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# Development of STEM - Project Based Learning Devices to Train 4C Skills of Students

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**ABSTRACT**

Penelitian bertujuan untuk mendeskripsikan kevalidan, keterlaksanaan, dan keefektifan perangkat pembelajaran STEM-PjBL. Penelitian ini merupakan penelitian *research and development* (R&D) dengan model Borg and Gall. Subjek uji coba skala luas adalah siswa kelas XI SMAN 16 Semarang berjumlah 106 siswa. Analisis data menggunakan deskriptif persentase. Hasil dan simpulan penelitian ini menunjukkan bahwa: (1) Perangkat pembelajaran sangat valid berdasarkan validasi ahli, validitas konstruk khususnya untuk tes kemampuan berpikir kritis diperoleh hasil valid dan reliabel; (2) perangkat pembelajaran *STEM-PjBL* terlaksana dengan baik (3) perangkat pembelajaran *STEM-PjBL* efektif meningkatkan kemampuan berpikir kritis siswa dengan >75% siswa memenuhi kriteria ketuntasan minimal, dan berdasarkan uji N-*gain* terjadi peningkatan kemampuan berpikir kritis dengan kriteria sedang. Perangkat Pembelajaran *STEM-PjBL* efektif melatih kemampuan berpikir kreatif, komunikatif, dan kolaboratif dengan kriteria tinggi.
**Keywords:** Perangkat Pembelajaran; PjBL; STEM.

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**ABSTRACT**

*The study aims to describe the validity, applicability, and effectiveness of the developed learning aids. This research is a research and development (R&D) research that uses the Borg and Gall model. The subjects of the wide-scale trial were 106 students of class XI at SMAN 16 Semarang. The data analysis used was descriptive percentages. The results and conclusions of this study indicate that: (1) overall learning aids are highly valid based on expert validation, and construct validity, especially for tests of critical thinking skills obtained valid and reliable results (2) learning aids are well implemented; (3) learning aids effectively improve students' critical thinking skills with >75% of students meeting the minimum completion criteria, and regarding N-gain test, there is an increase in critical thinking skills with moderate criteria. The STEM-PjBL Learning aids effectively trains the ability to think creatively, communicatively and collaboratively with high criteria.*
***Keywords:*** *Learning aids; PjBL; STEM.*

## INTRODUCTION

Improving the quality of learning is an effort that needs to be done in line with the challenges faced in the 21st century. One of the $21^{st}$-century skills that students need to have is learning and innovation skills which in the 2013 curriculum are termed the 4C abilities, which consist of critical thinking and problem-solving skills, communications, collaboration, creativity, and innovation (Trilling, B. & Fadel, 2009). The 21st adab skills align with the goals of the 2013 Curriculum. In order to achieve the purposes of the 2013 Curriculum, it is regulated by Permendikbud Number 22 of 2016 concerning process standards, namely the learning process in academic units is held interactively, inspiring, fun, challenging, motivating students to participate actively and provide sufficient space for initiative, creativity, and independence following the talents, interests, and physical and psychological development of students. In line with the competencies or skills that must be possessed by $21^{st}$-century students above, the 4C abilities of students are mandated in the 2013 Curriculum.

The 4C capabilities consist of critical thinking, creative thinking, communication and collaborative skills. Critical thinking ability is an ability that needs to be learned by students. Pedrosa-de-Jesus *et al*. (2014) emphasized that critical thinking skills are one of the highest orders of cognitive abilities and are recognized as crucial competencies in education, especially for science and technology. Students with critical thinking skills are more observant in making complex choices and providing reasonable ideas for a problem. In addition to critical thinking skills, the ability that students need to have is the ability to think creatively. Students can solve problems with the creativity they have. This aligns with the results of research conducted by Sambada (2012) that the level of student creativity plays a fundamental role in problem-solving abilities. The ability to think critically and creatively needs to be balanced with the ability to communicate and collaborate to face the challenges of the 21st century.

