UNESA Journal of Chemical Education *ISSN: 2252-9454*
Vol. 15, No. 2, pp. 126–135, May 2026

DEVELOPMENT OF STEM-PjBL BASED STUDENT ACTIVITY SHEETS ON GREEN CHEMISTRY TOPIC TO SUPPORT STUDENTS' COLLABORATION SKILLS

Elsa Kharisma Zulaicha* and Mitarlis

Department of Chemistry, FMNS, Universitas Negeri Surabaya

e-mail: elsa.22057@mhs.unesa.ac.id

Abstract

Emerging global issues require learning media to support students' collaboration skills to connect concepts and design solutions in order to solve contextual problems. This study aims to describe feasibility of student activity sheet (SAS) based on STEM (Science, Technology, Engineering, and Mathematics) approach and project-based learning on the topic of green chemistry to support collaboration skills. This research employed a research and development (R&D) method using 4D model, limited to the Define, Design, and Develop stages. The limited trial involved 32 tenth-grade students at a Senior High School in Surabaya. The research instruments include validation sheets, student response questionnaires, learning implementation observation sheets, student activity observation sheets, and collaboration skills self-assessment. Data were analyzed descriptively using median scores and percentages. The validity of SAS was assessed by two chemistry lecturers and one chemistry teacher with median 5 categorized as very valid criteria. The practicality of SAS was measured through student response questionnaires, obtaining percentage of 96,88% categorized as very practical criteria, learning implementation observation with median 5 categorized as very good criteria, and student activity observation with percentage of 94,56% categorized as very good criteria. The effectiveness of SAS was measured through collaboration skills self-assessment, obtaining 86,06% in the first meeting and 93,31% in the second meeting both categorized as very good. These findings indicate that the developed SAS is feasible for supporting students' collaboration skills in green chemistry topic.

Keywords: student activity sheet (SAS), STEM, project based learning, green chemistry, collaboration skills

INTRODUCTION

Current global challenges driven by behavioral shifts threatening environmental sustainability [1], [2]. In this context, secondary chemistry education aims to equip students with knowledge and skills relevant to foster resilience needed to navigate 21st century global challenges [3]. Consequently, education aims to produce graduates who possess 4C competencies, that is critical thinking, creativity, communication and collaboration. These skills are recognized as the core prerequisites for successfully addressing the challenges of the 21st century [4].

Collaboration skills refers to individual's capacity to engage in cooperative efforts to attain shared objectives. These competencies not only facilitate the completion of academic requirements but also equip students for future professional landscapes by fostering collective problem-solving capabilities [5]. Indicators of collaboration are responsibility, active contribution, productive work, flexibility and compromises, empathy, and manage project [6]. Furthermore, the integration of STEM approach in learning activity provides a robust environment for the refinement of these collaborative skills [7].

The STEM approach is an innovation in learning that demands active student participation [7]. The STEM approach focuses on the integration of science, technology, engineering, and mathematics that empowers students to design solution addressing real world problems [8]. In primary and secondary education, students are expected to analyze problem through scientific inquiry, technological design, and mathematical reasoning [9]. STEM approach facilitates meaningful learning through systematic integration of knowledge and skills [10]. The application of

 ISSN: 2252-9454

STEM approach can be carried out through project-based learning model [11].

Project based learning is a learning model facilitating students with authentic application [12]. The problems presented are authentic, aligned with curriculum, and encompass interdisciplinary study [13]. Project based learning model directs students to solve problems and emphasizes contextual learning through complex process, learning autonomy to explore, plan learning activities collaboratively, and implement projects in order to produce a product [14]. Project-based learning model consists of six stages, namely formulate essential questions, design and create project plans, create project schedule, implement project under teacher supervision, present the product, and evaluate as well as reflect on the product [12].

Green chemistry focuses on the strategic design of chemical product and manufacturing process to mitigate the presence of hazardous substances to human health, animal welfare, and environment [15]. The core pedagogical objective of green chemistry is to minimize the use of hazardous materials and optimize efficient energy within chemical processes [16].

The achievement of academic competencies is fundamentally dependent on the availability of comprehensive learning media. Student activity sheets provide targeted assignments that align with curriculum and ensure thematic relevance for students [17]. In the current educational landscape, it is imperative to develop a learning media that bridges theoretical concepts with contextualized real-world challenges for addressing global crisis.

