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## ABOUT IJSET

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# Development of Robotics-Assisted Acid-Base Titration Setup and Laboratory Activity for Grade 11 Stem

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**Abstract.** In the 21st century, the education sector is challenged to adapt to rapid scientific and technological innovations. Educational institutions should incorporate the development of 21st-century skills including creativity, collaboration, critical thinking, and communication. One educational technology that is becoming more prevalent worldwide is robotics. However, the application of this technology to education in the Philippines is relatively new and very limited. Titration for acid-base reactions is one of the essential laboratory activities in secondary chemistry education. However, traditional or classical laboratory setups possess several potential physical barriers that can prevent effective hands-on learning and the integration of robotics can minimize these barriers. This study aimed to develop a robotics-assisted acid-base titration setup and laboratory activity for Grade 11 STEM students taking General Chemistry. Furthermore, this paper investigated the students' basic science process skills during the implementation of the developed laboratory activity and determined the students' perceptions of the activity. This quantitative study utilized a descriptive and developmental research method. The results indicated that the developed set-up was rated “excellent” on the system usability scale by teacher and student evaluation. The developed laboratory activity gained a rating of “excellent” in the teacher evaluation of format, language, and content. These results manifest that the developed setup and activity are well-designed and effectively fulfill its educational objectives. The students' basic science process skills were also “excellent” during the implementation of the activity. Furthermore, the students' perception of the activity was “very high” in interest/enjoyment, value/usefulness, and perceived choice. These results show that the activity can enhance students' scientific understanding and skills, and is also engaging, relevant, and personally meaningful. These findings further emphasize the positive impacts of robotics integration on the overall teaching-learning process

**Keywords:** Educational Robotics, Laboratory Activity, Acid-Base Titration, Basic Science Process Skills, Student Activity Perception

## INTRODUCTION

In the 21st century, the education sector is challenged to adapt to rapid scientific and technological innovations (Delaney, 2019). Educational institutions should incorporate the development of 21st-century skills including collaboration, communication, creativity, and critical thinking (Hallerman et al., 2019). These challenges require changes to traditional teaching methods. McNulty (2021) argues that educational technology (ET) helps bridge the educational sectors toward 21st-century learning.

Technology in the classroom as an aid to learning has become a vital component in the success of the educational process. As reported by the World Bank Group (2021), ET empowers teachers to create personalized and contextualized learning for students. The integration of ET also shifts the learning environment toward one that is student-centered (D' Angelo, 2018).

One educational technology that is becoming more prevalent worldwide is robotics (Montemayor, 2018). Robotics refers to the design, construction, and operation of robots or machines that can autonomously or semi-autonomously perform physical tasks (Badeleh, 2018). The integration of robotics in the classroom, or educational robotics, is an effective tool that can promote multidisciplinary learning and facilitate the development of 21st-century skills including problem-solving, metacognition, divergent thinking, creativity, and collaboration (Gratani & Giannandrea, 2022). The application of this technology to education in the Philippines, however, is relatively new and very limited (Montemayor, 2018).

Laboratory experiences, on the other hand, are an integral part of chemistry instruction. The American Chemical Society (2020) highlighted that hands-on laboratory experiences facilitate mastery of the concept, problem-solving, critical thinking, and science process skills by allowing students to investigate chemical properties and reactions directly and safely. Titration for acid-base reactions is one of the essential laboratory activities in secondary chemistry education (Soong et al., 2019). Titration is an analytical technique that identifies the quantity of the unknown sample using the known properties of another sample (Britannica, 2022).

Soong et al. (2019), however, stated that traditional or classical laboratory setups, including manual titration, possess several potential physical barriers that can prevent effective hands-on learning. One method that can minimize physical barriers in traditional laboratory setups is the integration of robotics. Verner and Revzin (2011) also revealed that the use of robotics in performing laboratory activities can create a more accurate and safer environment and significantly reduce the time needed for operations and many typical errors while executing laboratory operations.

## RESEARCH OBJECTIVES

It is in this context that this study aimed to develop a robotics-assisted acid-base titration setup and laboratory activity for Grade 11 STEM students taking General Chemistry. Furthermore, this paper also investigated the students' basic science process skills during the implementation of the developed laboratory activity and determined the students' perceptions towards the activity.

## METHODOLOGY

This quantitative study utilized descriptive and development research design with qualitative support. This study was conducted in a Level 3 PAASCU-accredited basic education unit of a private university in Ozamiz City, Misamis Occidental, Philippines in the second semester of the academic year 2023-2024.

### Participants

The study used three robotics and five STEM teachers from the aforementioned school in the evaluation of the developed robotics-assisted acid-base titration setup and laboratory activity respectively. Also, during the implementation of the activity, a total of 40 Grade 11 STEM students, of the same section, currently enrolled in the identified school were utilized as the research participants. The General Chemistry subject is currently offered in the aforementioned grade level. These participants are divided into groups consisting of five members. Due to the limited number of developed setups, the laboratory activity was implemented one group at a time. The basic science process skills were observed by a General Chemistry teacher at the identified school. The observation was validated by the researcher. A total of two General Chemistry teachers were used throughout the implementation of the activity. Lastly, only the student participants during the implementation of the laboratory activity accomplished the administered questionnaires.

**Research Instruments**

The evaluation of the constructed robotics-assisted acid-base titration setup was done using the System Usability Scale (SUS) adapted from Paxton et al. (2018). The SUS tool is a five-point scale that ranges from Strongly Disagree to Strongly Agree and is composed of ten statements that are used for assessing the perceived user satisfaction and general usability of a system, product, or setup. In the tool are five positive and negative statements that are placed alternately. For the scoring, the score obtained from the odd-numbered questions was subtracted by one. While for the even-numbered questions, the score was subtracted from five. The scores were added, and the sum was multiplied by 2.5. The end score was then used to identify the adjective rating obtained by the set-up.

The evaluation of the developed robotics-assisted laboratory activity on acid-base titration was done using a questionnaire adapted from Catuday (2019) and DepEd's evaluation rating sheet for print resources. The questionnaire consists of three criteria: format; language; and content. Each criterion is composed of six questions.

The basic science process skills (observing, classifying, communicating, measuring and using numbers, predicting, and inferring) of the student participants were observed and evaluated by the researcher and the general chemistry teacher using the basic science process skills observation checklist adapted from Rani (2017) from laboratory planning until reporting.

An activity perception questionnaire was administered to identify the students' perceptions towards the developed laboratory activity. Adapted from Palisbo et al. (2022), the questionnaire comprises 25 statements that measure the student's level of perception towards the developed laboratory activity. This part of the questionnaire is categorized into three subscales: interest or enjoyment, value or usefulness, and perceived choice. A reversed scoring method was used for the negative statements in the instrument.

**Data Collection**

The development of the robotics-assisted acid-base titration setup and laboratory activity was detailed with the use of the ADDIE Model, as presented in Figure 1.

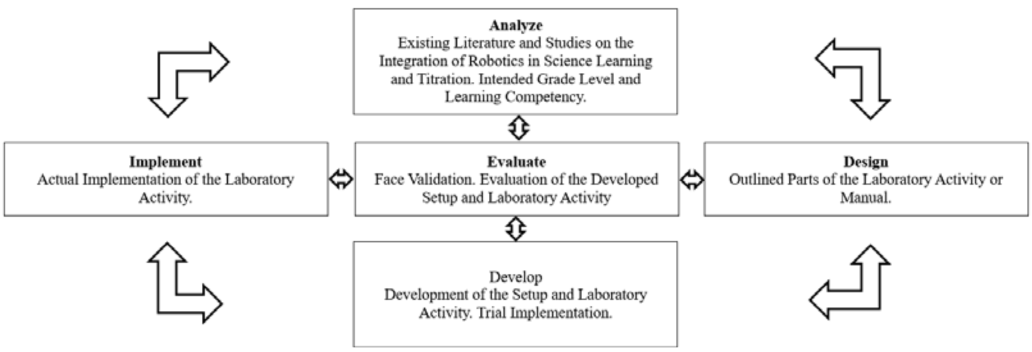


**Figure 1** *Development of Robotics-assisted Acid-Base Titration Setup and Laboratory Activity using the ADDIE Model*

Analysis. The first phase of the ADDIE model involves analysis, where existing literature and studies on the integration of robotics in science learning and titration, and intended grade level and learning competency are specified.

Educational robotics is an effective tool that can promote multidisciplinary learning and facilitate 21st-century skills including creative thinking, problem-solving, metacognition, divergent thinking, creativity, and collaboration (Gratani & Giannandrea, 2022). The application of this technology to education in the Philippines is relatively new and very limited, but there is still a lot to explore in the integration of robotics into the Philippine educational curriculum (Montemayor, 2018). Additionally, Soong et al. (2019) stated that traditional or classical laboratory setups, including manual titration, possess several potential physical barriers that can prevent effective hands-on learning. One method that can minimize physical barriers in traditional laboratory setups is the integration of robotics. Verner and Revzin (2011) also revealed that the use of robotics in performing laboratory activities can create a more accurate and safer environment and significantly reduce the time needed for operations and many typical errors while executing laboratory operations.

In the K to 12 Basic Education Curriculum Guide (2016) and Most Essential Learning Competencies (2020) of the General Chemistry of Grade 11 STEM, the laboratory activity is specified under the topic of the physical properties of solutions with the following learning objectives: perform acid-base titration to determine the concentration of solutions and describe laboratory procedures in determining the concentration of solutions.

Design. In the design phase, the parts and sequence of the laboratory manual are outlined specifically. The activity follows the standard parts of a laboratory manual. These parts are the following: introduction, objectives, materials, safety precautions, procedures, data presentation, questions, and conclusions. Additionally, the laboratory activity consisted of two parts: manual and robotics-assisted titration. While integrating robotics into the setup can offer several instructional advantages, manual titration intensively emphasizes laboratory and analytical skills (Worley, 2020). This dual approach can equip students with a broader set of laboratory skills, including traditional techniques and familiarity with automated instruments, which are increasingly prevalent in scientific settings. Moreover, this approach can further improve critical thinking and problem-solving by analyzing factors such as accuracy, precision, and the potential for human errors in manual titration versus the efficiency and consistency of automated titration (Worley, 2020).

Including at this stage is the development of the manual for the laboratory activity. The first version of the activity went through trial implementation with Grade 11 STEM students of a different section of the same school. Another version of the activity was developed taking into consideration the comments and suggestions made by the the students. After, the activity underwent evaluation by five STEM teachers using the adapted evaluation questionnaire.

Implement. In the implementation phase, the developed laboratory activity is delivered to the identified research participants, the Grade 11 STEM of the same section. Prior to implementation, a pre-laboratory session was conducted. The session involved the overall discussion of the developed setup and laboratory activity, and the distribution of consent forms to the student participants, parents, and school heads. Due to the limited number of developed setups, the laboratory activity was implemented in one group, composed of five student participants, at a time. Student safety and supervision were ensured during the implementation of the activity.

During the implementation of the laboratory activity, the students' basic science process skills were observed by one General Chemistry teacher and validated by the researcher using the identified checklist adapted from a study. A total of two General Chemistry teachers were used throughout the implementation of the activity. After the implementation of the laboratory activity, the activity perception questionnaire was administered to the student participants to assess the students' perceptions towards the developed laboratory activity. Also at this stage, the student participants evaluated the developed robotics-assisted acid-base titration setup.

Evaluation. At every phase of the process, face validation by the STEM experts was done. Comments and suggestions were taken into consideration to improve the steps taken at every phase. Additionally, the developed robotics-assisted acid-base titration setup and laboratory activity underwent evaluation.

### Data Analysis

The study utilized mean to present the quantitative data and scores obtained from the system usability scale, developed laboratory activity evaluation questionnaire, and activity perception questionnaire. Moreover, a percentage was used to present the data obtained from the basic science process skills checklist. The mean and percentage were identified using MS Excel.

## RESULTS AND DISCUSSION

### Development of Robotics-Assisted Acid-Base Titration Setup and Laboratory Activity

There were several prototypes or versions of the setup that were developed. Before going to the setup evaluation, after each development of a prototype, the setup undergoes a series of validations to test the product output. Necessary adjustments were made to improve the setup. Figure 2 displays the final version of the robotics-assisted acid-base titration setup.

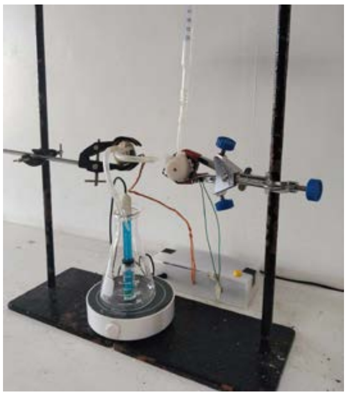

**Figure 2** *Robotics-Assisted Acid-Base Titration Setup*

A burette, which holds the titrant, was connected to a peristaltic liquid pump, INTLLAB DP-DIY, using silicone hose tubing and appropriate pipe connectors. This arrangement ensures controlled and consistent delivery of the titrant throughout the titration procedure. The pump operation was regulated by a push-button switch, providing ease of control to the operator. To monitor the progress of the titration, a pH meter was employed. The DFRobot Gravity Analog pH V2 model offers reliable pH measurements throughout the titration process, facilitating precise determination of the equivalence point. Additionally, a magnetic stirrer, the JOANLAB MS3, was incorporated to automate stirring, ensuring thorough mixing of reagents.

These individual components were seamlessly interconnected using the ESP32 microcontroller and the IIC I2C level conversion module. The microcontroller serves as the central control unit, orchestrating the operation of the entire setup. One of the notable features of this setup is its ability to transmit data wirelessly over WiFi. Utilizing the ESP32 microcontroller, the system can communicate the collected data to external devices such as smartphones or computers. The webpage interface of the setup facilitates direct downloading of a spreadsheet file containing the collected data. Figure 3 presents a sample display of the transmitted data in a smartphone of the setup and a sample downloaded spreadsheet file containing the collected data and generated titration graph.

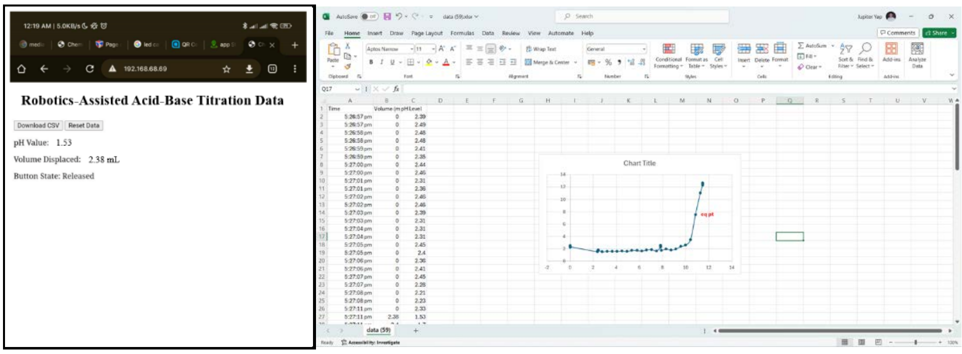


**Figure 3** *Sample Display of the Transmitted Data in a Smartphone, Downloaded Spreadsheet File, and Generated Titration Graph*

Table 1 shows the teacher and student evaluation of the developed robotics-assisted acid-base titration setup. These results imply that the developed setup is easy to use and operate. Moreover, the results also reveal that the setup is uncomplicated and that the different parts and functions of the setup are well integrated. It was also noted by Evaluator 02 that the setup transmits output data consistently with minimal errors. However, the results also display that the setup needs substantial technical support prior to the operation of the developed setup. With this, the laboratory activity should incorporate an intensive pre-laboratory session that demonstrates the operation of the setup to minimize errors during the actual laboratory activity to maximize instructional time.

**Table 1** *Teacher and Student Evaluation of the Developed Robotics-Assisted Acid-Base Titration Setup*

| **Indicators** | **Mean** | | | **Qualitative Description** |
|---|---|---|---|---|
| *The developed robotics-assisted acid-base titration set-up …* | **Teacher** | **Student** | **Overall** | |
| makes users like to use the setup frequently. | 4.67 | 4.87 | 4.77 | Strongly Agree |
| is unnecessarily complex. | 1.33 | 1.22 | 1.28 | Strongly Disagree |
| is easy to use and operate. | 4.67 | 4.67 | 4.67 | Strongly Disagree |
| needs support from a technical person to use the setup. | 2.33 | 3.11 | 2.72 | Neutral |
| has various functions that are well integrated. | 4.67 | 3.78 | 4.23 | Strongly Agree |
| has too much inconsistency. | 1.67 | 1.78 | 1.73 | Strongly Disagree |
| would be quickly learned by most people. | 3.67 | 4.44 | 4.06 | Agree |
| is very awkward to use. | 1.00 | 1.33 | 1.17 | Strongly Disagree |
| makes users confident while using the setup. | 4.33 | 4.67 | 4.50 | Strongly Agree |
| has a lot of things to be learned before using the setup. | 2.67 | 3.67 | 3.17 | Neutral |

*Note: 4.20-5.00: Strongly Agree, 3.40-4.19: Agree, 2.60 – 3.39: Neutral, 1.80 – 2.59: Disagree, 1.00 – 1.79: Strongly Disagree*

These results also align with the comments made by student 35 stating that the "robotics-assisted method is easier to operate than manual titration". This is because the latter involves a greater number of failed or unaccepted attempts compared to the former. Student 12 remarked that they have "difficulty controlling the liberation of the titrant and observation of color changes using the manual titration ". This constitutes students surpassing the correct endpoint using the traditional method. These statements show that the robotics-assisted titration method is more consistent in producing acceptable trials. This finding also allows for optimization of laboratory resources by efficient utilization of chemicals and reagents, and reduction of chemical waste (Toledo, 2013).

It was also discussed by student 27 that the "manual method has an increased chance of incidents involving untoward exposure to chemical reagents compared to the robotics-assisted method". This statement agrees with the findings of Verner and Revzin (2011) that the integration of robotics in performing laboratory activities provides a safer environment.