Based on a preliminary study conducted in five schools in the form of filling out a questionnaire related to the learning process they had received, 47% stated that the method used by the teacher was the lecture, 37% the discussion method, and 22% other methods. Overall, the learning implementation plan developed by several teachers already pays attention to the 4C aspects. Still, the designed learning process does not clearly describe activities to develop students' 4C abilities, so the teacher's learning process has not increased students' 4C skills. A student questionnaire about projects reinforced this; 76% of students answered that they had never designed a project in groups, while 24% of students responded that they had designed a project but had not done it independently. The data shows that students' thinking skills and creativity must be developed. One way is through project-based learning that trains thinking skills or stimulates students' creativity in designing projects. This is supported by Santos (2017), who says that the main problem in developing students' critical thinking in science is because science learning is carried out with a focus on content and students' memorization abilities, not on creativity, meaningful understanding and or students' critical thinking.

Learning using a science, technology, engineering, and mathematics (STEM) approach can develop the ability to think critically, communicatively, collaboratively and creatively. The characteristics of STEM learning are very relevant to the 2013 Curriculum. As stated in the 2013 Curriculum document, one of the improvements to the mindset developed in the 2013 Curriculum is strengthening multidisciplinary learning patterns and critical learning patterns (Rusilowati *et al.,* 2018). STEM's innovative approach needs to be implemented with an appropriate learning model. Project-based learning is one of the proper learning models applied to the STEM approach. Project-based learning is more suitable for interdisciplinary learning because it naturally involves many different academic skills, such as reading, writing, and mathematics. It is appropriate for building conceptual understanding by assimilating different subjects (Capraro *et al.*, 2013). Research on the application of STEM has been carried out previously in science learning but with different variables. Based on the results of research conducted by Furi *et al*. (2018) the results showed that the application of project-based STEM learning could increase the creativity of junior high school students, so it is suggested in the journal to examine the application of STEM learning to other 4C aspects, namely the ability to think critically, collaboratively, and communicative. The aspects of creativity studied are limited to 3 aspects, namely aspects of fluency, flexibility, and novelty. Learning with the STEM approach integrated with projects is still limited to certain variables.

Based on this background, this research develops learning tools and analyzes the application of STEM learning tools with project designs in groups so students can train critical thinking skills and think creatively, communicatively, and collaboratively. This study aimed to describe learning devices' validity, applicability, and effectiveness on respiratory system material with STEM-PjBL in Class XI SMA students.

## METHODE

This research is a research and development (R&D) study. This study developed STEM-PjBL learning tools on respiratory system material, which includes syllabi, lesson plans, teaching materials, student worksheets, and evaluation instruments. The research steps refer to Borg, W.R. & Gall (1989) which consists of 10 steps, namely: (1) Potential and problems, (2) Data collection, (3) Product design, (4) Design validation, (5) Design revision, (6) Product trials, (7) Product revision, (8) Trial use, (9) Product revision and (10) Mass production. However, this research only reached the product revision stage.

Material/content experts, learning design experts, and educational practitioners carry out validation. Expert validation is carried out to determine product validity in terms of content validity and construct (design) validity of the learning tools developed. Learning devices that have been validated are then revised according to suggestions and input from the validator and then a limited-scale trial is carried out. The results of the limited-scale trials were then revised to produce the main product. This product revision was carried out based on input, suggestions, criticisms, assessments, and findings in the field during limited trials. The main product is then used in large-scale trials to determine the implementation and effectiveness of learning tools.

