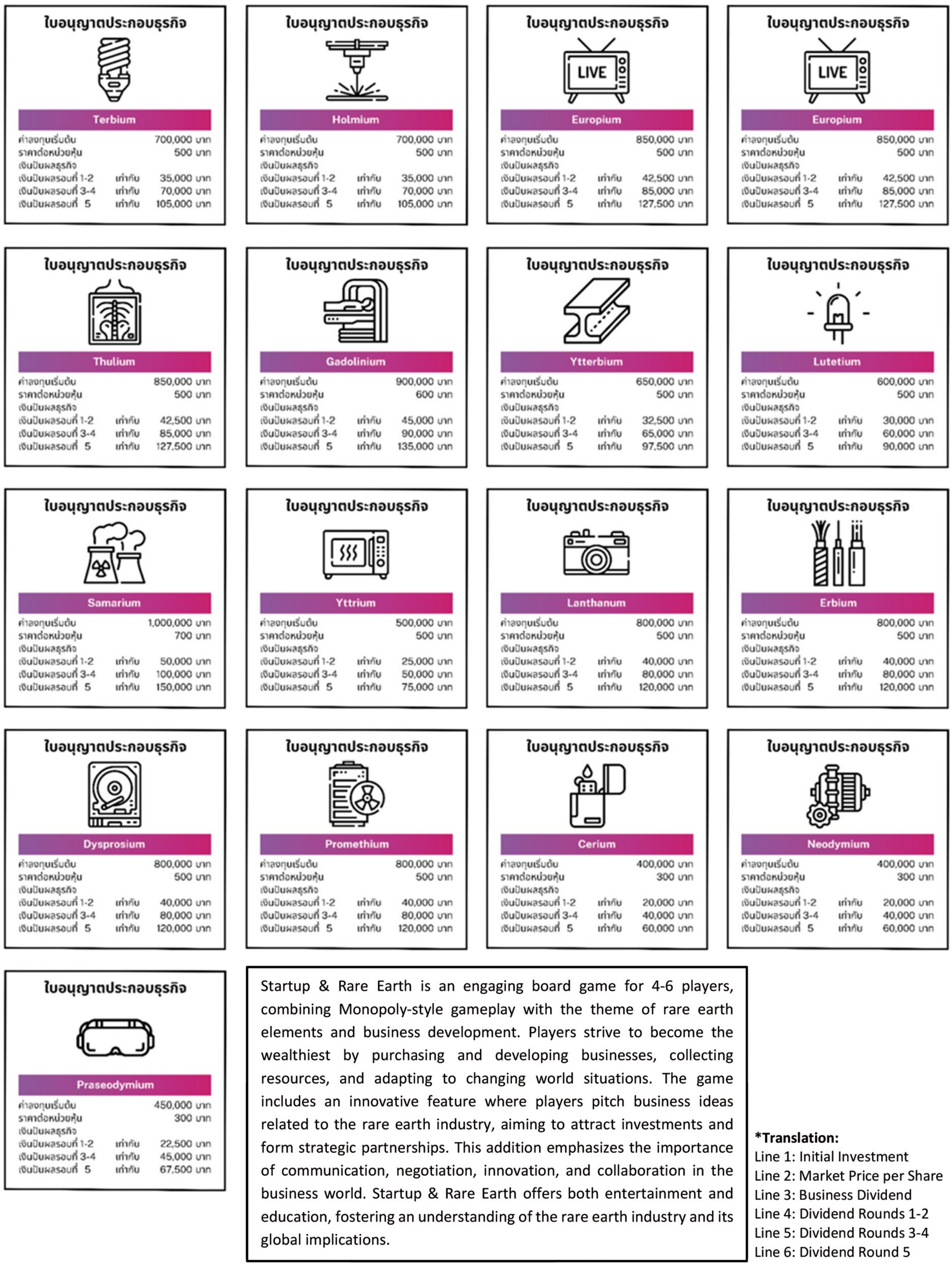

Figure 11. An example of a business license card corresponding to the Rare Earth property

3.1.5. Activity Module 5 Motion Sensor Activity

In Module 5, the researchers focus on concepts in physics, particularly the application of motion sensors in a conceptual framework for safety. These motion sensors can be used to detect the entry and exit of people in a house or place, as well as unusual movements, such as falls among the elderly. This is particularly relevant in the context of an aging society.

