The Development of Learning Tools Based on STEM with PBL model on Bacteria Material to Train Critical Thinking Skills, Creative, and Cognitive Learning Outcomes for 10th Grade Students

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Abstract: 21st-century skills can be applied to STEM education. The Merdeka Curriculum also has a passion to support teachers and schools in exploring and implementing STEM as a learning approach to improve student competence. The study aims to develop learning tools consisting of the syllabus, lesson plans, and student worksheets (SLS) that are valid and practical. This study uses the ADDIE development model. The research involved 43 participants at SMAN 6 Malang. Learning tools are validated by material experts, learning experts, and field practitioners. The research was conducted only as a trial or formative evaluation in the development stage. Formative evaluation includes three stages of testing, namely individual tests of 3 students, small group tests of 10 students, and field tests of 30 students that have passed the material of bacteria. The results of practicality obtained through questionnaires on student responses to worksheets on individual tests, small groups, and field tests showed percentages of 89.85%, 88.14%, and 89.08%. These results indicate that STEM-PBL model on bacterial material is very valid and practiced using and can train critical thinking skills, creativity, and cognitive learning outcomes of 10th-grade students.

Keywords: Critical thinking, creative thinking, cognitive learning outcomes, PBL, STEM.

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Introduction

Education is one of the main foundations for the development of a country. The demand for an increase in human resources globally encourages developments in education. The results of PISA Indonesia in 2018 have decreased in rank compared to 2015. Low scientific ability at 396 or 38% lower than the average percentage can indicate that only some students can be critical, analytical, and creative in applying science-related knowledge in various situations. The implementation of the Merdeka Curriculum is expected to prepare students' competencies in accordance with 21st-century skills such as critical thinking skills, creative thinking skills, communication skills, and collaboration (4Cs) (Sudarmin et al., 2023).

The level of complexity of the problems and challenges of global life that are increasingly high encourage 21st-century education to hone intellectual skills, especially high-level skills that include critical and creative thinking skills (Spector & Ma, 2019). Critical thinking skills are needed in various disciplines and life, one of which is when entering the world of work (Mater et al., 2022). The challenges of an increasingly dynamic and uncertain life, creative thinking skills are needed in learning (Hadzigeorgiou et al., 2012). Therefore, creative thinking skills can be said to be the basis of science (Beers Sue Z., 2019).

The 21st-century skills can be further trained with the STEM approach. The Merdeka Curriculum has a passion for supporting teachers and schools in exploring and implementing STEM as a learning approach to improve student competence (Sudarmin et al., 2023). STEM can improve students' ability to learn (Kelley & Knowles, 2016). STEM is expected to be the key and path for the development of the country, the development of human resources who have 21st-century skills, and the ability to compete globally (Jang, 2016). STEM is an approach that links the fields of Science, Technology, Engineering, and Mathematics.

According to the findings of the interviews and questionnaires, there were no STEM-based teaching materials in the learning process. It was also found that students' critical and creative thinking skills were also low. The average percentage of each aspect of critical thinking skills shows a figure of 49.65% of students who are less skilled in critical thinking. The average percentage for each aspect of creative thinking skills also shows that 51.63% of students still have difficulty in developing ideas and 82% of students need tools that encourage students to find and express ideas. The difficulty experienced by students is that the material in studying bacteria is abstract (observation of bacteria and their characteristics), so it is very difficult to study them.

The difficulties experienced affect the cognitive scores of students when doing tests (Kusmahardhika et al., 2023). One model based on contextual problems that can improve students' thinking skills is Problem Based Learning (PBL). PBL encourages students to think critically, analytically, and discover through various sources (Smith et al., 2022). Thus, the PBL model can encourage students to think critically about a problem and increase students' creativity in finding solutions to a problem (Sudarmin et al., 2023; Sumarni & Kadarwati, 2020). As a result, the purpose of this research is to provide tools for learning, such as a syllabus, lesson plans,

and student worksheets (SLS), based on the STEM-PBL model, to train critical thinking, creativity, and cognitive learning outcomes at SMAN 6 Malang.

Method

The conducted research is categorized as Research and Development (R&D) and focuses on the development of SLS. The products developed based on the STEM-PBL model on bacteria material. The development process follows the ADDIE development model, which was adapted from Branch's (2009) framework. This model comprises five stages: Analyze, Design, Develop, Implement, and Evaluate. The subjects of this study consisted of 43 participants at SMAN 6 Malang. The research was conducted onlyas a trial or formative evaluation in the development stage. Formative evaluation includes three stages of testing, namely the individual tests of 3 students, small group tests of 10 students, and large-scale tests of 30 students that have passed the material of bacteria.