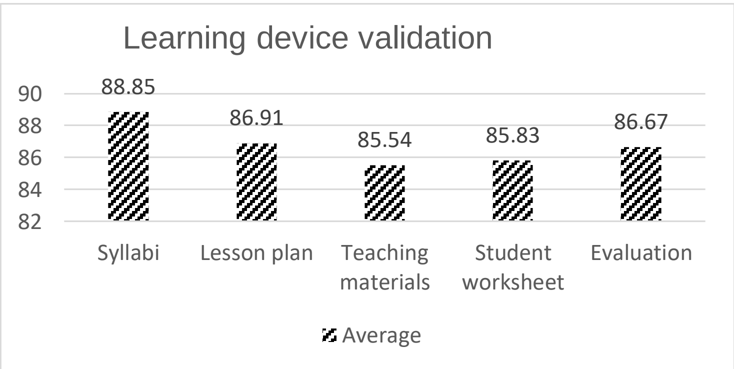
The subjects of the large-scale trial in this study were 3 class XI students at SMAN 16 Semarang, totalling 106 students. The sampling technique for a large-scale trial uses a purposive side design with a one-group pretest-posttest design (Cresswell, 2013). Data collection techniques are carried out through the validation stage, observation sheets, and tests. The data collection instrument used to test product validity is in the form of an expert validation sheet. Implementation of learning devices using observation sheets. The instrument to test the effectiveness was a critical thinking skill test in the form of multiple choice of 25 items whose validity had been tested by experts. The instrument to measure creative, communicative and collaborative thinking skills used observation sheets. Data were analyzed by descriptive percentage analysis.

## RESULTS AND DISCUSSION

The research results obtained include 1) the validity of the STEM-PjBL learning tools by experts; 2) the implementation of STEM-PjBL learning tools; and 3) the effectiveness of STEM-PjBL learning tools on students' critical, creative, communicative, and collaborative thinking skills.

### The validity of STEM-PjBL learning tools by experts

At the research stage, the researcher prepared the product design and then validated the design with an expert validator. In stage I, validation was carried out regarding the completeness of the components contained in the learning device after passing the stage I validation, followed by stage II validation which examined the learning device being developed. The results of expert validation are used as material for product revision. Three main components are referenced in validating learning devices: content feasibility, linguistic components, and presentation. The results of the validity assessment of the learning device are presented in Graph 1.




**Graph 1. Learning Device Validation**

Based on Graph 1, it is obtained that the average content validity of the learning device is very valid. This shows that overall, validator 1 (material), validator 2 (learning design), and validator 3 (educational practitioners) provide a good assessment of the learning device. A good assessment of the learning tools developed because the learning tools developed have complied with the aspects that must be considered in the development of learning tools. The syllabus and learning implementation plans developed are very valid in writing format, content, and language, as for suggestions from the validator, namely adding material and assessment to the lesson plan and adjusting the time because timeliness is essential in lesson planning. This is supported by Nesusin *et al.* (2014), namely that learning implementation plans must be appropriate to the time and can improve students' thinking processes so that the scope of content must be reduced and learning activities reduced to allow students to spend time in their thinking processes. Effective teacher planning skills can be seen in implementing effective lesson plans, good time management, and organizing classrooms and teaching materials well (Papa-Gusho & Biçaku-Çekrezi, 2015).

The developed student worksheets are very valid regarding material presentation, activity planning, and appearance. Validator 1's assessment is very appropriate in material presentation, activity planning, and display. Validator 3's assessment is very suitable for the presentation of the material but less suitable for the aspects of activity planning and appearance because the work allocation and discussion questions have not been included. Furthermore, the LKS was repaired according to the advice of experts, namely the addition of time allocation so that the teacher could plan learning time well. Overall the student worksheets developed are very valid. Activities in STEM-based worksheets help students to be able to solve problems and make scientific conclusions (Sulistiyowati *et al.,* 2018).

The teaching materials developed are very valid. This is because assessing the aspects of the feasibility of the content components, language components, and presentation components is very appropriate so that the teaching materials are in accordance with the STEM-PjBL approach. Good teaching materials must pay attention to the feasibility of the content, at least referring to the goals to be achieved by students, namely basic competencies (BNSP, 2014). The development of teaching materials adapted to the guidelines for developing teaching materials includes learning instructions, competencies to be achieved, elaboration of materials adapted to STEM-PjBL, supporting information, and evaluation in accordance with the requirements of good teaching materials according to the Depdiknas (2008). The advantage of this STEM-PjBL teaching material is that it is contextual by making it explicit to various learning activities that integrate STEM-PjBL so that it can train students' higher-order thinking skills.

