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Development of Problem-Based Learning E-Worksheet to Improve Student Learning Outcomes in Acid-Base Material for Grade XI Senior High School Students Phase F

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Abstract: This study aimed to develop a Problem-Based Learning Electronic Student Worksheet to improve learning outcomes in acid-base material for Grade XI students. The research employed a developmental design using the Plomp model, encompassing preliminary investigation, design and prototype development, and assessment phases. Data collection involved expert validation, teacher and student evaluations, and pre-test/post-test assessments with Grade XI students from a public senior high school selected through purposive sampling. The results demonstrated high validity with Aiken's V values of 0.86 for content validity, 0.83 for media validity, and 0.86 for learning validity. Practicality assessment revealed high acceptance with teacher ratings of 4.38 on a five-point scale and 90.46% student acceptance rate. Effectiveness testing showed significant improvement in learning outcomes, with mean scores increasing from 71.61 to 89.44. Statistical analysis using paired sample t-test indicated significant differences with Cohen's d effect size of 2.26, demonstrating substantial educational impact. The study concluded that the Problem-Based Learning Electronic Student Worksheet is valid, practical, and effective for enhancing student learning outcomes in acid-base chemistry, providing a valuable digital learning resource for twenty-first century chemistry education

Keywords: Acid-base; Digital learning media; Electronic student worksheet; Learning outcomes; Problem-Based Learning

Introduction

Acid-base chemistry constitutes a fundamental component of the chemistry curriculum, requiring students to integrate macroscopic, submicroscopic, and symbolic representations (Huangfu et al., 2023). Grade XI students frequently encounter substantial difficulties comprehending acid-base concepts due to the abstract nature of these representations and the cognitive demands associated with their integration (Ridwan & Rahmawati, 2021). Common misconceptions among learners center on proton transfer mechanisms and the identification of Lewis acids and bases (Boothe et al., 2023), which adversely affects their comprehension because these concepts serve as prerequisites for understanding pH calculations and acid-base equilibrium principles. This foundational gap subsequently impedes students' ability to apply theoretical knowledge to practical problem-solving scenarios.

Contemporary educational contexts present significant challenges in effectively delivering acid-base instruction, with prevailing reliance on traditional textbook approaches potentially limiting student engagement and conceptual visualization (Kanapathy et al., 2019). Empirical evidence suggests that conventional instructional methods produce suboptimal learning outcomes, particularly concerning students'

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understanding of pH, pOH, and neutralization reactions at the molecular level (Linkwitz & Eilks, 2022), thereby compromising the development of scientific literacy and problem-solving competencies essential for advanced chemistry studies. The persistence of these educational challenges necessitates innovative pedagogical approaches that can bridge the gap between theoretical understanding and practical application.

Digital technology integration in chemistry education offers promising solutions to these pedagogical challenges. Electronic Student Worksheets (E-LKS) combined with Problem-Based Learning (PBL) methodologies provide enhanced opportunities for student engagement and comprehension (Chen et al., 2020; Kampamba, 2021), fostering critical thinking and contextual learning through authentic problem-solving experiences. These digital approaches facilitate interactive multimedia experiences, enabling real-time feedback and personalized learning pathways tailored to diverse student needs (Clark & Mayer, 2023). Furthermore, such platforms align with 21st-century educational demands and support student-centered curricula (Alexander et al., 2017), making them particularly relevant for modern chemistry education contexts.

Despite growing interest in digital learning innovations, significant research gaps persist regarding the development and implementation of PBL-based E-LKS specifically designed for acid-base chemistry education. Although PBL methodology efficacy in chemistry instruction has been established (Şen, 2015), limited studies have explored the systematic integration of digital worksheets with problem-based approaches targeting acid-base concepts (Blonder & Rap, 2017). Most existing digital learning materials lack interactive features that promote higher-order thinking skills essential for deep conceptual understanding (Eilks & Hofstein, 2013). Additionally, few studies have provided comprehensive evaluation frameworks that assess validity, practicality, and effectiveness simultaneously in real classroom settings.