Student 18 expressed that the laboratory activity is "exciting yet, particularly with the robotics-assisted method, challenging". Initially, the students perceived the second method as intimidating but with repeated attempts, the students felt comfortable with the use of the setup with the assistance of the teacher. It was also mentioned by student 34 that the generated results from the manual and robotics-assisted titration methods are "relatively the same or with no significant difference". However, the student's responses on the laboratory report sheets indicate different factors that contribute to the results generated from the two titration methods. This finding further reinforces that the dual approach of the developed laboratory activity permits critical thinking and problem-solving by allowing students to analyze the varying factors that contribute to the results generated from the two methods (Worley, 2020). Lastly, it was also specified by Student 05 that to improve the robotics-assisted titration, "the construction of titration graphs and calculation of the molar concentration of the solution should be integrated into the system". Furthermore, the generated results from the developed robotics acid-base titration setup should be subjected to accuracy and precision testing to establish the reliability and validity of the output data.

Table 2 displays the overall system usability score of the developed robotics-assisted acid-base titration setup by teacher and student evaluation. Following the scoring procedure, the sum of the scores of each indicator is multiplied by 2.5 resulting in an overall score of 80.53 obtained by the developed setup with an adjective rating of excellent. This rating provides an overall positive and favorable impression of user satisfaction and general usability (Paxton et al., 2018).

**Table 2** *System Usability of the Developed Robotics-Assisted Acid-Base Titration Setup*

| Evaluation | Mean Score | Verbal Interpretation |
|---|---|---|
| Teacher | 82.50 | Excellent |
| Student | 78.33 | Good |
| Overall | 80.53 | Excellent |
| *Note: >80.3: Excellent, 68-80.3: Good, 68: Okay, 51-68: Poor, <51: Awful* | | |

The developed laboratory activity follows the standard parts of a laboratory manual. These parts are the following: introduction, objectives, materials, safety precautions, procedures, data presentation, questions, and conclusions. The introduction section provides a general overview of acid-base titration, explaining the concept of stoichiometry in the neutralization reactions between acids and bases. Additionally, it discusses the two methods of titration: manual and robotics-assisted.

The objectives section outlines the specific learning goals of the activity as specified according to the DepEd learning competencies of the intended grade level and subject. The objectives are: to balance the chemical reaction involved in the titration, perform an acid-base manual and robotics-assisted titration to determine the molar concentration of the sodium hydroxide solution using KHP, and compare the percentage errors of the calculated molar concentration obtained from the two titration methods.

The materials section lists the equipment and chemicals needed for the conduct of the experiment. This includes the Erlenmeyer flask, graduated cylinder, analytical or electronic balance, burette, dropper, iron stand, spatula, the robotics-assisted titration setup, phenolphthalein indicator solution, sodium hydroxide solution of unknown concentration, and potassium hydrogen phthalate.

The safety precautions section emphasizes the importance of handling chemicals and laboratory equipment safely during the acid-base titration experiment. This includes wearing appropriate laboratory attire, including coats, safety goggles, and gloves, handling chemicals with care and avoiding skin contact; working in a well-ventilated area or under a fume hood, being cautious when handling glassware to prevent breakage and cuts, in case of spillage, neutralizing with appropriate chemicals and notifying the instructor, and disposing of waste chemicals as per the institution's guidelines.

The procedures section provides step-by-step instructions for conducting the acid-base titration experiment utilizing both the manual and robotics-assisted titration methods.

This includes setting up the titration set-up, adding the titrant (unknown solution) to the analyte (standard) while monitoring the changes in the color and pH of the solution, recording the volume of titrant required to reach the endpoint, indicated by a color change or pH shift, performing calculations to determine the concentration of the unknown solution based on the volume and concentration of the titrant used, and construction of the titration graphs.

The data presentation section presents the experimental data collected during the acid-base titration in a clear and organized manner. This includes a table showing the initial and final volumes of titrant used or the volume of the titrate at the equivalence point along with the corresponding molarity of the unknown solution, and graphs or charts illustrating the titration curve and the equivalence point.

The questions section prompts students to reflect on the students' observations and analysis of the results of the experiment. The questions include: "What is the molar concentration of the NaOH solution using the manual titration method and robotics-assisted titration method?"; "What is the percentage error of the average molar concentration of the NaOH solution using the manual and robotics-assisted titration methods?"; "Which method of titration generated a lesser and greater percentage error?"; and "What factors during the conduct of the activity influenced the calculated percentage errors?".

The conclusions section summarizes the findings and insights gained from the acid-base titration experiment. This includes the determination of the concentration of the unknown solution based on the titration results and reflections on any sources of error or uncertainties encountered during the experiment of the two titration methods.

Table 3 exhibits the teacher evaluation of the format of the developed laboratory activity. Catuday (2019) defined format as the adaptation of the form and writing style of the material to various instructional standards. The findings show that the overall mean score of the format criteria was 4.93 with a verbal interpretation of excellent. These results manifest that the developed laboratory activity features an acceptable format that is understandable and appropriate for the intended users. Although, as commented on by Evaluator 02, the illustrations displayed in the activity "can be improved to better depict the laboratory procedures".

**Table 3** *Teacher Evaluation of the Format of the Developed Laboratory Activity*

| **Indicators** | **Mean** | **Verbal Interpretation** |
|---|---|---|
| Vocabulary words used in the laboratory activity are within students' level of understanding. | 5.00 | Excellent |
| The sentence structures used in the laboratory activity are varied and understandable. | 5.00 | Excellent |
| The laboratory activity contains diagrams/pictures sufficient to illustrate ideas and concepts. | 4.60 | Excellent |
| The tables found in the laboratory activity are accurate, easy to understand, and properly labeled. | 5.00 | Excellent |
| Text, visuals, illustrations, layout, and design are interesting and suitable for the target learners. | 5.00 | Excellent |
| The ideas in the laboratory activity are developed adequately in a logical manner and are easy to follow. | 5.00 | Excellent |
| Overall | 4.93 | Excellent |
| *Note: 4.20-5.00: Excellent, 3.40-4.19: Very Satisfactory, 2.60 - 3.39: Satisfactory, 1.80 - 2.59: Fair, 1.00 - 1.79: Poor* | | |

Table 4 presents the teacher evaluation of the language of the developed laboratory activity. Language relates to the approach used in the material for expressing ideas and feelings toward the learners or activity users (Catuday 2019). The findings display that the overall mean score of the language criteria was 4.80 with also a verbal interpretation of excellent. These results imply the language used in the developed laboratory activity is understandable and appropriate for the intended learners. Moreover, the instructions in the activity are easy to follow and apply.

**Table 4***Teacher Evaluation of the Language of the Developed Laboratory Activity*

| **Indicators** | **Mean** | **Verbal Interpretation** |
|---|---|---|
| The language used in the laboratory activity is simple and easy to understand. | 5.00 | Excellent |
| The sentences are simple and concise. | 4.80 | Excellent |
| The activities indicated in the laboratory activity are clearly explained. | 4.60 | Excellent |
| The rules, procedures, and meanings of the laboratory activity are easy to follow and apply. | 4.60 | Excellent |
| The language and/or visuals are appropriate to the maturity level of the target learner. | 5.00 | Excellent |
| The instruction and learning tasks are well illustrated and made easy. | 4.80 | Excellent |
| Overall | 4.80 | Excellent |
| *Note: 4.20-5.00: Excellent, 3.40-4.19: Very Satisfactory, 2.60 - 3.39: Satisfactory, 1.80 - 2.59: Fair, 1.00 - 1.79: Poor* | | |

Table 5 shows the teacher evaluation of the content of the developed laboratory activity. Catuday (2017) refers to content as the extent to which the instructional material effectively satisfies the intended purpose. The findings suggest that the overall mean score of the content criteria was 4.97 with a verbal interpretation of excellent. These results demonstrate that the developed laboratory activity effectively fulfilled its educational objectives. Additionally, the content of the activity is appropriate for the target learners, promotes student's interest and higher-order thinking skills, and can provide a safe environment.

**Table 5** *Teacher Evaluation of the Content of the Developed Laboratory Activity*

| **Indicators** | **Mean** | **Verbal Interpretation** |
|---|---|---|
| The content of the laboratory activity is aligned with the intended learning competencies. | 4.80 | Excellent |
| The content of the laboratory activity is appropriate for the target learners. | 5.00 | Excellent |
| The laboratory activity promotes the development of higher cognitive skills such as critical thinking, creativity, learning by doing, problem-solving, and other similar skills. | 5.00 | Excellent |
| The laboratory activity has the potential to arouse the interest of target learners. | 5.00 | Excellent |
| The laboratory activity provides adequate warning/cautionary notes for safety and/or health concerns. | 5.00 | Excellent |
| The laboratory activity is free of ideological, cultural, religious, racial, and gender biases and prejudices. | 5.00 | Excellent |
| Overall | 4.93 | Excellent |
| *Note: 4.20-5.00: Excellent, 3.40-4.19: Very Satisfactory, 2.60 - 3.39: Satisfactory, 1.80 - 2.59: Fair, 1.00 - 1.79: Poor* | | |

The positive results across the different criteria manifest that the developed laboratory activity is well-designed and effectively fulfills its educational objectives.

**Students' Basic Science Process Skills During Implementation of the Developed Laboratory Activity**

As presented by Afnidar & Hamda (2015), science process skills are cognitive processes that are associated with scientific learning and teaching. The basic science process skills include observing, classifying, communicating, measuring and using numbers, predicting, and inferring (Rani, 2017). Table 6 displays the students' basic science process skills during the implementation of the developed laboratory activity. The findings show the percent observed indicators of basic science process skills (observing, classifying, communicating, measuring and using numbers, predicting, and inferring) of the two evaluators.

**Table 6** *Students' Basic Science Process Skills During the Implementation of the Developed Laboratory Activity*

| Science Process Skills | Percent Observed Skills | | | Verbal Interpretation |
|---|---|---|---|---|
| | Evaluator 1 | Evaluator 2 | Mean | |
| Observing | 90.63 | 87.50 | 89.06 | Excellent |
| Classifying | 82.14 | 78.57 | 80.36 | Excellent |
| Communicating | 95.00 | 85.00 | 90.00 | Excellent |
| Measuring and Using Numbers | 100.00 | 91.67 | 95.83 | Excellent |
| Predicting | 85.71 | 78.57 | 82.14 | Excellent |
| Inferring | 96.43 | 85.71 | 91.07 | Excellent |
| Overall | 91.65 | 84.50 | 88.08 | Excellent |
| *Note: 81 - 100: Excellent, 71 - 80: Good, 61 - 70: Fair, 51 - 60: Poor, 0 - 50: Very Poor* | | | | |

It was identified that observing, communicating, measuring and using numbers, predicting, and inferring skills received a mean percentage score of 89.06, 90.00, 95.83, 82.14, and 91.07 respectively with a verbal interpretation of excellent. Meanwhile, the classifying skills obtained a mean score of 80.36 with a verbal interpretation of good. The table also revealed that the implementation of the developed laboratory activity gained an overall percentage of observed skills of 88.08 with a verbal interpretation of excellent. These findings suggest that the activity facilitated the demonstration of basic science process skills and thus effectively engaged the students.

The mean percentage score of 89.06 for observing skills indicates that students excelled in identifying objects, utilizing multiple senses, and accurately describing properties and changes. This suggests that students were keen observers throughout the titration process, utilizing both qualitative and quantitative observations effectively. This includes observing the color and pH changes during titration and stopping titration if the endpoint is reached (as noted by color or pH changes).

While the mean score of 80.36 for classifying skills, students demonstrated skills such as the classification of factors involved in the results obtained from the titration methods and the categorization of the reaction components based on stoichiometry in the calculation of the molar concentration. However, multiple ways of sorting and formation of subgroups were limited according to the observance of the evaluators.

The mean percentage score of 90.00 for communicating skills highlights students' ability to accurately identify and describe objects and events, as well as to formulate logical arguments and transmit information effectively. This suggests that students were able to articulate their observations and findings clearly, both verbally and in written formats. This includes communicating data collected and results obtained in the laboratory report sheets, communicating observations including color and pH changes and measurements, and detailing titration results using the prescribed tables and titration graphs.

The mean percentage score of 95.83 for measuring and using numbers skills underscores students' proficiency in selecting appropriate measurement types and units, utilizing measurement instruments properly, and applying measurement techniques accurately. This indicates a strong grasp of quantitative analysis and its application in scientific investigation. This includes appropriately recording measurements taken from the used instruments (volume from burette and graduated cylinder, pH from pH meter), and indicating measurement readings (volume and pH) with appropriate significant figures and units.

The mean percentage score of 82.14 for predicting skills reflects a demonstration of the skill. The students demonstrated the ability to form and extend patterns, make simple predictions, and apply the prediction process appropriately. This includes predicting the volume of the titrant by relying on the volume obtained in the initial trial and providing an accurate time estimate to conclude the titration, considering the volume of the titrant acquired during the initial trial.

With a mean percentage score of 91.07, students exhibited strong proficiency in inferring skills, including describing relations among objects and events, making inferences based on evidence, and applying the inference process effectively. This suggests that students were adept at drawing logical conclusions from observed data and interpreting experimental results. This includes responding to the questions in the laboratory report sheets that require analysis of the experimental data as reflected in the provided tables and titration graphs, making conclusions following the data obtained and the objective of the activity, and analyzing factors involved in the results obtained from the titration methods.

Adiningsih et al. (2020) detailed that a titration activity allows the observance of the following skills: formulating hypotheses, controlling variables, designing investigations, classifying, measuring observing, predicting, interpreting, applying the concept, concluding, and communicating. In addition, as specified by one of the evaluators, the robotics-assisted titration method permits the conduct of laboratory skill sets not seen during the traditional method. These skills include technology integration and operation of the set-up. This finding is consistent with Worley (2020) who stated that a dual approach in titration can equip students with a broader set of laboratory skills, including traditional techniques and familiarity with automated instruments.

**Students' Perceptions Towards the Developed Laboratory Activity**

The first criterion of the tool assesses the interest or enjoyment that participants experience during the implementation of the developed laboratory activity. Monteiro et al. (2015) recognized that this is the most direct tool for identifying self-reported intrinsic motivation. Table 7 presents the students' perception of interest and enjoyment towards the developed laboratory activity. These findings show that the overall mean score of the students' perception of interest and enjoyment towards the developed laboratory activity is 4.55 with a verbal interpretation of very high. These results indicate that the participants had highly positive perceptions and experiences of the developed laboratory activity, describing it as interesting, enjoyable, and fun.

**Table 7** *Students' Perception of Interest and Enjoyment Towards the Developed Laboratory Activity*

| Indicators | Mean | Verbal Interpretation |
|---|---|---|
| While I was doing the laboratory activity, I was thinking about how much I enjoyed it. | 4.58 | Very High |
| The laboratory activity was fun to do. | 4.67 | Very High |
| I enjoyed doing the laboratory activity very much. | 4.42 | Very High |
| I felt like I was enjoying the laboratory activity while I was doing it. | 4.42 | Very High |
| I thought the laboratory activity was very boring. | 1.42 | Very Low |
| I thought this was a very interesting activity. | 4.83 | Very High |
| I would describe the laboratory activity as very enjoyable. | 4.33 | Very High |
| I would describe the laboratory activity as very fun. | 4.58 | Very High |
| Overall | 4.55 | Very High |
| *Note: 4.20-5.00: Very High, 3.40-4.19: High, 2.60 - 3.39: Moderate, 1.80 - 2.59: Low, 1.00 - 1.79: Very Low* | | |

The next criterion of the instrument evaluates the perceived value or usefulness of the developed laboratory activity. This aims to understand whether student participants find the developed laboratory activity meaningful or beneficial in some way (Monteiro et al., 2015). Table 8 explores the students' perception of the perceived value and usefulness towards the developed laboratory activity. The findings determine that the overall mean score of the students' perception of value and usefulness towards the developed laboratory activity is 4.53 with a verbal interpretation of very high. These findings suggest that students not only recognize the significance of the laboratory activity but also strongly believe in its usefulness and potential benefits for their academic improvement.

**Table 8** *Students' Perception of Perceived Value and Usefulness Towards the Developed Laboratory Activity*

| Indicators | Mean | Verbal Interpretation |
|---|---|---|

| | | |
|---|---|---|
| I believe that doing the laboratory activity could be of some value to me. | 4.65 | Very High |
| I believe that doing the laboratory activity is useful for improved concentration. | 4.67 | Very High |
| I think the laboratory activity is important for my improvement. | 4.46 | Very High |
| I think this is an important activity. | 4.58 | Very High |
| It is possible that the laboratory activity could improve my studying habits. | 4.42 | Very High |
| I am willing to do the laboratory activity again because I think it is somewhat useful. | 4.40 | Very High |
| I believe doing the laboratory activity could be somewhat beneficial for me. | 4.58 | Very High |
| I believe doing the laboratory activity could help me do better in school. | 4.35 | Very High |
| I would be willing to do the laboratory activity again because it has some value for me. | 4.64 | Very High |
| Overall | 4.53 | Very High |
| *Note: 4.20-5.00: Very High, 3.40-4.19: High, 2.60 - 3.39: Moderate, 1.80 - 2.59: Low, 1.00 - 1.79: Very Low* | | |

Lastly, the third criterion explores the participants' sense of autonomy and control over the activity. It assesses whether individuals feel that they have a choice in participating and if they perceive the activity as voluntary or imposed (Monteiro et al., 2015).

**Table 9** *Students' Perception of Perceived Choice Towards the Developed Laboratory Activity*

| **Indicators** | **Mean** | **Verbal Interpretation** |
|---|---|---|
| I believe I had some choice about doing the laboratory activity. | 4.33 | Very High |
| I did not have a choice about doing the laboratory activity. | 1.83 | Low |
| I did the laboratory activity because I wanted to. | 4.58 | Very High |
| I felt like I had no choice but to do the laboratory activity. | 1.42 | Very Low |
| I felt like I had to do the laboratory activity. | 1.50 | Very Low |
| I did the laboratory activity because I had to. | 1.58 | Very Low |
| While doing the laboratory activity, I felt like I had a choice. | 4.67 | Very High |
| I felt like it was not my own choice to do the laboratory activity. | 1.67 | Very Low |
| Overall | 4.45 | Very High |
| *Note: 4.20-5.00: Very High, 3.40-4.19: High, 2.60 - 3.39: Moderate, 1.80 - 2.59: Low, 1.00 - 1.79: Very Low* | | |

Table 9 exhibits the students' perception of perceived choice towards the developed laboratory activity. The findings specified that the overall mean score of the students' level of perception of perceived choice towards the developed laboratory activity is 4.45 with a verbal interpretation of high. These findings indicate that students generally felt a high degree of autonomy and choice in participating in the laboratory activity. This suggests that the design and implementation of the laboratory activity successfully fostered a sense of voluntary engagement among the students.