The evaluation developed is very valid. This is because the validator's assessment of the material, construction, and language aspects is very appropriate so that valid is used to measure students' critical thinking skills. In addition, the evaluation questions developed are proportional to all aspects of STEM-based on comments and suggestions from experts. The evaluation instrument was carried out by expert content validation, followed by testing empirical validity, especially for critical thinking skills tests. The construct validity test on a limited scale, especially for the critical thinking ability test using the Anates 4.0 program, obtained an r count of 0.54 > r table of 0.304 so that the test item is valid, the test reliability is 0.70 so that the item is declared reliable on a strong scale so that it can measure students' critical thinking skills accurately. This is in accordance with Nuswowati *et al.* (2010) that the validity and reliability of the items affect the appropriateness of measuring student achievement competencies.

Overall the factors that affect the results of the validity of the learning device are very valid because (1) the components of the learning device have been adjusted to the assessment aspects of the validity instrument, (2) the learning device is validated in stages by making improvements according to suggestions and comments at each validation stage, (3) development of learning tools using communicative language and following the level of students' cognitive development, and (4) fulfilling the criteria of content and construct validity. The respiratory system PjBL STEM learning device developed meets valid criteria and is practically used in learning (Kurniahtunnisa *et al.,* 2020).

## Implementation of STEM-PjBL learning tools

Observation of the implementation of learning is carried out by two observers using the observation guidelines that have been provided. Three aspects are observed: preliminary activities, core activities, and closing. Data from observations of the implementation of learning are presented in Table 2.

**Table 2. The results of observing the implementation of learning**

| No | Activities assessed | Skor maks | NA 1 | NA 2 | NA 3 | Average | Percentage (%) | Category |
|---|---|---|---|---|---|---|---|---|
| 1 | Preliminary | 16 | 14,5 | 14,5 | 14 | 14 | 87.50 | High |
| 2 | Core activities | 54 | 49 | 48,5 | 48 | 48.5 | 89.81 | High |
| 3 | Closing | 8 | 7 | 7 | 7 | 7 | 87.50 | High |
| | Amount | 82 | 72 | 72 | 72 | 72 | 87.80 | High |

Based on the results of observations made by two observers, the average implementation of the learning process using the STEM-PjBL learning tools for each class is in the high implementation category. The aspects assessed in the learning process are preliminary, core, and closing activities. The implementation of learning in the preliminary activities received a high category, meaning that it carried out things that needed to be done in the preliminary activities, namely providing motivation, carrying out apperception activities, conveying the outline of the material, the learning objectives to be achieved, and the activities carried out. The implementation of preliminary activities affects the implementation of the learning process at a later stage.

The implementation of learning in the core activities gets a high category. The STEM-PjBL syntax is well executed. Following the syntax of STEM-PjBL learning, the first syntax that students do is to determine the theme and formulation of the problem (start with the essential question). At this stage, didactic anticipation is applied by providing an overview of the project. This is because students are unfamiliar with project-based learning that produces a product, so didactic anticipation is needed by providing an overview of the project so the learning process is carried out correctly. In this study, didactic anticipation was applied by providing an overview of the project to be carried out so that learning could take place well. This is in accordance with the didactic theory expressed by Brousseau (2002: 230) that a teacher's actions in the learning process will create a situation that can be the starting point of the learning process.

The second syntax is to design investigative projects and technology products (design a plan for the project). Students work together in small groups of 5-6 people at this stage. The learning process at this stage in each class is done well because students work in groups and collaborate with others. Each group member sparked ideas and ideas in designing the project and gave each other input. The teacher acts as a facilitator so learning activities can be carried out correctly. The success of facilitating student activities depends on how well teachers have prepared themselves to face the challenges they will face when teaching in class (Ejiwale, 2015).