Preliminary research was done by distributing pre-research questionnaire to 25 students in grade XI that has studied green chemistry. The result showed 80% of students state that chemistry is an interesting subject. However, chemistry learning is mainly explained by teacher. As number of students of 41% showed interest in learning chemistry through project and 29% students are motivated to connect chemistry with real world application. Previous research has found that utilization of SAS oriented with STEM-PjBL facilitates students' learning through contextual problem in electrolyte and non-electrolyte material [12]. However, few studies have investigated the utilization of SAS oriented with STEM-PjBL in green chemistry topic to support students' collaboration skills. These data indicate the needs of learning media that linked core material with real world application.

Based on the problems and needs analysis, this research aims to develop a student activity sheets based on STEM approach with PjBL on green chemistry topic oriented towards supporting students' collaboration skills as an effort to create meaningful chemistry learning and encourage deeper understanding of concepts.

METHOD

This research employed the Research and Development (R&D) method designed by Thiagarajan and Semmel using 4D model, , limited to the Define, Design, and Develop stages [18]. The research subject was 32 grade X students from SMAN 5 Surabaya.

Data for this study were collected using several instruments, including validation sheets to assess the validity of SAS using Likert scale 1-5 distributed to three validators, learning implementation observation sheets to evaluate the practicality of the learning process using Likert scale 1-5 distributed to five observers, student activity observation sheet using percentages distributed to five observers, student response questionnaire, and collaboration skills self-assessment.

The validity data obtained were analyzed using Likert scale as shown in Table 1. Validity of SAS was analyzed descriptively using median to identify the central tendency of expert evaluations. SAS is considered valid if the median ≥4 in good to very good criteria [19].

Table 1. Likert Scale

Score	Criteria
1	Bad
2	Not Good
3	Average
4	Good
5	Excellent

The result of learning implementation observation was analyzed using Likert scale in

 ISSN: 2252-9454

Table 1. SAS is considered practical if the median ≥4 in good to very good criteria [19].

Student response questionnaire was analyzed using Guttman scale depicted in Table 2.

Table 2. Guttman Scale

Statement	Criteria	Score
Positive	Yes	1
	No	0
Negative	Yes	1
	No	0

Student response data were analyzed using percentages with the formula.

$$\text{Percentage}=\frac{\Sigma\text{ score for each statement}}{\text{respondents}}\times 100\% \quad [20]$$

The practicality percentages from student response questionnaire and student activity observation were interpreted according to the criterion presented in Table 3. SAS is practical if the student response and student activity observation percentage ≥61% with good to very good criteria [21].

Table 3. Student Activity Criteria

Percentage	Criteria
0-20%	Bad
21-40%	Not Good
41-60%	Average
61-80%	Good
81-100%	Excellent

The effectiveness of SAS determined by collaboration skills self-assessment. A limitation in the study is acknowledged as collaboration skills were measures through self-assessment. Collaboration skills self-assessment data collected using Collaboration Self-Assessment Tool (CSAT) score ranging from 1 to 4 [22].

Table 4. CSAT Score

Score	Criteria
1	Never
2	Rarely
3	Frequently
4	Always

Collaboration skills self-assessment data were analyzed using percentages with the formula.

$$\text{Percentage}=\frac{\Sigma\text{ score for each statement}}{\text{number of statements}}\times 100\%$$

The scoring guidelines for collaboration skills self-assessment Table 4. SAS is considered effectively support students' collaboration skills if percentage increased from the first meeting to the second meeting.

RESULTS AND DISCUSSION

The result of this development research is a student activity sheet based on STEM approach and PjBL learning model on green chemistry topic, designed to support students' collaboration skills.

Define Stage

The define stage aims to obtain general overview of the learning conditions of green chemistry material at a Senior High School in Surabaya. In this stage, front-end analysis, learner analysis, task analysis, concept analysis, and formulation of learning objectives were conducted. Front-end analysis was collected through interview with chemistry teacher and distribution of preliminary questionnaire to grade XI students in order to identify obstacles in chemistry learning. Learner analysis aims to map students' characteristics, including age, cognitive development, and academic performance. Task analysis aims to identify competencies that must be mastered according to Independent Curriculum and Learning Goals. Concept analysis was conducted by identifying the main concepts in green chemistry topic as shown in Figure 1. The learning objectives was created by referring to the chemistry learning goals.