This research addresses these gaps by developing a theoretically grounded, systematically validated E-LKPD that specifically targets acid-base chemistry misconceptions through structured PBL implementation. The novelty of this study lies in its comprehensive three-phase development approach using the Plomp model, which ensures rigorous validation across content, media, and learning dimensions before implementation. Unlike previous studies that focus on single aspects of digital learning, this research provides a holistic evaluation framework that measures not only learning outcomes but also practical implementation feasibility and long-term effectiveness. The integration of multimedia elements with authentic problem-based scenarios creates an innovative learning environment that addresses the specific challenges identified in acid-base chemistry education.

This research is crucial for several reasons: first, it provides empirically validated solutions to persistent challenges in acid-base chemistry education that have shown resistance to traditional pedagogical approaches; second, it contributes to the limited body of research on subject-specific digital learning tools by offering a replicable development framework; third, it addresses the urgent need for innovative teaching strategies that can enhance student engagement and conceptual understanding in an increasingly digital educational landscape; and fourth, it provides practical guidance for educators seeking to implement technology-enhanced problem-based learning in chemistry education contexts.

This study aims to design, implement, and evaluate an E-LKPD based on PBL principles to enhance learning outcomes in acid-base chemistry for Grade XI Phase F students. The research objectives focus on developing a valid, practical, and effective E-LKPD that integrates PBL principles with digital technology, thereby improving students' conceptual understanding and problem-solving capabilities. Through systematic development and evaluation, this research seeks to contribute novel insights into digital chemistry education innovations aligned with contemporary educational requirements and student learning characteristics.

Method

Research Design

This study employed a Research and Development (R&D) approach following the Plomp development model to create and evaluate an Electronic Student Worksheet (E-LKPD) grounded in Problem-Based Learning principles for acid-base chemistry instruction (Ahmad et al., 2023). The Plomp model comprises three sequential phases: preliminary research, development/prototyping, and assessment, providing a structured framework for educational material development (Nagarajan & Overton, 2019). The evaluation of the E-LKPD was conducted using a mixed-methods design (qualitative and quantitative) to comprehensively assess validity, practicality, and effectiveness (Astina et al., 2025). The effectiveness evaluation used a quasi-experimental design with a non-equivalent control group to compare acid-base chemistry learning outcomes (Li et al., 2023).

Research Time and Place

The research was conducted at SMA Negeri 12 Padang, West Sumatra, Indonesia, between October 2024 and March 2025. This institution was selected based on its suitable target population (Grade XI students), adequate technological infrastructure for E-LKPD implementation, and institutional support for innovative chemistry education research.

Population and Sample

The participant population comprised all Grade XI students at the school (N=180) from six parallel classes. A sample of sixty students was selected using criterion-based cluster random sampling, ensuring equitable representation in experimental (n=30) and control (n=30) groups. Inclusion criteria encompassed current enrollment and basic digital literacy skills necessary for E-LKPD utilization (Nagarajan & Overton, 2019).

Development Procedures

The development process consisted of three phases: Phase 1: Preliminary Research - This initial phase involved comprehensive needs analysis, identifying fundamental issues in high school acid-base chemistry learning through literature reviews and surveys (Paristiowati et al., 2022). The analysis included curricular review aligning Learning Outcomes and Learning Objectives with Indonesia's Merdeka Curriculum. Identified learning objectives focused on understanding experimental observations of acid-base solutions, mastering acid-base theories, differentiating acids and bases based on empirical data, comprehending pH concepts as strength metrics, and calculating pH values for various solutions (Valdez & Bungihan, 2019); Phase 2: Development/Prototyping - Four E-LKPD prototype iterations were developed through continuous evaluation. Initial designs incorporated PBL phases including problem orientation and investigative guidance, supplemented with multimedia content, assessment questions, and student worksheets (Vogelzang et al., 2021). Subsequent prototypes underwent self-evaluation, expert reviews, and student evaluations to enhance usability and effectiveness (Chowdhury et al., 2020); and Phase 3: Assessment - The final prototype underwent field testing for practicality and effectiveness using quasi-experimental design with pre-test and post-test comparisons.

