Development of Robotics-Assisted Acid-Base Titration Setup and Laboratory Activity for Grade 11 STEM Learners

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Abstract: In the 21st century, education must adapt to rapid scientific and technological advancements, including the growing role of robotics in skill development. However, in the Philippines, robotics in education remains limited. Integrating robotics into acid-base titration can help overcome physical barriers in traditional chemistry laboratory setups enhancing hands-on learning. This study employed a developmental research design using the ADDIE model to develop a robotics-assisted acid-base titration setup and laboratory activity for Grade 11 STEM learners taking General Chemistry. Furthermore, applying a descriptive research design, this paper also determined the students' perceptions towards the laboratory activity. This study was conducted in a private basic education institution in Ozamiz City, Misamis Occidental, utilizing 15 teachers and 40 students as respondents. In the evaluation of the developed materials, the results indicates that the set-up was rated "excellent" on the system usability scale by teacher and student evaluation. Meanwhile, using an adapted activity evaluation questionnaire, the 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. Moreover, using an adapted student perception questionnaire, the students' perception of the activity was "very high" in interest/enjoyment, value/usefulness, and perceived choice. These results show that the activity is engaging, relevant, and personally meaningful. These findings further emphasize the positive impacts of robotics integration on the overall teaching-learning process. Future studies should refine the setup and evaluate its impact on student learning and 21st-century skills.

Key Words: educational robotics, laboratory activity, acid-base titration, student activity perception

1. 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). In the K to 12 Basic Education Curriculum Guide (2016) and Most Essential Learning Competencies (MELCS) (2020) of the General Chemistry of Grade 11 Science, Technology, Engineering, and Mathematics (STEM), the laboratory activity on titration is specified under the topic on 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.

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.

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 determined the students' perceptions towards the activity.

2. 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.

2.1 Research Respondents

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. Only the student participants during the implementation of the laboratory activity accomplished the administered questionnaires.

2.2 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. 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.

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 toward 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.

2.3 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.

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).

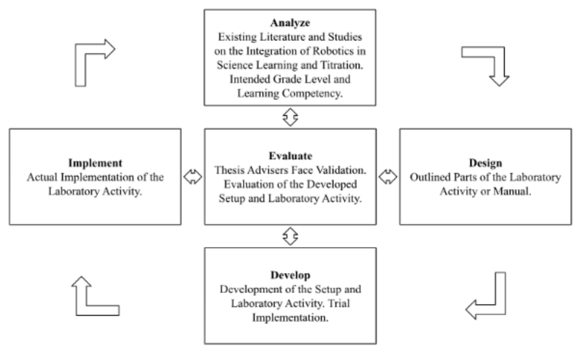

Fig. 1. Development of Robotics-Assisted Acid-Base Titration Setup and Laboratory Activity using the ADDIE Model

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).

Included 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 students. Afterward, 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 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.

2.4 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. The mean and percentage were identified using MS Excel.

The responses of the robotics and STEM teachers and student participants from the open-ended questions provided in the questionnaires were coded accordingly as qualitative support. This study meticulously and randomly assigned a distinct code to each individual participant, safeguarding the confidentiality of their responses and ensuring the utmost protection of their identities. The robotics teacher evaluators of the robotics-assisted acid-base titration setup are coded as E-RS01 to E-RS03 representing the three evaluators. The STEM teacher evaluators of the robotics-assisted acid-base titration laboratory activity are coded as E-LA01 to E-LA05 representing the five evaluators. Moreover, the student participants during the implementation of the developed laboratory activity are coded as S-LA01 to S-LA40 representing the forty student participants.

3. RESULTS AND DISCUSSION

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

Several prototypes or versions of the setup 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.

Fig. 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.