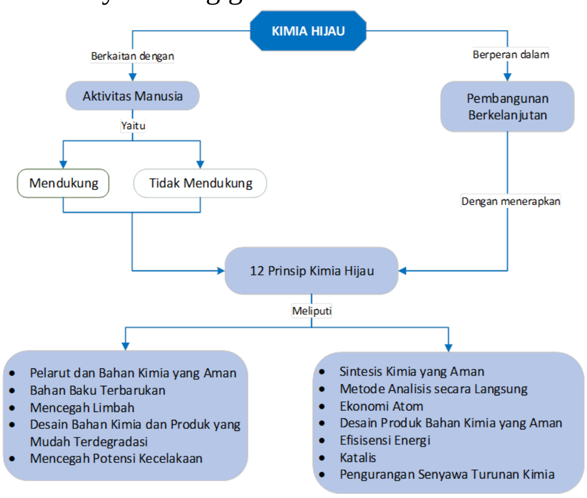

Figure 1. Green Chemistry Concept Map

Design Stage

The design stage is the process of format selection and initial design of student activity sheet based on STEM approach and PjBL learning model. Format selection involves curation of learning resources and identification of appropriate learning models, while ensuring strategic alignment between curriculum and students' needs. At this stage, product design was systematically developed to ensure alignment between learning needs and the media format. The SAS consists of three projects: SAS 1 preparation of natural ink, SAS 2 preparation of dish soap from soapberry fruit, and SAS 3 preparation of compost. Each SAS is design by integrating four aspects of STEM and six phases of PjBL with five collaboration skill aspects as shown in Table 5.

Table 5. SAS Structure Design

PjBL Syntax	STEM Aspects	Collaboration Skills
Formulate Essential Question	Science	
Design Project	Technology and Engineering	Active Contribution
Make Project Schedule		Manage Project
Project Implementation under Teacher Supervision	Engineering and Mathematics	Responsibility and Work Productively
Presenting Project		
Evaluate and Reflection of Project		Flexibility and Compromise

SAS cover principles of green chemistry and the application in real life context as shown in Table 6. Students learn principles number 1 waste prevention prioritize the waste prevention rather than cleaning and treating waste after it has been created, number 5 safer solvents choose the safest solvent available for any given step, number 7 renewable products use materials which are made from renewable sources, number 10 design product for degradation design chemicals that degrade and can be discarded easily, and number 12 accident prevention develop chemical procedures that are safer and minimize the risk of accidents. Comprehensive integration of concepts helps students understand and applied green chemistry concept to address authentic environmental issues.

Table 6. Green Chemistry Principles on Each SAS

SAS	Green Chemistry Principles
SAS 1 preparation of natural ink,	Number 1 Waste Prevention Number 5 Safer Solvents Number 12 Accident Prevention
SAS 2 preparation of dish soap from soapberry fruit	Number 5 Safer Solvents Number 10 Design Product for Degradation Number 12 Accident Prevention
SAS 3 preparation of compost	Number 1 Waste Prevention Number 7 Renewable Products Number 12 Accident Prevention

The STEM aspects on each page of SAS is highlighted in a box to make it easier for students to identify the STEM aspects being studied and making the learning activity meaningful. The first aspect is science by analysis of a phenomena and their impacts, students construct actionable solutions for identified problem. The second aspect is technology, students engage in information collection to select appropriate methods require for product design and prototype. The third aspect is engineering, students configure materials and procedural design facilitated through product pilot testing. The fourth aspect is mathematics, students perform data analysis using mathematical operations.

SAS effectively incorporated Science aspects by following the steps of PjBL. The initial stage of PjBL is formulation of essential question shown in Figure 2. In SAS 2 preparation of dish soap from soapberry fruit, students investigate river water contamination in one of the river in Surabaya by domestic waste. This authentic problem allows students to recognize the immediate impact of domestic waste management. Students can bridge the gap between green chemistry topic and real-world application through investigation. After students identify the main problem, students are asked to formulate essential question: What sustainable mitigation can be developed to effectively reduce domestic waste into local river?