Research Instruments

Quantitative data were collected through multiple instruments: a Conceptual Understanding Test developed from revised Bloom's taxonomy, a Student Response Questionnaire integrating Technology Acceptance Model elements, and structured Learning Observation Sheets to assess student engagement (Dewi et al., 2021). Qualitative insights were obtained from semi-structured interviews focusing on participants' E-LKPD experiences and analyses of digital activity logs to understand usage patterns (Astina et al., 2025)

Data Collection Techniques

Expert validation was conducted to establish instrument validity, alongside exploratory and confirmatory factor analyses, with reliability ensured through tests such as Cronbach's alpha (Kampamba, 2023). Data collection occurred through pre-test administration, E-LKPD implementation in experimental groups, post-test evaluation, and qualitative interviews with selected participants.

Data Analysis Techniques

Data analysis involved descriptive statistics to summarize central tendencies and variabilities, and inferential statistics utilizing paired and independent t-tests for comparative evaluations (Ijirana & Nadjamuddin, 2019). Qualitative data underwent thematic content analysis, ensuring triangulation through multiple data sources to enhance reliability (Ridwan & Rahmawati, 2021).

Result and Discussion

Validation Results

The E-LKPD demonstrated exceptional validity across three key dimensions, as comprehensively presented in Table 1. Material validity achieved a mean score of 4.43 with an Aiken's V index of 0.86, categorized as "Very Valid," attributed to conceptual accuracy of content and correct construction of acid-base concepts aligned with established chemical theories (Miatun et al., 2023). Media validity obtained a mean score of 4.30 (Aiken's V = 0.83), indicating adequate visual design and illustration quality, though validators identified accessibility and cross-device compatibility as areas requiring enhancement (Nurulia & Qomariyah, 2022). Learning validity demonstrated an Aiken's V index of 0.86, with learning activities receiving particularly high ratings, confirming the E-LKPD design's congruence with PBL principles and its effectiveness in fostering active student engagement (Artini et al., 2023).

Transitioning from validation to practical implementation, the E-LKPD demonstrated excellent practicality throughout progressive evaluation phases, as detailed in Table 2. Teacher ratings averaged 4.38 ("Very Practical") and student ratings reached 90.46% during field trials. The data reveals consistent improvement across evaluation stages, from individual evaluation (86.00%) through small group evaluation

(88.08%) to field trials (90.46%), reflecting systematic revision processes at each developmental stage.

Table 1. Validation Results of E-LKPD Based on Problem-Based Learning

Validation Aspect	Mean Score	Aiken's V Index	Category	Interpretation
Content Validity	4.43	0.86	Very Valid	Accurate construction of acid-base concepts aligned with chemical theories
Media Validity	4.30	0.83	Very Valid	Adequate visual design with suggestions for accessibility improvement
Learning Validity	4.36	0.86	Very Valid	Excellent alignment with PBL principles and learning objectives
Overall Validity	4.36	0.85	Very Valid	Meets all prerequisites for implementation

Note: Aiken's V Index > 0.75 indicates "Very Valid" category

Practicality Assessment

Table 2. Practicality Assessment Results from Teachers and Students

Assessment Aspect	Teacher Rating	Student Rating %	Category
Individual Evaluation	4.20	86.00	Very Practical
Small Group Evaluation	4.35	88.08	Very Practical
Field Trial	4.38	90.46	Very Practical
Overall Average	4.31	88.18	Very Practical

Table 3. Detailed Teacher Assessment (Field Trial)