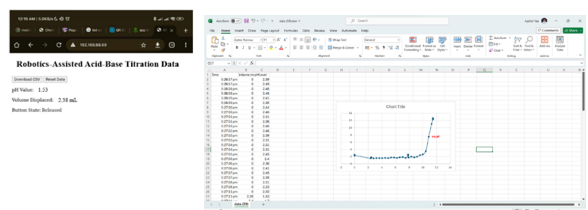

Fig. 3. Sample Display of the Transmitted Data in a Smartphone, Downloaded Spreadsheet File, and Generated Titration Graph

Table 1 shows the teacher and student evaluation of the developed robotics-assisted acid-base titration setup. In the teacher evaluation, the results show that the indicators “makes users like to use the setup frequently”, “is easy to use and operate”, “has various functions that are well integrated” and “makes users confident while using the setup” received the highest average rating with the qualitative description of strongly agree. Moreover, the indicators “has a lot of things to be learned before using the setup” acquired the lowest mean rating with the qualitative description of disagree. The results show that the indicators “makes users like to use the setup frequently”, “is easy to use and operate”, “has various functions that are well integrated” and “makes users confident while using the setup” received the highest average rating with the qualitative description of strongly agree. Moreover, the indicators “has a lot of things to be learned before using the setup" acquired the lowest mean rating with the qualitative description of disagree.

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 Agree
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 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 E-RS2 that the setup transmits output data consistently with minimal errors. Highlighting the importance of user-friendly design and integrated functionality in enhancing user satisfaction with the setup showcases the overall positive and favorable impression of user satisfaction and general usability (Paxton et al., 2018).

However, the results also display that the setup needs substantial technical support prior to the operation of the developed setup. Technical support and user feedback mechanisms should be established before and during the laboratory activity needs to be addressed to optimize the usability of the setup over time (Paxton et al., 2018). 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.

In the student evaluation, the data shows that the indicator "makes users like to use the setup frequently" received the highest mean rating with a qualitative description of strongly agree. Moreover, the indicator "has a lot of things to be learned before using the setup" obtained the lowest rating with a qualitative description of strongly disagree.

These results align with the comments made by S-LA35 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. S-LA12 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).

S-LA18 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 S-LA34 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 S-LA05 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".

Table 2 displays the overall system usability score of the developed robotics-assisted acid-base titration setup by teacher and student evaluation.

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

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).

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 (a), and compare the percentage errors of the calculated molar concentration obtained from the two titration methods (b).

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.

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

Catuday (2019) defined format as the adaptation of the form and writing style of the material to various instructional standards. The statements "vocabulary words used in the laboratory activity are within students' level of understanding", "the sentence structures used in the laboratory activity are varied and understandable, "the tables found in the laboratory activity are accurate, easy to understand, and properly labeled", "text, visuals, illustrations, layout, and design are interesting and suitable for the target learners", and "the ideas in the laboratory activity are developed adequately in a logical manner and are easy to follow" obtained the highest mean rating with a verbal interpretation of excellent.

Meanwhile, the indicator "the laboratory activity contains diagrams/pictures sufficient to illustrate ideas and concepts" acquired the lowest mean rating with a verbal interpretation of excellent. As commented by E-LA02 the illustrations displayed in the activity "can be improved to better depict the laboratory procedures". These findings suggest that while the visuals were present, there might be room for improvement in quality. Marasigan et al. (2019) highlighted the effectiveness of visuals in enhancing student understanding of the instructional materials.

These results manifest that the developed laboratory activity features an acceptable format that is understandable and appropriate for the intended users. This feature not only enhances student engagement with the activity but also lays the foundation for effective learning. A well-designed format with clear language, logical flow, and appropriate visuals can minimize confusion and cognitive overload, allowing students to focus on the scientific concepts being explored during the activity (El-Darazi, 2020).