As discussed earlier, the observations made by the participants detailed that the laboratory activity, particularly with the robotics-assisted method, is both exciting and challenging. Initial perceptions of intimidation were noted with the use of the robotics-assisted titration method among students, but with repeated attempts, the participants grew more comfortable using the setup. Student 03 noted that the "use of Arduino in the titration method makes the activity more interesting". These observations suggest that the integration of technology enhances student engagement. This is further supported by several students stating that they find the activity engaging.

Additionally, it was remarked by Student 44 that the activity allowed them to "collaborate with the members of the group, especially with the second part of the activity". Elbir and Cakiroglu's (2018) findings explain that the aid of robotics during the laboratory activity increased students' engagement and motivation. The increased engagement and motivation are attributed to the ability of robotics to keep the students mentally and physically active. Cuperman and Verner (2013) also argued that using robotics in the classroom can trigger students' curiosity and drive students' inquiry.

Lastly, it was identified that the observations made by Student 16 stating that "while there are several things to consider and learn in the operation of the robotics-assisted titration method, the pre-laboratory session conducted by the teacher allows the students to control the set-up with minimal assistance and supervision from the teacher during the actual conduct of the activity". However, it was observed by Student 09 that the "laboratory activity needs an extension of instructional time longer than a 50-minute period". Given the multiple parts involved, the current time allocation for a single class period is insufficient to complete the entire laboratory activity.

## CONCLUSION AND IMPLICATIONS

Based on the findings of the study, the following conclusions are drawn: the developed acid-base titration set-up possesses an overall positive and favorable impression of user satisfaction and general usability; and the developed robotics-assisted laboratory activity on acid-base titration is well-designed and effectively fulfills its educational objectives, allows the conduct and enhancement of basic science process skills, and provides an engaging, relevant, and personally meaningful learning experience.

These results identify that the integration of the educational technology in the lesson is an effective tool for creating an engaging, relevant, and personally meaningful instructional experience that enhances students' scientific understanding and skills which further emphasizes the positive impacts of robotics integration on the overall teaching-learning process.

## RECOMMENDATIONS

The following recommendations are worthy of consideration for future studies. The developed robotics acid-base titration setup and laboratory activity should be further improved and developed. Taking into consideration the feedback and comments from the experts and student participants, and the results of the evaluation of the setup and the activity. The construction of the robotics-assisted titration setup could be also integrated into the laboratory activity. However, this integration might extend the instructional time. Hence, it is advisable to coordinate with the robotics subject, suggesting that the construction phase aligns with the subject, while the operational phase occurs within the General Chemistry subject. Future research papers should explore additional parameters to comprehensively evaluate the effectiveness of the developed laboratory activity. Considerations may encompass assessing student achievement, measuring motivation and engagement levels, and evaluating the impact on the enhancement of 21st-century skills. This broader scope of analysis will provide a more holistic understanding of the activity's educational impact and contribute valuable insights to the field. The integration of robotics can extend to various secondary science laboratory experiences, paving the way for the development of a comprehensive robotics-assisted laboratory workbook or manual. By compiling these activities, educators can create a resource that facilitates structured and hands-on learning, providing students with practical insights into scientific concepts through the utilization of robotics technology.

## REFERENCES

Adiningsih, M., Karyasa, I. & Muderawan I. (2020). Profile of students' science process skills in acid base titration practicum at Class XI MIPA 3 SMA Negeri 1 Singaraja Bali. International Conference on Mathematics and Natural Sciences. Journal of Physics: Conference Series. doi:10.1088/1742-6596/1503/1/012037

Afnidar, A. & Hamda, S. (2015). Improving Students' Science Process Skill and Achievement Through Experiment in Laboratory: Volumetric Titration. International Conference on Technical Vocational Education and Training (ICTVET). 13-16 September 2015, Penang - Malaysia.

American Chemical Society. (2022). Importance of hands-on laboratory science. Public Policy Statement 2020-2023. Retrieved from https://www.acs.org/content/dam/acsorg/policy/publicpolicies/education/computersimulations/hands-on-science.pdf

Badeleh, A. (2018). The effects of robotics training on students' creativity and learning in physics. Education and Information Technologies. Volume 26. DOI: 10.1007/s10639-019-09972-6.

Britannica, T. Editors of Encyclopaedia (2022). Titration. Encyclopedia Britannica. https://www.britannica.com/science/titration

Catuday, R. (2019). Development and validation of laboratory workbook in plant biology. International Journal of Current Research. Vol. 11, Issue, 03, pp.2194-2204. DOI: https://doi.org/10.24941/ijcr.34191.03.2019

Cuperman, D., & Verner, I. (2013). Learning through creating robotic models of biological systems. International Journal of Technology and Design Education. Volume 23. DOI: 10.1007/s10798-013-9235-y

D'Angelo, C. (2018). The impact of technology: student engagement and success. https://techandcurriculum.pressbooks.com/chapter/engagement-and-success/

Department of Education. (2016). General chemistry curriculum guide. K to 12 basic education curriculum.

Department of Education. (2020). Most essential learning competencies (MELCS). K to 12 basic education curriculum.

Department of Education. (2009). Guidelines and processes for LRMDS assessment & evaluation. Retrieved from: https://lrmds.deped.gov.ph/docs/LRMDSGuidelines.pdf

Elbir, B., Cakiroglu, B. (2018). Stem education: robotics integration in science laboratory. International Journal of Science and Research. Volume 7 Issue 6. DOI: 10.21275/ART20183371

Gratani, F., & Giannandrea, L. (2022). Towards 2030. Enhancing 21st-century skills through educational robotics. DOI: 10.3389/feduc.2022.955285

Hallerman, S., Lewis, C., & Dresbach, B. (2019). What is a 21st-century education? https://www.battelleforkids.org/learning-hub/learning-hub-item/what-is-a-21st-century-education/

McNulty, N. (2021). If you're not teaching 21st Century skills using educational technology your students are in trouble. Here's why. https://www.niallmcnulty.com/2016/07/why-teaching-21st-century-skills-using-educational-technology-is-essential/

Montemayor, T. (2018). Why include robotics in the PH school curriculum? https://www.pna.gov.ph/articles/1040784

Palisbo, V., Pusta, A., Razo, J. & Malayao, S. (2022). Dual development of board game and guided-inquiry activity in teaching electricity for grade 5. International Journal of Science Education and Teaching. Vol. 1, No. 3, pp. 160-179, Sep.– Dec. 2022. http://doi.org/10.14456/ijset.2022.13

Paxton, C., Jonathan, F., Hundt, A., Mutlu, B., & Hager, G. D. (2018). Evaluating methods for end-user creation of robot task plans. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). DOI: 10.1109/IROS.2018.8594127.

Rani, S. A. (2017). Literature study: characteristics of hands-on physics experiment to improve science process skills. 4th ICRIEMS Proceedings. The Faculty of Mathematics and Natural Sciences. Yogyakarta State University.

Soong, R., Agmata, K., Doyle, T., Jenne, A., Adamo, A. & Simpson, A. (2019). Rethinking a timeless titration experimental setup through automation and open-source robotic technology: making titration accessible for students of all abilities. Journal of Chemical Education. Volume 96 (7) page 1497-1501. DOI: 10.1021/acs.jchemed.9b00025

Verner, I. M. & Revzin, L. B. (2011). Characteristics and educational advantages of laboratory automation in high school chemistry. 2011 IEEE Global Engineering Education Conference (EDUCON), Amman, Jordan, 2011, pp. 8-13. DOI: 10.3991/ijoe.v7iS1.1787

World Bank Group. (2021). Digital technologies in education. https://www.worldbank.org/en/topic/edutech#2

Worley, C. (2020). Automated titration vs. manual titration. Retrieved from https://www.xylem.com/siteassets/brand/si-analytics/resources/technical-brochure/automated-titration-vs-manual-titration-blog.pdf

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# Development of Creative-Based Learning Management Platform on Transformational Leadership Educational Management in Digital Education for Graduate Learner

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**Abstract.** The objectives of this research were to 1) design and create, test, use and evaluate a prototype of creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner; and 2) propose a creative-based learning management platform developed. This research is research and development. The sample group consisted of 38 graduate students in the master and doctoral of education program at the Rajamangala University of Technology Rattanakosin in the academic year 2024**.** The target group is fifteen experts in ICT systems and educational innovations. The research method consisted of four steps: 1) analysis of user requirement, 2) system design and development, 3) usability testing and evaluation, and 4) improving system performance. Quantitative data analysis by using statistical packages to show mean and standard deviation. The qualitative data analysis was used content analysis. The research results were as follows: 1) the prototype of a platform developed uses a DBLC development process. Experimenting with the operational system for graduate learning involves learning alongside technology with a simple implementation. Students have a highest level of satisfaction with the platform prototype that is evolving, and 2) this platform has a structure that consists of a website, lecturer and student database, knowledge record, knowledge assessment, discussion board, download documents, related case studies, and pictures of various activities. In addition, the prototype platform will provide students with practical skills in learning Transformational Leadership Educational Management in Digital Education, including better developing skills in the use of ICT systems in education.

**Keywords:** Creative-Based Learning, Transformational Leadership, Educational Management, Digital Education, Graduate Learner

## INTRODUCTION

Information and Communication Technology: ICT is a critical and valuable system for the nation's development to progress. It is also very relevant to people's way of life in modern society. All societies have changed and adapted to becoming an electronic society (e-Society) completely. Hence, ICT has become a system that is necessary for every operation in various departments. Organizations developing and implementing appropriate ICT systems will help executives and operators receive accurate and timely information. As a result, the decision-making in planning the organization's operations is more efficient. Solving problems is possible on time. This is the ability to compete for advantage and efficiently develop services to customers (Laudon & Laudon, 2019). Therefore, studying how to apply the appropriate ICT system for the organization is essential. The practical application of ICT to make timely decisions requires concrete management planning (Phakamach, 2023). This includes various strategies in systematic management so that the organization achieves its objectives and has continuous development and sustainable growth (Sinlarat, 2020). The role of universities is to understand the changes and learn new ways to keep up with modern Thai and international technology in education management (Demir et al., 2021) with the introduction of modern management and management techniques. These are applied to educational administration in institutions for maximum academic efficiency and effectiveness (Garbin, Ten Caten, & Jesus Pacheco, 2022).

The Ministry of Higher Education, Science, Research and Innovation saw the importance of ICT by encouraging the use of ICT to develop and apply in order to enable learners to learn and develop to a higher level of knowledge. This is in line with the government's policy according to the 20-year national strategy 2017-2036, and under the ICT Master Plan 3 (ICT Master Plan 3) Higher Education Act B.E. and more educational platforms due to the global connection of information, it is a new avenue for education. People use this main road as a path to intellectual treasures and to develop new learning styles (Buasuwan, 2018: Lyapina et al., 2019; Phakamach, Senarith, & Wachirawongpaisarn, 2022). Therefore, the Ministry has established policies and standards to encourage educational institutions and agencies to implement the policy to promote the development of ICT for education by providing teachers. Educational personnel and learners have developed the ability to use educational platforms to benefit teaching and learning. Educational institutions at all levels need to have an ICT management system for educational innovation development as a standard system for improving the quality of education at all levels (Panjarattanakorn & Phakamach, 2020).

Teaching in the era of transformational change (Education Disruption) has a variety of teaching and learning management models that are used to promote and solve educational management problems in various fields, especially in the situation of the epidemic of Coronavirus (Ismaili, 2021). Teaching and learning management must align with the new learning paradigm. This enables learners to be able to seek knowledge on their own. This is specially true of the ability to fully use innovation and educational technology in pursuing knowledge. The principles under the Higher Education Act B.E. 2562 show that thinking process skills are still essential and must be encouraged for learners because thinking is an intrinsic factor influencing a person's actions and expressions. People with high thinking abilities will be able to solve problems. They are accomplished and develop their own lives. Therefore, the development of thinking ability is an integral part of the development of learners to live happily in a changing society (Gioiosa & Kinkela, 2022). Creative-Base Learning (CBL) is based on the aim of developing students' intellectual abilities by providing them with research skills, thinking skills, and group work skills. New knowledge can be linked to previous knowledge, with instructors encouraging students to use their creativity to present ideas that can be applied for effective teaching and learning (Gabaree et al., 2020; Asad et al., 2021; Xiao & Wang, 2023). The CBL learning process consists of 5 steps as follows: 1) stimulating interest, which is a positive stimulus that results in learners wanting to learn. Curious, eager to find answers and alert in search of self-knowledge; 2) problem setting and segmentation, such as what is the benefit of the content taught or how it will be used. What stories are relevant to real life?; 3) the search and thinking stage is the voluntary, interest, and cooperation of learners; 4) presentation stage, after researching and coming to a conclusion, the students will come out and present their work one by one. Group members also develop collaboration skills, research skills, and thinking skills. Instructors promote skills by supporting and providing opportunities to demonstrate their abilities according to their aptitude; and 5) evaluation stage Assessment needs to cover all three areas: knowledge, skills, and attributes, and should be displayed separately and not combined so that learners can use the assessment results to improve themselves. Therefore, if the challenge-based learning management process is considered for graduate students' teaching and learning, it will also affect the quality of education appropriately.

Transformational Leadership Educational Management in Digital Education is a core course in the Master of Education program at the Rajamangala University of Technology Rattanakosin; many institutes provide teaching and learning at the graduate level and are compulsory courses for modern educational administrators. This is because it is a course learned for effective leadership development for education administration in the digital era (Phakamach, Wachirawongpaisarn, & Panjarattanakorn, 2021). Most of the learning takes place in a regular classroom, creating severe obstacles to student learning if there is no good source of support for the use of modern management techniques and operating systems to build an educational platform. It is worthwhile considering using learning materials on web applications, a teaching and learning process management system that connects learners with teachers and learners with learners. It provides digital learning materials and teaching materials with instructors acting as trainers (Adele, Ellinger, McWhorter, & Egan, 2023) and are inspirers by designing experiential proactivity activities that correspond to the course content (Huang & Lai, 2020), which is a self-paced learning model that supports knowledge management in a given course, helping to solve problems and obstacles that arise in students' learning. In particular, graduate teaching and learning focus on creating learning challenges in order to create new knowledge to appear with quality.

Based on this idea, the researcher is interested in developing a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner. This system will change the learning process by using the learning management system platform to support teaching and learning activities. To be a complete learning organization, this design and development present educational innovations with specific dimensions: 1) electronic learning media; 2) a knowledge management support system, i.e., knowledge repository, knowledge record, chat board, and a knowledge assessment form; 3) a database of teachers and students as well as academic services; 4) online electronic bulletin boards to exchange learning; and 5) linkage with universities (e-MIS). The prototype will be a model of a learning management system using software and services. as well as assessing the efficiency and satisfaction of the learners. Performance improvements are based on expert feedback The model system is suitable for serving graduate students. It can be used to respond to the needs of students and contribute to learning about the effective management of Transformational Leadership Educational Management in Digital Education.

## RESEARCH OBJECTIVES

1. To design, create, test, use and evaluate a prototype of a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner.

2. To propose a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner.

## RESEARCH CONCEPTUAL FRAMEWORK

Research concepts can be formulated from the literature review and related research process design. The goal is to create a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner, as shown in Figure 1.

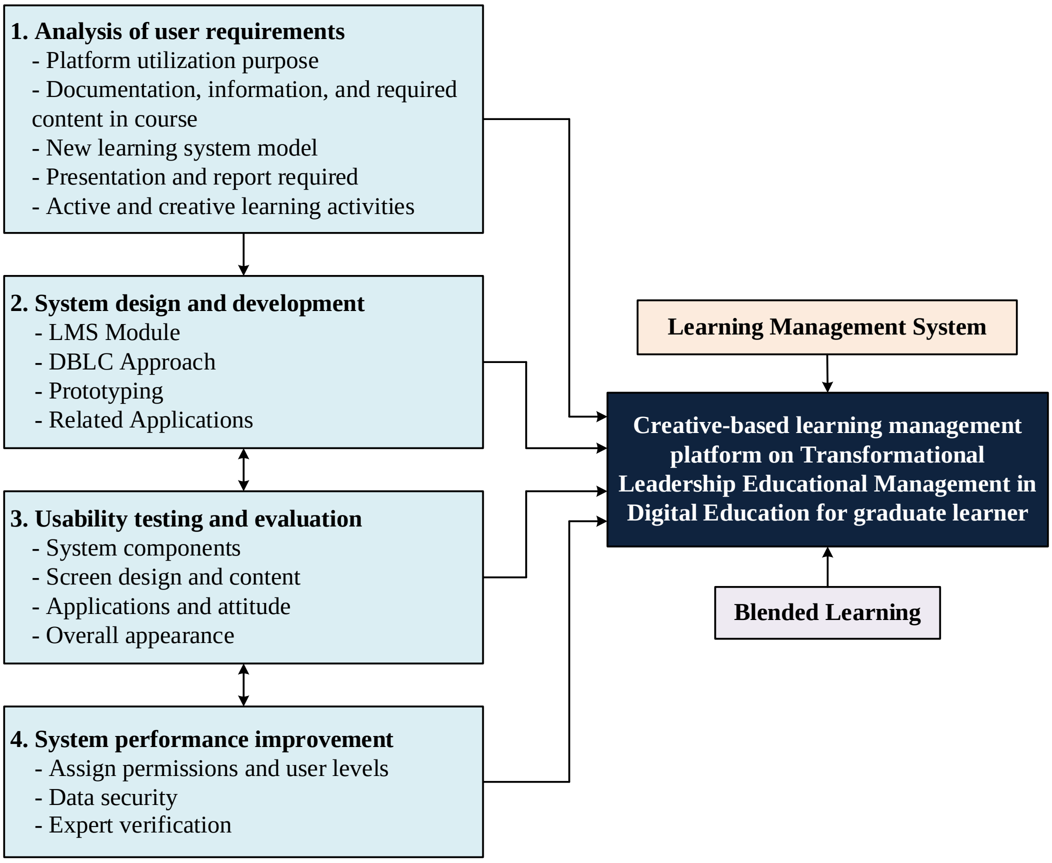


**Figure 1: Research Conceptual Framework**

## METHODOLOGY

This research includes research and development with related details as follows:

### Population and Sample

The population used in this research were graduate learners of the Master and Doctoral of Education program at Rattanakosin International College of Creative Entrepreneurship, Rajamangala University of Technology Rattanakosin, Enrolled in Transformational Leadership Educational Management in Digital Education in the first semester of the academic year 2024, there are 38 students because the total study population is small and requires data based on the opinions of all learners. Therefore, the panel used a method of selecting the entire population by defining it as a sample. The target group would be 10 experts in ICT systems and educational innovation.

