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Development of Electronic Portfolio Assessment to Improve Students' Habits of Mind on Acid Base

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Abstract: This study aimed to develop a valid and reliable electronic portfolio assessment instrument to support learning and potentially improve students' habits of mind on acid-base material. Using a Research and Development (R&D) approach with the 4D model (Define, Design, Develop, and Disseminate), the instrument was tested on 30 eleventh-grade students in a public high school in Cimahi City. The habits of mind focused on three indicators: self-regulation, critical thinking, and creative thinking. The instrument included various tasks relevant to the acid-base topic. Validation results showed strong content validity (CVR = 1.00) and reliability (Cronbach's Alpha values ranging from 0.70 to 1.00). A limited trial suggested potential improvements in students' habits of mind, with observed levels of self-regulation categorized as medium to high, and critical and creative thinking ranging from low to high. However, these findings are preliminary, and further research using a more robust experimental design is needed to confirm the instrument's effectiveness.

Keywords: Acid base learning; Assessment development; Assessment for learning; Electronic portfolio; Habits of mind

Introduction

The rapid development of the modern era presents students with increasingly complex challenges, requiring them to adapt and solve problems through higher-order thinking skills (Aringga et al., 2020; Kirkwood et al., 2014). To support this, learning must be directed toward meaningful knowledge construction, and assessment plays a central role in this process (Earl, 2007; Fitriana et al., 2020; Muchlis, 2020; Widiyanti, 2013). According to the Indonesian Ministry of Education and Culture Regulation No. 21 of 2022, assessment in education is classified into summative and formative. Summative assessment is usually conducted at the end of a learning period to evaluate achievement against competency standards (Ardiansyah et al., 2023; Magdalena et al., 2021), while formative assessment provides feedback during the learning process to guide instructional adjustments (Hattie et al., 2007; Mujiburrahman et al., 2023).

Based on their functions, assessments are further categorized into Assessment of Learning (AoL), Assessment as Learning (AaL), and Assessment for Learning (AfL) (Budiono et al., 2023). AfL emphasizes feedback, dialogue, and reflection between teachers, students, and peers (Sobarningsih et al., 2018; Widiastuti et al., 2022). Effective implementation requires clear objectives and constructive feedback, which play a key role in improving learning (Nurlitasari et al., n.d.; Rahmawati et al., 2015). Previous studies show that AfL can effectively enhance student achievement in high school chemistry (Dini et al., 2022).

One formative strategy aligned with AfL is portfolio assessment, which collects and organizes students' work systematically to document learning progress (Aminudin et al., 2021; Farihah, 2021; Rizal et al., 2021). Portfolios enable reflection, provide feedback, and support instructional planning (Barrett, 2007; Hossain et al., 2008; Marzuki, 2023). With digital integration, electronic portfolios (e-portfolios) expand these benefits by including multimodal evidence such as

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videos, concept maps, and infographics. More importantly, e-portfolios not only serve as assessment tools but also have the potential to foster students' Habits of Mind (HoM), which encompass critical thinking, creative thinking, and self-regulation (Marzano et al., 1993; Nurmiati et al., 2025; Safitri, 2017). HoM are fundamental for solving complex problems in academic and everyday contexts (Handayani, 2015; Yandari et al., 2019).

Several studies confirm the positive impact of formative assessment with feedback on HoM (Gloria et al., 2020; Hatcher, 2015; Li et al., 2025) and show that e-portfolio-based assessments can improve HoM in buffer solution learning (Nahadi et al., 2025). However, most of these studies emphasize only critical thinking, while creative thinking and self-regulation remain underexplored (Susilawati et al., 2023; Susilo et al., 2025). In addition, few valid and reliable instruments exist for assessing HoM in acid-base learning, even though this topic is conceptually difficult for students and central in high school chemistry curricula (Ardianti et al., 2021; Contakes, 2016; Salam et al., 2021).

Therefore, the novelty of this study lies in developing a valid and reliable electronic portfolio assessment instrument that comprehensively measures and improves students' HoM—covering critical thinking, creative thinking, and self-regulation—in the context of acid-base material within the Kurikulum Merdeka. This research is important because it addresses the lack of valid instruments, integrates authentic assessment into chemistry learning, and supports the development of 21st-century skills.

Method

This study employed a Research and Development (R&D) design using the 4D model developed by (Barkley, 2010; Thiagarajan et al., 1974), consisting of four stages: Define, Design, Develop, and Disseminate. However, due to time and contextual limitations, the implementation was carried out only up to the Develop stage (small-scale pilot test). The Disseminate stage was not conducted. The research procedure is summarized in Figure 1.

