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Development of an Acid–Base Module Based on Problem-Based Learning Integrated with TPACK to Improve Senior High School Students' Learning Outcomes

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Abstract: The Merdeka Curriculum emphasizes students' ability to understand and apply their conceptual knowledge to solve contextual problems. This study aims to determine the validity, practicality, and effectiveness of an acid–base module based on problem-based learning integrated with TPACK in improving the learning outcomes of Phase F senior high school (SMA/MA) students. The development model used in this research was the 4-D model. The acid–base module was validated by three chemistry lecturers and two chemistry teachers. The practicality test of the module was conducted by three chemistry teachers and 31 students. The effectiveness of the module in improving learning outcomes was analyzed using the N-gain test. The validity test was analyzed using Aiken's V, which consisted of content and construct validity, yielding results of 0.89 and 0.91, respectively, both categorized as valid. The practicality results from teachers and students were 98.61% and 86.87%, respectively, both in the high category. The N-gain analysis resulted in a value of g = 0.79, categorized as high. Based on the hypothesis test, the calculated *t*-value was greater than the critical *t*-value. These findings confirm that the developed acid–base module based on problem-based learning integrated with TPACK is valid, practical, and effective for significantly enhancing students' learning outcomes.

Keywords: Acid–base; Learning outcomes; Module; Problem Based Learning (PBL); Technological Pedagogical Content Knowledge (TPACK)

Introduction

The *Merdeka Curriculum* provides students with opportunities to engage in learning from diverse sources, thereby enriching their educational experiences, fostering the ability to solve real-world problems, and enhancing their skill development (Ningtyas & Juliantari, 2022). These aims can be realized through the use of well-designed instructional materials and the effective integration of technology into the learning process. Acid–base solutions are among the chemistry topics taught to Grade XI.F SMA/MA students. A survey of 127 students revealed that the current instructional materials for this topic lack integration with contextual problems and have not fully utilized available technological tools. Moreover, students often struggle to grasp acid–base concepts because they are unable to connect their existing knowledge to contextual problems encountered in daily life. Consequently, there is a pressing need for instructional materials that incorporate contextual problem-solving tasks, enabling students to apply their conceptual understanding in authentic, real-world contexts (Andromeda et al., 2023). Instructional materials in the form of a module are a collection of learning content designed for students to engage in

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independent learning activities (Pitung & Setiawan, 2020). Modules can be integrated with learning models to make the learning process more structured and goal-oriented (Safitri et al., 2024). One relevant learning model that can enhance students' problem-solving skills is the Problem-Based Learning (PBL) model (Asda et al., 2025). Problem-Based Learning is an instructional approach that emphasizes the development of critical thinking, problem-solving, communication, and collaborative skills (Ghani et al., 2021). Through this approach, students reconstruct their prior knowledge by integrating it with new knowledge to find solutions to contextual problems, either individually or in groups, thereby making the learning experience more meaningful (Seibert, 2021).

Education in the era of Society 5.0 presents new challenges and opportunities in the use of technology (Kurniawati et al., 2023). Learning integrated with *Technological Pedagogical Content Knowledge* (TPACK) combines knowledge of technology, pedagogy, and chemistry content. TPACK-integrated learning offers a more interactive and relevant learning experience, fosters a more engaging learning environment, and improves students' understanding (Rumondor et al., 2024). The integration of TPACK into the learning process can help make instruction more effective and efficient. An acid–base module based on Problem-Based Learning (PBL) and integrated with the application of Technological Pedagogical Content Knowledge (TPACK) can serve as an alternative instructional material to improve students' conceptual mastery and learning outcomes (Koehler et al., 2013). The module is equipped with the PBL model, enabling students to apply their conceptual understanding to solve contextual problems. The integration of TPACK into the module can help address students' diverse learning styles, thereby supporting differentiated learning (Khairani & Rosita, 2025). This is made possible as students can access audio, video, and complete evaluation tasks using electronic devices, allowing the module to be accessed either in print or digitally (Khairani & Rosita, 2025).

A study conducted by Tanjung et al. (2022), found that the implementation of the Problem-Based Learning (PBL) model can improve students' conceptual understanding. The application of Technological Pedagogical Content Knowledge (TPACK) in chemistry learning has also been shown to increase student engagement in the learning process and effectively enhance learning outcomes (Bunuan et al., 2024; Yani et al., 2020). Previous research has produced several instructional materials based on PBL that successfully improved students' learning outcomes (Islamiati et al., 2024). However, no instructional material in the form of an acid–base module based on PBL and integrated with TPACK has yet been developed to align with the requirements of the *Merdeka Curriculum* and to support differentiated learning. Based on this gap, the present study aims to "Develop an Acid–Base Module Based on Problem-Based Learning Integrated with TPACK to Improve Students' Learning Outcomes.