**Research Instruments**

The research tools consisted of (1) a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner and (2) the tools used for data collection were:

(1) Quality assessment form (for experts) in ICT systems and educational innovations is a 5-level rating scale that assesses the efficiency of the system in terms of system components, design and development, as well as usability.

(2) The student satisfaction assessment form is a 5-level rating scale that assesses the suitability of the system in terms of system components, screen design and content, as well as usability and attitude.

(3) Structured interview form for interviewing students' use of the system on issues of (1) knowledge and implementation, (2) behavior and response, (3) participation, (4) results of use, and (5) problems and suggestions.

**Procedures for Conducting Research**

This research is research and development. The research method consisted of four steps:

(1) Analysis of user requirements, which is the study and analysis of user needs for both faculty and students. This establishes the necessary requirements for building a learning management system promotes solving current challenges through a five-step learning process. Starting from 1) Stimulate creativity and imagination, 2) Consider issues creatively, 3) Seek findings, 4) Exchange learning creatively, and 5) Evaluate and expand to dissemination, etc.

(2) System design and development, by using learning management system and programs related to the development of both offline and online teaching materials. This entails designing a case study related to the course, including a preliminary test.

(3) Usability testing and evaluation, platform quality and suitability checks by ICT and educational innovation by 10 experts. This is a 3-month trial phase, and satisfaction is tested by students enrolled in course.

(4) Improving system performance, by taking the test and evaluation results obtained from Step 3 for confirmation and improving the performance of the creative-based learning management platform on Transformational Leadership Educational Management in Digital Education to be effective for graduate learner.

The process of creating tools used in teaching and learning management includes: 1) Studying the curriculum/course and analyzing the content of the Transformational Leadership Educational Management in Digital Education course at the graduate level; 2) Defining the learning objectives to determine the scope of content in each unit including creating and challenging learning activities accordingly; 3) Determine the format for presenting content by collaborating academic seminars in accordance with the learning management approach that promotes the solution of challenging problems in 5 steps. Start with (i) Stimulate creativity and imagination, (ii) Consider issues creatively, (iii) Seek findings, (iv) Exchange learning creatively, and (v) Evaluate and expand to dissemination, etc.; 4) Write a flowchart of the learning management platform to define internal communication channels for convenience; 5) Design the storyboard according to a hierarchical structure based on proactive knowledge management techniques; 6) Develop the platform layout using LMS tool box and related computer programs; 7) Conduct trial to revise the platform; and 8) Evaluate the quality and satisfaction of the platform.

**Experiment and Data Collection**

The experimental model and the data collection were set as follows.

The preparation of the experiment includes: (1) ask for permission for the data collection and test the system by collecting data and testing the system in the first semester of the academic year 2024; (2) prepare the developed prototype and put it on the Dr.Darunee Learning Center, send the data to the server, and test its use; and (3) prepare the location and the computer, and schedule the experiment by testing the operating system in the content of educational platform development.

Take a system prototype that has been evaluated by an expert and test it for performance evaluation according to the following format.

*One to One Testing:* an experiment with three students who have taken this course before selected on the basis of high, medium and low grades based on their average grades in the past semester. Using a simple random sampling method, test the system to find defects and then use it to improve and fix it with the value $E_1/E_2$ = 61.75/62.86

*Small Group:* Testing Experiment with nine students who have taken this course before by selecting students with high, medium and low grades based on the average of the course scores in the past semester as criteria. Using a simple random sampling method, test the system to find bugs and use them to improve $E_1/E_2$ = 71.84/72.93

*Field testing, including:*

(1) Bring the system to students for a one-month workshop experiment by selecting a sample group of 38 students and organizing a pretesting knowledge meeting. The meeting is carried out in the following order: (1) Pretest by having students test from the achievement test of 40 items, (2) let learners study by using a challenge-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner, (3) allow learners to do exercises from the system ten items per learning unit, and (4) then post-test by having learners test from the achievement test of 40 items and evaluate the overall efficiency of $E_1/E_2$ with a value of $E_1/E_2$ = 81.95/ 83.22

(2) Interview a sample group of students, who use it regularly it, about their use.

(3) Analyze the results of the interview summarized in an essay manner and improve the system to be suitable and complete.

**Data Analysis**

The data obtained in the research process were analyzed in the following order:

1) Analysis of user requirements: summarized in an essay to illustrate the details that consist of (a) the purpose of using the system, (b) the required documents, information and content, (c) new learning system model, (d) presentation and report required (e) Active and CBL activities, and (f) practical activities.

2) System design and development: by ten experts in ICT systems and innovations for education administration, summarized in an essay format to illustrate the details, which consist of (a) LMS Module, (b) DBLC Approach, (c) Prototyping, and (d) related applications.

3) Usability testing and evaluation: Assessment of the efficiency of the prototype system by experts and based on the satisfaction by 38 students using a 5-level rating scale.

The research at this stage will apply the process in steps 1 and 2 by assessing the effectiveness and satisfaction of use. The information in step 2 can adjust the process as appropriate. There is a practical test. as well as study according to the prescribed format in order to obtain a system that is suitable for creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner.

The study population at this stage can be divided into two groups as follows: Group 1: the target group is 10 ICT experts and educational innovations and Group 2: the sample group consisted of 38 students in Transformational Leadership Educational Management in Digital Education course at Rajamangala University of Technology Rattanakosin.

The tool used to collect the data is an unstructured interview form to test its effectiveness. Problems and obstacles, as well as corrective guidelines. Data collection can be divided according to the study population as follows: Group 1: workshops and interviews and Group 2: was a workshop facilitation and participant observation. The questionnaire consisted of checklist questions. Text form and a 5-level estimation scale, with the questionnaire having three parts with details as follows:

Part 1: Information about the respondents.

Part 2: Opinions on using a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner. Will be an analysis to determine the efficiency and satisfaction of the system's users.

The criteria for using the score measurement are as follows: Strongly Agree; the weight was scored as 5, Agree; the weight was scored as 4, Neutral; the weight was scored as 3, Disagree; the weight was scored as 2, and Strongly Disagree; the weight was scored as 1.

Part 3: Suggestions and guidelines for developing a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner.

Creation and verification of the questionnaire tools draft will be submitted to experts to verify content validity and the appropriateness of language and wording. Then the next step is to test the reliability of the questionnaire using Cronbach's Alpha Coefficient formula. The reliability of the whole questionnaire was .942.

The data were then analyzed by statistical methods using statistic computer program. to find the efficiency and satisfaction of using a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner and present a statistical model for assessing efficiency and user satisfaction as follows:

Data analysis of group 1: Bring the data to analyze and synthesize in order to find ways to improve and develop the system. Also, recommend the correct usage according to the prescribed format so that users can use it effectively.

Data analysis of group 2: Part 1: Information that is the status of the respondents analyzed by frequency distribution and percentage.

Part 2: Information about opinions on using a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner. It is approximate scale data and is analyzed by calculating the mean and standard deviation.

Part 3: Information on recommendations and guidelines for developing a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner, which is text-based information. Use content analysis to obtain recommendations and development guidelines.

The mean was obtained from the estimation scale questionnaire data from the data analysis in group 2 and was compared with the criteria. The criteria for interpreting the mean, in summary, are as follows: 4.21-5.00 means efficiency and satisfaction are at the highest level; 3.41-4.20 means efficiency and satisfaction are at a high level; 2.61-3.40 mean efficiency and satisfaction are moderate; 1.81-2.60 means that efficiency and satisfaction are at a low level; and 1.00-1.80 means that efficiency and satisfaction are at the lowest level. where the spectral range is determined by the formula = (5-1)/5 = 0.8

4) Improving system performance:

The research at this stage will apply the results of the 3rd step to improve a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner. Next, conduct interviews with five experts in ICT systems and educational innovations using a non-structured interview, focused interview method verification for opinions and suggestions. Then apply the examination results to improve the system's performance and complete the learning requirements according to the teacher's council's compulsory course criteria.

## RESULTS

An example of a prototype system is shown in Figures 2-5, respectively. Developing a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner.

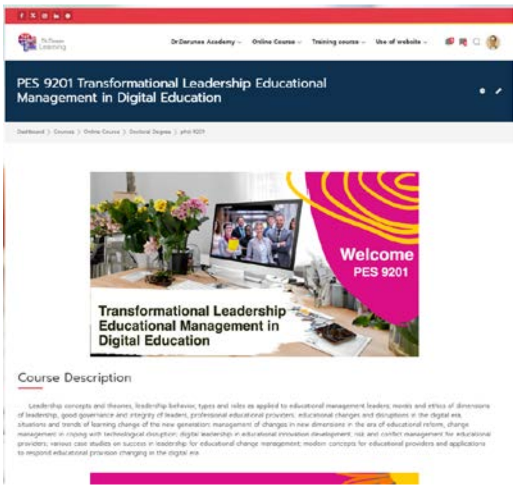


**Figure 2: Creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner**

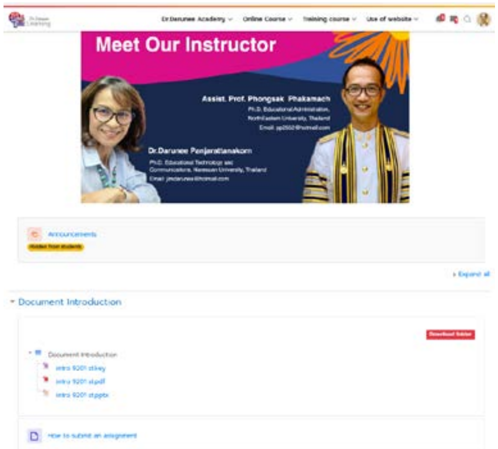


**Figure 3: Example of teaching materials**

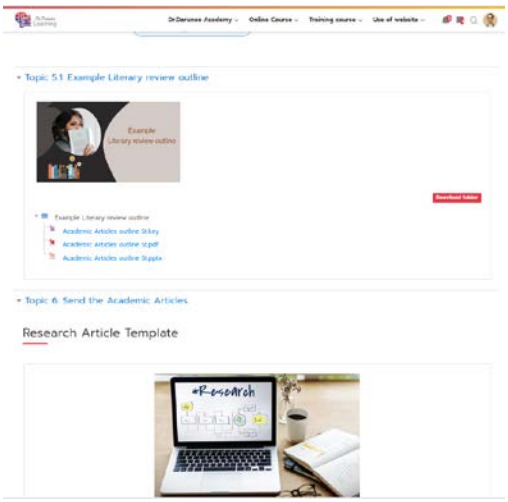

**Figure 4: Example of active learning and assignments**

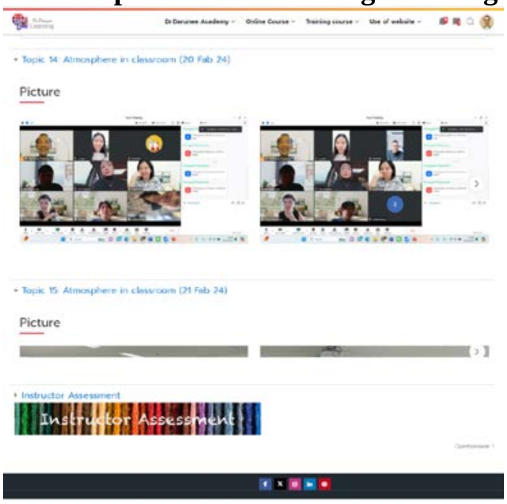


**Figure 5: Example of class and student activities**

The results of the research were as follows:

**Research results according to objective 1**

Design and create, test, use and evaluate a prototype of a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner. The findings can be listed as follows:

***Analysis user requirements results***

1) The results of analysis of user requirements in order to use data to design and build a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learners. Users have commented on their needs in critical areas, including: (a) It must be a platform that can be used to support teaching and learning in a given course; (b) The platform must support the process of teaching and learn with complete support functions; (c) the platform should provide operating parts that are consistent with the course content; (d) the platform should have relevant practical learning and case studies to enhance knowledge and understanding; and (e) the platform designed and built must be able to operate according to the schedule. designated classes

2) Guidelines for developing a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner and recommendations. One should study the information related to academic Transformational Leadership Educational Management in Digital Education before teaching management. Then, the system development method should be chosen according to the standard model. DBLC has the proper research and development process to achieve an operational learning system combined with case study learning on Transformational Leadership Educational Management in Digital Education. That responds to the complete knowledge management model in the course.

***System design and development results***

System design and development will use the DBLC standard method to make the system efficient. The key steps are (1) System Analysis, (2) System Design, (3) System Implementation, (4) System Installation, (5) System Operation and Evaluation, and (6) System Maintenance and Evolution, resulting in a learning management system for the course.

***Usability testing and evaluation***

The results of the test and trial of a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner with students enrolled in course in the first semester of the academic year 2024 by quality assessment by experts and the satisfaction assessment by students showed the following:

1) The results of evaluating the effectiveness of a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner based on the opinions of 10 experts, as shown in Table 1.

**Table 1: Results of efficacy assessment by experts**

| Topics and Assessment Items | | $\bar{x}$ | S.D. | Interpreting |
|---|---|---|---|---|
| System components | 1. Website | 4.25 | 0.55 | Highest |
| | 2. Record knowledge | 4.19 | 0.65 | High |
| | 3. Measuring and evaluating knowledge | 3.95 | 0.50 | High |
| | 4. Discussion board | 4.25 | 0.55 | Highest |
| | 5. Knowledge repository | 4.07 | 0.65 | High |
| | 6. Learning activities | 4.29 | 0.65 | Highest |
| | 7. Pictures of various activities | 4.02 | 0.55 | High |
| Design and development | 8. Content and Consistency | 4.40 | 0.55 | Highest |
| | 9. Format and font size | 4.12 | 0.45 | High |
| | 10. Font color and background | 4.08 | 0.65 | High |
| | 11. Visual and sound effects | 4.18 | 0.50 | High |
| | 12. Multimedia system | 3.76 | 0.55 | High |
| | 13. Instructions and Manuals | 3.72 | 0.50 | High |
| | 14. Overall screen | 4.45 | 0.65 | Highest |
| | 15. Design process | 4.38 | 0.55 | Highest |
| Usability | 16. Membership system | 4.18 | 0.45 | Highest |
| | 17. Back-end system | 4.18 | 0.65 | High |
| | 18. Link section | 4.23 | 0.65 | Highest |
| | 19. Interaction section | 4.40 | 0.45 | Highest |
| | 20. Search system | 4.02 | 0.55 | High |
| | 21. How to use it for the purpose | 4.46 | 0.55 | Highest |
| | 22. Practice in the course | 4.33 | 0.45 | High |
| | Total | 4.18 | 0.55 | High |

From Table 1, shows system performance evaluation by experts in three areas: system components, screen design and content, and usability. It was found that the system's overall quality was at a high level in all aspects ($\bar{x}$=4.18, S.D.=0.55). When considering each aspect, it was found that as for the components of the system, 7 items, the overall picture was at a high level ($\bar{x}$=4.15), arranged in order of averages from highest to lowest in 3 sequences: 1) learning activities, 2) website, and 3) discussion board respectively, with the highest level, is the website. In terms of design and development, 8 items were overall at a high ($\bar{x}$=4.13), arranged in order of averages from highest to lowest in 3 sequences: 1) overall screen, 2) content and consistency, and 3) design process accordingly sequence, with the highest level on the overall screen as a whole. As for the usability aspect of the 7 items, the overall picture was high ($\bar{x}$=4.27). The mean was sorted from highest to lowest in 3 orders, namely 1) how to use it for the purpose, 2) interaction section, and 3) practice in the course. Respectively, with the highest level in terms of how to use it for the purpose.

2) The results of the satisfaction assessment of the use of the model of a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner according to the opinions of 38 students are shown as follows: Table 2.