Figure 2. Phase 1 in Project 2 (Preparation of Dish Soap from Soapberry Fruit)

Technology and engineering aspects incorporated in the second stage of PjBL create project design. During this phase, students formulate strategic solution, including selection of materials and project procedure shown in Figure 3. Collaboration skill aspect developed in the second stage is proactive contribution where students communicate their ideas regarding the project design.

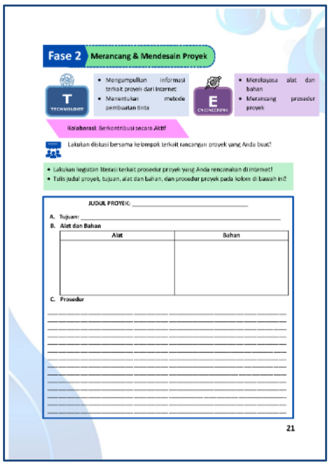

Figure 3. Phase 2 in Project 2 (Preparation of Dish Soap from Soapberry Fruit)

In the third stage of PjBL project scheduling, students create a project timeline and assigned responsibilities for each group member according to their ability. Collaboration skill aspect developed is effective project management where students align task with group member abilities. Students learn to manage the project in order to complete the task efficiently and on time.

In the fourth stage of PjBL project implementation monitored by teacher. This stage Engineering and Mathematics aspect were incorporated. Students write down empirical observation and perform data analysis shown in Figure 4. The engineering aspect is shown by trials for the product optimization, while mathematics aspect is applied through calculation for data analysis. In addition, students developed responsibility and work productively resulting in efficient and deadline-compliant project.

Figure 4. Phase 4 in Project 2 (Preparation of Dish Soap from Soapberry Fruit)

The fifth stage of PjBL project presentation, students present their product in front of the classroom and received peer-to-peer feedback mediated by teacher.

The final stage of PjBL evaluating and reflecting of product, students assess their performance, learn to mitigate project challenges, and reflect on product quality. Student developed collaboration skill aspect that is flexibility and collaborative compromises.

The integration of STEM approach with PjBL model enables students to internalize both conceptual understanding of product development and product engineering and design. The PjBL model facilitates problem solving through authentic learning [12]. Students empowered with the autonomy to explore and plan collaborative learning activities, and perform project to produce a product [23].

Develop Stage

The development stage resulted in student activity sheet by integrating four aspects of STEM and six phases of PjBL with five collaboration skill aspects for green chemistry topic. The initial design was then expert reviewed, validated, revision, and a performed limited trial. The initial design was reviewed by supervisor to gather input and suggestions for SAS improvement prior to media validation.

Validity

Media validation was assessed by two chemistry lecturers from Universitas Negeri Surabaya and one chemistry teacher from SMAN 5 Surabaya to assess the feasibility of SAS including content validity and construct validity.

Content validity encompasses the suitability with independent curriculum, learning goals, and learning objectives, suitability of green chemistry material, suitability with STEM aspects, suitability with PjBL model, suitability with collaboration skill aspects, suitability of collaboration skill aspects with STEM aspects, and suitability of collaboration skill aspects with PjBL model.

Table 7. Content Validity Results

Assessed aspect	V_1	V_2	V_3	Median	Criteria
Suitability with Independent Curriculum, Learning Goals, and Learning Objectives	4	5	5	5	Very Valid
Suitability of green chemistry material	4	5	5	5	Very Valid
Suitability with STEM aspects	4	4	5	4	Valid
Suitability with PjBL model	5	4	5	5	Very Valid
Suitability with collaboration skill aspects	4	4	5	4	Valid
Suitability of collaboration skill aspects with STEM aspects	4	4	5	4	Valid
Suitability of collaboration skill aspects with PjBL model	4	5	5	5	Very Valid

Table 8. Construct Validity Result

Assessed aspect	V_1	V_2	V_3	Median	Criteria
Language	4	5	5	5	Very Valid
Presentation	4	4	5	4	Valid
Graphic	4	4	5	4	Valid

According to Table 8, the SAS developed has a median of 5 for content validity categorized as very valid. In Table 8, showed that SAS has a median of 4 for construct validity categorized as valid. Overall, the validity of SAS for both content and construct validity has a median of 5 categorized as very valid. Hence, SAS is suitable as learning media in chemistry.

In addition, the research instruments used in this study were tested for validity through expert assessment and analyzed using median scores before limited trial as presented in Table 9.