Method

This study is a research and development (R&D) project employing the 4-D development model (Sugiyono, 2013). The 4-D model consists of four stages: define, design, develop, and disseminate. The first stage, *define*, comprises five components: front-end analysis; learner analysis; task analysis; concept analysis; and learning objectives analysis. The second stage, *design*, involves planning the acid–base module based on Problem-Based Learning integrated with TPACK. This stage includes developing test criteria, selecting instructional materials, choosing the format, and producing the initial draft of the module.

The third stage is *developt*, which involves evaluating three aspects of the developed module: validity, practicality, and effectiveness. The validity test consists of two components: construct validity and content validity. This validation was conducted by three chemistry lecturers and two chemistry teachers to determine the validity level of the developed acid–base module. The practicality test was carried out by three chemistry teachers and 31 students to assess the ease of use of the learning media, time efficiency, and the benefits of the designed material. The effectiveness test aimed to determine the extent to which the acid–base module improved students' learning outcomes. This test involved 70 Grade F students of SMAN 2 Padang Panjang in the 2024/2025 academic year. The results of these evaluations served as a basis for determining whether the developed module could be implemented on a wider scale. The final stage is *disseminate*, which involves distributing the PBL-based acid–base module integrated with TPACK to a broader audience. The developed module was distributed to several SMA/MA in West Sumatra to be utilized as an alternative instructional material for the acid–base topic.

The data collection instruments used in this study consisted of an acid–base module validity questionnaire and a practicality questionnaire for the validated acid–base module. The effectiveness of the module was measured based on the improvement in learning outcomes of Grade F students at SMA Negeri 2 Padang Panjang. The effectiveness test of the acid–base module was conducted using a multiple-choice test instrument that met the criteria for good validity, reliability, discrimination index, and difficulty index. The data obtained from the product validity test were analyzed using Aiken's V formula, as shown in Equation 1.

$$V = \frac{\sum s}{n(c-1)} \quad (1)$$

Information: s : r – Io, r : Ratings provided by the validators, Io : lowest validity value, n : number of expert validators, dan c : highest validity score (Aiken, 1985). The data obtained from the practicality test were analyzed using the formula shown in Equation 2.

$$P = \frac{f}{N} \times 100\ \% \quad (2)$$

Information: P : final value, f : score and N : maximum score.

The effectiveness test was conducted using two sample classes, namely Grade XI.F6 and XI.F7, selected through purposive sampling. The sample classes were given a pretest before the start of the lesson and a posttest at the end of the lesson. The pretest and posttest results were analyzed using the N-gain formula, as shown in Equation 3.

$$\text{N-gain} = \frac{Posttest\ Score - Pretest\ Score}{100 - Pretest\ Score} \quad (3)$$

The data analysis technique in this study employed quantitative analysis using hypothesis testing. To determine the type of hypothesis test to be used, normality and homogeneity tests of the sample classes were first conducted. The normality test was performed using the Liliefors test, while the homogeneity test was analyzed using Fisher's test. Hypothesis testing in this study utilized the independent sample *t*-test (two-tailed) because the data were normally distributed and homogeneous. The decision parameter for the hypothesis test was based on the *t*-table value: if t-value > t-table, H_0 is rejected and if t-value < t-table, H_0 is accepted (Arikunto, 2019).

Result and Discussion

Define Stage (definition)

In the front-end analysis stage, the results indicated that: the instructional materials used for the acid–base topic have not incorporated content integrated with contextual problems and have not utilized technology; and the instructional materials have not facilitated students in applying their conceptual understanding to solve contextual problems. In the learner analysis stage, it was found that students experienced difficulties in understanding the acid–base topic because its concepts are abstract and difficult to relate to contextual problems. In the task analysis stage, an analysis was carried out on the intended learning outcomes, namely the application of acid concepts in everyday life. Based on this analysis, the following learning objectives were formulated: to explain the acid–base theories proposed by Arrhenius, Bronsted–Lowry, and Lewis; to identify several acid–base solutions using natural and synthetic indicators; and to calculate acidity (pH), the degree of ionization, and the equilibrium constants of acids and bases.

The concept analysis stage was carried out by identifying the main concepts to be taught in the acid–base topic, while the learning objectives analysis stage was formulated based on the task analysis and concept analysis. Based on the results of the front-end analysis, learner analysis, task analysis, concept analysis, and learning objectives analysis, an acid–base module based on Problem Based Learning integrated with Technological Pedagogical Content Knowledge (TPACK) was developed to improve students' learning outcomes.