The researchers also study the use of motion sensors in the automation of systems. To build upon this knowledge, the researchers studied the form of motion sensors, including ready-made motion measurement devices used in physics classrooms, such as the Pasco motion detection kit and the LabQuest 2 and Motion 2 devices for detecting the movement of objects. However, both sets of equipment are expensive which may not be easy to purchase or procure in the actual classroom. The researcher, therefore, studied whether using a cheap device as a motion sensor is possible. It was found that the device that can be invented is a KidBright microcontroller with an ultrasonic sensor, as shown in Figure 12.

Figure 12. KidBright and Ultrasonic Sensor kit (Top left) for detecting the movement of objects

However, even though such devices are not very expensive and can be invented as a DIY motion detector device, the price is still relatively high. Including the research period is still during the outbreak of COVID-19 causing researchers to be interested in bringing code writing with a simulation system or simulation into research work. It was found that it can be used as an activity in a manner called Tinker, and coding with simulations is realistic and can practice coding skills for students. Figure 13 shows coding as well. The block-based model does not require any knowledge of computer programming, it is also possible to write code and display board operations. The researchers found that it was suitable to be used as an example of the DIY Tinker Maker activity, which matched the objectives of this research.

Upon completing all five modules, the researchers developed a series of STEM activities based on the DIY, Tinker, Maker concept. To ensure the content quality and validity of these modules, three experts in the field were invited to review and provide feedback on the developed materials. The researchers then refined and revised the modules based on the experts' suggestions and recommendations, ensuring a high-quality learning experience for users (teacher interns). Once the validity and credibility assessment process were completed, all materials, including documents, video lectures, and links to further study, were shared on Google Classroom.

The researchers had provided basic information about the STEM activities developed through the DIY Tinker Maker concept and the number of self-learning hours required for each module as follows:

Introduction and clarification activities for project participants (duration 2 hours)

Activity Module 1: UVC Box Experiment (duration 2 hours)

Activity Module 2: Digital pH Meter (duration 2 hours)

Activity Module 3: Air Sensor (Carbon dioxide) (duration 2 hours)

Activity Module 4: Chemistry Board Game (duration 2 hours)

Activity Module 5: Motion Sensor (duration 2 hours)

The researchers uploaded data into Google Classroom, including the research conceptual framework, principles of STEM activities based on the DIY, Tinker, and Maker conceptual frameworks, video modules, lecture slides, and other learning resources. They provided learning modules for teacher interns, emphasizing the potential of integrating maker lab activities with physical computing. This approach focuses on incorporating computational thinking and computational-making approaches within the STEM education environment, as suggested by Juškevičienė, Dagienė and Dolgopolovas (2021). This innovative method treats computing science and computational thinking as interconnected elements rather than separate subjects, facilitating a better connection between STEM subjects and the arts. It offers supportive techniques to develop the professional skills of teacher interns (Pears, Barendsen, Dagienė, Dolgopolovas & Jasutė, 2019). The researchers reported that data collection involved receiving two lesson plans from each teacher intern to analyze their competencies in designing and teaching. This data was then subjected to further qualitative analysis to meet the research objective, to study the competence of teacher interns in designing and implementing STEM activities based on DIY, Tinker, and Maker frameworks.

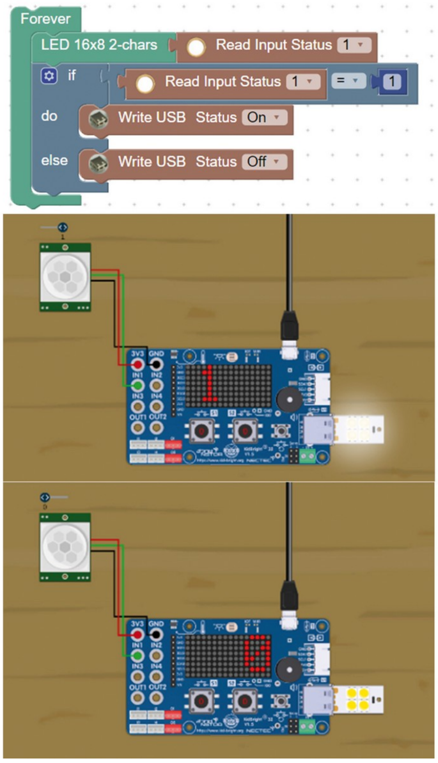

Figure 13. A simple example of coding for motion sensor control using KidBright Simulation