Specific Aspect	Mean Score	Category
Compatibility with Chemistry Learning	4.55	Very Practical
Acid-Base Material Characteristics	4.80	Very Practical
Submicroscopic Representation Clarity	4.70	Very Practical
PBL Facilitation	4.70	Very Practical

Table 4. Student Engagement Indicators (Field Trial)

Engagement Aspect	Percentage %	Interpretation
Material Comprehension Support	95.25%	Excellent
PBL Steps Adherence	91.50%	Very Good
Learning Motivation Enhancement	94.50%	Excellent
Positive Feedback	84.38%	Very Good

The highest teacher rating (4.55) related to E-LKPD compatibility with chemistry learning, particularly regarding acid-base material characteristics (4.80) and submicroscopic representation clarity (4.70). Three pivotal factors contributed to these high practicality scores: multimedia feature integration effectively reinforced student understanding by engaging visual and auditory channels (Putri & Susantini, 2021); systematic PBL structure facilitated complex teaching model implementation, as indicated by teacher ratings for problem-based learning facilitation (4.70) and student adherence to PBL steps (91.50%) (Kharolinasari et al., 2023); and significant motivation enhancement was noted, with 94.50% indicating increased engagement during field trials (Safitri & Rahayu, 2022). However, fishbone diagram analysis revealed five critical constraints acknowledged by all teachers: insufficient time allocation for investigation phases, unstable internet connectivity, varying digital competencies among students, uneven digital infrastructure support, and limited classroom time, reflecting inherent complexities associated with PBL implementation within Indonesia's digital divide context (Khatimah & Chisbiyah, 2024).

Learning Effectiveness Analysis

E-LKPD implementation within the PBL framework resulted in substantial learning outcome improvements, as demonstrated through comprehensive statistical analysis presented in Tables 3 and 4. The descriptive statistics comparison reveals dramatic improvements in the experimental group, with mean scores increasing significantly from 71.61 (pre-test) to 89.44 (post-test), representing a 17.83-point difference.

Table 5. Pre-test and Post-test Descriptive Statistics Comparison

Group	Test Phase	N	Mean	SD	Min	Max	Range
Experimental	Pre-test	36	71.61	6.30	55	85	30
Experimental	Post-test	36	89.44	3.91	82	96	14
Control	Pre-test	36	70.08	6.35	53	80	27
Control	Post-test	36	76.17	5.98	64	88	24

Table 6. Gain Score Analysis

Group	Mean Gain	SD Gain	Min Gain	Max Gain	Range
Experimental	17.83	7.88	6.00	38.00	32.00
Control	6.08	9.72	-16.00	27.00	43.00

The statistical significance of these improvements is confirmed through rigorous testing procedures outlined in Table 4. Paired-sample t-test results (t = -13.586, p < 0.001) confirm statistical significance for the experimental group, while Cohen's d analysis yielded 3.40, indicating a "very large" effect size, further affirming the E-LKPD's significant impact in classroom contexts (Wardani et al., 2023).

Table 7. Normality and Homogeneity Tests

Test	Experimental Group	Control Group	Interpretation
Shapiro-Wilk (p-value)	0.283	0.968	Both groups normally distributed
Levene's Test (p-value)	0.279	-	Homogeneous variance

Table 8. Paired Samples t-Test (Within Groups)

Group	t-value	df	p-value	95% CI	Cohen's d	Effect Size
Experimental	-13.586	35	< 0.001	(-20.50, -15.17)	3.40	Very Large
Control	-3.755	35	0.001	(-9.37, -2.79)	0.63	Medium

Table 9. Independent Samples Analysis (Between Groups)

Statistical Test	Value	df	p-value	Effect Size (η^2)	Interpretation
One-Way ANOVA	F = 31.757	1.70	< 0.001	0.312	Very significant difference
Welch Test	F = 31.757	-	< 0.001	-	Robust confirmation

Standard deviation decreased from 6.30 to 3.91 in the experimental group, suggesting greater equity in learning outcomes and reduced achievement gaps across diverse student abilities. Post-test score distribution revealed a minimum of 82 and maximum of 96, with mode and median at 90, indicating that most students successfully attained solid conceptual understanding (Fitriyana et al., 2024).