The third syntax is to create a schedule and project launch. At this stage, each group must organize their work and materials, divide tasks according to the characteristics or talents of each member, and arrange their own project time so that learning activities can be carried out correctly. This is in line with Woro (2015); Mahasneh & Alwan (2018) that in PjBL learning, students will design their products and effective time management so that the product can be completed according to the allotted time. Project-based learning is characterized by depth of inquiry, occurs over time, students are self-sufficient to a certain extent and require formal presentation of results or products (Ravitz & Blazevski, 2014).

The fourth syntax is to monitor students and the project's progress (monitor the students and the project's progress). Students are accustomed to analyzing the project work process (procedures, calculations, and engineering stages) at this stage. The fifth stage is evaluation or assessment (assess the outcome). The teacher evaluates the process and results of student products. Students present project results, discuss project results, and evaluate the strengths and weaknesses of the projects/products produced to build student knowledge. This is supported by Han *et al.* (2015), which state that students can build knowledge with an in-depth understanding of scientific disciplines through learning with a STEM approach with the PjBL model.

Overall, STEM-PjBL learning can be carried out well. Learning can be carried out well because the learning tools developed are very valid based on expert judgment. This is in line with the research of Bariyah *et al.* (2014) that generally, the success of implementing a person's learning is determined mainly by the quality of the planning he makes. Factors that play a role in the implementation of PjBL learning are student support, teacher support, effective work groups, balancing didactic instruction with independent investigative work methods, emphasis on reflection and evaluation, as well as elements of choice and independence in students will help students feel ownership and control in learning (Kokotsaki, 2016). In this lesson, there is an element of choice for students because the distribution of projects is based on a lottery so that students can accept and have a sense of ownership of the project.

The teacher's ability to apply STEM learning properly influences the learning process's success. Based on the observation results, the learning process was implemented well because the teacher understood the STEM-PjBL learning syntax through workshop activities. This is supported by Toto *et al.* (2021), showing an increased understanding of STEM concepts for science teachers and an increase in teacher readiness to implement them in science learning after participating in workshops and simulation activities. This aligns with Nugroho *et al*. (2019) that science teachers in Indonesia understand STEM learning well.

STEM-PjBL learning can be done well, but several aspects have not been appropriately implemented. This is because teachers are unfamiliar with STEM-PjBL learning and lack examples of implementing STEM learning. This is supported by Ryu *et al.* (2018); Shernoff *et al.* (2017), who said that the teacher's obstacles in implementing STEM learning were the structure and teaching practices that already existed in schools, limited interdisciplinary understanding of STEM, and the absence of guidelines because STEM integration had not been widely implemented in schools. Meanwhile, according to El-Deghaidy *et al*. (2017), the teacher obstacles in implementing STEM are the views of teachers who have not fully developed STEM learning, school culture, and the absence of partnerships with professional communities and universities in implementing STEM.

**The effectiveness of STEM-PjBL learning tools**

The effectiveness of learning tools is determined based on learning outcomes in the form of critical thinking skills. The value of students' critical thinking skills was obtained from the pretest and posttest scores. Then the N-gain test was carried out to determine the increase in students' critical thinking skills. The average N-gain test was obtained at 0.67 with moderate criteria. So it can be seen that students' critical thinking skills have increased.

Furthermore, students critical thinking skills were analyzed by comparing the posttest scores with the Minimum Completeness Criteria (KKM) ≥ 75. Based on the results of the t-test calculation in the SPSS 23 program, a significance value/Sig.(2-tailed) of 0.000 was obtained for each class, indicating differences in critical thinking ability scores before and after learning using PjBL STEM learning tools. Based on these findings, it was concluded that the learning tools developed effectively trained students' critical thinking skills. This is because the project-based learning process integrated with the science, technology, engineering, and mathematics (STEM) approach makes students more active and encourages students to think critically during the learning process. This is supported by the results of Soros *et al.* (2018), which show that the application of STEM learning encourages students to think critically, have problem-solving skills, and improve the learning achievement of class X students in physics material. The process of finding information or sources relevant to the project theme is an inductive process that can improve students' critical thinking skills. This is because, in the learning process, students identified problems in daily life and then designed a project to solve those problems in a small group. This aligns with Kurniahtunnisa *et al.* (2016) that learning-based problems in group discussion and collaboration can improve students' critical thinking skills. Kumar & James (2015) said that peer learning involves students collaborating in learning, discussing, and explaining their understanding and ideas, which helps support students' critical thinking.