Define Stage

The purpose of this stage was to identify needs and gather initial information as a foundation for instrument development. Data were collected through a literature review of national and international studies on electronic portfolio assessment and Habits of Mind, field surveys and interviews with two chemistry teachers from a public high school in Cimahi City, content analysis of acid–base topics in the Kurikulum Merdeka (Phase F), and task analysis to identify alternative learning tasks. The information obtained was then used to design portfolio tasks such as concept maps, laboratory reports, and infographics that were aligned with Habits of Mind indicators.

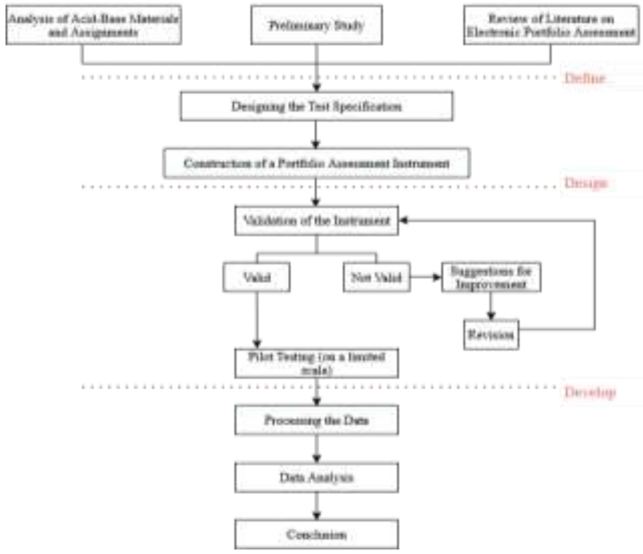

Figure 1. Research procedure flow chart

Design Stage

At this stage, a prototype of the electronic portfolio-based assessment instrument was developed. The prototype consisted of three portfolio tasks related to acid–base learning, an assessment rubric containing indicators and criteria aligned with Habits of Mind, and the use of Google Classroom as the chosen platform for portfolio submission. Expert discussions were also carried out to ensure that the rubric reflected appropriate performance indicators and that the tasks were feasible for high school implementation.

Develop Stage

This stage aimed to refine the prototype through validation, reliability testing, and limited trials. Content validity was tested by five experts consisting of two chemistry education lecturers, and three senior chemistry teachers using the Content Validity Ratio (CVR) and Content Validity Index (CVI). Reliability was examined through inter-rater reliability using Cohen's Kappa from two independent assessors, as well as internal consistency reliability using Cronbach's Alpha. A limited pilot test was then conducted with thirty Grade XI students at a public high school in Cimahi City over a four-week period. During the trial, students completed the portfolio tasks, received teacher feedback, revised their work, and resubmitted it before final scoring. The data obtained from validation, reliability testing, and pilot implementation were analyzed descriptively to evaluate the feasibility of the instrument in assessing students' Habits of Mind in acid–base learning.

Result and Discussion

The limited trial of the electronic portfolio assessment instrument was conducted with 30 eleventh-grade students using Google Classroom. Students completed three tasks: (1) concept maps, (2) laboratory reports, and (3) infographics. Each task was assessed with rubrics, and students were given written feedback before resubmission. The quantitative results are presented in Tables 1–4.

Task 1: Concept Maps

Students were asked to construct a concept map on acids, bases, their properties, and indicators as the first task in the electronic portfolio. The initial submissions indicated that most students struggled to distinguish between concept mapping and mind mapping, which resulted in weak hierarchical structures and the absence of logical connections between concepts. Many maps also contained unclear or missing linking words, leading to fragmented ideas and less coherent representation of the relationships between acid–base concepts. After receiving targeted feedback through Google Classroom, students were able to revise their work by reorganizing the hierarchy, adding appropriate linking phrases, and refining their connections. The resubmitted concept maps showed clearer relationships among the concepts, which suggests that feedback played a crucial role in helping students improve the accuracy and logical flow of their scientific understanding (Afriana et al., 2016).

Table 1. Average Scores of Concept Map (Task 1)

Aspect	Initial Mean	Final Mean	N-Gain	Category
Hierarchichal Structure	2.13	3.40	0.66	Medium
Concept Accuracy	2.43	3.50	0.56	Medium
Linking Words	1.26	3.00	0.64	Medium
Interrelationships Between Concepts	1.96	3.43	0.73	High
Overall Average	1.95	3.33	0.68	Medium

The assessment of students' concept maps on acids and bases (Table 1) revealed clear improvement after feedback and revision. The overall average score increased from 1.95 to 3.33, with an N-Gain of 0.68, which is categorized as medium. This result demonstrates that the electronic portfolio assessment facilitated meaningful progress in students' ability to construct and refine scientific representations of knowledge.