Table 9. Instrument Validation Results

Research Instrument	Median	Criteria
Student response questionnaire	5	Very Valid
Learning implementation observation	5	Very Valid
Student activity observation	4	Valid
Collaboration skill self-assessment	5	Very Valid

It can be seen from the data in Table 9, that the student response questionnaire obtained a median score 5 in very valid category. The learning implementation observation obtained a median score 5 in very valid category. The student activity observation obtained a median score 4 in valid category. The collaboration skill self-assessment obtained a median score 5 in valid category. This indicates that the instruments are valid for research purpose.

Practicality

The practicality of SAS was assessed through student response questionnaire, learning implementation observation, and student activity observation.

Student response questionnaire consists of 23 questions regarding SAS, learning activity, and collaboration skill aspects. The result obtained from the student response are shown in Table 10.

Table 10. Student Response Results

Aspect	Percentage	Criteria
Response to SAS	96,36%	Very Practical
Response to STEM Approach	94,38%	Very Practical
Response to PjBL	98,22%	Very Practical
Response to Collaboration Skill	98,13%	Very Practical
Average	96,88%	Very Practical

According to Table 10, the student response questionnaire achieved an overall percentage of 96,88% in highly practical category.

The learning implementation observation and student activity observation aim to assess the practicality of SAS as learning media. The observation was done by five observers, each observer filled out the learning implementation observation by giving scores between 1 to 5. The data was analyzed using median. The result of learning implementation observation in two meetings showed that learning took place very good with median 5. The result is presented in Figure 5.

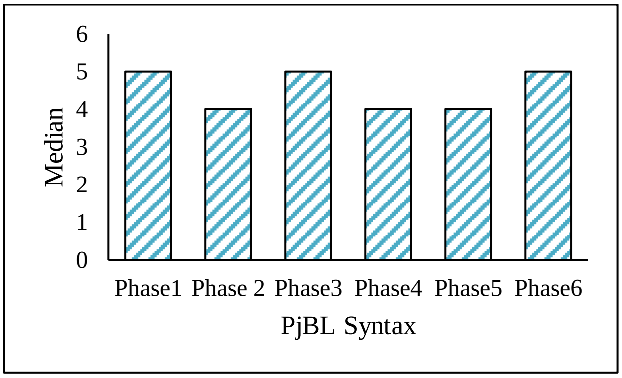

Figure 5. Learning Implementation Observation Results using PjBL from Phase 1 until Phase 6

Student activity observation filled out by five observers each 3 minutes during learning activity. The result presented in Table 11.

Table 11. Student Activity Results

Meeting	Percentage	Criteria
Meeting 1	93,56%	Excelled
Meeting 2	95,56%	Excellent
Average	94,56%	Excellent

According to Table 11, the student activity observation achieved an overall percentage of in highly practical category.

Effectiveness

The effectiveness of SAS was determined through collaboration skills self-assessment. According to Figure 6, significant improvement in students' collaboration skill across five aspects between the first meeting and second meeting. This finding highlights the importance of collaboration as a foundational 21st century skill, where the complexity of global dynamic requires students to demonstrate adaptability and optimal productivity working in groups [5].

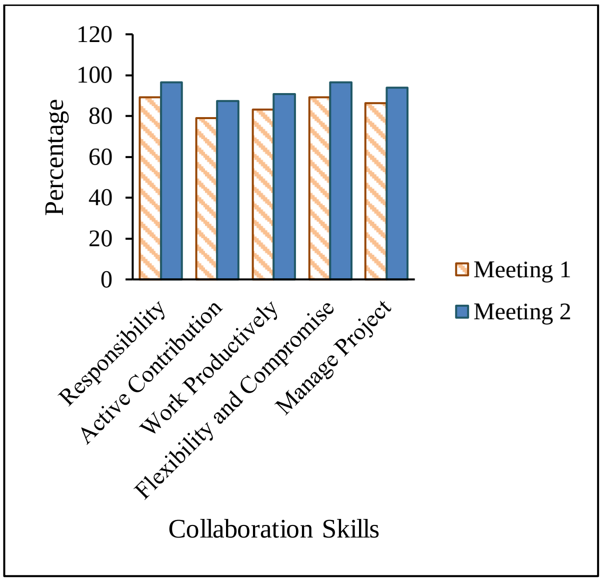

Figure 6. Collaboration Self-Assessment Results

Responsibility is an attitude that requires students to attend group meetings and complete tasks on time [24]. Based on Figure 6, the average increased from 89,22% in the first meeting to 95,56% in the second meeting categorized as excellent. This represents 7,34 percentage point in responsibility aspect, resulting in overall percentage 92,89% categorized as excellent.