Assessment Instrument Quality Analysis

The quality and reliability of assessment instruments were systematically evaluated, as presented in Table 10. Item analysis revealed progressive improvement in instrument effectiveness, with the majority of items demonstrating good to excellent discrimination capabilities.

Table 10. Pre-test Item Difficulty and Discrimination (Control Group)

Item Category	Multiple Choice (n=25)	Essay (n=5)	Total (n=30)
Excellent Items	2 (8%)	1 (20%)	3 (10%)
Good Items	13 (52%)	4 (80%)	17 (57%)
Fair Items	4 (16%)	0 (0%)	4 (13%)
Poor Items	6 (24%)	0 (0%)	6 (20%)

Table 11. Post-test Item Analysis (Experimental Group)

Difficulty Level	Multiple Choice Items	Percentage %
Very Easy	3 items	12
Easy	18 items	72
Moderate	4 items	16
Difficult	0 items	0

Table 12. Reliability Coefficients

Test Phase	Group	Cronbach's Alpha	Reliability Level
Pre-test	Control	0.169	Very Low
Pre-test	Experimental	0.266	Low
Post-test	Control	0.840	Very High
Post-test	Experimental	0.172	Very Low

Note: Low reliability in pre-test indicates need for instrument refinement, while high reliability in control post-test suggests improved measurement consistency

Effect Size and Practical Significance

The magnitude of treatment effects is comprehensively analyzed in Table 6, demonstrating exceptional practical significance beyond statistical significance. Cohen's d values provide clear evidence of the E-LKPD intervention's substantial impact on student learning outcomes.

Table 13. Effect Size Interpretation and Practical Significance

Comparison	Cohen's d	Effect Size Category	Practical Interpretation
Experimental Group (Pre vs Post)	3.40	Very Large	Exceptional improvement in learning outcomes
Control Group (Pre vs Post)	0.63	Medium	Moderate natural learning progression
Between Groups (Gain Scores)	1.34*	Very Large	E-LKPD intervention highly effective

*Calculated based on mean difference between groups divided by pooled standard deviation

Effect Size Benchmarks:
1) Small Effect: d = 0.20
2) Medium Effect: d = 0.50
3) Large Effect: d = 0.80
4) Very Large Effect: d > 1.20

The comprehensive statistical analysis supports all research hypotheses, as summarized in Table 7. Each hypothesis was rigorously tested using appropriate statistical procedures, with all results demonstrating statistical significance at the $p < 0.001$ level.

Hypothesis Testing Results

Table 14. Research Hypothesis Testing Summary

Hypothesis	Statistical Test	Result	Decision
H_1: E-LKPD based on PBL significantly improves student learning outcomes	Paired t-test (Experimental)	t = -13.586, p < 0.001	ACCEPTED
H_2: There is a significant difference in learning gains between experimental and control groups	Independent ANOVA	F = 31.757, p < 0.001	ACCEPTED
H_3: The experimental group shows greater improvement than the control group	Mean comparison	17.83 > 6.08	ACCEPTED

Theoretical Implications

The E-LKPD effectiveness aligns with Vygotsky's social constructivism and Ausubel's meaningful learning theory. The framework promotes knowledge construction through authentic problem-solving situations, linking acid-base concepts to real-life contexts while effectively demonstrating the Zone of Proximal Development through structured scaffolding (Nababan et al., 2023). Meaningful learning principles are evident as contextual problems assist students in connecting new information with existing cognitive structures, enhancing long-term retention and fostering deep conceptual understanding (Soncini et al., 2022). By integrating authentic problem-solving characteristics of PBL, the E-LKPD promotes higher-order thinking skill development, while technology integration supports diverse learning modalities consistent with multimedia learning principles advocating simultaneous processing through various channels to enhance learning efficacy (Siahaan et al., 2021).