Design Stage (design)

Based on the data and problems identified in the *define* stage, an acid–base module based on Problem-Based Learning integrated with TPACK was developed. The developed acid–base module follows the PBL learning steps as follows:

Orientation of Students to the Problems

At this stage, students read the text, listen to the audio, and watch the video provided in the module, which presents contextual problems related to the acid–base topic integrated with TPACK. An example of this stage is shown in Figure 1.

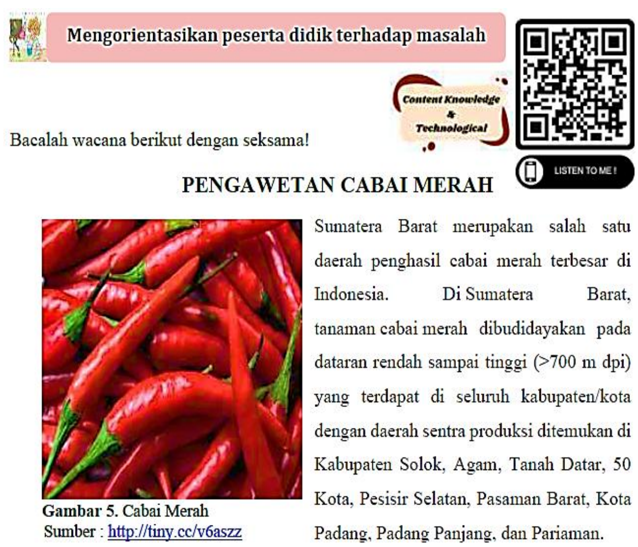

Figure 1. Orientation of students to the problems stage

Organizing Students to Learn

At this stage, students gather information related to the predetermined acid–base material. In doing so, they obtain facts relevant to the problem presented in the previous stage. An example of this stage is shown in Figure 2.

Mengorganisasikan peserta didik untuk belajar

Duduklah berdasarkan kelompok yang telah ditentukan oleh guru untuk mendiskusikan dan melakukan studi literatur dari berbagai sumber tentang :

1. Teori asam basa Arrhenius
2. Teori asam basa Bronsted-Lowry
3. Teori asam basa Lewis

Figure 2. Organizing students to learn stage

Guiding Individual/Group Investigations

In this stage, students engage in data collection through investigations or experiments aimed at identifying solutions to the problem presented in the preceding stage. An illustration of this step is provided in Figure 3.

Membimbing penyelidikan individu/kelompok

Karena pembelajaran mengenai teori asam basa telah selesai, untuk memperkuat dan memperluas pengetahuan yang telah kamu dapatkan, kerjakanlah soal soal berikut ini !

1. Tuliskan persamaan reaksi ionisasi senyawa berikut dan tentukan apakah senyawa bersifat asam atau basa !
   a. HNO_3
   ……………………………………………………………………………………
   ……………………………………………………………………………………

Figure 3. Guiding individual/group investigations stage

Develop and Present the Work

At this stage, students design or present a product that reflects the solutions derived from the problem-solving process, in the form of a Power Point presentation, video, or other relevant models. An example of this stage is illustrated in Figure 4.

Menyajikan dan Mengembangkan Hasil /Karya

Presentasikanlah jawaban yang anda berikan untuk memecahkan permasalahan sesuai dengan hasil diskusi kelompok baik dalam bentuk video, *powerpoint* ataupun media lainnya ! kamu juga dapat mengumpulkan hasil diskusimu pada barcode berikut !

Figure 4. Develop and present the works stage

Analyze and Evaluate the Problem-Solving Process

At this stage, students reflect on and evaluate both the solutions and the processes employed in solving the problem. An example of this stage is shown in Figure 5.

Menganalisis dan Mengevaluasi Proses Pemecahan Masalah

Setelah kelompok kamu mempresentasikan hasil yang telah diperoleh, kemudian kelompok lain memberikan tanggapan berupa saran maupun alternatif jawaban yang lain. Tuliskanlah kritik/ saran dari kelompok lain kemudian evaluasilah proses pemecahan masalah yang anda susun!

No	Nama Siswa	Kritik/ Saran
1		
2		

Figure 5. Analyze and evaluate the problem-solving process stage

Develop Stage (development)

Validity Test

The validity test of the acid–base module comprised content validity and construct validity (Govindasamy et al., 2024). Content validity covered the alignment of the module's content with the syntax of problem-based learning and the scientific accuracy of the material in accordance with chemical principles. Meanwhile, construct validity encompassed the evaluation of the module's content components, presentation components, linguistic components, and graphical components. Based on the data analysis, the average content validity score of the module was 0.89, while the average construct validity score was 0.91, both of which fall into the "valid" category. Therefore, it can be concluded that the developed problem-based learning integrated TPACK acid–base module is valid and suitable for classroom implementation. The results of the content validity test are presented in Table 1, and the results of the construct validity test are presented in Table 2.