Learning tools' effectiveness is also determined based on learning outcomes in the form of creative thinking, communication, and collaboration skills. Data on students' creative, communicative, and collaborative thinking skills are presented in Table 3.

**Table 3. Students' critical, communicative, and collaborative thinking skills**

| Aspect | Class average | | | Average | Criteria |
|---|---|---|---|---|---|
| | NA1 | NA2 | NA3 | | |
| Creative thinking skill | 73 | 73 | 71 | 66 | high |
| Communication skills | 79 | 80 | 75 | 78 | high |
| Collaboration capabilities | 77 | 77 | 78 | 78 | high |

Based on the data in Table 3, the average student's creative thinking ability is in the high criteria. This is because, in project-based STEM learning, students design product designs and manufacture products that stimulate students' creativity and critical thinking skills in creating product creations. This aligns with Siew *et al.* (2015) that STEM vision learning with the PjBL model makes students creative and develops their critical thinking skills to solve problems. According to research by Ismayani (2016), the application of STEM project-based learning effectively increases students' creativity in learning mathematics in Vocational High Schools. Curricula involving STEM students promote learning strategies that challenge students to innovate and discover (Kennedy & Odell, 2014). improving critical and creative thinking skills. According to the research results by Luthvitasari *et al.* (2012), project-based learning can enhance critical thinking skills, creativity, and generic science skills. This is also supported by the research results of Milla *et al.* (2019); Munawaroh *et al.* (2018); Putri & Zulyusri (2022), which shows that project-based learning is effective for improving students' science process skills and creativity.

The average of students' communication skills is in the high criteria. This is because, in the learning process with STEM-PjBL, students communicate with each other in designing and making projects and doing project presentations in groups. The ability to express ideas by presenting in front of the class makes students accustomed to communicating orally (Prabowo & Ariani, 2018). This is supported by the research results of Siew *et al.* (2015) that implementing STEM project-based learning can improve students' scientific work skills, especially in communication and interpretation and planning experiments. PjBL learning based on everyday problems and integrated with the STEM approach is a collaborative teaching strategy that can and has been proven to improve student's communication skills effectively (Husin *et al.,* 2016).

The average student collaboration ability is at high criteria. This is because, in the learning process with STEM-PjBL, students design and carry out projects in groups. Project-based learning with a STEM approach improves students' collaboration skills because each group has to manage their work, materials, and individual assignments and manage their own time. This aligns with Woro (2015) that students will design their products and effective time management to complete the product according to the allotted time. In the implementation of the PjBL model, that has optimal results are creativity, communication, and collaboration skills (Rochmawati *et al.*, 2020). Participants in several studies expressed positive views of teamwork. This is supported by research conducted by Crowder & Zauner (2013); Zhou (2012) describes how group members encourage collaboration and help each other when misunderstandings occur. Another study shows that 70% of students prefer group work because it encourages self-evaluation and starts negotiations when there is disagreement (Papanikolaou & Boubouka, 2010).

## CONCLUSIONS AND SUGGESTIONS

Based on the results of the research and discussion that have been put forward, the developed respiratory system material learning device with STEM-PjBL is valid based on the results of validation by experts; STEM-PjBL learning is well implemented; The STEM-PjBL learning materials on the respiratory system that have been developed are effective in training critical thinking skills; think creatively, communicatively, and collaboratively (4C) students.

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