While the majority of the students exhibited proactive development in responsibility, a few students achieved <75% situating them in good

 ISSN: 2252-9454

category. These students demonstrated foundational responsibility, they still require sustained intervention aligning with character development is an iterative process requiring regular integration to the curriculum [25].

Active contribution is the ability to convey ideas and solutions during group discussions. The active role of group members helps achieve goals because every student contributes their knowledge [25]. Based on Figure 6, the average increased from 78,91% in the first meeting categorized as good to 87,3% in the second meeting categorized as excellent. This represents 8,40 percentage point in active contribution aspect, resulting in overall percentage 83,89% categorized as excellent.

The majority of students demonstrated enhanced contribution, but several students recorded <75% situating them in good category. This passive engagement may stem from low self-efficacy or limited opportunities for verbal participation. Consequently, pedagogical scaffolding directed by teacher is essential to provide discussion platform for these students to communicate their insights [25].

Work productively refers to students assign roles according to their abilities to facilitate efficient and timely goals [26]. Based on Figure 6, the average increased from 83,28% in the first meeting to 90,63% in the second meeting categorized as excellent. This represents 7,34 percentage point increase in work productively aspect, resulting in overall percentage 83,89% categorized as excellent.

Despite the students generally exhibited positive progress, but several students struggle to work efficiently and on time due to poor time management or task distribution that did not match their abilities. Addressing these challenges require fair task distribution and time management.

Flexibility and compromise evaluate the students' ability to accept collective decision and navigate different perspective to achieve goal [26]. Based on Figure 6, the average increased from 89,19% in the first meeting to 96,48% in the second meeting categorized as excellent. This represents 7,29 percentage point in flexibility and compromise aspect, resulting in overall percentage 92,84% categorized as excellent.

While the majority of students demonstrated enhanced adaptive collaboration, but a few students tend to hold onto their own opinions and have difficulty accepting different insights. As a result, moderated discussion is essential to bridge different insights and ensure that all student contributions are equitably facilitated [25].

Manage project refers to students' ability to implement project activity in accordance with systematic plan [25]. Based on Figure 6, the average increased from 89,22% in the first meeting to 95,56% in the second meeting categorized as excellent. This represents 7,34 percentage point in manage project aspect, resulting in overall percentage 92,89% categorized as excellent.

Although majority of students showed positive development, several students encounter challenges in planning strategically. In order to address this, structured task and timelines is essential to foster project management [25].

This finding aligns with previous research confirming that the integration of STEM oriented PjBL significantly support students' collaboration skills [27]. The interdisciplinary STEM compels students to investigate main problem, propose solutions using appropriate methodologies, and validate outcomes through trial and empirical analysis. This approach requires collaborative work from students to ensure project efficiency [28].

CONCLUSION

Based on the results of the research on the development of student activity sheet (SAS) based on STEM approach with project-based learning are feasible for enhancing collaboration skills on green chemistry topic. Feasibility of SAS indicated by validity of SAS obtained median of 5 with very valid criteria for both content validity and construct validity, practicality of SAS obtained from student response percentage 96,88% with very practical, supported by learning implementation observation median of 5 with very good criteria and student activity percentage 94,56% with very good criteria. Furthermore, effectiveness of SAS obtained from collaboration skills improvement from first meeting with percentage 86,06% to 93,31%in second meeting. It can be concluded that SAS with STEM approach and PjBL is suitable as learning media and has potential to support students' collaboration skills in green chemistry topic.

ACKNOWLEDGEMENTS

The author would like to express gratitude to SMAN 5 Surabaya for the permission during research. In particular, author would like to thank supervisor, validators, teachers, and students as well as all parties contributed to the completion of this research.

REFERENCES

1. Ekselsa, R. A., Purwianingsih, W., Anggraeni, S., and Wicaksono, A. G. C. 2023. Developing System Thinking Skills Through Project-Based Learning Loaded With Education for Sustainable Development. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, Vol. 9, No. 1, pp. 62–73.