Table 1. Content Validity Analysis Results

Rated Aspect	Value V	Category
Suitability of the contents with Problem Based Learning syntax	0.89	Valid
Correctness the contents of module with chemical scientific content	0.89	Valid
Average	0.89	Valid

Table 2. Construct Validity Analysis Results

Rated Aspect	Value V	Category
Content Component	0.88	Valid
Construct Component	0.90	Valid
Language Component	0.88	Valid
Graphics Component	0.98	Valid
Average	0.91	Valid

Practicallity Test

The practicality of the problem-based learning PBL integrated TPACK acid–base module was assessed through a practicality questionnaire administered to three chemistry teachers and thirty-one students. The practicality analysis focused on three aspects: ease of use, learning time efficiency, and overall usefulness.The results indicated that the average practicality score given by the three teachers was 98.61%, falling into the "highly practical" category, while the average score given by the thirty-one students was 86.87%, also categorized as "highly practical." The detailed results of the practicality questionnaire assessment for each component, as evaluated by both teachers and students, are presented in Table 3.

Table 3. Practicality Analysis of Teachers and Students

Rated Aspect	Teachers %	Students %	Category
Ease to use	95.83	87.90	Very practical
Time efficiency	100	86.29	Very practical
Benefit	100	86.41	Very practical
Average	98.61	86.87	Very practical

Based on the practicality analysis of the developed acid–base module, the ease-of-use aspect, as evaluated by chemistry teachers and students, achieved practicality scores of 95.83% and 87.90%, respectively, both categorized as "highly practical." This indicates that the Problem Based Learning integrated TPACK acid–base module contains materials, videos, audio, and images that are easy to understand and convenient to use in the learning process (Mansour et al., 2024). For the aspect of learning time efficiency, the practicality scores were 100% for chemistry teachers and 86.29% for students, both in the "highly practical" category. This finding demonstrates that the module supports efficient learning within limited instructional time.

Regarding the usefulness aspect, the practicality scores for chemistry teachers and students were 100% and 86.41%, respectively, again categorized as "highly practical." These results show that the module is beneficial in supporting the teaching and learning of acid–base concepts. Overall, the data analysis confirms that the developed PBL-integrated TPACK acid–base module is both valid and practical, making it a viable alternative learning resource for students and suitable for further effectiveness testing in instructional settings.

Effectivity Test

This stage aimed to determine the effectiveness level of the Problem Based Learning integrated TPACK acid–base module in improving students' learning outcomes. The research data were primary data obtained after conducting the study and collecting data at SMAN 2 Padang Panjang. The research subjects were students of class XI.F6, designated as the experimental group, who received instruction using the Problem Based Learning -integrated TPACK acid–base module.

The effectiveness of the module in enhancing students' learning outcomes was measured using multiple-choice test items that had been validated in terms of content validity, reliability, difficulty index, and discrimination index, all falling within the "good" category (Febrila, 2024). To assess students' prior knowledge, a pretest was administered before the learning process began. The pretest results provided valuable insights for teachers to identify concepts that required more in-depth coverage during instruction, ensuring more efficient use of classroom time (Yani et al., 2020). Following the instructional intervention, a posttest was conducted to measure students' comprehension and learning achievements. The average scores from the assessment are presented in Table 4.

Table 4. Average Result of Pretest and Posttest

Average	Pretest	Posttest
Experimental class	36.29	86.14
Control class	38.19	80.42

Based on Table 4, it was found that the average pretest score of students in the experimental class was lower than that of the control class. However, after the learning process using the acid–base module, the posttest scores of the experimental class were higher than those of the control class, with a difference of 5.72 points. This result indicates an improvement in students' comprehension and learning outcomes following the use of the acid–base module. The effectiveness category of the acid–base module was further analyzed using the N-Gain test. The results of the N-Gain analysis are presented in Table 5.

Table 5. Average Result of N-Gain Score

Sample	Average	Category
Experimental class	0.79	High
Control class	0.68	Medium

Based on Table 5, it can be concluded that the N-Gain score of the experimental class was higher than that of the control class. This finding indicates that the acid–

base module based on Problem-Based Learning integrated with TPACK is effective in improving students' learning outcomes. To confirm whether the observed improvement in learning outcomes was statistically significant, a hypothesis test was conducted. The hypothesis testing procedure took into account the normality and homogeneity of the research data. Therefore, normality and homogeneity tests were performed on the sample classes. The results of the normality test for the sample classes are presented in Table 6.