Among the specific aspects evaluated, the highest improvement was observed in interrelationships between concepts (N-Gain = 0.73, high category). This finding indicates that after feedback, students were better able to connect acid–base concepts in a coherent network, reflecting more structured and meaningful learning. Similarly, the hierarchical structure of the maps improved significantly (N-Gain = 0.66, medium), showing that students became more adept at organizing general and specific concepts systematically. This improvement aligns with the findings of Mardhiyati et al. (2017), who emphasized that concept maps can foster critical thinking by helping students visualize and structure abstract concepts.

On the other hand, the lowest improvement occurred in concept accuracy (N-Gain = 0.56, medium). Some students continued to include irrelevant concepts, such as acid–base titration, which was outside the intended learning scope, suggesting that feedback on this aspect requires more emphasis. Linking words also showed moderate improvement (N-Gain = 0.64), where students became more precise in expressing relationships between concepts, although some still used generic or vague connectors. These results highlight that while feedback effectively supported revisions, additional scaffolding is needed to ensure accuracy and precision in scientific language.

Overall, the results suggest that iterative feedback and revision through the electronic portfolio not only improved the structure of students' concept maps but also enhanced their ability to demonstrate logical relationships between scientific ideas. This supports the view of Novak et al. (Novak et al., 2008) and also Expósito et al. (2020), who argued that concept mapping is an effective tool for promoting deeper understanding when students are guided through reflection and revision.

Task 2: Laboratory Reports

In the second task, students were assigned to create a group laboratory report on natural, synthetic, and universal indicators. The initial reports revealed several weaknesses (Kusumawati, 2022), particularly in writing concise conclusions that were aligned with the objectives of the experiment; many students tended to write overly long and unfocused statements. After feedback was provided, students were given time to revise their reports, and the final submissions demonstrated clearer organization, improved presentation of data, and more accurate conclusions that reflected experimental findings. This improvement suggests that feedback not only helped students refine their scientific writing but also encouraged them to think critically about how to summarize and interpret experimental results effectively.

Table 2. Average Scores of Laboratory Reports (Task 2)

Aspect	Initial Mean	Final Mean	N-Gain	Category
Title & Objectives	1.73	3.13	0.61	Medium
Theoritical Foundation	2.36	3.53	0.76	High
Tools & Materials	1.96	3.36	0.72	High
Procedures & Observation Data	2.16	3.37	0.66	Medium
Discussion	2.10	3.23	0.66	Medium
Conclusion	1.96	3.53	0.76	High
References	1.96	3.36	0.72	High
Overall Average	2.16	3.37	0.66	Medium

The results of the laboratory report assessment (Table 2) indicate a substantial improvement in student performance across all aspects after receiving feedback. The overall average score increased from 2.16 to 3.37, with an N-Gain of 0.66, which falls into the medium category. Among the assessment aspects, the greatest improvements were observed in the theoretical foundation and conclusion sections, both with N-Gain values of 0.76 (high category). This finding suggests that students became more capable of integrating scientific concepts with experimental results after revising their reports. Initially, students struggled to write focused conclusions and to connect experimental observations with theoretical explanations, but feedback helped them refine these weaknesses.

Moderate gains were observed in the aspects of title and objectives (N-Gain = 0.61), procedures and observation data (N-Gain = 0.66), and discussion (N-Gain = 0.66). The revisions made by students resulted in clearer alignment between the objectives and the content of their reports, as well as more systematic descriptions of procedures and data. However, these aspects still achieved only medium categories, indicating that students required more guidance to improve clarity and depth in scientific writing. Similar findings were reported by Contakes (2016) and Zainuddin et al. (2020), who emphasized that lab report writing is a valuable tool for fostering analytical reasoning, but students often need structured scaffolding to achieve high-level performance.

Furthermore, the improvement in tools and materials (N-Gain = 0.72, high category) and references (N-Gain = 0.72, high category) demonstrates that students became more attentive to the accuracy of experimental design and citation practices. The increase in these technical aspects highlights the role of feedback in developing students' awareness of scientific conventions and academic integrity. This aligns with Anugrahaini et al. (2017), who noted that collaborative lab report activities not only improve critical thinking but also strengthen students' responsibility in following academic standards.