**Table 2: Results of the satisfaction assessment by students**

| Topics and Assessment Items | | $\bar{x}$ | S.D. | Interpreting |
|---|---|---|---|---|
| System components | 1. Website | 4.44 | 0.68 | Highest |
| | 2. Record knowledge | 4.23 | 0.46 | Highest |
| | 3. Measuring and evaluating knowledge | 4.19 | 0.75 | High |
| | 4. Discussion board | 4.25 | 0.59 | Highest |
| | 5. Knowledge repository | 4.08 | 0.51 | High |
| | 6. Learning activities | 4.37 | 0.67 | Highest |
| | 7. Pictures of various activities | 4.30 | 0.62 | Highest |
| Screen design and content | 8. Content and Consistency | 4.41 | 0.58 | Highest |
| | 9. Format and font size | 4.25 | 0.59 | Highest |
| | 10. Font color and background | 4.22 | 0.60 | High |
| | 11. Visual and sound effects | 4.12 | 0.73 | High |
| | 12. Multimedia system | 4.18 | 0.69 | High |
| | 13. Instructions and Manuals | 4.33 | 0.64 | High |
| | 14. Overall screen | 4.37 | 0.68 | Highest |
| | 15. Screen design process | 4.27 | 0.54 | Highest |
| Usability and attitude | 16. Membership system | 4.01 | 0.75 | High |
| | 17. Back-end and search system | 3.93 | 0.73 | High |
| | 18. Link and interaction section | 4.28 | 0.61 | Highest |
| | 19. How to use it for the purpose | 4.19 | 0.68 | High |
| | 20. Practice in the course | 4.42 | 0.75 | Highest |
| | 21. Cognition of learning activities | 4.45 | 0.69 | Highest |
| | 22. Implementation for Education Administrators | 4.38 | 0.71 | Highest |
| | Total | 4.27 | 0.67 | Highest |

Table 2 showed student satisfaction with using the system in three areas: system components, screen design and content, and usability. It was found that the overall system satisfaction was at a highest level in all aspects ($\bar{x}$=4.27, S.D.=0.67). When considering three aspects, it was found that for 7 items of the system, the overall picture was at a high level ($\bar{x}$=4.25). The averages were sorted from least to most significant in 3 orders: 1) website, 2) learning activities, and 3) pictures of various activities, respectively, with the highest level on the website. In terms of screen design and content, 8 items, the overall picture was at a high level ($\bar{x}$=4.22), arranged in 3 descending orders of average values: 1) content and consistency, 2) overall screen, and 3) instructions and manuals, respectively, with the highest level of content and consistency. As for the usage aspect, 7 items, the overall picture was also high ($\bar{x}$=4.34). The mean was sorted from highest to lowest in 3 orders, namely 1) cognition of learning activities, 2) practice in the course, and 3) implementation for Education Administrators. respectively, with the highest level in terms of cognition of learning activities.

3) The results of the interviews about student' opinions towards the model of a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner included 5 issues, as follows:

3.1 Knowledge and implementation found that students have a learning management system suitable for teaching and learning styles at the graduate level for issues related to Transformational Leadership Educational Management in Digital Education. As well as the ability to apply knowledge to become an educational administrator in the digital era, including future research design.

3.2 Behavior and response were found that students use the interaction section with the instructor and between learners together; that they practice this in the course (as group discussion, One-on-one discussion, brainstorming, doing exercises and presentation of assignments); they can use a search system and link sections related to the course, and record knowledge for exchanging and sharing knowledge. The students can also develop themselves. Moreover, Learners can enhance their competencies and potential as digital transformation administrators to prepare them to become future education administrators.

3.3 Participation found that the system can motivate students to use it to create an atmosphere of exchange and transfer knowledge in social media, participatory operations, and creative-based learning. It also helps students to update leadership skills and strategies for building a modern educational platform.

3.4 The utilization results showed that students were satisfied with the system by applying their knowledge and skills of creative leadership. It also helped build learning skills in effective transformation leadership educational management in digital education.

3.5 Problems and suggestions found students want a system to customize the screen by themselves to be more beautiful, as well as more attractive. When accessing this course, as with other social networks, practice sessions should be timed appropriately for both learning theory and practice in the course.

***System performance improvement results***

The research team synthesized the results of testing and trials of the system from the expert quality assessment and student satisfaction assessment to improve the system's efficiency. Then, five experts in ICT systems and education innovation were interviewed for a definitive review. An experts continue to provide feedback and suggestions for further improvements in system performance by developing interactive digital content. Online interactions include other techniques and methods for further improvement of academic achievement.

**Research results according to objective 2**

Designing and creating, testing, using and evaluating a prototype of the creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner found that the system developed according to the methods presented here can be assured of sufficient quality for effective implementation of this system in teaching and learning at the graduate level.

## CONCLUSION AND DISCUSSION

The research results can be summarized and discussed in crucial issues according to the objectives and research process as follows:

### Conclusion

1) Research and development methods for a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner consisted of 4 steps: 1) Analysis of user requirements, 2) System design and development, 3) Usability testing and evaluation, and 4) System performance improvement. Design and development result in a system with important characteristics, such as a system that can actually be used for teaching and learning in the course. The system must support the teaching and learning process with complete support functions, provide operating sections consistent with the course content, and have practical learning and relevant case studies to enhance knowledge and understanding. In addition, the system must be able to operate according to the specified schedule and should use a Content Management System to make the system perfect.

2) Design and development of a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner. A standard ICT development process should be used to develop a learning system.

It determines clear procedures and practices to obtain a system that can fully respond to learning management in a given course or content.

3) An analysis of the study analyzing the efficiency and satisfaction of using a creative-based learning management platform on Transformational Leadership Educational Management in Digital Education for graduate learner yield this results:

3.1 The efficiency of using the system from experts' opinions was a high level ($\bar{x}$=4.18, S.D.=0.55), indicating that the developed system could be used as a tool for teaching in the course. This system can be used as effective learning and implementation tool in course. It can also support learning about Transformational Leadership Educational Management in Digital Education.

3.2 Overall satisfaction from the students' opinions of using the system was a highest level ($\bar{x}$=4.27, S.D.=0.67), indicating that the students who used this system had a satisfactory level of satisfaction because this system can respond well to the management of learning about Transformational Leadership Educational Management in Digital Education.

**Discussion**

Discussion of this research includes, related parts under these headings:

1) Developed system prototype the researcher has applied the conceptual framework for research and development from the ideas of Murai & Muramatsu (2020), Kant, Prasad, and Anjali (2021), and Kim, Beyerlein, Wang, and Han (2023). to design the following steps: (1) course content analysis; (2) system design by ordering content, classify subject subjects according to learning principles, assign learning activities, determine the relevant research resources, creating a virtual learning room, and knowledge processing; (3) the development of the system based on the principles of 4Is: Information, Interactive, Individual and Immediate Feedback; (4) the use of the system for teaching and learning based on the communication channels provided; and (5) testing for the efficiency of the system is mainly based on the opinions of students.

2) The evaluation results by experts found that the developed system is suitable for a high level. It shows that the developed prototype system has this quality and that it can be used in practice because the researcher develops the lessons systematically from the study and analysis of the data using the ADDIE process, which experts have reviewed. After that, the data are tested with the sample to evaluate the efficacy and to apply the results for improvement. It is a method of conducting media production according to research and development (R&D) and relying on trials and modifications to be as complete as possible. That is consistent with the research work of Phakamach, Wachirawongpaisarn, and Panjarattanakorn (2021), Demir, Maroof, Sabbah Khan, and Ali (2021), Trivedi, Patra, and Singh (2022), Ma, Lu, and Tang, (2023), and Xiao & Wang (2023). However, to get a good model and make students understand the subject matter more, some aspects of multimedia and graphics system design should be improved related to the operation. This is required to make the system more complete and provide more educational options.

3) The satisfaction assessment results by students found that the developed system showed highest satisfaction. It shows that students can learn about Transformational Leadership Educational Management in Digital Education. The system can support learning management very well. That is consistent with the research by Raymundo (2020), Wang et al. (2021), Singh, Sharma, and Paliwal (2021), Hamdan et al. (2022) and Xiao & Wang (2023) that found that developing a sound model system requires at least four elements: i. data source and content, ii, support resources; iii, discussion boards; iv, online learning activities; and that case studies help learners understand, which can be used to create a virtual learning model. (Parramore, 2019). Therefore, the prototype system has all the elements that can be used as a system to support learning management in this course.

4) The results of confirmation of the system used by experts from group interviews found that the challenge-based learning management platform can be a support system for teaching and learning at the graduate level. It can enable students to gain theoretical knowledge and practice learning experiences in the study. Therefore, it can be confirmed that the system's efficiency was developed from the international elements and procedures for developing a quality learning management system (Presicce et al., 2020; Kant, Prasad, & Anjali, 2021; Tam, 2022; Gioiosa & Kinkela, 2022).

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## REFERENCES

Asad, M.M., Hussain, N., Wadho, M., Khand, Z.H., & Churi, P.P. (2021). Integration of e-learning technologies for interactive teaching and learning process: an empirical study on higher education institutes of Pakistan. *Journal of Applied Research in Higher Education,* 13(3): 649-663.

Buasuwan, P. (2018). Rethinking Thai higher education for Thailand 4.0. *Asian Education and Development Studies,* 7(2): 157-173.

Demir, A., Maroof, L., Sabbah Khan, N.U. & Ali, B.J. (2021). The role of e-service quality in shaping online meeting platforms: A case study from higher education sector. Journal of Applied Research in Higher Education, 2021, 13(5), 1436-1463.

Gabaree, L., Rodeghiero, C., Presicce, C., Rusk, N., & Jain, R. (2020). Designing creative and connected online learning experiences. *Information and Learning Sciences,* 121(7/8): 655-663.

Garbin, F.G.d.B., Ten Caten, C.S., & Jesus Pacheco, D.A.d. (2022). A capability maturity model for assessment of active learning in higher education. *Journal of Applied Research in Higher Education,* 14(1): 295-316.

Gioiosa, M.E., & Kinkela, K. (2022). Assessing the outcomes of an active learning exercise. Journal of Applied Research in Higher Education, 14(4), 1496-1508.

Hamdan, K.M., Al-Bashaireh, A.M., Zahran, Z., Al-Daghestani, A., AL-Habashneh, S., & Shaheen, A.M. (2021). University students' interaction, internet self-Efficacy, self-regulation and satisfaction with online education during pandemic crisis of COVID-19 (SARS-CoV-2). International Journal of Educational Management, 35(3), 713-725.

Huang, X., & Lai, C. (2020). Connecting formal and informal workplace learning with teacher proactivity: a proactive motivation perspective. Journal of Workplace Learning, 32(6), 437-456.

Ismaili, Y. (2021). Evaluation of students' attitude toward distance learning during the pandemic (Covid-19): A case study of ELTE university. On the Horizon, 29(1), 17-30.

Kant, N., Prasad, K.D., & Anjali, K. (2021). Selecting an appropriate learning management system in open and distance learning: a strategic approach. Asian Association of Open Universities Journal, 16(1), 79-97.

Kim, J., Beyerlein, M., Wang, J., & Han, S.J. (2023). Building a nomological network for creative learning transfer focusing on leadership development. *Leadership & Organization Development Journal,* 44(5): 643-656.

Kayes, D.C., Wirtz, P.W., & Burgi-Tian, J. (2024). Overcoming unpleasant affective experiences while learning: latent profiles of resilience while learning. *Journal of Management Development,* 43(1): 103-123.

Laudon, K.C. & Laudon, J.P. (2019). *Management Information Systems.* (15th ed.). New York: Pearson Education Indochina.

Lyapina, I., Sotnikova, E., Lebedeva, O., Makarova, T. & Skvortsova, N. (2019). Smart technologies: perspectives of usage in higher education. International Journal of Educational Management, 33(3), 454-461.

Ma, J., Lu, Y., & Tang, J. (2023). The differential effect of learning from others on creative performance over individual tenure: empirical evidence from open innovation communities. *Journal of Knowledge Management,* 27(9): 2329-2349.

Murai, Y., & Muramatsu, H. (2020). Application of creative learning principles within blended teacher professional development on integration of computer programming education into elementary and middle school classrooms. *Information and Learning Sciences,* 121(7/8): 665-675.

Panjarattanakorn, D. & Phakamach, P. (2020). Development of a learning management system platform for educational administration theory and innovation. *Proceedings of the Academic conference and dissemination of selected research results in national education disciplines for the year 2020.* 3 February 2020, Association of Private Higher Education Institutions of Thailand, Thailand, 817-828.

Parramore, S. (2019). Online active-learning: information literacy instruction for graduate students. Reference Services Review, 47(4), 476-486.

Phakamach, P. (2023). Educational innovation: elements and mechanisms for the development of Thai educational institutions towards internationalization. Journal of Education and Innovative Learning, 3(2), 161-179.

Phakamach, P., Senarith, P., & Wachirawongpaisarn, S. (2022). The metaverse in education: The future of immersive teaching & learning. RICE Journal of Creative Entrepreneurship and Management, 3(2), 75-88.

Phakamach, P., Wachirawongpaisarn, S., & Panjarattanakorn, D. (2021). Development of active learning management platform using constructivism on the topic of ICT system and innovation for educational administration at graduation level. Journal of Education and Innovative Learning, 1(3), 219-237.

Presicce, C., Jain, R., Rodeghiero, C., Gabaree, L.E., & Rusk, N. (2020). WeScratch: an inclusive, playful and collaborative approach to creative learning online. *Information and Learning Sciences,* 121(7/8): 695-704.

Raymundo, M.R.D.R. (2020). Fostering creativity through online creative collaborative group projects. *Asian Association of Open Universities Journal,* 15(1): 97-113.

Singh, A., Sharma, S. & Paliwal, M. (2021). Adoption intention and effectiveness of digital collaboration platforms for online learning: the Indian students' perspective. Interactive Technology and Smart Education, 18(4), 493-514.

Sinlarat, P. (2020). The path to excellence in Thai education. RICE Journal of Creative Entrepreneurship and Management, 1(2), 60-75.

Tam, S. (2022). Humor and learning styles: toward a deeper understanding of learning effectiveness in the virtual environment. Qualitative Research Journal, 22(2), 143-156.

Trivedi, S.K., Patra, P. & Singh, S. (2022). A study on intention to use social media in higher education: the mediating effect of peer influence. Global Knowledge, Memory and Communication, 2022, 71(1/2), 52-69.

Wang, X., Lin, W., Jiang, Y., Wu, Y., Liu, Y., & Zhou, W.-Q. (2021). Active learning and instructor accessibility in online talent training: a field experiment in China during COVID-19. Development and Learning in Organizations, 36(1), 14-16.

Xiao, W.H., & Wang, M. (2023). A new conceptual model for assessing the role of knowledge cloud in stimulating subordinate creativity. *Kybernetes,* 52(1): 75-96.

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# A Review: The Impact of Micro: Bit-Assisted STEM Education

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**Abstract.** BBC micro:bit is seen to enhance students' creativity especially in solving interdisciplinary problems such as STEM Education. However, there is limited literature that examines the effect of BBC micro:bit-assisted STEM learning. Thus, this study seeks to present a review of the characteristics of micro:bit-assisted STEM research, the effect of micro:bit-assisted STEM learning on student learning outcomes, and opportunities for micro:bit-assisted STEM research. This study reviews empirical research results from 12 papers published over the past five years. The papers are generally from Scopus and web of science indexed journals. Apparently, a lot of micro:bit-assisted STEM education research was conducted in 2022. The respondents came from primary school, secondary school, elementary school, and teachers. BBC micro:bit is implemented in STEM, STEAM, informatics, robotics, and technology learning content. Micro:bit-assisted STEM learning can improve students' 21st-century skills, attitudes, and knowledge that are meaningful to themselves and the environment. In addition, there are many opportunities to develop micro:bit-assisted STEM learning strategies such as looking at the performance of male and female students after solving problems with micro:bit.

**Keywords:** Micro: bit, STEM, Micro: bit-assisted STEM

## INTRODUCTION

BBC micro:bit is a pocket-sized computer operated with coded programs mainly using the block coding system or Micropython (see figure 1)(Fojtík et al., 2023; Voštinár & Knežník, 2020). Micro:bit is part of the BBC which was created in 2014 in collaboration with 29 expert companies and institutions such as Microsoft, Lenovo Foundation, Nominet, and others (Cheng et al., 2021). Since 2016, micro:bit has been distributed to 11-12-year-old students in the UK. The Micro:bit is cost-effective, online coding, and requires no installation, allowing projects to be simple or complex through advanced code and periphery units (Digranes et al., 2021; Videnovik et al., 2018). Micro:bit was developed to enhance the digital skills of youth. Micro:bit supports STEM education, especially for primary and secondary school students. Diversifying students who choose STEM subjects as they progress in school and in their careers is the goal of micro:bit. An estimated 44 million young people from 60 countries have benefited from learning with micro:bit. Micro:bit is a great help for young people in mastering digital skills especially those who want to pursue a career in STEM.

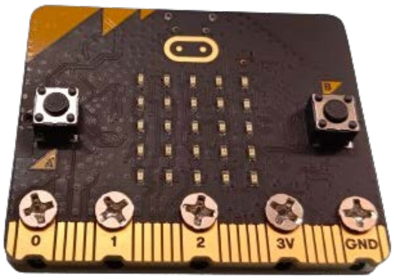


Figure 1. Micro:bit display

Teachers and students in England have widely recognized that micro:bit has a positive impact on students. There are several reasons England chooses micro:bit for learning, namely: student motivation is increased even for students who come from different backgrounds (Krnac et al., 2020). When creating projects with micro:bits there is often cooperation between equipment and nature (Krnac et al., 2020). Various complex and challenging tasks can train students to work together in teams naturally. Another advantage is to train students to solve STEM interdisciplinary problems. Many students recognize that micro:bit is useful for solving programming problems and creating real-world classifications (Krnac et al., 2020). In addition, students can also make connections between devices and STEM fields (Krnac et al., 2020). Therefore, micro:bit encourages students to think more complexly in solving problems.

Micro:bit supports STEM learning, especially science. STEM learning incorporates physical computing applications, microcontroller boards, digital components, sensors, motors, and other technological tools to encourage active learning of STEM topics through individual and group projects (Garcia-Ruiz et al., 2021). Previous research has reviewed the effect of micro:bit on student learning outcomes. Students and teachers had favorable attitudes towards micro:bit, showed enthusiasm, and found it interesting. Students think it encourages creativity and can help them understand conceptual and procedural knowledge related to computational thinking and problem-solving (Kalogiannakis et al., 2021). However, the research has not focused on STEM fields. Another similar study identified several challenges associated with the use of Micro:bit in science education, such as the lack of teacher training and support, limited access to technology, and the need for further research into its effectiveness (Quyen et al., 2023). However, these studies have not provided an overview of the influence of micro:bit on student performance and only focus on the field of science. Therefore, it is interesting to review the literature on the effect of BBC micro:bit-assisted STEM education. Hopefully, future teachers and researchers will be able to develop effective interdisciplinary learning strategies that suit the needs of students.

## RESEARCH OBJECTIVES

1. What are the characteristics of micro:bit-assisted STEM research?
2. How does micro:bit-assisted STEM affect student learning outcomes?
3. What are the opportunities of micro:bit-assisted STEM research for future studies?