3.2 The Development of Teacher Interns' Competencies of Science Instructional Design and Implementation

Researchers collected data on teacher interns' competencies in designing and implementing science lessons by having them create and execute two lesson plans during the second semester of the 2020 academic year. The conceptual framework for this analysis was High Impact Practices (HIPs), which include well-designed lessons, project-based learning, opportunities for reflection, learning progression, student-centered approaches, and Technological Pedagogical Content Knowledge (TPACK). To evaluate the data, the researchers developed a five-level assessment rubric and conducted content analysis to assess the level of ability in designing and implementing science learning between the first and second lesson plans. The results indicated that the ability level was high and consistent across all aspects. These findings are presented in Table 2 and illustrated in Figure 14.

High-impact Practices (HIPs)	Lesson plan 1	Lesson plan 2	Difference
Well-design lesson	4.23	4.54	0.31
PBL/Task	4.31	4.62	0.31
Reflection	3.92	4.08	0.16
Learning Progression	4.15	4.38	0.23
Student-centred Approach	4.62	4.69	0.07
TPACK	4.08	4.54	0.46
Average	4.34	4.53	0.19

Table 2. Comparison of High-impact Practices (HIPs) Score Levels in Lesson Plan 1 and Lesson Plan 2

This data set shows six High-Impact Practices (HIPs) scores in two lesson plans. The HIPs included in the data set are well-designed, PBL/Task, Reflection (Writing/Drawing), Learning Progression, Student-Centered Approach, and TPACK. The scores for each HIPs are based on a scale of 1 to 5, with higher scores indicating a higher level of implementation or effectiveness. The average score for the first lesson plan is 4.34, and for the second lesson plan is 4.53. This indicates that the second lesson plan has a higher overall rating than the first. The highest scores were achieved for the Student-Centered Approach, with a score of 4.62 in Lesson Plan 1 and 4.69 in Lesson Plan 2. The lowest scores were for Reflection, with a score of 3.92 in Lesson Plan 1 and 4.08 in Lesson Plan 2. There are some HIPs where there is a noticeable difference in the score between the two lesson plans, such as PBL/Task, Reflection, and TPACK, with the second lesson plan scoring higher in all three. However, the difference is relatively small for Student-Centered Approach, with only a 0.07-point increase. The web chart in Figure 15 presents the data in the table in a more explicit illustration format.

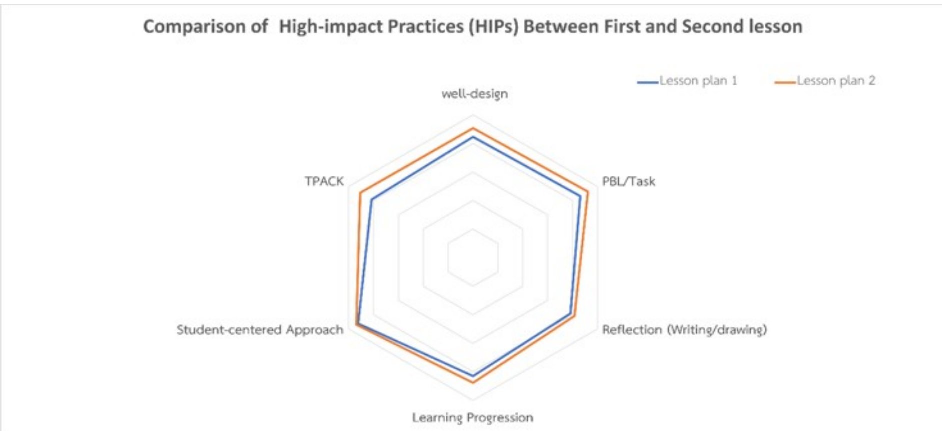

Figure 14. The comparison of High-impact Practices (HIPs) Between the First and Second lesson