Overall, the findings from Task 2 confirm that the use of electronic portfolio assessments, supported by feedback and opportunities for revision, effectively enhances students' abilities in both technical and cognitive aspects of scientific reporting. The data-driven improvements in multiple components of the lab report illustrate the potential of this approach to strengthen critical thinking and self-regulation, consistent with previous studies on formative assessment in chemistry learning.

Task 3: Infographics

The third task required students to work in pairs to design an infographic illustrating acid–base phenomena found in everyday life. This task aimed to assess students' ability to synthesize conceptual understanding with creative visual communication. Initially, the submitted infographics showed limited creativity, with some students presenting dense text, minimal visual variety, and weak connections between scientific explanations and real-life contexts. After receiving feedback through Google Classroom, students were encouraged to simplify their content, enhance the visual layout, and ensure the accuracy of the information presented. The revised infographics demonstrated notable improvement in terms of content clarity, creativity, and design aesthetics, indicating that students were able to combine scientific accuracy with engaging visual representation.

Table 3. Average Scores of Infographics (Task 3)

Aspect	Initial Mean	Final Mean	N-Gain	Category
Content Material	3.00	4.00	1.00	High
Language	2.36	3.40	0.70	Medium
Layout & Design	1.96	3.36	0.72	High
Overall Average	2.67	3.68	0.79	High

The assessment results for the infographic task (Table 3) show a significant improvement in students' performance after the revision process. The overall average score increased from 2.67 to 3.68 with an N-Gain of 0.79, categorized as high. This indicates that the electronic portfolio assessment, combined with feedback and opportunities for revision, effectively enhanced students' ability to integrate scientific content with creative visual expression.

The highest improvement was observed in the content material aspect (N-Gain = 1.00, high category), demonstrating that students were able to present acid–base phenomena more accurately and contextually after receiving feedback. Initially, many students struggled to select relevant examples or simplify scientific explanations for visual presentation. After revision, their infographics displayed more precise and concise scientific content, supported by clear and relevant examples from daily life. This improvement aligns with Salam et al. (2021) and Lopez-Pernas (2021), who found that infographic-based learning encourages students to reorganize complex information into more comprehensible and engaging visual formats.

Significant progress was also found in the layout and design aspect (N-Gain = 0.72, high category). Students showed better understanding of visual balance, color harmony, and font readability, which contributed to more appealing and informative infographics. The enhancement in visual presentation reflects students' growing awareness of how design elements can influence communication of scientific concepts (Muliyadi et al., 2023; Susilawati et al., 2021). This supports the findings of Iftene et al. (2018), who highlighted that digital visualization activities improve students' creative thinking and communication skills in science learning.

Meanwhile, the language aspect demonstrated a medium improvement (N-Gain = 0.70). Although students became more concise and accurate in their wording, some still used informal expressions or incomplete scientific terms. This suggests that while students developed visual and conceptual skills, additional guidance in scientific writing remains necessary. Overall, the data indicate that the infographic task successfully fostered creativity, critical thinking, and communication competence through the integration of science content, technology, and design.

The Improvement Habits of Mind

In addition to assessing student performance on individual tasks, this study also examined changes in students' Habits of Mind (HOM) before and after the implementation of the electronic portfolio assessment. The HOM aspect was measured through a self-assessment rubric adapted from Marzano et al. (1993), covering three main domains: self-regulation, critical thinking, and creative thinking. Students completed the rubric twice once before the acid base learning activities and once after all portfolio tasks had been completed and revised. The comparison of pre- and post-assessment data provided insights into how the feedback-driven learning process influenced students' thinking dispositions. The results revealed a positive trend in all three aspects of HOM, indicating that the integration of electronic portfolio assessments fostered students' reflective habits, responsibility in learning, and creative engagement with scientific problems (Marzano et al., 1993; Nurmiati et al., 2025; Wassalwa et al., 2022).

Table 4. Average Scores of Habits of Mind

Aspect	Initial Mean	Final Mean	N-Gain	Category
Self regulation	2.36	3.53	0.73	High
Critical thinking	2.11	3.41	0.68	Medium
Creative thinking	2.07	3.2	0.58	Medium
Overall Average	2.67	3.68	0.79	High

The analysis of students' Habits of Mind (HOM) before and after the implementation of the electronic portfolio assessment (Table 4) showed an overall increase in all three measured aspects. The overall average score rose from 2.67 to 3.68, with an N-Gain value of 0.79 categorized as high. This finding indicates that the use of electronic portfolio assessments effectively promoted positive thinking dispositions and reflective learning behaviors among students.