Table 6. Normality Test Result

Class	Lh	Lt	Category
Experimental class	0.127	0.149	Normal
Control class	0.141	0.147	Normal

The analysis presented in Table 6 indicates that the data from the sample classes were normally distributed. Subsequently, a homogeneity test was performed for each sample class using the Fisher test. The results of the homogeneity test for the sample classes are shown in Table 7.

Table 7. Homogeneity Test Result

Class	Fcount	Ftable	Category
Experimental class	1.685	1.692	Homogen
Control class			

Based on Table 7, it can be observed that the calculated F-value is smaller than the critical F-table , indicating that the data from the sample classes are homogeneously distributed. The results of the normality and homogeneity tests confirm that the research data are normally and homogeneously distributed. Therefore, the hypothesis testing was conducted using an independent sample t-test. The results of the hypothesis test are presented in Table 8.

Table 8. Hypothesis Test Result

Class	Tcount	Ttable
Experimental class	3.62	1.66
Control class		

Table 8 shows that the results of the hypothesis testing indicate that the calculated *t*-value (3.62) is greater than the critical *t*-table (1.66), thus the research hypothesis is accepted. Based on the analysis conducted, it can be concluded that the use of the acid–base module based on problem-based learning integrated with TPACK is effective in significantly improving the learning outcomes of Phase F students. The improvement in learning outcomes in the experimental class is attributed to the fact that students who learned using the acid–base module based on problem based learning integrated with TPACK developed scientific attitudes that enabled them to discover concepts and apply their knowledge in solving contextual problems in accordance with the steps outlined in the module.

The improvement in students' learning outcomes is influenced by the use of teaching materials based on problem based learning (Manurung & Simaremare, 2022). Problem based learning makes learning more applicable as it prioritizes the practical use of students' existing concepts and is reinforced by scientific discoveries related to contextual problems (Liu & Pásztor, 2022). Chemistry learning that incorporates problem-based learning helps students study chemistry in relation to contextual problems they encounter in everyday life (Andromeda et al., 2024). The integration of TPACK into the module also addresses the limitations of students' learning styles, as they can access videos and audio from the developed module. TPACK involves the complex integration of technology, content, and pedagogy in the learning process (Yeh et al., 2021). TPACK-integrated learning provides a more contextual and meaningful learning experience, enabling students to observe abstract concepts in the acid–base material (Zahroh, 2025).

The product developed in this study is an acid–base module based on problem-based learning integrated with TPACK. The development of learning modules can be complemented with instructional models to make the learning process more structured (Mansour et al., 2024). One model that can be applied to the module is problem-based learning. The acid–base module based on problem-based learning can be used to help students solve problems independently, as problem-based learning involves the abilities and intelligence of individuals or groups in solving meaningful, relevant, and contextual problems encountered in daily life through effective interaction and collaborative inquiry (Sari & Radiansyah, 2024). In addition, the improvement in students' learning outcomes is also influenced by the module integrated with TPACK.

Other studies have also revealed that the use of modules based on problem-based learning integrated with TPACK is effective in improving students' learning outcomes (Tanjung et al., 2022). The developed acid–base module based on problem-based learning integrated with TPACK can serve as a teaching resource that helps students achieve the intended learning objectives (Yuliani & Saputri, 2024). Students who learn using modules based on problem-based learning integrated with TPACK can follow the lessons more easily as they are guided by the steps in accordance with the problem-based learning model (Zimmermann et al., 2021). Based on the analysis conducted, it can be concluded that the developed acid–base module based on problem-based learning integrated with TPACK is valid, practical, and effective in significantly improving students' learning outcomes.

Conclusion

Based on the research findings and data analysis, it can be concluded that the validity of modules which included content and construct validity, yielding scores of 0.89 and 0.91, categorized as valid. The practicality results from teachers and students were 98.61% and 86.87%, respectively, both categorized as high. The N-gain analysis obtained a score of g = 0.79, which falls into the high category. Hypothesis testing further revealed that the calculated t-value was greater than the critical t-table value. These findings confirm that the developed of an Acid-Base Module Based on Problem Based Learning (PBL) Integrated with Technological Pedagogical and Content Knowledge (TPACK) is valid, practical, and effective in significantly improving students' learning outcomes.

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Conceptualization, creating research instruments, guiding the research process, and writing articles, Rela Farad and Desy Kurniawati; validating of module, Budhi Oktavia and Alizar.

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Conflicts of Interest
The authors declare no conflict of interest.

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