From the Figure 14, the HIPs with the largest difference in score between the two lesson plans is TPACK, with a difference of 0.46. This indicates that the second lesson plan had a significantly higher implementation of TPACK compared to the first lesson plan. It is because participation in maker education activities, such as DIY Tinker Maker conceptual framework, can enhance science teacher interns' TPACK (Technological Pedagogical Content Knowledge) in several ways. For example, hands-on experience with technology and tools can increase their technological knowledge and understanding of technology integration in the classroom. Through the integration of technology and pedagogy in maker activities, science teacher interns can see the potential for technology to enhance teaching and learning. Technological knowledge, a component of the TPACK model (Mishra & Koehler, 2006; Class, 2023), is a crucial aspect of maker education. Lin et al. (2020) discovered that over 90% of the platforms and resources utilized in maker activities are technology-based. In this study, the researchers discovered that participation in technology-rich activities fosters the integration of technological aspects into the classrooms of teacher interns. This engagement contributes to the enhancement of their TPACK self-efficacy, which is evident in the observed improvements in the design and implementation of the second lesson.

Furthermore, these progressions exemplify the development of teacher trainees' TPACK proficiency levels within High-Impact Practices (HIPs), which present chances for science teacher trainees to include and merge these components into the creation and execution of science lessons, nurturing a STEM education atmosphere. Additionally, creator activities regularly involve students in analytical and critical-thinking procedures. These encounters can ease the shift of science teacher trainees from a conventional pedagogical viewpoint to a modern paradigm highlighting 21st -century abilities, such as critical thinking and problem-solving.

Conversely, the High Impact Practices (HIPs) aspect with the smallest difference in ratings between the two lesson plans was the Student-Centered Approach, showing a slight variance of only 0.07. This indicates a consistent application of the Student-Centered Approach across both plans, which already ranked highest among the six HIPs elements. Generally, the performance across all HIPs aspects was fairly consistent. Nonetheless, the second lesson plan consistently scored higher than the first across all HIPs. The researchers conducted a deeper analysis to identify areas of most and least improvement, assess the consistency of the data, determine which aspects needed the most attention, and highlight the significant differences between each HIPs aspect. The difference in scores for well-designed lessons and Project-Based Learning (PBL)/Task was minimal, each showing a 0.31-point increase from the first to the second lesson plan. However, the scores for Technological Pedagogical Content Knowledge (TPACK), Learning Progression, and the Student-Centered Approach exhibited more significant changes, with differences of 0.46, 0.23, and 0.07 points, respectively, between the two plans.

Based on the data, Contemplation necessitates the most enhancement, as it possesses the lowest ratings among all the HIPs. The most substantial distinction among HIPs facets can be observed between Contemplation and Student-Oriented Method, with a 0.7-point difference in Lesson Blueprint 1 and a 0.61-point difference in Lesson plan 2. To tackle this disparity, it may be advantageous to focus on integrating contemplative practices into the student-oriented method and ensure their efficient execution in the lesson design and implementation.

The fundamental principles of a DIY Tinker and Making conceptual framework, which results in STEM activities, encompass a student-oriented learning ambiance and project-based/task-oriented endeavors. The Maker movement finds its roots in the writings of Dewey, Piaget, and Montessori, which stress active learning and constructivism (Hsu, Baldwin & Ching, 2017). This approach facilitates a student-oriented learning ambiance where students actively participate in their education, nurturing innovation, problem-solving abilities, and a deeper understanding of the subject matter (Fernandez, Hochgreb-Haegele, Eloy & Blikstein, 2024).