## METHODOLOGY

To assess the current use of BBC micro:bit in STEM education, we conducted a systematic review from 2020 to 2024. The first database source was the Researchrabbit website with the keywords micro:bit, STEM, and education with a total of 2 papers search results. The second source, namely a search via Google Scholar using the keywords micro:bit and STEM, obtained 1,400 search results. The criteria for accepted papers are English language, full paper available, empirical research, and The studies should be in the field of STEM education with the support of micro:bit. The study steps are deleting duplicate papers, reading the title and abstract deleting papers that do not meet the criteria, reading the full paper, and deleting papers that do not meet the criteria. Finally, there were 12 papers that met the criteria for review that had been published over the last five years. These papers generally came from Scopus-indexed journals (n = 8 papers), Web of Science (n = 3 papers), and non-indexed journals (n = 1 paper). Detailed information about the papers analyzed can be found in Appendix 2 including the country of origin of the first author and journal index.

## RESULTS AND DISCUSSION

### Characteristics of micro:bit studies

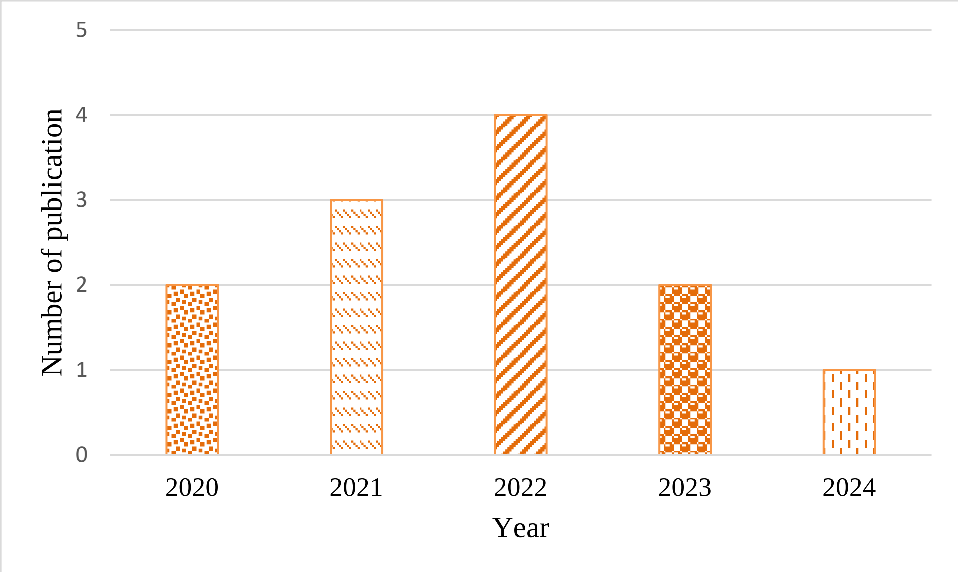


**Figure 2. Existence of literature on micro:bit research, spanning the last five years**

Science learning assisted by micro:bit has appeared since 2020. Based on Figure 2, the most research on the application of micro:bit in learning was carried out in 2022, namely 4 publications. From 2021 to 2022, research on micro:bit increases and decreases again in 2023. In 2020-2021 and 2023-2024 research on micro:bit is quite stable.

**Table 1. Characteristics of Micro:bit assisted STEM Learning**

| First Author | Education level | Sample | Instructional strategy | Education content | Data Analysis |
|---|---|---|---|---|---|
| (Minić & Deretić, 2023) | Primary school | 28 (students) | Not mentioned | Technique and Technology | Descriptive statistics |
| (Kalelioglu & Sentance, 2020) | Not mentioned | 50 (teachers) | Not mentioned | Computing | Quantitative data using IBM SPSS Statistics 24 and quantitative data using coding |
| (Lu et al., 2022) | Primary school | 3 (students) | PBL-oriented STEAM | STEAM Subjects | Not mentioned |
| (Cederqvist, 2022b) | Primary and high school | 14 (students) | Paper tutorial | Programmed technological solutions (PTS) | Coding and analysis in a systematic way |

**Table 2 (Cont')**

| First Author | Education level | Sample | Instructional strategy | Education content | Data Analysis |
|---|---|---|---|---|---|
| (Cederqvist, 2022a) | Primary and high school | 14 (students) | Paper tutorial | Programmed technological solutions (PTS) | Analysed by taking the phenomenographic approach |
| (Shahin et al., 2022) | Secondary school girls | 203 (students), 31 (mentors) | Workshop | Women in STEM and Entrepreneurship (WISE) program | SPSS Statistics 26 software and coding by NVIVO |
| (Kvaššayová et al., 2022) | Informatics in-service teachers | 388 students | Online webinar, Online course | Informatics | KMO and Bartlett's Test |
| (Kelly & Seeling, 2020) | High school | 41 students | Hands-on exercises | STEM related disciplines, with Computer Science and Software Engineering | ANOVA |
| (Cheng et al., 2021) | Elementary school | 22 students | Not mentioned | STEAM | Wilcoxon signed rank test and correlation test |
| (Fojtík et al., 2023) | Lower-secondary school | 121 (students) & 2 (teachers) | Not mentioned | STEM Activities | Transcribed and analysed using grounded theory |
| (Campina López et al., 2024) | secondary school | 26 (students) | A teaching-learning sequence based on inquiry, modelling, and computational thinking | STEM Context | Not mentioned |
| (Tan et al., 2021) | Secondary students | 22 (students) | Not mentioned | Robotics, technology, science | Triangulation EDA (electrodermal activity) data analysis |

Micro:bit-assisted STEM learning has been researched with various specific elements as shown in Table 1. Micro:bit has been applied at primary and secondary school levels with samples of 3 to 388 students. The micro:bit-assisted STEM studies involved students, teachers, and mentors. The learning strategies used include problem-based learning-oriented STEAM, paper tutorials, workshops, online webinars, online courses, hands-on exercises, and teaching-learning sequences based on inquiry, modeling, and computational thinking. Micro:bit-assisted STEM learning was implemented in the subjects of engineering and technology, computers, STEAM, STEM activities, programmed technological solutions (PTS), the Women in STEM and Entrepreneurship (WISE) program, Robotics, and informatics.

Data analysis is divided into two, namely qualitative data and quantitative data. Most quantitative data was analyzed using SPSS software, while qualitative data was analyzed using coding. More detailed characteristics of research in the STEM field using micro:bit can be found in Appendix 1.

**Impact of Micro:bit on pupils**

Previous research has examined the effect of micro: bits on learning, especially STEM-integrated science learning. The results showed an influence on students' knowledge, attitudes, and skills. The purpose of applying micro: bit in STEM learning is to increase students' knowledge and experience (Kelly & Seeling, 2020; Lu et al., 2022), for example, to encourage students' understanding of concepts (Campina López et al., 2024). Voštinár & Knežník (2020) found that students liked the lessons they worked on with BBC micro:bit and considered this work to be interesting and meaningful. Because the device promotes critical thinking and coding abilities among students by allowing them to program it themselves (Mersinllari & Papajorgji, 2022).

Micro:bit-assisted science learning has a positive impact on student performance in engineering and technology subjects (Minić & Deretić, 2023). The implementation of micro:bit-assisted STEAM curriculum improves disability creativity competence (Lu et al., 2022). In addition, the application of micro:bits is expected to assist students in solving real-world problems (Cederqvist, 2022a, 2022b; Shahin et al., 2022). STEM learning activities using micro:bit improve students' proportional reasoning, probabilistic reasoning, and ability to analyze a problem (Cheng et al., 2021). Micro:bit lessons with OGS significantly improve students' reasoning abilities. Because students are encouraged to solve problems by redesigning programming strategies or changing hardware when encountering difficulties (Cheng et al., 2021). It can be concluded that micro:bit can provide a complex science learning experience.

One example of implementing micro:bit to practice real-world problem solving skills is seen in Figure 3 and Figure 4 (Cederqvist, 2022b). A pair of students wanted to use a light sensor to detect differences in light levels if a cupboard door is open, which would activate a speaker to produce sound. To solve the problem, they discuss while arranging the appropriate blocks. With micro:bit, they can easily test whether the block works or not by connecting the micro:bit component to a computer/laptop. For example, students succeeded in uniting the IF/THEN block and connecting the other blocks with real world conditions. This learning is very interesting and challenging for students because what they have designed may have parts that need to be replaced or added. This really helps them in solving real world problems.

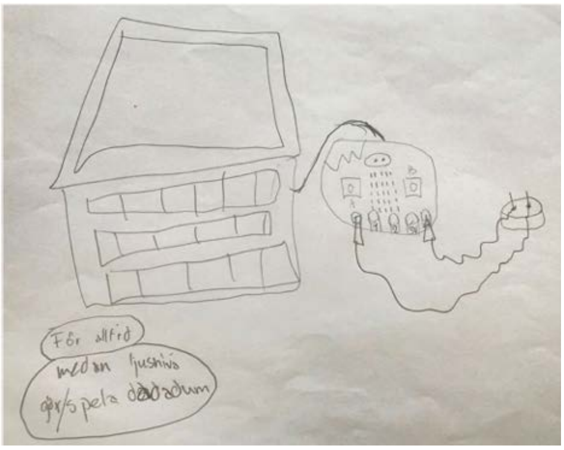

Figure 3. A pair of students create sketches to code the solution (Cederqvist, 2022b)

Figure 4. A pair of students start arranging blocks to find the right solution (Cederqvist, 2022b)

Micro:bit-assisted learning also influences students' positive attitudes. For example, research by Kvaššayová et al. (2022) revealed that the micro:bit has a positive impact on self-efficacy for instructional strategies. Science learning by applying micro:bit can increase positive attitudes toward computer science (Kelly & Seeling, 2020). Students become more sensitive to environmental problems and try to find solutions.

**Future research opportunities**

Research opportunities regarding micro:bit-based STEM learning are still quite extensive. Several recommendations presented by previous research to support the development of subsequent studies:

1. A comprehensive evaluation is warranted to assess the efficacy of integrating the micro:bit across educational levels, encompassing both teacher and student proficiency (Minić & Deretić, 2023).
2. Delve deeper into specific case studies to examine teachers' utilization of the micro:bit in teaching, analyzing their pedagogical approaches, and empirically studying its impact on programming comprehension. Additionally, investigate preferred learning modalities in physical programming (Kalelioglu & Sentance, 2020).
3. Explore the advantages and limitations of various programming materials for teaching content related to Programming, Technology, and Society (PTS) in design activities (Cederqvist, 2022b).
4. Investigate the procedural evolution of designing PTS using programming tools like the BBC Micro:bit, assessing its facilitative and constraining factors on digital and technological literacy (Cederqvist, 2022a).
5. Conduct similar research utilizing alternative technologies to the BBC Micro:bit within the same demographic, enriching insights with microteaching analysis of the teaching process (Kvaššayová et al., 2022).
6. Examine gender disparities in online STEM courses, given previous findings suggesting differing interests between male and female students. Notably, post-Micro:bit course, there appears to be an increased interest in coding among girls (Cheng et al., 2021; Berweger et al., 2014; Videnovik et al., 2018).

Micro:bit-supported STEM education presents significant opportunities, particularly in Asian contexts. Initiatives should prioritize training for STEM educators to effectively integrate the micro:bit into their teaching methodologies.

## CONCLUSION AND IMPLICATIONS

This study reviews previous research on the influence of micro:bit in STEM learning. The number of articles that met the criteria was 12 articles, which generally came from Scopus-indexed journals. Over the last five years, micro:bit has been studied in 2022, with 4 papers. Most micro:bits are trained in STEM learning content including technology, informatics, and STEAM programs. Micro:bit has been widely used at secondary and primary school levels. STEM learning using micro:bit can significantly improve students' knowledge, attitude, and skills. Future research opportunities include a study of teachers' trends in designing STEM learning using micro:bit. In addition, future research can examine the differences in the performance of female and male students in micro:bit-assisted STEM learning.

## REFERENCES

Berweger, S., Buschor, C. B., Frei, A. K., & Kappler, C. (2014). Was braucht es, damit die Ingenieurwissenschaften bei der Studienwahl von an MINT-Fächerninteressierten Gymnasiastinnen in die enge Wahl kommen? (What does it take for engineering sciences to be on the short list when choosing a course of study for high school students interested in MINT subjects?). Gruppe. Interaktion. Organisation. Zeitschrift Für Angewandte Organisationspsychologie (GIO), 4(45), 339–358. http://dx.doi.org/10.1007%2Fs11612-014-0250-6

Campina López, A. C., Lorca Marín, A. A., De Las Heras Pérez, M. Á., & Bosnjak Stepanovic, M. (2024). The concept of pH and its logarithmic scale: A Micro Bit experience through inquiry, modeling, and computational thinking. Eurasia Journal of Mathematics, Science and Technology Education, 20(4), em2424. https://doi.org/10.29333/ejmste/14378

Cederqvist, A.-M. (2022a). An exploratory study of technological knowledge when pupils are designing a programmed technological solution using BBC Micro:bit. International Journal of Technology and Design Education, 32(1), 355–381. https://doi.org/10.1007/s10798-020-09618-6

Cederqvist, A.-M. (2022b). Designing and coding with BBC micro:bit to solve a real-world task – a challenging movement between contexts. Education and Information Technologies, 27(5), 5917–5951. https://doi.org/10.1007/s10639-021-10865-w

Cheng, P.-J., Liao, Y.-H., & Yu, P.-T. (2021). Micro:bit Robotics Course: Infusing Logical Reasoning and Problem-Solving Ability in Fifth Grade Students Through an Online Group Study System. The International Review of Research in Open and Distributed Learning, 22(1), 21–40. https://doi.org/10.19173/irrodl.v22i1.4844

Digranes, I., Hoem, J., & Stenersen, A. L. (2021). Learning about materiality through tinkering with Micro:bits. FormAkademisk - Forskningstidsskrift for Design Og Designdidaktikk, 14(4). https://doi.org/10.7577/formakademisk.4636

Fojtík, M., Cápay, M., Medová, J., & Valovičová, Ľ. (2023). Activities with BBC micro:bit as a Foundation for Statistical Reasoning of Lower-Secondary Students. Mathematics, 11(14), 3206. https://doi.org/10.3390/math11143206

Garcia-Ruiz, M. A., Alvarez-Cardenas, O., & Iniguez-Carrillo, A. L. (2021). Experiences in Developing and Testing BBC Micro: Bit Games in a K-12 Coding Club during the COVID-19 Pandemic. 2021 IEEE/ACIS 20th International Fall Conference on Computer and Information Science (ICIS Fall), 161–164. https://doi.org/10.1109/ICISFall51598.2021.9627364

Kalelioglu, F., & Sentance, S. (2020). Teaching with physical computing in school: The case of the micro:bit. Education and Information Technologies, 25(4), 2577–2603. https://doi.org/10.1007/s10639-019-10080-8

Kalogiannakis, M., Tzagaraki, E., & Papadakis, S. (2021). A systematic review of the use of BBC micro: Bit in primary school. International conference New Persspectives in Science Education.

Kelly, D. G., & Seeling, P. (2020). Introducing underrepresented high school students to software engineering: Using the micro:bit microcontroller to program connected autonomous cars. Computer Applications in Engineering Education, 28(3), 737–747. https://doi.org/10.1002/cae.22244

Krnac, R., Capay, M., & Koprda, S. (2020). Education with physical device BBC micro:bit. 2020 18th International Conference on Emerging eLearning Technologies and Applications (ICETA), 352–357. https://doi.org/10.1109/ICETA51985.2020.9379166

Kvaššayová, N., Cápay, M., Petrík, Š., Bellayová, M., & Klimeková, E. (2022). Experience with Using BBC Micro:Bit and Perceived Professional Efficacy of Informatics Teachers. Electronics, 11(23), 3963. https://doi.org/10.3390/electronics11233963

Lu, S.-Y., Wu, C.-L., & Huang, Y.-M. (2022). Evaluation of Disabled STEAM – Students' Education Learning Outcomes and Creativity under the UN Sustainable Development Goal: Project-Based Learning Oriented STEAM Curriculum with Micro:bit. Sustainability, 14(2), 679. https://doi.org/10.3390/su14020679

Mersinllari, E., & Papajorgji, P. (2022). The impact of micro:bit technology use on improving students' coding skills. Ingenious, 2(1), 29–36. https://doi.org/10.58944/wusw7877

Minić, S., & Deretić, N. (2023). Experience with using BBC micro: Bit in teaching. Obrazovanje i Vaspitanje, 18(20), 33–44. https://doi.org/10.5937/obrvas18-47112

Quyen, K. T., Bien, N. V., & Thuan, N. A. (2023). Micro: Bit in Science Education: A Systematic Review. Jurnal Penelitian Dan Pembelajaran IPA, 9(1), 1. https://doi.org/10.30870/jppi.v9i1.19491

Shahin, M., Gonsalvez, C., Whittle, J., Chen, C., Li, L., & Xia, X. (2022). How secondary school girls perceive Computational Thinking practices through collaborative programming with the micro:bit. Journal of Systems and Software, 183, 111107. https://doi.org/10.1016/j.jss.2021.111107

Tan, A. L., Gillies, R., & Jamaludin, A. (2021). A Case Study: Using a Neuro-Physiological Measure to Monitor Students' Interest and Learning during a Micro:Bit Activity. Education Sciences, 11(8), 379. https://doi.org/10.3390/educsci11080379

Videnovik, M., Zdravevski, E., Lameski, P., & Trajkovik, V. (2018). The BBC Micro:bit in the International Classroom: Learning Experiences and First Impressions. 2018 17th International Conference on Information Technology Based Higher Education and Training (ITHET), 1–5. https://doi.org/10.1109/ITHET.2018.8424786

Voštinár, P., & Knežník, J. (2020). Education with BBC micro:bit. International Journal of Online and Biomedical Engineering (iJOE), 16(14), 81. https://doi.org/10.3991/ijoe.v16i14.17071

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# Development of Grade 11 Students' the 21st Century Skills about Critical Thinking in Learning about Reproduction of Flowering Plants through Science Technology and Society (STS) Approach

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**Abstract**. This research aimed to enhance Grade 11 students' 21st century skills about critical thinking in learning about reproduction of flowering plants through Science Technology and Society (STS) Approach. Methodology regarded interpretive paradigm. The participants of this study were 45 Grade 11 students consisted of 29 females and 16 males (aging between 16-17 yours old) in a large sized urban public high school located in the northeastern of Thailand. The STS reproduction unit consisted of 5 lesson plans (7 hours) aligned with each stage of Yuenyong (2006) STS approach. Students' critical thinking abilities were interpreted via participant observations, students' worksheets, and informal interviews. The data analysis aimed to categorize students' abilities align with Nakmanurak (1994) structured framework of critical thinking. This structured framework comprising seven steps: 1) identifying the problem, 2) collecting information, 3) evaluating the credibility of information sources, 4) identifying relevant information, 5) formulating hypotheses, 6) drawing conclusions, and 7) evaluating the process and outcomes. Findings revealed that the majority of students held good ability of critical thinking. Even though students could share their ability thinking in the same ability, they had different levels of ability in each element.