2. Szozda, A. R., Mahaffy, P. G., and Flynn, A. B. 2023. Identifying Chemistry Students' Baseline Systems Thinking Skills When Constructing System Maps for a Topic on Climate Change. *Journal of Chemical Education*, Vol. 100, No. 5, pp. 1763–1776.

3. Putri, K. R. D., Widiana, I. W. W., and Sukmana, A. I. W. I. Y. 2022. Pengaruh Pembelajaran Literasi Baca Tulis Berbasis Keterampilan Abad 21 terhadap Keterampilan Berpikir Tingkat Tinggi Siswa. *Mimbar Pendidikan Indonesia*, Vol. 3, No. 2, pp. 242–248.

4. Miller, T. B., Camarda, A., Mercier, M., Burkhardt, J.-M., Morisseau, T., Bourgeois-Bougrine, S., Vinchon, F., El Hayek, S., Augereau-Landais, M., Mourey, F., Feybesse, C., Sundquist, D., and Lubart, T. 2023. Creativity, Critical Thinking, Communication, and Collaboration: Assessment, Certification, and Promotion of 21st Century Skills for the Future of Work and Education. *Journal of Intelligence*, Vol. 11, No. 3.

5. Miterianifa, Firdaus, R., and Sa'adah, A. N. 2025. Literature Review: Keterampilan Kolaborasi Siswa melalui Model Pembelajaran Project Based Learning pada Pembelajaran Kimia. *Journal of Chemical Education*, Vol. 14, No. 2, pp. 73–81.

6. Greenstein, L. 2012. *Assessing 21st Century skills: A Guide to Evaluating Mastery and Authentic Learning*. California: Corwin Press.

7. Kemdikdasmen. 2025. *Panduan Pembelajaran STEM (Sains, Teknologi, Enjinering Matematika) untuk Guru Pendidikan Anak Usia Dini, Jenjang Pendidikan Dasar dan Jenjang Pendidikan Menengah*. Jakarta: Pusat Kurikulum dan Pembelajaran Badan Standar, Kurikulum, dan Asesmen Pendidikan Kementerian Pendidikan Dasar dan Menengah Republik Indonesia.

8. Muttaqiin, A. 2023. Pendekatan STEM (Science, Technology, Engineering, Mathematics) pada Pembelajaran IPA untuk Melatih Keterampilan Abad 21. *JURNAL PENDIDIKAN MIPA*, Vol. 13, No. 1, pp. 34–45.

9. Davidi, E. I. N., Sennen, E., and Supardi, K. 2021. Integrasi Pendekatan STEM (Science, Technology, Enggeenering and Mathematic) untuk Peningkatan Keterampilan Berpikir Kritis Siswa Sekolah Dasar. *Scholaria: Jurnal Pendidikan dan Kebudayaan*, Vol. 11, No. 1, pp. 11–22.

10. Aulya, R. A., Asyhar, R., and Yusnaidar, Y. 2021. Pengembangan E-Modul Kimia Berbasis PjBL-STEM untuk Pembelajaran Daring Siswa SMA pada Materi Larutan Penyangga. *Journal of The Indonesian Society of Integrated Chemistry*, Vol. 13, No. 2, pp. 84–91.

11. Ma'wa, A. J., Toto, T., and Kustiawan, A. 2022. Pengaruh Model PjBL-STEM dalam Pembelajaran IPA pada Materi Bioteknologi terhadap Motivasi Belajar Siswa. *J-KIP (Jurnal Keguruan Dan Ilmu Pendidikan)*, Vol. 3, No. 1, pp. 307.

12. Ma'sumah, A., and Mitarlis, M. 2021. Pengembangan LKPD Berorientasi STEM dengan Model PjBL Materi Larutan Elektrolit Nonelektrolit dengan Memanfaatkan Bahan Sekitar. *Jurnal Inovasi Pembelajaran Kimia*, Vol. 3, No. 1, pp. 22.

13. Diana, N., Yohannes, and Sukma, Y. 2021. The Effectiveness of Implementing Project-Based Learning (PjBL) Model in STEM Education: A Literature Review. *Journal of Physics: Conference Series*, Vol. 1882, No. 1, pp. 012146.