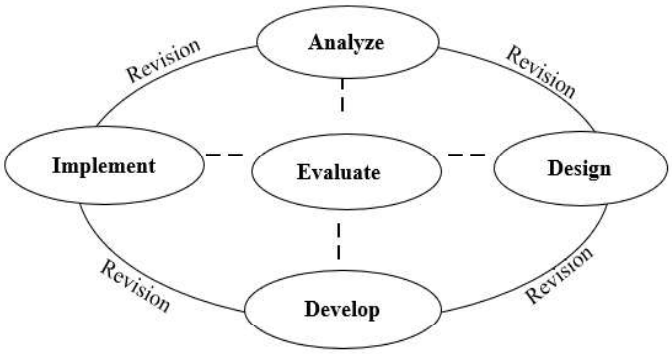


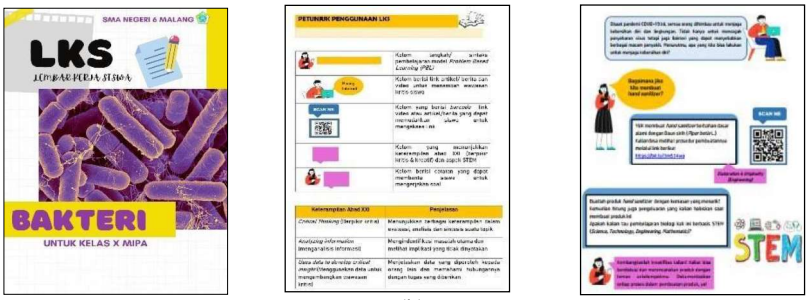
Figure 1. ADDIE model cycle (Branch, 2009)

The data collection process involved gathering both qualitative and quantitative data. Qualitative data were collected through input and suggestions from experts in learning tools, material experts, education practitioners, and 10th-grade science students. On the other hand, quantitative data were obtained from the expert validation results and the practicality response questionnaire for the students' worksheets. The assessment scale on expert validation and student responses uses a score with a scale of 1 to 4 with detailed scores from less (1), enough (2), good (3), and very good (4).

Results

The SLS developed was adapted based on the STEM-PBL model on bacteria material. The worksheets were developed with various student activities that train students' abilities on the material and project activities related to bacteria material (Figure 2). In each activity, there are indicators that show aspects of the skills being trained such as critical thinking aspects which refer to (Greenstein, 2012), and creative aspects which refer to

(Treffinger et al., 2002).



(a) (b) (c)

Figure 2. Student worksheets cover for bacterial material (a) Guidance and instructions (b) STEM-based activities (c)

The results of evaluations by material experts, learning experts, and field practitioners utilizing approval sheets are used to determine the validity of learning tools, which are then computed using percentage analysis by Akbar (2013). The average scores for the syllabus, lesson plans, and student worksheets were 99.58%, 99.75%, and 98.48%, respectively, according to the findings of the product validity test. However, a product redesign is necessary based on the validators' recommendations.

Table 1. The Validity Test Results.

Learning Tools	Material Experts	Learning Experts	Field Practitioner	Average (%)	Criteria
Syllabus	100.0	100.0	98.75	99.58	Very Valid
Lesson plans	100.0	99.25	100.0	99.75	Very Valid
Student worksheets	100.0	100.0	95.45	98.48	Very Valid

The practicality test was conducted through three stages which included individual tests, small group tests, and field tests (Table. 2). Practical results data were obtained from student response questionnaires which included indicators of ease of use, ease of understanding, attractiveness, 21st-century skills (critical and creative thinking), and STEM aspects. The practicality of learning tools in the form of worksheets is measured through a questionnaire response from 10th-grade students. The average score for the three stages of individual, small group, and field tests are 89.85%, 88.14%, and 89.08%, and shows that the worksheets that have been developed are included in the very practical category, meaning that these worksheets can be used.

Table 2. The Practicality Test Results.

Stages	Student Response (%)	Criteria
Individual tests	89.85	Very Valid
Small groups tests	88.14	Very Valid
Field tests	89.08	Very Valid

Discussion

The high value of the validity and practicality test of learning tools proves that the STEM-PBL model is in accordance with the assessment criteria for each validator which refers to Permendikbud No. 22 of 2016 concerning Basic and Secondary Education Standards which contains the systematics of learning tools (Permendikbud, 2016). Each competency achievement indicator is equipped with additional information on related STEM aspects. Competency achievement indicators show the abilities that will be carried out by students and become a reference for the extent to which students have achieved the basic competencies of a material (Sukmagati et al., 2020). Therefore, this syllabus will assist teachers in determining student competency outcomes that are integrated with STEM aspects.