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 statements "the language used in the laboratory activity is simple and easy to understand", and "the language and/or visuals are appropriate to the maturity level of the target learner" obtained the highest mean rating with a verbal interpretation of excellent. Meanwhile, the statements "the activities indicated in the laboratory activity are clearly explained, " and "the rules, procedures, and meanings of the laboratory activity are easy to follow and apply" generated the lowest mean rating with a verbal interpretation of excellent. Table 9 also exhibits that the overall mean score of the language criteria was 4.80 with also a verbal interpretation of excellent.

This finding implies that the language used in the developed laboratory activity is not only understandable and appropriate for the intended learners but also promotes clear communication of instructions, making the activity easy to follow and apply. Consequently, students are likely to encounter fewer obstacles due to language barriers and can focus on the scientific concepts being explored (Cabanillas, 2023).

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 statements “the content of the laboratory activity is appropriate for the target learners, “the laboratory activity promotes the development of higher cognitive skills such as critical thinking, creativity, learning by doing, problem-solving, and other similar skills, “the laboratory activity has the potential to arouse the interest of target learners, “the laboratory activity provides adequate warning/cautionary notes for safety and/or health concerns, and “the laboratory activity is free of ideological, cultural, religious, racial, and gender biases and prejudices acquired the highest mean rating with a verbal interpretation of excellent. While the indicator “the content of the laboratory activity is aligned with the intended learning competencies” received the lowest mean rating with a verbal interpretation of excellent.

Content validation serves as the foundational cornerstone in the process of material or instrument development, representing the initial and essential step in ensuring the quality, relevance, and effectiveness of the content being created (Catuday, 2019). Marasigan et al. (2019) further discussed that this stage involves systematically assessing the alignment between the content of the material or instrument and its intended objectives, ensuring that it accurately represents the constructs, concepts, or information it seeks to measure. These findings imply that the developed laboratory activity is a well-designed learning experience that achieves its intended outcomes. Additionally, the content is appropriate for the target learners and implies a parallel between the activity's difficulty and the students' knowledge level, potentially leading to successful learning. Furthermore, the activity promotes student interest which can lead to increased motivation and engagement, fostering a positive learning environment (Elbir & Cakiroglu, 2018). When students are interested, they are more likely to actively participate, ask questions, and explore the concepts in greater depth.

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

Overall, these results manifest that the developed laboratory activity is well-designed and effectively fulfills its educational objectives. These findings imply that: the format enhances student engagement with the activity but also lays the foundation for effective learning. A well-designed format with clear language, logical flow, and appropriate visuals can minimize confusion and cognitive overload, allowing students to focus on the scientific concepts being explored during the activity (El-Darazi, 2020); the language used in the developed laboratory activity is not only understandable and appropriate for the intended learners, but also promotes clear communication of instructions, making the activity easy to follow and apply (Cabanillas, 2023); and the content is appropriate for the target learners implies a match between the activity's difficulty and the students' knowledge level, potentially leading to successful learning. Furthermore, the activity promotes student interest which can lead to increased motivation and engagement, fostering a positive learning environment (Elbir & Cakiroglu, 2018).

3.2 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 6 presents the students' perception of interest and enjoyment towards the developed laboratory activity. All statements obtained a verbal interpretation of very high. Moreover, the overall mean score of the students' perceptions of interest and enjoyment towards the developed laboratory activity is 4.55 with a verbal interpretation of very high.

Science activities designed to be interesting and enjoyable can foster a more positive learning environment, leading to increased student motivation. Motivated students are then more likely to actively participate in class, persevere through challenges, and retain information effectively. Cuperman and Verner (2013) stated that the use of robotics can trigger students' curiosity and drove students' inquiry, ultimately increasing their motivation. Elbir and Cakiroglu (2018) attributed the increased motivation to the ability of robotics to keep the students mentally and physically active. Verner & Revzin (2011) further identified that students' motivation was also higher compared to a classical chemistry laboratory where learners prefer laboratory experiences that integrate modern technology such as robotics. Robotics also promotes problem-solving, inquiry, and higher-order thinking skills (Robinson, 2005). The support of these skills increases the participation and engagement of students during classroom instruction.