14. Octaviyani, I., Kusumah, Y. S., and Hasanah, A. 2020. Peningkatan Kemampuan Berpikir Kreatif Matematis Siswa melalui Model

Project-Based Learning dengan Pendekatan STEM. *Journal on Mathematics Education Research*, Vol. 1, No. 1.

15. Rasyih, H., Noer, A. M., and Rasmiwetti, R. 2024. Pengembangan E-Modul Berbasis Social Scientific Issue (SSI) untuk Meningkatkan Kemampuan Berpikir Kritis dan Enviromental Care pada Materi Kimia Hijau di Kelas X SMA dengan Menggunakan Aplikasi Fliphtml5. *Jurnal Penelitian Pendidikan IPA*, Vol. 10, No. 8, pp. 6059–6069.

16. Mitarlis, Azizah, U., and Yonata, B. 2022. Adaptation of Basic Chemistry Learning with Green Chemistry Oriented. *Jurnal Pembelajaran Kimia*, Vol. 7, No. 2, pp. 80–89.

17. Pratiwi, N. L. P. A. D., and Luh Indrayani. 2023. Pengembangan Lembar Kerja Peserta Didik (LKPD) Berbasis Profil Pelajar Pancasila dalam Mata Pelajaran Ekonomi di SMAN 1 Singaraja. *Ekuitas: Jurnal Pendidikan Ekonomi*, Vol. 11, No. 1, pp. 143–150.

18. Thiagarajan, S., Semmel, D. S., and Semmel, M. I. 1974. *Instructional Development for Training Teachers of Exceptional Children: A Sourcebook.* Indiana: Indiana University.

19. T. M. Haladyna and M. C. Rodriguez. 2013. *Developing and Validating Test Items*. New York: Routledge.

20. Sudjana. 2005. *Metode Statistika*, 6th ed., Vol. 3. Bandung: PT Tarsito.

21. Warsa, N. D. A., and Kholiq, A. 2022. Development of MolBEST (STEM-Based Mobile Learning) on Elasticity Materials. *Prisma Sains: Jurnal Pengkajian Ilmu dan Pembelajaran Matematika dan IPA IKIP Mataram*, Vol. 10, No. 3, pp. 618.

22. Ofstedal, K., and Dahlberg, K. 2009. Collaboration in Student Teaching: Introducing the Collaboration Self-Assessment Tool. *Journal of Early Childhood Teacher Education*, Vol. 30, No. 1, pp. 37–48.

23. Sari, K. D., and Pradita, A. P. 2018. Implementasi Model Pembelajaran Discovery Learning Menggunakan Media Spreadsheet pada Materi Hukum Ohm untuk Meningkatkan HOTS pada Peserta Didik. *Prosiding Seminar Nasional Pendidikan Sains*, pp. 116–122.

24. Khasanah, L. N., Maksum, M. N. R., and Zahid, N. N. B. 2025. The Implementation of Project-Based Learning to Enhance Collaborative Skills in Senior High School. *Suhuf: International Journal of Islamic Studies*, Vol. 37, No. 1, pp. 113–122.

25. Mona, N., and Rachmawati, R. C. 2023. Penerapan Model Project Based Learning untuk Meningkatkan Keterampilan Kolaborasi dan Keterampilan Kreativitas Peserta Didik. *Jurnal Pendidikan Guru Profesional*, Vol. 1, No. 2, pp. 150–167.

26. Marita, B., Jamaluddin, J., and Rasmi, D. A. C. 2023. Hubungan Kemampuan Kolaborasi dan Hasil Belajar Biologi Peserta Didik SMAN di Kota Mataram. *Jurnal Ilmiah Profesi Pendidikan*, Vol. 8, No. 3, pp. 1850–1858.

27. Haleda, P., Isa, I., Munandar, H., Bialangi, N., Tangio, J. S., Thayban, T., and Kurniawati, E. 2025. The Effect of STEM Integrated Project Based Learning Model on Students' Collaboration Skills in Atomic Structure. *Jambura Journal of Educational Chemistry*, Vol. 7, No. 2, pp. 79–86.

28. Syahiddah, D. S., Pramudya, D. A. P., and Supriadi, B. 2021. Pengembangan E-Modul Fisika Berbasis STEM (Science, Technology, Engineering, and Mathematics) pada Materi Bunyi di SMA/MA. *Jurnal Literasi Pendidikan Fisika (JLPF)*, Vol. 2, No. 1, pp. 1–8.