The developed lesson plans are equipped with a description of STEM aspects on each formulated competency achievement indicator. STEM-based learning has many benefits, including enhancing students' skills by presenting them with a task that needs to be solved (Furner & Kumar, 2007; Stohlmann et al., 2012). The learning steps in the lesson plans are adapted to the PBL model and are equipped with information on aspects of critical and creative thinking skills that can be trained through the activities conducted. The Problem Based Learning (PBL) model greatly influences the course of the learning process. Through this model, students are invited to learn through the problems that are around them (Stockwell et al., 2015). The results obtained indicate that the student worksheets developed fulfil various aspects of the assessment. In addition to showing identity and conformity with the selected Basic Competencies (KD), student worksheets are also equipped with several components such as general instructions and instructions for using student worksheets. The general instructions outline how to work on the student worksheets, while the instructions for using the student worksheets present various symbols or icons and explanations of 21st-century skills that special students will encounter in these student sheets. Linguistic and graphic aspects are also considered, such as the use of language that is easy for students to understand, the sentences used are clear and precise, as well as colours and illustrations that attract students' interest (Sukmagati et al., 2020).

Teaching materials that attract students can increase student engagement so that it is easier for students to understand and absorb the material (Kelley & Knowles, 2016). Learning that integrates STEM can improve students' abilities and creativity in coming up with an idea or innovation in facing global challenges (Murnawianto et al., 2017). PBL is the best educational method for teaching actual, real-world problems that require interdisciplinary STEM (Smith et al., 2022). PBL model will encourage student-centred learning so that they are trained to always actively participate in discussion activities and solve problems given (Gordon et al., 2022). PBL requires students to actively participate in using their knowledge and conducting extensive research to learn more about the unstructured problem, then combining and employing metacognitive processes to address the difficulties, encouraging the use of higher-order thinking skills (Capraro et al., 2013; Gomez-del Rio & Rodriguez, 2022). The student worksheets also list learning steps that are in accordance with the PBL model. The problems in the student worksheets are real problems that students can find so that it is easier for students to

process information and analyse a problem.

The PBL model, which can improve students' cognitive, is the most effective way to teach STEM subjects (Kusmahardhika et al., 2023). STEM places a strong emphasis on knowledge depth in the areas of linking new ideas to prior understanding, connecting information to practical applications, integrating knowledge in problem-solving, and critically evaluating the benefits and drawbacks of proposed solutions (Capraro et al., 2013). Students will be able to convey their thoughts, combine information from several subjects, and use technology to accelerate their learning by putting this style of learning into reality (Bear & Skorton, 2019; Lee et al., 2020).

Conclusion

STEM-based learning has many benefits, including enhancing students' skills by presenting them with a task that needs to be solved. The practicality of learning tools in the form of worksheets is measured through a questionnaire response from 10th-grade students. The average score for the three stages of individual, small group, and field tests is 89.85%, 88.14%, and 89.08%, respectively. It can be concluded that the development of STEM-PBL model on bacterial material is very valid and practical to train critical thinking skills, creative, and cognitive learning outcomes of 10th-grade students. However, to find out the accuracy of learning tools, further research is needed, especially in the implementation stage.

Recommendations

As for suggestions for further development, it can be implemented, evaluated, and disseminated products to wider targets as well as product development for different topics to decide the exactness of the STEM-PBL model in learning.

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References

Akbar, S. D. (2013). *Instrumen Perangkat Pembelajaran*. PT. Remaja Rosdakarya Offset.

Bear, A., & Skorton, D. (2019). The World Needs Students With Interdisciplinary Education. *Issues in Science and Technology*, *35*(2), 60–62. https://issues.org/the-world-needs-students-with-interdisciplinary-education/

Beers Sue Z. (2019). 21st Century Skills: Preparing Students for THEIR Future. *Stem*, *22*(3), 1–6.

Branch, R. M. (2009). Approach, Instructional Design: The ADDIE. In *Department of Educational Psychology and Instructional Technology University of Georgia* (Vol. 53, Issue 9).

Capraro, R. M., Capraro, M. M., & Morgan, J. R. (2013). STEM project-based learning an integrated science, technology, engineering, and mathematics (STEM) approach. *STEM Project-Based Learning an Integrated Science, Technology, Engineering, and Mathematics (STEM) Approach*, *January 2013*, 1–210. https://doi.org/10.1007/978-94-6209-143-6

Furner, J. M., & Kumar, D. D. (2007). The mathematics and science integration argument: A stand for teacher education. *Eurasia Journal of Mathematics, Science and Technology Education*, *3*(3), 185–189. https://doi.org/10.12973/ejmste/75397

Gomez-del Rio, T., & Rodriguez, J. (2022). Design and assessment of a project-based learning in a laboratory for integrating knowledge and improving engineering design skills. *Education for Chemical Engineers*, *40*(April), 17–28. https://doi.org/10.1016/j.ece.2022.04.002

Gordon, S. J. G., Bolwell, C. F., Raney, J. L., & Zepke, N. (2022). Transforming a Didactic Lecture into a Student-Centered Active Learning Exercise—Teaching Equine Diarrhea to Fourth-Year Veterinary Students. *Education Sciences*, *12*(2). https://doi.org/10.3390/educsci12020068

Greenstein, L. (2012). Assessing 21st Century Skills: A Guide to Evaluating Mastery and Authentic Learning. *Corwin*, 75–76.