**Keywords:** Science Technology and Society, Critical thinking, Reproduction

## 1. INTRODUCTION

Scientific literacy is a key focus for Thai citizens in order to help them and the nation or survive in a globally competitive economy. Scientific literacy related to student ability of applying scientific knowledge for solving issues in everyday life (Yuenyong and Narjaikaew, 2009). Critical thinking plays a vital role in science learning, enabling students to analyze information, evaluate evidence, and construct informed conclusions. This literature suggested that the integration of critical thinking in science education, examining theoretical perspectives, instructional strategies, and empirical research on fostering critical thinking skills in the context of science learning (Dam and Volman, 2004; Yuenyong, 2017; Zoller, 1993).

Education of Thailand should be modification because learners in the 21st century need to be developed learning skills to be able to live in society effectively. Then, student must cultivate the necessary skills to sustain life (Osman et al., 2009). In addition to promoting deep understanding of the content and supplement 21st century skills into all core subjects (Bellanca& Brandt, 2011). Many educators have believed the ability to learn is more important than specific knowledge that important skill is critical thinking (Kitroongrueng, 2010). Science education researchers have shown that students may be successful in performing such assignments provided they were exposed to teaching that included both critical thinking and required student practice (Zoller et al., 2002; Ten Dam and Volman, 2004). Due to, critical thinking are higher-order cognitive skills (HOCS) that require deep conceptual understanding (Zoller, 1993). In terms of working, people with the thinking skills and communication skills as well, it will lead to fast learner, can solve the problem, creativity and able to offer their opinion clearly. Thus, teaching should focus on the development of critical thinking (Bassham et al., 2005). Characteristics of instruction that are assumed to enhance critical thinking are promoting active learning, problem-based curriculum, stimulating interaction between students and learning based on real-life situations (Dam and Volman, 2004).

To construct the framework of critical thinking for educational research, we found that critical thinking was perceived in various definitions. However, it has some consensus. We can detect considerable commonality: Good critical thinking is reasonable, critical thinking involves a careful consideration of evidence; Critical thinking is oriented towards making a definite judgment; the ideal " critical thinker" thinks critically whenever it is appropriate; being a critical thinker involves knowledge, skills, attitudes, and dispositions.

According to the vague definition of critical thinking, some literatures suggested that we may consider beyond definitions to descriptions of critical thinking skills as well as attitudes and behavioral inclinations of a "critical thinker". Ennis (1987), Facione (1990), Fisher, and Scriven (1997) advanced the most developed theories of critical thinking's component skills. Ennis (1987) and Facione (1990) presented detailed descriptions of sub-skills. Despite variances, it has some fundamental critical thinking skills, such as clarifying meaning, analysing arguments, evaluating evidence, determining whether a conclusion follows, and drawing warranted conclusions. Additionally, some literatures developed conceptions of the dispositional and attitudinal components of a critical thinker (Ennis, 2016; Facione, 1990). The dispositional and attitudinal characteristics of a critical thinker shared common views such as open-minded, fair-minded, searching for evidence, trying to be well-informed, attentive to others' views and their reasons, proportioning belief to the evidence, and welling to consider alternatives and revise beliefs.

As a cognitive skill, Ennis (1987) offered a thorough framework for evaluating critical thinking in their seminal work. Their approach focuses on assessing both critical thinking dispositions and abilities, which include cognitive processes like inference, deduction, and analysis. The framework establishes explicit criteria and indicators for assessing critical thinking, allowing for a systematic evaluation of people's reasoning abilities. There are also differences about the role and importance of deduction in critical thinking, about the tolerance of imprecision, and about the relationship between critical thinking and the logical analysis of arguments. Nakmanurak (1994) suggested that critical thinking is a multifaceted skill essential for effective problem-solving and decision-making. This literature review examines research on analyzing students' critical thinking abilities through a structured framework comprising seven steps: identifying the problem, collecting information, evaluating the credibility of information sources, identifying relevant information, formulating hypotheses, drawing conclusions, and evaluating the process and outcomes.

Step 1: Identifying the Problem: Effective problem identification is foundational to critical thinking. Research suggests that students' ability to identify and define problems accurately correlates with their overall critical thinking skills. Studies have explored various instructional approaches, such as problem-based learning and case studies, to enhance students' problem identification abilities and foster critical thinking.

Step 2: Collecting Information: Gathering relevant information is a crucial aspect of critical thinking. Research has investigated the strategies students employ to collect and organize information effectively, including search strategies, information literacy skills, and use of digital resources. Additionally, studies have examined the impact of inquiry-based learning and research projects on students' information-gathering skills and critical thinking competencies.

Step 3: Evaluating the Credibility of Information Sources: Assessing the credibility of information sources is essential for informed decision-making. Research has examined students' ability to evaluate the reliability, validity, and bias of sources, including print and digital resources. Educational interventions focusing on media literacy and source evaluation skills have been shown to improve students' critical evaluation of information sources.

Step 4: Identifying Relevant Information: Discerning relevant information from a plethora of data is a critical thinking skill. Studies have explored students' ability to identify and prioritize information based on its relevance to the problem or inquiry at hand. Instructional strategies emphasizing concept mapping, graphic organizers, and concept-based learning have been found to support students in identifying and synthesizing relevant information effectively.

Step 5: Formulating Hypotheses: The formulation of hypotheses involves generating plausible explanations or predictions based on available evidence. Research has investigated students' proficiency in generating hypotheses, testing assumptions, and refining their thinking through iterative reasoning processes. Inquiry-based learning approaches, scientific inquiry tasks, and argumentation activities have been utilized to develop students' hypothesis-formulation skills and enhance critical thinking.

Step 6: Drawing Conclusions: Drawing logical conclusions based on evidence is a hallmark of critical thinking. Studies have examined students' ability to synthesize information, analyze patterns, and draw reasoned conclusions from data. Educational interventions focusing on structured reasoning tasks, argument mapping, and reflective writing have been shown to facilitate students' ability to draw informed conclusions and support their reasoning with evidence.

Step 7: Evaluating the Process and Outcomes: Reflection and evaluation are integral components of the critical thinking process. Research has explored strategies for promoting metacognitive awareness and self-assessment skills in students. Methods such as peer review, self-assessment rubrics, and reflective journals have been utilized to encourage students to evaluate their thinking process, monitor their progress, and identify areas for improvement in critical thinking skills.

Critical thinking is essential in science education because it allows students to gain scientific literacy and actively participate in the inquiry process. Theoretical frameworks, instructional tactics, assessment methodologies, and empirical studies all help us understand how to promote critical thinking in science education. By tackling obstacles and embracing creative techniques, educators may continue to improve students' critical thinking abilities and prepare them for active involvement in a scientifically literate society (Wongsila and Yuenyong, 2019; Yuenyong, 2013).

Several theoretical frameworks support the introduction of critical thinking into science education. The cognitive constructivist perspective stresses students' active participation in sense-making activities, which promotes inquiry-based learning and critical thinking. Social constructivism emphasizes the collaborative nature of knowledge formation, encouraging students to engage in discourse and arguments to improve their critical thinking skills. STS pedagogy frameworks emphasize the integration of real-world problems to promote critical thinking and ethical reasoning in science education (Attapan and Yuenyong, 2019; Suparee and Yuenyong, 2019; Yuenyong, 2006; Yuenyong, 2017).

Science technology and society approach begins with the society issues; learner must be aware of the social problems and find out the cause of problem. Then, students are finding a suitable ways for solving problems that using Prior Knowledge to develop ideas of the students. In addition, students collaborate with group members as well as the exchange of knowledge. Teachers should prepare issues that are related to science and sophisticated issues. As students will use the knowledge of many fields for find the answer (Yingchana, 2011). The goal of STS approach, enhance the scientific knowledge, enhance motivation to learning science and technology, Provides learners with critical thinking, creatively solve problems and make decisions based on credible information (Aikenhead, 1994). In this study, we use STS approach framework of Yuenyong (2006) consists of 5 stages: 1) identification of social issues 2) identification of potential solutions 3) need for knowledge 4) decision-making and 5) socialization stage that focuses on student's center. STS approach of Yuenyong (2006) has been used in the teaching of science subjects including physics, chemistry and biology. Many researchers have brought this method for teaching various subjects in biology such as genetics and DNA technology, genetics and biotechnology, biodiversity, homeostasis, etc. A results showed that higher achievement and development in various skills such as scientific literacy, decision making, analytical thinking, problem solving ability, understanding of the nature of science and aware of the social problems. (Aryowong, 2011; Phonhan, 2011; Ruksapukdee, 2012; Thipruetree, 2012; Waisalong 2012). This suggested that STS approach can promote critical thinking because critical thinking can be using efficacy solving problem (Hudgings and Edelman, 1988).

The STS approach is appropriate for teaching biology since biology is relevant to daily living. However, biology is difficult to master due to the nature of scientific teaching methods (Lazarewitz and Penso, 1992). They're interested in learning how to decline. Due to activities that do not align with the students' interests, a large amount of content, and a lack of opportunities to comment (Osborne and Collins 2001; Zeidan 2010). Furthermore, students believe that the subject is irrelevant or unrelated to everyday life, which leads to misconceptions (Griffthes, 2003). Students have misconceptions about fundamental principles such as pollination, plant reproduction, photosynthesis, plant physiology, and plant hormones. (Hershey, 2005). As a result, the purpose of this study was to investigate students' critical thinking abilities on the reproduction of blooming plants using Yuenyong (2006) STS approach. Regarding on Nakmanurak (1994), analyzing students' critical thinking through a structured framework comprising seven steps provides a comprehensive lens for understanding and assessing their cognitive processes. Research in this area underscores the importance of scaffolding instruction, providing authentic problem-solving tasks, and fostering metacognitive awareness to enhance students' critical thinking skills across diverse contexts.

## 2. METHODOLOGY

This research was a qualitative study focused on interpretive paradigm for study about grade 11 students' critical thinking while learning about the reproduction of flowering plants through Yuenyong (2006) Science Technology and Society approach, during the second semester of 2015 years, Banphai School. The study would emphasize on the importance of the students' critical thinking behaviour, expression during participating in learning activities, reflecting in their worksheet and writing diary for reflecting. Then data were interpreted and summarize

### *2.1 Participants*

The participants of this study were 45 eleventh – grade students consisted of 29 females and 16 males (aging between 16-17 yours old) in a large sized urban public high school located in the northeastern of Thailand. All of them never learned about plant reproduction.

*2.2 The intervention of STS unit of reproduction of flowering plants*

The unit consisted of 5 lesson plans (7 hours) aligned with each stage of Yuenyong (2006) STS approach.

The 1st lesson plan lasted one hour. The activities aligned into the stage of identification of social issues and stage of identification of potential solutions. The social issue was the farmer as newbies learning to grow pumpkins. The story of farmers as newbies learning to grow pumpkins was discussed in classroom. This story may engage students to identify the problems about growing pumpkins. And students raised the questions related to the issues in order to propose the possible solutions and what they need to learn about growing and selling pumpkins. Then, the issue of need for knowledge of reproduction of the plants was raised.

The 2nd lesson plan lasted two hours. The activities aligned with the stage of need for knowledge. First, activity of think pair share of "Why are the pumpkin flowers blooming in large numbers but there are few fruits?" was provided. Then, students did an experiment of studying the structure of different types of flowers, and experiment of classification of flower characteristics according to various criteria. Then, the activities for the stage of need for knowledge were further provided for two hours of the 3rd lesson plan. These activities included studying the characteristics and components of stamens and pistils, watching a video on fertilization of flowering plants, studying pollination and germination of pollen tubes, and summary of factors affecting pollination.

The 4th lesson plan lasted one hour to be provided aligning with the decision-making stage. The learning activities included listing of applying knowledge of science and other sciences for designing solutions to problems in the following issues: how to select the feasibility of that method, the cost of the solution to increase pumpkin yield, and methods that must increase both productivity and income for agriculture. And then, the activities of evaluating the benefits and disadvantages of each option were provided.

The 5th lesson plan lasted one hour to be provided aligned with the socialization stage. The learning activities included creating and sharing clip video of growing pumpkins to get good yields, and reporting the lesson learned from comments and reflection on the clip video.

*2.3 Data collection and analysis*

Students' critical thinking abilities were clarified during students' learning in the STS unit of reproduction of flowering plants. Students' critical thinking abilities were interpreted via participant observations, students' worksheets, and informal interviews. The data analysis aimed to categorize students' abilities align with Nakmanurak (1994) structured framework of critical thinking. This structured framework comprising seven steps: 1) identifying the problem, 2) collecting information, 3) evaluating the credibility of information sources, 4) identifying relevant information, 5) formulating hypotheses, 6) drawing conclusions, and 7) evaluating the process and outcomes. Students' critical thinking abilities, then, will be illustrated through score rubric as shown in Table 1. According to the table 1, the students' critical thinking will be categorized into very good ability when at least 3 elements fall into very good level, to be categorized good ability when 2 elements fall into very good level, and to be categorized poor ability when only one element fall into very good level or none.

Table 1: Rubric of students' critical thinking abilities regarding on Nakmanurak (1994) structured framework

| Elements of critical thinking abilities | Levels of ability | | |
|---|---|---|---|
| | Very good (3) | Good (2) | Poor (1) |
| Identify the Problem (IP) | Students' ability to identify and define problems accurately correlates the issues. And students have various approaches for the issues. | Students' ability to identify and define problems accurately correlates the issues. | Students identify the problem but did not relate to the issues. |
| Collecting Information (CI) | Students employ to collect and organize information effectively, including apply prior knowledge, search strategies, information literacy skills, and use of digital resources. Those collecting information support their problem solving. | Students employ to collect effectively, including apply prior knowledge, search strategies, information literacy skills, and use of digital resources. | Students employ prior knowledge for collect information. |
| Evaluating the Credibility of Information Sources (ECS) | Students assess the credibility of information sources is essential for informed decision-making. And students evaluate the reliability, validity, and bias of sources, including print and digital resources. | Students assess the credibility of information sources is essential for informed decision-making. | Students could find some information sources, however, it is not essential for informed decision-making |
| Identifying Relevant Information (RI) | Students identify and synthesize relevant information effectively by using concept mapping, graphic organizers, and so on. Then, students prioritize information based on its relevance to the problem or inquiry at hand. | Students identify and synthesize relevant information effectively by using concept mapping, graphic organizers, and so on. | Students identify relevant information but they did not provide clearly supporting. |
| Formulating Hypotheses (H) | Students generate hypotheses, testing assumptions, and refining their thinking through iterative reasoning processes (e.g. scientific inquiry tasks, argumentation activities, and so on). | Students generate hypotheses, and testing assumptions; but they did not refine their thinking based on available evidences. | Students provide some claims without direction of testing. |
| Drawing Conclusions (DC) | Students synthesize information, analyze patterns, and draw reasoned conclusions from data to inform pros and cons, use or abuse, advantage or disadvantage. And, their conclusion could be tracked reasoning with evidences; for example, they show structured reasoning, argument mapping, reflective writing, and so on. | Students synthesize information, analyze patterns, and draw reasoned conclusions from data to inform the orientation of decision making. | Students provide some claims without providing reasoning based on evidences. |
| Evaluating the Process and Outcomes (E) | Students evaluate the process and outcomes to confirm conclusion. And they apply methods (e.g. peer review, self-assessment rubric, reflective journals, and so on) to evaluate and improve their thinking. | Students evaluate the process and outcomes to confirm conclusion. | Students could not provide some information to confirm the conclusion. |

## 3. FINDINGS

The findings present the highlight overview of students' thinking abilities and how the STS unit of reproduction of flowering plants foster students' critical thinking abilities.

### *3.1 Overview of students' thinking abilities*

Students' critical thinking abilities were interpreted via participant observations, students' worksheets, and informal interviews during their studied in the STS unit of reproduction of flowering plants. Regarding on the table 1, students' critical thinking abilities could be categorized as the table 2.

Table 2: Categories of students' critical thinking abilities regarding on Nakmanurak (1994) structured framework

| Students' critical thinking ability | Category | Number of students |
|---|---|---|
| Very good | Very good ability category 1 | 1 |
| | Very good ability category 2 | 3 |
| Good | Good ability category 1 | 6 |
| | Good ability category 2 | 7 |
| | Good ability category 3 | 12 |
| | Good ability category 4 | 9 |
| Poor | Poor ability category 1 | 4 |
| | Poor ability category 2 | 3 |
| | Total | 45 |

According to the table 2, majority of students held good ability of critical thinking. Even though students could share their ability thinking in the same ability, they had different levels of ability in each element. These could be seen as the radar web for each category as below figure.