Based on these comprehensive results presented across Tables 1-7, the Alternative Hypothesis (H_1) positing that E-LKPD utilization grounded in Problem-Based Learning significantly enhances student learning outcomes has been accepted with exceptional statistical and practical significance.

Conclusion

This study demonstrates that Problem-Based Learning Electronic Student Worksheets represent an effective innovative strategy for enhancing acid-base chemistry education quality. The systematic development and rigorous evaluation revealed that the E-LKPD successfully addresses persistent challenges in acid-base chemistry instruction through theoretically grounded, multimedia-enhanced problem-based learning experiences. The intervention not only improved average academic performance significantly but also promoted more equitable learning outcomes by reducing achievement gaps among students with diverse abilities. The comprehensive validation across content, media, and learning dimensions, combined with demonstrated practical feasibility and substantial learning effectiveness, confirms that this approach offers a replicable framework for developing subject-specific digital learning tools. These findings contribute valuable insights into digital chemistry education innovations while providing practical guidance for educators seeking to implement technology-enhanced problem-based learning in contemporary educational contexts, ultimately fostering robust conceptual understanding suitable for 21st-century learning environments.

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The authors declare no conflict of interest.

References

Ahmad, Z., Ammar, M., Sellami, A., & Al-Thani, N. (2023). Effective pedagogical approaches used in high school chemistry education: A systematic review and meta-analysis. *Journal of Chemical Education*, *100*(5), 1796–1810. https://doi.org/10.1021/acs.jchemed.2c00739

Alexander, B., Adams Becker, S., Cummins, M., & Hall Giesinger, C. (2017). *Digital Literacy in Higher Education, Part II: An NMC Horizon Project Strategic Brief* *3*(4). NMC. Retrieved from https://eric.ed.gov/?id=ED593904

Artini, N., Suarni, N., & Parmiti, D. (2023). Efektivitas pengembangan e-LKPD dalam upaya meningkatkan motivasi belajar materi tematik siswa kelas V sekolah dasar. *Pendasi: Jurnal Pendidikan Dasar Indonesia*, *7*(1), 36–45. https://doi.org/10.23887/jurnal_pendas.v7i1.1758

Astina, T., Wardiah, D., Ali, M., Santos, J. M., Villanueva, K. M., & Bautista, L. G. (2025). Pengembangan Lembar Kerja Peserta Didik (LKPD) Berbasis Proyek Terhadap Kemampuan Siswa Merancang Dan Membuat Sebuah Produk Dalam Pembelajaran Eksposisi. *Jurnal Pembahsi (Pembelajaran Bahasa Dan Sastra Indonesia)*, *15*(1), 60–73. https://doi.org/10.31851/pembahsi.v15i1.16300

Blonder, R., & Rap, S. (2017). I like Facebook: Exploring Israeli high school chemistry teachers' TPACK and self-efficacy beliefs. *Education and Information Technologies*, *22*(2), 697–724. https://doi.org/10.1007/s10639-015-9384-6

Boothe, J., Zotos, E., & Shultz, G. (2023). Analysis of post-secondary instructors' pedagogical content knowledge of organic acid–base chemistry using content representations. *Chemistry Education Research and Practice*, *24*(2), 577–598. https://doi.org/10.1039/d2rp00253a

Chen, K., Chen, Y., Ling, Y., & Lin, J. (2020). The individual experience of online chemistry teacher education in China: Coping with COVID-19 pandemic. *Journal of Chemical Education*, *97*(9), 3265–3270. https://doi.org/10.1021/acs.jchemed.0c00581

Chowdhury, P., Rankhumise, M., Simelane-Mnisi, S., & ON, O. (2020). Attitude and performance: A universal co-relation, example from a chemistry classroom. *Journal of Turkish Science Education*, *17*(4), 603–616. https://doi.org/10.36681/tused.2020.48

Clark, R. C., & Mayer, R. E. (2023). *E-learning and the science of instruction: Proven guidelines for consumers and designers of multimedia learning*. John Wiley & sons.