The highest improvement was observed in the aspect of self-regulation (N-Gain = 0.73, high category). This result suggests that students became more capable of managing their learning processes, setting goals, and evaluating their own performance after receiving iterative feedback. The portfolio-based tasks, which required students to revise and resubmit their work, encouraged them to plan more effectively and respond constructively to feedback. This finding is consistent with Kulacki et al. (2024), who emphasized that reflective feedback cycles within collaborative learning environments can strengthen students' self-regulatory capacity and metacognitive awareness.

Critical thinking also showed notable progress, increasing from an average of 2.11 to 3.41 with an N-Gain of 0.68 (medium category). This improvement reflects students' growing ability to analyze information, evaluate evidence, and construct reasoned conclusions across the three portfolio tasks. In particular, the concept mapping and laboratory report activities provided structured opportunities for students to apply logical reasoning and connect theoretical knowledge with experimental data. This finding aligns with Contakes (2016), who found that scientific writing and inquiry-based assignments foster higher-order analytical skills in chemistry education.

Meanwhile, creative thinking improved from 2.07 to 3.20, with an N-Gain value of 0.58 (medium category). Although the increase was slightly lower than in other aspects, students demonstrated enhanced creativity, especially in designing infographics that combined scientific content with visual appeal. This moderate improvement suggests that creativity can be developed gradually when students are given opportunities to express ideas through multiple modalities. The result supports Salam et al. (2021), who noted that infographic-based learning can enhance creative engagement and divergent thinking when supported by feedback and peer review.

Overall, these findings confirm that the implementation of electronic portfolio assessment—characterized by feedback, revision, and reflection—can foster self-regulated, critical, and creative learners. Such outcomes are in line with Marzano et al. (1993), who conceptualized Habits of Mind as essential dispositions for lifelong learning and adaptive problem-solving in complex contexts.

This study successfully developed and implemented an electronic portfolio assessment instrument for acid base learning, integrating feedback and revision as core components of formative assessment. The instrument, which consisted of concept map, laboratory report, and infographic tasks, was validated and tested using the Google Classroom platform. Quantitative results from the limited trial showed consistent improvement across all tasks, with N-Gain values ranging from medium to high categories. Specifically, the concept map task improved students' ability to establish conceptual relationships (N-Gain = 0.68), the laboratory report enhanced their scientific reasoning and conclusion-writing skills (N-Gain = 0.66), and the infographic task significantly strengthened creativity and visual communication (N-Gain = 0.79).

In terms of students' Habits of Mind, the findings revealed positive development in all three domains: self-regulation (N-Gain = 0.73, high), critical thinking (N-Gain = 0.68, medium), and creative thinking (N-Gain = 0.58, medium). These results confirm that the electronic portfolio assessment not only functions as a valid and reliable evaluation tool but also supports reflective learning behavior and higher-order cognitive growth. The iterative feedback process allowed students to actively monitor, evaluate, and improve their learning, fostering independence and creativity consistent with 21st-century learning goals.

Overall, this research contributes to chemistry education by demonstrating that electronic portfolio assessment can effectively bridge assessment and learning. It promotes a culture of continuous reflection and improvement while aligning with the formative principles of the Kurikulum Merdeka. Future research is recommended to expand the implementation to broader topics and larger samples to examine the long-term impact of this approach on students' metacognitive development and academic achievement.

Conclusion

Based on the limited trial, the implementation of the electronic portfolio assessment on acid base learning showed positive improvement across all tasks. Students' performances in concept mapping, laboratory reporting, and infographic creation increased with N-Gain values between 0.66 and 0.79 (medium to high categories). The Habits of Mind indicators—self-regulation (0.73, high), critical thinking (0.68, medium), and creative thinking (0.58, medium)—also improved after iterative feedback and revision. These findings indicate that the developed electronic portfolio assessment has the potential to enhance students' reflective habits, creativity, and higher-order thinking skills through continuous feedback-based learning.

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Author Contributions

Conceptualization, methodology, A.S.E and N.; validation, N., and S.S.F.; original draft writing and editing, A.S.E.; review, N. and S.S.F. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest

This research was carried out based on the mandate of the institution as part of its commitment to improving the quality of education through the development of innovative assessment tools. The study aims to enhance students' *habits of mind* by integrating electronic portfolio assessment into the learning process. It is expected that the results of this research can contribute positively to the development of 21st-century learning skills, particularly in fostering reflective thinking, creativity, and self-directed learning. Moreover, the findings are expected to support the advancement of human resources in the academic field and promote innovation in educational practices.

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