Hadzigeorgiou, Y., Fokialis, P., & Kabouropoulou, M. (2012). Thinking about Creativity in Science Education. *Creative Education*, *03*(05), 603–611. https://doi.org/10.4236/ce.2012.35089

Jang, H. (2016). Identifying 21st Century STEM Competencies Using Workplace Data. *Journal of Science Education and Technology*, *25*(2), 284–301. https://doi.org/10.1007/s10956-015-9593-1

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1). https://doi.org/10.1186/s40594-016-0046-z

Kusmahardhika, N., Imam, T., & Wati, B. M. (2023). *The development of learning tools based on STEM-PjBL to increase cognitive learning outcomes for 10 th grade students The Development of Learning Tools Based on STEM-PjBL to Increase Cognitive Learning Outcomes for 10 th Grade Students*. *020024*(January).

Lee, I., Grover, S., Martin, F., Pillai, S., & Malyn-Smith, J. (2020). Computational Thinking from a Disciplinary Perspective: Integrating Computational Thinking in K-12 Science, Technology, Engineering, and Mathematics Education. *Journal of Science Education and Technology*, *29*(1), 1–8. https://doi.org/10.1007/s10956-019-09803-w

Mater, N. R., Haj Hussein, M. J., Salha, S. H., Draidi, F. R., Shaqour, A. Z., Qatanani, N., & Affouneh, S. (2022). The effect of the integration of STEM on critical thinking and technology acceptance model. *Educational Studies*, *48*(5), 642–658. https://doi.org/10.1080/03055698.2020.1793736

Murnawianto, S., Sarwanto, S., & Rahardjo, S. B. (2017). Stem-Based Science Learning in Junior High School: Potency for Training Students' Thinking Skill. *Pancaran Pendidikan*, *6*(4), 69–80. https://doi.org/10.25037/pancaran.v6i4.86

Permendikbud. (2016). *Peraturan Menteri Pendidikan dan Kebudayaan Republik Indonesia Nomor 22 Tahun 2016 tentang Standar Proses Pendidikan Dasar dan Menengah*. *53*(9), 1689–1699.

Smith, K., Maynard, N., Berry, A., Stephenson, T., Spiteri, T., Corrigan, D., Mansfield, J., Ellerton, P., & Smith, T. (2022). Principles of Problem-Based Learning (PBL) in STEM Education: Using Expert Wisdom and Research to Frame Educational Practice. *Education Sciences*, *12*(10). https://doi.org/10.3390/educsci12100728

Spector, J. M., & Ma, S. (2019). Inquiry and critical thinking skills for the next generation: from artificial intelligence back to human intelligence. *Smart Learning Environments*, *6*(1). https://doi.org/10.1186/s40561-019-0088-z

Stockwell, B. R., Stockwell, M. S., Cennamo, M., & Jiang, E. (2015). Blended Learning Improves Science Education. *Cell*, *162*(5), 933–936. https://doi.org/10.1016/j.cell.2015.08.009

Stohlmann, M., Moore, T., & Roehrig, G. (2012). Considerations for Teaching Integrated STEM Education [Consideraciones para enseñar educación STEM integrada]. *Journal of Pre-College Engineering Education Research*, *2*(1), 28–34.

Sudarmin, S., Pujiastuti, R. S. E., Asyhar, R., Tri Prasetya, A., Diliarosta, S., & Ariyatun, A. (2023). Chemistry project-based learning for secondary metabolite course with ethno-STEM approach to improve students' conservation and entrepreneurial character in the 21st century. *Journal of Technology and Science Education*, *13*(1), 393. https://doi.org/10.3926/jotse.1792

Sukmagati, O. P., Yulianti, D., & Sugianto, S. (2020). Pengembangan Lembar Kerja Siswa (LKS) Berbasis STEM (Science, Technology, Engineering, and Mathematics) untuk Meningkatkan Kemampuan Berpikir Kreatif Siswa SMP. *UPEJ Unnes Physics Education Journal*, *9*(1), 18–26. https://doi.org/10.15294/UPEJ.V9I1.38277

Sumarni, W., & Kadarwati, S. (2020). Ethno-stem project-based learning: Its impact to critical and creative thinking skills. *Jurnal Pendidikan IPA Indonesia*, *9*(1), 11–21. https://doi.org/10.15294/jpii.v9i1.21754

Treffinger, D. J., Young, G. C., Selby, E. C., & Shepardson, C. (2002). Assessing Creativity: A Guide for Educators. In *Journal of Education and Learning* (Issue December).