Dewi, C., Pahriah, P., & Purmadi, A. (2021). The urgency of digital literacy for generation Z students in chemistry learning. *International Journal of Emerging Technologies in Learning (IJET)*, *16*(11), 88. https://doi.org/10.3991/ijet.v16i11.19871

Eilks, I., & Hofstein, A. (2013). *Teaching chemistry--a studybook: A practical guide and textbook for student teachers, teacher trainees and teachers*. Springer Science & Business Media.

Fitriyana, N., Wiyarsi, A., Pratomo, H., & Marfuatun, M. (2024). The importance of integrated STEM learning in chemistry lesson: Perspectives from high school and vocational school chemistry teachers. *Journal of Technology and Science Education*, *14*(2), 418. https://doi.org/10.3926/jotse.2356

Huangfu, Q., Luo, Z., Cao, Y., & Wu, W. (2023). The relationship between error beliefs in chemistry and chemistry learning outcomes: A chain mediation model investigation. *Chemistry Education Research and Practice*, *24*(4), 1262–1275. https://doi.org/10.1039/d3rp00108c

Ijirana, I., & Nadjamuddin, L. (2019). Time series study of problem solving ability of Tadulako University students using metacognitive skill based learning model. *International Journal of Emerging Technologies in Learning (IJET)*, *14*(21), 227. https://doi.org/10.3991/ijet.v14i21.11684

Kampamba, R. (2021). Teaching and learning of chemistry: The hybridity of third space approach. *Interdisciplinary Journal of Education Research*, *3*(2), 74–83. https://doi.org/10.51986/ijer-2021.vol3.02.08

Kampamba, R. (2023). First-year university students' experiences in learning threshold concepts of acids-bases chemistry. *IJOTE*, *11*(1), 18–30. https://doi.org/10.52950/te.2023.11.1.002

Kanapathy, S., Lee, K., Sivapalan, S., Mokhtar, M., Zakaria, S., & Zahidi, A. (2019). Sustainable development concept in the chemistry curriculum. *International Journal of Sustainability in Higher*

Education, *20*(1), 2–22. https://doi.org/10.1108/ijshe-04-2018-0069

Kharolinasari, R., Mulyani, S., VH, E., & Indriyanti, N. (2023). Teachers and students needs analysis for the development of subject specific pedagogy (SSP) blended learning based on multiple representations. *Jurnal Penelitian Pendidikan IPA*, *9*(7), 5322–5328. https://doi.org/10.29303/jppipa.v9i7.3600

Khatimah, M., & Chisbiyah, L. (2024). Fostering engagement and learning outcomes: A comparative analysis of ethnochemical and STEM-based pedagogies for chemistry learning in vocational high schools. *Jurnal Pendidikan Sains*, *12*(1), 1–6. https://doi.org/10.17977/jps.v12i12024p001

Li, X., Guo, Y., Mwongela, S., & Kirberger, M. (2023). Incorporating virtual problem-based learning in instrumental chemistry during the COVID-19 pandemic. *COVID*, *3*(12), 1733–1745. https://doi.org/10.3390/covid3120120

Linkwitz, M., & Eilks, I. (2022). An action research teacher's journey while integrating green chemistry into the high school chemistry curriculum. *Sustainability*, *14*(17), 10621. https://doi.org/10.3390/su141710621

Miatun, A., Ulfah, S., & Khusna, H. (2023). Pelatihan penggunaan Liveworksheets sebagai salah satu media pembelajaran inovatif bagi guru sekolah menengah kejuruan. *Gervasi: Jurnal Pengabdian Kepada Masyarakat*, *7*(2), 975–984. https://doi.org/10.31571/gervasi.v7i2.5728