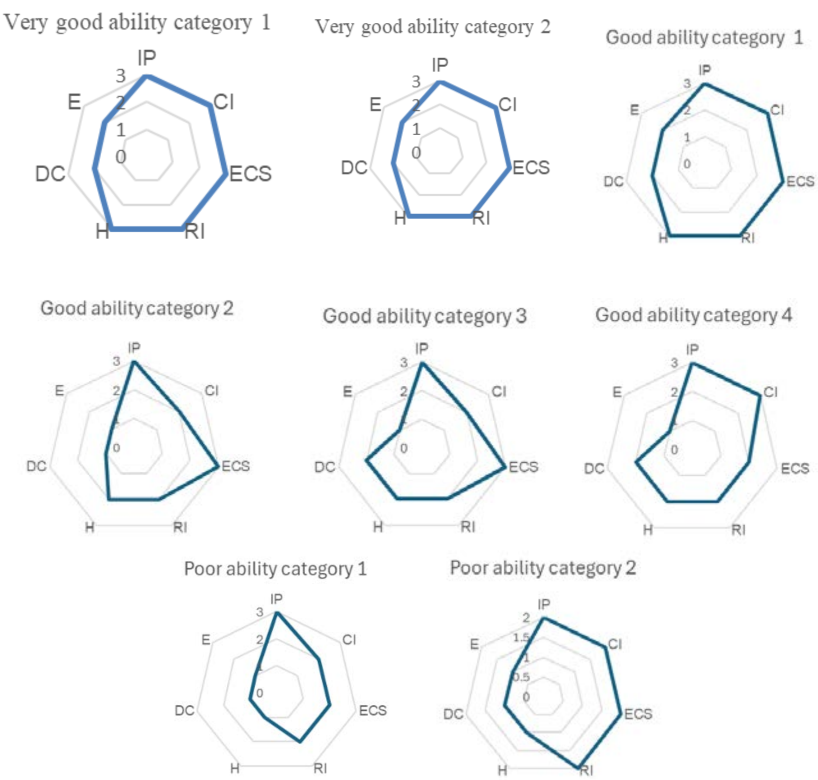


Figure 1: Categories of students' critical thinking abilities

*3.2 STS unit of reproduction of flowering plants foster students' critical thinking abilities*

Students' critical thinking abilities were clarified during students' learning in the STS unit of reproduction of flowing plants.

This research is qualitative research focusing on interpreting from word or passage of students that indicate to critical thinking. Student learning on reproduction of flowering plants by using STS approach in framework of Yuenyong (2006) that focuses on linking with everyday scientific that teacher teachers presented the problems in society of students or the situations that arise surrounding the students. There are 5 stages; each stage of STS teacher encourages students by question to promote thinking skills. The results from worksheets diary and observation in a classroom shown as follows.

First of all, identification of social issues stage began with situation about after the out of harvest season, farmer turned to plant pumpkin which it use less water and it spend less time harvest about three mouths.

When preparing to plant until pumpkin flower bloom but it found fewer products, thus didn't meet the expected targets. So farmers have slight profit which compared to the money invested. A situation is used to encourage students to resolve a problem. Because students are in the agricultural community. First of all, students need to identify of problems and the cause of trouble, for solving problems effectively. This activity will encourage students' critical thinking.

Stage 1 identification of social issues stage that students read the situation, they must say the main problem. Most students can identify issues correctly and to the point.

> "Pumpkins have many flowers but it lack fruit, As a result, it isn't followed in in target." (Watchaphol)
> "There are a lot of flowers, but pumpkins are less fruit." (Kanungnit)
> "Pumpkin has a little fruit." (Chomphoonuch)

Stage 2 identification of potential solutions stage, this stage student looking for a solution for help farmers to increase productivity. Then, member of each group brainstorm to consider the various issues that will be the only one of issues. After that, a representative of each group to present their group's opinion and tell the reasons solution was selected. Each group investigates information to help answer and assessment impart feasibility of the approach. Each groups brainstorm ideas that they should look for more information to encourage approach that are more credibility. This stage, student demonstrated the ability to think critically in terms of hypothesis. Students can use prior Knowledge to propose the ways for resolve the issue. It was found that they can propose interesting ideas and there is Reliable information which indicates that students can apply prior knowledge to find the answer. These are the following examples.

> "Human brings pollen to fertilize the female." (Kornkanok)
> "staminate flower are tapped into pistillate flower, using insects for pollination." (Wararat)
> "Farmers should plant more pumpkins and we don't use pesticides for keep insects to pollinate." (Chonlada)

Stage 3 Need for knowledge stage; Students learn biological content about reproductive flowering plants that consists of the structure of the flower, creating reproductive cells of flowering plants, Pollination and double fertilization. After learning about scientific knowledge, students will be check their knowledge gained from the activity in classroom and to study by them that there is enough information to solve the problem. According to analysis, form the answer question in activity found students shown behaviour about critical thinking 3 stages include; collecting information, credibility of sources of information, identify information.

**Collecting information**: students are learned in the classroom or inquiry from a variety of sources, they must choose content to solving problems that knowledge must be relevant to the issues. Form students' answers that it shown students have collecting information ability. In addition, there is knowledge from the activities in the classroom; there is another source such as books, website, from parents or village philosophers. Shows that students are interested, and students have ability to inquiry of knowledge. For example:

> "The structure of flowers consists of 4 parts; petal, sepal, stamen and pistil. Pumpkins flower are imperfect flowers which had affected difficult pollination, pollination of flowers in nature, fertilization of flowering plants. Pollen and egg were fertilized which called double fertilization. Finally, the flowers become fruit." (Kittipan)
>
> "Pumpkin is a biennial plant, solitary flower, monoecious. Insects are good pollinators. Some plants hormones can bring transformed male flowers to the female flowers. Pollination is the stamen fall on the stigma that It is important Plant breeding, if don't have pollination it doesn't have fruit." (Samita)
>
> "Pumpkin flowers are monoecious, stamen and pistil are each flower. Creating reproductive cells of flowering plants, male is sperms and female is egg cell which combination it will develop as a fruit. Insect water wind and rain are pollinators. Human can help plant breeding too." (Sirimanee)

**Credibility of sources of information**: The analysis is based on the knowledge that students have to solving problem. Students must identify credible information which must be able to tell sources of information. Found that students can determine the reliability of the data such as Get knowledge from teacher book, observing the laboratory and their experience. For example, as follows students' answers:

> "Content about structure of flower consist of 4 parts, data is reliable because it is derived from books and teachers." (KingKeaw)
>
> "Content about Pumpkin flowers aremonoecious which making difficult to breeding, information is reliable because of observation on activities in the classroom and teacher consultation and read a book." (Yodsaadee)
>
> "Some hormones can be transformed male flowers to the female flowers; there is credibility because I ask my parent who used this method that it can actually flowers gender." (Samita)

**Identify information**: Knowledge' students have already been mentioned above. They must able to identify the type of data such as fact, data from previous experience or opinion.Because, the students have realized that before decision solving problem, they requires enough knowledge and accurate. Students are able to solve the problem. The example illustrating student ability to identify information is given below:

> "Content about pumpkin flowers are monoecious which is fact. Due to the flowers of pumpkin is always monoecious." (Issariyaporn)
>
> "Plants must fertilize before it develops into a fruit. As well as the fertilization of human. But, plant occurs double fertilization that hybridization between sperm and egg and sperm and polar nuclei. It is the theory because has been studied until to publish a book." (Ratchaneekorn)

This stage, from students' answers is showed that when students learn about the reproduction of flowering plants. Students can conclude the cause of the problem more clearly. Due to, they are adopting knowledge about structure and type of flower to be the cause of the problem correctly such as farmers have been less producing because the nature of a pumpkin flower is imperfect flower which led to chance of pollinators difficult.

Stage 4 Decision-making stage, this stage is very important because students are applying the knowledge from need for knowledge stage and various sources, for analysis and conclusions in order to finding appropriate solutions and finding better ways of increasing productivity. In this stage, students expressed behavior of critical thinking 2 stages include; hypothesis and conclusion.Student are offered a solution, it appears that they are propose the ways more than two alternative, indicating most students know the cause of the problem which is caused by the morphology of the pumpkin flowers that lead to hard-pollination. Students are presented a rather solution direct cause. Students are using their skills to hypothesize the cause of the problem and selection of the data is used appropriately that they are offered a variety of possible solutions, explanation principle and explanation about good point and limitation of solution. Using scientific knowledge, expenses concerns, environmental concerns and concerns for producer and consumer safety etc. Moreover, students apply their knowledge for used to solve problems rationally. For example, content of plant hormones, agricultural knowledge and knowledge gained from the experience of the students. This activity promotes students to have analytical thinking about hypothesis and conclusion as explained in the following:

> "Important factors in pollination are insects that occur in nature. So, I want to raise bees around plot of field to pollinator's flowers. In order to have thoroughly insects and there are more chances of pollination, and income from the sale of honey. But, I Not sure bees can pollinate them 100%." (Praewa)
>
> "Important of insects are pollination. Therefore, I need to lure the insects to swarming the flowers. When insects like sucking nectar which brings hake's blue boy syrup mix with water that spraying to pumpkin at morning time to lure insects." (Kittisak)
>
> "Campaign to reduce the use of pesticides in the community because that will destroy insect that pollinators. Although, our garden isn't use it. But, other garden are used, it can reduce insects. The member. So, the campaign is a good approach, sustainability and safety of consumers. However, this way may take a long time." (Waraporn)
>
> "I would use plant hormones. I learned that auxin hormone which changes from male to female. This hormone is sold in the market because I've seen parents bring infuse longan, it Increase ovary when there are many ovary that the fruit has increased. But, It may be that fewer male flowers." (Boonsiri)

After students have presented various ways for solving problem. Student had to choose just one approach that is most appropriate. At this stage, students will illustrate the conclude ability which the consideration of the advantages and disadvantages of solution. There is an example described in the following.

> "Reducing use of pesticides for increase insects to pollination. Although, this way to destroy increasingly pumpkin. But it will be good for the environment and farmers, to increase pollination better." (Kittipan)
>
> "I chose to feed insects that it are bees and reduce usage of pesticides, because both have strong point that insects is a good pollinators which aren't pests, so it don't bite stem of pumpkins. It also helps increase income from sales of honey and honeycomb made beeswax. (Praewa)"
>
> "I want to hire worker for pollination because pollination will likely be the inevitable result. Although I pay hire workers, but the pumpkins have set well. As, pollen moves on the stigma." (Winutcha)
>
> "Applied perfume to lure insects because we don't have to hire a mixed that the use of natural resources to benefit." (Yodsawadee)

Stage 5 Socialization stages, in this stage, each member of the group to propose their solutions and discussion for choose the one suitable approach to offer to the community. The students in each group must choose a person and presentation methods to present. While each group discussions, they to apply their knowledge or recommendations from discussion, for consider possible solutions of their own. The results showed that the students had to evaluate their own conclusions that some people continue to do the same. But some people have been modified after discussion. For example, that the following words.

> "The consultant our group, I think that would combine two approaches which take plants hormone to transform sexual of pumpkin flower and beekeeping near the planation to use bees pollinate it." (Samita)

"I still use the same approach which is people are the main pollinators and I will reduce the use of pesticides, with a negative effect on health." (Salit)
"Using fabric softeners may affect to the pumpkin flowers is withered. I may use syrup instead of fabric softeners." (Prissana)

This stage, group of students transfer their knowledge to the community. The students choose the way of presentation, location, and person to present by themselves.

**4. Conclusions**

This research led Science technology and society approach used to teach biology, this approach is appropriate. Because biology related organisms which is located around the students. Thus, the issues happened for stimulating students' interest. From interpretation that students apply the knowledge and previous experience to answer the problem correctly. The students learned about the contents of the structure of the flower. They answered the question correctly about the cause of problem. Students apply knowledge from the classroom activities for designed to find solutions that there are rationale. The analysis illuminates that the process of critical thinking. STS approach can encourage students' critical thinking at each stage. As follows: First stage, this stage promotes in identify problem of students. Next, identification of potential solutions stage promotes students' hypothesis ability. Need for knowledge stage promotes critical thinking 3 processes; collecting information, credibility of sources of information and identify information that 3 processes used in step 4 is decision-making stage. This stage encouraging to students showed conclusion and evaluation behavior. Finally, the socialization stage encourages students' evaluation ability. Nowadays, in addition to promoting scientific knowledge. Teachers need to encourage thinking skills for students to apply in daily life effectively and they learn about lifestyle in their local communities. In order to provide students, see that science are important to subsistence.

**5. References**


Aikenhead, G.S. (1994). *What is STS teaching?*. (Solomon, J. &Aikenhead, G., Eds.), STS education: International perspectives on reform. New York: Teachers College Press, 47-59.

Aryowong, N. (2011). *Scientific literacy of grade 12 student through teaching and learning about genetic*.Degree of Master of Education Thesis in Science Education GraduateSchool Khon Kaen University.Bassham, G., Irwin, W., Nardone, H. & Wallace, M.J. (2011). *Critical Thinking*. 4thed. New York: McGraw-Hill.

Attapan, N. and Yuenyong, C. (2019). Explicit Nature of Science in the STS Contact Lens "Big Eyes" Unit. *Journal of Physics: Conference Series*, 1340 (1), 012066

Bellanca, J. & Brandt, R. (2011).*21st century skills: Rethinking how students learn*. (Panit, W &Jittaruek, A.(translated). Bankkok: Openworlds.

Ennis, R.H. (1987). A taxonomy of critical thinking dispositions and abilities. In J. Baron & R. Sternberg (Eds.), Teaching thinking skills: Theory and practice. (pp. 9-26). New York: W.H. Freeman.

Ennis, R. H. (2016). Critical thinking across the curriculum: A vision. TOPOI: An International Review of Philosophy DOI:10.1007/s11245-016-9401-4.

Facione, P. (1990). Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction." Available as a download on the Insight Assessment website, under Resources.

Fisher, A. & Scriven, M. (1997). Critical thinking: Its definition and assessment. Point Reyes, CA: Edgepress.

Griffthes, A.J.F. (2003). *Community Based Biology*. Canada: University of British Columbia.

Hudgins, B.B., & Edelman, S. (1988). Children's thinking in physic science. *Journal of ducationReserch*, 88, 15-26.
Jumpatong, S. and Yuenyong, C. (2018). Developing the STS sound pollution unit for enhancing students' applying knowledge among science technology engineering and mathematics. *AIP Conference Proceedings*. 1923, 030023-1 – 030023-7.
Kitroongrueng, P. (2010). *The development of an instructional model using case based learning based on science of teaching to enhance student teachers' critical thinking*.Doctor of Education Thesis in Department of Curriculum and Instruction Graduate School Silpakorn University.
Lazarowitz, R., &Penso, S. (1992). High school students' difficulties in learning biology concepts.*Journal of Biological Education*, 26(3), 215-224.
Nakmanulack, P. (1994). *Development of Learning Model for Enhancing Pre-Service Teacher' Critical Thinking*. Chulalongkorn University: Bangkok
Nongkhunsarn, A., Yuenyong, C., Tupsai, J., and Sranamkam, T. (2019). Grade 11 Student's Mental Model of Fluid and Analytical Thinking in Science Teaching Through Science Technology and Society (STS) Approach. *Journal of Physics: Conference Series*, 1340 (1), 012043
Office of the National Education Commission. (2003). *Synopsis of the National Scheme of Education of B.E.(2002-2016)* (2nd ed.), Bangkok: Office of the National Education Commission.
Osborne, J. & Collins, S. (2001). Pupils' views of the role and value of the science curriculum.*International Journal of Science Education*, 23(5), 441-467.
Osman, K., Abdul Hamid, S.H., and Hassau, A. (2009). "Standard Setting: Inserting Domain of the 21$^{th}$ Century Thinking Skills into the Existing Science Curriculum in Malaysia. *Social and Behavioral Sciences*, 1(1), 234-241.
Phonhan, A. (2011). *Grade 10 students'learning achievement and decision making ability about homeostasis based on Yuenyong (2006) science technology and society (STS)approach.* Degree of Master of Education Thesis in Science Education Graduate School Khon Kaen University.
Ruksapukdee, P. (2012). *Matayomsuksa 6 students' decision-making ability and achievement about genetics and DNA technology in science learning through science technology and society (STS) approach*. Degree of Master of Education Thesis in Science Education Graduate School Khon Kaen University.
Suparee, M., and Yuenyong, C. (2021). Enhancing Grade 11 Students' Learning and Innovation Skills in the STS Electric Unit. *Asia Research Network Journal of Education*, 1 (2), 96-113
Thipruetree, S. (2012). *Problem solving ability and science learning achievement about genetic and biotechnology of mathayomsuksa IV students taught through science technology and society (STS approach)*. Degree of Master of Education Thesis in Science Education Graduate School Khon Kaen University.
Volman, M. (2004). Critical thinking as a citizenship competence: teaching strategies, *Learning and Instruction*, 14, 359-379.
Waisalong, P. (2012). *Students' understanding of the nature of science by using science technology and society (STS) approach in biodiversity*. Degree of Master of Education Thesis in Science Education Graduate School Khon Kaen University.
Wongsila, S. and Yuenyong, C. (2019). Enhancing Grade 12 Students' Critical Thinking and Problem-Solving Ability in Learning of the STS Genetics and DNA Technology Unit. *Journal for the Education of Gifted Young Scientists*, 7(2), 215-235.
Yuenyong, C. (2006). *Teaching and Learning about Energy: Using STS approach*. Doctor of Education Thesis in Science Education Graduate School Kasetsart University
Yuenyong, C. and Narjaikaew, P. (2009). Scientific literacy and Thailand science education.*International Journal of Environmental and Science Education*,4(3), 335-349.

Yuenyong, C. (2013). Enhancing Scientific Literacy in Thailand. *Global Studies of Childhood*, 3(1): 86 – 98

Yuenyong, C. (2017). Enhancing Thai Students' Thinking Skills about Energy issues: Influence of Local Values. *Chemistry: Bulgarian Journal of Science Education*, 26 (3): 363 – 376

Zeidan, A. (2010). The Relationship between grade 11 Palestinian attitudes toward biology and their perceptions of the biology learning environment. *International Journal of Science and Mathematics Education*, 8, 783-800.

Zoller, U. (1993). Lecture and learning: are they compatible? Maybe for LOCS: unlikely for HOCS, *Journal of Chemical Education*, 70, 195-197.

Zoller, U., Dori, Y. & Lubezky, A., (2002). Algorithmic, LOCS and HOCS (chemistry) exam questions: performance and attitudes of college students, *International Journal of Science Education*, 24, 185-203.

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