Project-centered and assignment-focused tasks, often referred to as Project-Based Learning (PBL), offer a dynamic educational strategy that immerses students in authentic real-world issues, fostering cooperative efforts to devise solutions or innovations. This educational approach not only enhances analytical thinking, problem resolution, and communication skills but also promotes the integration of knowledge across multiple disciplines (Krajcik & Blumenfeld, 2006). Such methodologies are particularly effective in improving the capabilities of science educator trainees, empowering them to create instructional sessions that emphasize practical and experiential learning, urging students to develop, produce, and test their personal conceptions (Honey & Kantar, 2013).

The burgeoning creator movement has inspired extensive research into how these unique educational experiences can be integrated effectively into formal education settings. Creator education, with its emphasis on students crafting physical items from a variety of materials ranging from digital technologies to traditional crafts, holds significant promise for enriching STEM education (Simpson, Burris & Maltese, 2020). These tasks often involve programming and tangible computation, offering interactive experiences that allow for the manipulation of the physical world through digital means, thus providing educator trainees with the tools to devise innovative project-centered learning experiences (Spieler et al., 2022).

Moreover, the shift towards learner-centered education encourages educators to rethink their teaching methods, aiming for a more participatory approach that fosters active student engagement rather than relying solely on traditional lecture-based instruction. This pedagogical shift aligns with foundational educational theories such as constructivism and constructionism, which advocate for learning environments where learners construct knowledge through experience (Valente & Blikstein, 2019). Reflective practices within maker activities, as highlighted by Moore, Roche, Bell and Neenan (2020), enhance the educational process, providing facilitators in maker spaces and museums with the means to support effective learning experiences. The process of making in educational settings, particularly through projects like e-textiles in K-12 education, not only engages students in STEM fields but also serves as a catalyst for further research and development in educational practices (Hébert & Jenson, 2020). Additionally, the study of tinkering as a reasoning process sheds light on its educational applications, particularly in enhancing computational thinking and problem-solving skills within computer science education (Kim, Belland, Baabdullah, Lee, Dinç & Zhang, 2021).

Finally, the emotional and cognitive engagement involved in maker activities plays a crucial role in enhancing both individual and collective creativity, thereby fostering a deeper connection between students' learning experiences and their personal and communal growth (Shi et al., 2023). This blend of project-based, learner-centered, and maker-oriented education strategies not only involves students deeply in their own learning process but also equips them with essential 21st-century skills, preparing them to tackle complex challenges in innovative ways. The Contemplation aspect posed a difficulty for the science educator trainees. This facet encompasses formulating lessons that enable learners to ponder on their learning through composing, sketching, or speaking. Genuine and developmental evaluation is vital, as it offers a means for educators to acquire insights into learners' learning through their expressions. The evidence implies that the DIY Tinker Maker structure should prioritize learning routes throughout projects/tasks and genuine and developmental evaluation while also granting learners opportunities to articulate themselves. It is crucial to emphasize that the structure should concentrate more on the educational aspect of learner learning evaluation (Hattie & Clarke, 2019; Darling-Hammond, Flook, Cook-Harvey, Barron & Osher, 2020).

4. Conclusion

The study developed five STEM activities anchored in the DIY, Tinker, and Maker conceptual framework, emphasizing the innovation, creation, and customization of tools to fulfill users' needs. These activities, which incorporate microcontrollers and board games, offer significant potential for enhancing science education and facilitating teacher professional development. Further, the competencies of science teacher interns in the design and execution of science learning were markedly improved through the engagement with STEM activities within this conceptual framework, facilitated via digital platforms such as Google Classroom. This program, comprising five distinct modules equipped with instructional videos and work samples, enables learners to progress at their own pace. Analysis revealed that the competencies of science teacher interns in designing and implementing science lessons were notably robust, with minor differences observed between their initial and subsequent lesson plans. This outcome indicates that the interns possess a solid foundation in science teaching and learning, suggesting that the DIY, Tinker, and Maker frameworks can significantly broaden the scope for teacher interns to develop creative and innovative approaches to education. Importantly, the application of the DIY, Tinker, and Maker framework within a STEM context was instrumental in enhancing the lesson design and implementation skills of the interns, particularly reflected in the substantial improvements in their Technological Pedagogical Content

Knowledge (TPACK). Future research should thus focus on the integration of authentic and formative assessments to better capture student reflections and learning outcomes.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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