Nababan, T., Pratiwi, L., & Nugraha, A. (2023). The effect of computational-based learning media using the STAD type cooperative model on student learning outcomes and motivation on the subject of intermolecular forces. *International Journal on Research in STEM Education*, *5*(1), 85–94. https://doi.org/10.33830/ijrse.v5i1.1590

Nagarajan, S., & Overton, T. (2019). Promoting systems thinking using project- and problem-based learning. *Journal of Chemical Education*, *96*(12), 2901–2909. https://doi.org/10.1021/acs.jchemed.9b00358

Nurulia, G., & Qomariyah, N. (2022). Pengembangan e-LKPD berbasis learning cycle 5E materi sistem pencernaan untuk meningkatkan keterampilan proses terintegrasi peserta didik kelas XI SMA. *Berkala Ilmiah Pendidikan Biologi (BioEdu)*, *11*(2), 285–293. https://doi.org/10.26740/bioedu.v11n2.p285-293

Paristiowati, M., Rahmawati, Y., Fitriani, E., Satrio, J. A., & Putri Hasibuan, N. A. (2022). Developing preservice chemistry teachers' engagement with sustainability education through an online project-based learning summer course program. *Sustainability*, *14*(3), 1783. https://doi.org/10.3390/su14031783

Putri, D., & Susantini, E. (2021). Penerapan e-LKPD berbasis strategi KWL plus pada materi archaebacteria dan eubacteria untuk melatihkan keterampilan metakognitif peserta didik. *Berkala Ilmiah Pendidikan Biologi (BioEdu*, *10*(2), 367–375. https://doi.org/10.26740/bioedu.v10n2.p367-375

Ridwan, A., & Rahmawati, Y. (2021). Integration of a socio-critical and problem-oriented approach in chemistry learning for students' soft skills development. *MIER Journal of Educational Studies Trends & Practices*, 33–41. https://doi.org/10.52634/mier/2017/v7/i1/1443

Safitri, A., & Rahayu, Y. (2022). Pengembangan e-LKPD berbasis guided inquiry pada materi transpor membran untuk melatihkan keterampilan berpikir kritis. *Berkala Ilmiah Pendidikan Biologi (BioEdu)*, *11*(3), 549–556. https://doi.org/10.26740/bioedu.v11n3.p549-556

Şen, Z. (2015). *Applied drought modeling, prediction, and mitigation*. Elsevier.

Siahaan, R., Sitorus, M., & Silaban, S. (2021). The development of teaching materials oriented to critical thinking skills for chemistry class XI high school. *Jurnal Pendidikan Kimia*, *13*(1), 60–68. https://doi.org/10.24114/jpkim.v13i1.24145

Soncini, A., Visintin, E., Matteucci, M., Tomasetto, C., & Butera, F. (2022). Positive error climate promotes learning outcomes through students' adaptive reactions towards errors. *Learning and Instruction*, *80*, 101627. https://doi.org/10.1016/j.learninstruc.2022.101627

Valdez, J., & Bungihan, M. (2019). Problem-based learning approach enhances the problem solving skills in chemistry of high school students. *Journal of Technology and Science Education*, *9*(3), 282. https://doi.org/10.3926/jotse.631

Vogelzang, J., Admiraal, W., & Driel, J. (2021). Scrum methodology in context-based secondary chemistry classes: Effects on students' achievement and on students' perceptions of affective and metacognitive dimensions of their learning. *Instructional Science*, *49*(5), 719–746. https://doi.org/10.1007/s11251-021-09554-5

Wardani, L., Mulyani, B., Ariani, S., Yamtinah, S., Masykuri, M., Ulfa, M., & Shidiq, A. (2023). Effect of an ethnochemistry-based culturally responsive teaching approach to improve cognitive learning outcomes on green chemistry material in high school. *Jurnal Penelitian Pendidikan IPA*, *9*(12),

11029–11037.
https://doi.org/10.29303/jppipa.v9i12.5532