Table 6. 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.	4.58	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 mean for the fifth statement presents the reversed score.

These results indicate that the participants had highly positive perceptions and experiences of the developed laboratory activity, describing it as interesting, enjoyable, and fun. These findings suggest that incorporating robotics can be an effective strategy for promoting student motivation during science learning.

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 7 explores the students' perception of the perceived value and usefulness towards the developed laboratory activity.

Table 7. 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

All statements received a verbal interpretation of very high. The overall mean score of the students' perceptions of value and usefulness towards the developed laboratory activity is 4.53 with a verbal interpretation of very high.

Carril et al. (2021) highlighted the positive impacts of student-perceived value on the learning process. When students find activities meaningful and beneficial, they are more likely to be: intrinsically motivated, actively engaged, and focused on learning goals. These attributes are further supported by the integration of robotics into the activity. The increased motivation is attributed to the ability of robotics to keep the students mentally and physically active (Elbir & Cakiroglu, 2018). Robotics also promotes problem-solving, inquiry, and higher-order thinking skills which increases the participation and engagement of students during classroom instruction (Robinson, 2005).

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. This high perceived value can allow students to invest effort in understanding the concepts being explored, increase the significance students place on the learned information leading to better retention over time., and foster positive attitudes towards science (Carril et al., 2021).

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 8 exhibits the students' perceptions of perceived choice towards the developed laboratory activity.

Table 8. 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.	4.17	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.	4.58	Very Low
I felt like I had to do the laboratory activity.	4.50	Very Low
I did the laboratory activity because I had to.	4.42	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.	4.33	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. The mean for Statements 2, 4, 5, 6, and 8 presents the reversed score.

The statements "I believe I had some choice about doing the laboratory activity.", "I did the laboratory activity because I wanted to.", "I felt like I had no choice but to do the laboratory activity.", "I felt like I had to do the laboratory activity.", "I did the laboratory activity because I had to.", "While doing the laboratory activity, I felt like I had a choice.", and "I felt like it was not my own choice to do the laboratory activity." obtained a verbal interpretation of very high. Meanwhile the statement "I did not have a choice about doing the laboratory activity." obtained a verbal interpretation of high.

These findings emphasize the importance of learner autonomy in science education. Learner autonomy, or the ability of students to take control of their own learning processes, is crucial in science education for several reasons including fostering student motivation, promoting critical thinking and problem-solving skills, nurturing creativity and innovation, and enhancing metacognitive skills (Uslu & Durak, 2022). These skills are further supported by the integration of robotics into the activity.

Badeleh (2018) reported a direct relationship between robotics and creativity in science learning as indicated by the amount of detailed explanation, innovation, flexibility, and fluidity demonstrated by the students with the use of robotics in the classroom. This was further supported by Koç and Büyük (2021) noting that the use of technology allows students to solve scientific problems using their imagination and search for alternative solutions producing students that are active science and technology creators rather than passive technological consumers.

Gorakhnath and Padmanabhan (2020) also indicated a positive contribution of utilizing robots as tools for science teaching to the enhancement of students' motivation, metacognition, engagement, positive attitudes toward education, and critical thinking and that the construction and programming of robots provide a completely new learning environment that permits students to solve complex problems and think logically.

These results indicate that students generally felt a high degree of autonomy and choice in participating in the laboratory activity. Also, the design and implementation of the laboratory activity successfully fostered a sense of voluntary engagement among the students. These findings suggest that incorporating robotics can be an effective strategy for promoting deeper learning, enhancing critical thinking, and increasing self-efficacy.

Overall, the uniform positive feedback across various dimensions indicates that the design and implementation of the laboratory activity are engaging, relevant, and personally meaningful.

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. S-LA03 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 S-LA44 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 S-LA16 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 S-LA09 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.

4. CONCLUSIONS AND RECOMMENDATIONS

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.

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.

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