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

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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.

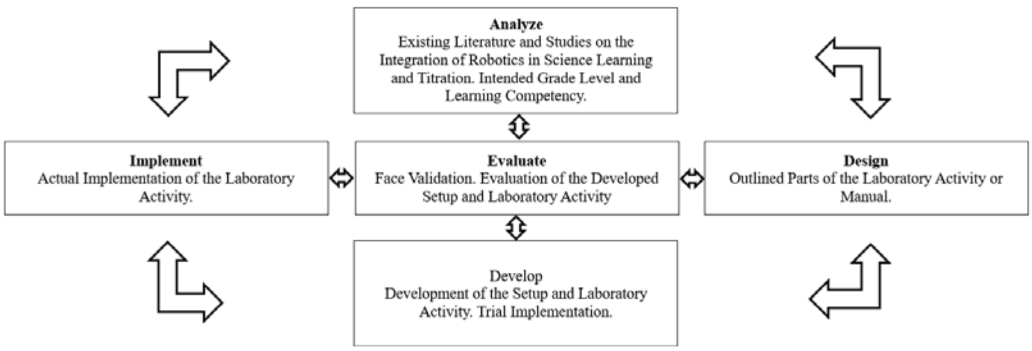

Figure 1 *Development of Robotics-assisted Acid-Base Titration Setup and Laboratory Activity using the ADDIE Model*

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.

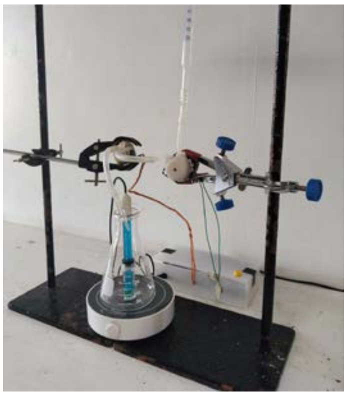

Figure 2 *Robotics-Assisted Acid-Base Titration Setup*

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.

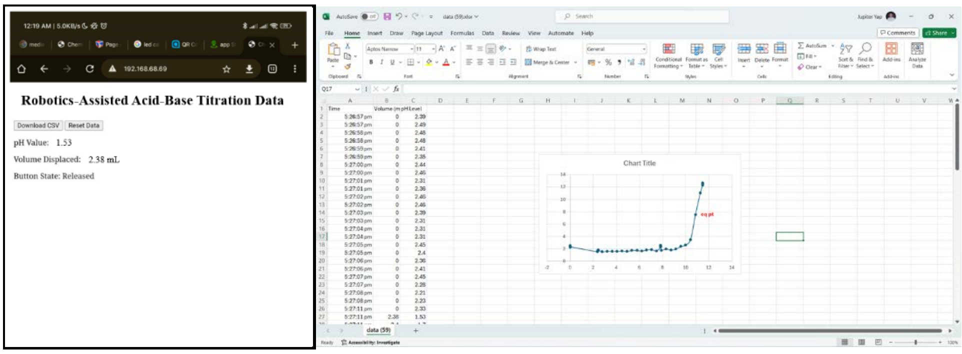

Figure 3 *Sample Display of the Transmitted Data in a Smartphone, Downloaded Spreadsheet File, and Generated Titration Graph*

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.

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