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Project-Based Learning with STEM Approach in Automotive Engineering: A Study of Increasing Students' 21st Century Skills

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Abstrak

Lemahnya keterampilan abad 21 pada siswa pendidikan kejuruan khususnya jurusan otomotif merupakan polemik besar yang perlu dipecahkan. Menyelenggarakan pembelajaran berbasis proyek merupakan solusi ampuh dalam meningkatkan keterampilan abad 21 pada siswa. Apalagi integrasi pendekatan STEM memungkinkan kolaborasi antar berbagai disiplin ilmu sekaligus. Penelitian ini menganalisis penerapan pembelajaran berbasis proyek dengan pendekatan STEM (PjBL-STEM) untuk meningkatkan keterampilan abad 21. Penelitian quasi-experimental design menggunakan nonequivalent control group design dengan melibatkan 214 siswa SMK sebagai sampel penelitian. Data yang dihasilkan berupa konsep dan implementasi PjBL-STEM serta data nilai observasi keterampilan abad 21 yang diukur dengan metode observasi. Analisis data meliputi uji t sampel berpasangan dan uji t sampel independen yang didahului dengan uji normalitas dan homogenitas. Hasil penelitian menunjukkan bahwa model PjBL-STEM terbukti dapat meningkatkan keterampilan abad 21 berdasarkan efek berpasangan dari pretest to posttest dan perbedaan rata-rata posttest kelas eksperimen lebih tinggi daripada kelas kontrol. Hasil tersebut menjadi rekomendasi khususnya pada pendidikan vokasi dalam rangka peningkatan keterampilan abad 21 yang saat ini menjadi kualifikasi penting dalam dunia kerja, membekali siswa dengan multi kompetensi, karena mengintegrasikan berbagai disiplin ilmu.

Kata kunci: *Keterampilan Abad 21, Pembelajaran Berbasis Proyek, Pendekatan STEM, Pembelajaran Teknik Otomotif*

Abstract

The weakness of 21st century skills in vocational education students, especially in the automotive department, is a big polemic that needs to be solved. Organizing project-based learning is a strong solution in improving 21st century skills in students. Moreover, the integration of the STEM approach allows collaboration between various disciplines at once. This study analyses the implementation of project-based learning with a STEM approach (PjBL-STEM)to improve 21st century skills through. A quasi-experimental study using a nonequivalent control group design was used by involving 214 vocational education students as the research sample. The data generated are in the form of the concept and implementation of PjBL-STEM and the value data from the observation of 21st century skills which are measured using the observation method. Data analysis involved paired sample t-test and independent sample t-test preceded by normality and homogeneity tests. The results showed that the PjBL-STEM model was proven to improve 21st century skills based on the paired effect of pretest to posttest and the difference in the posttest mean of the experimental class was higher than the control class. These results become recommendations, especially in vocational education in order to improve 21st century skills which are currently an important qualification in the world of work, equipping students with multi-competence, because it integrates various disciplines.

Keywords: 21st Century Skills, Project-Based Learning, STEM Approach, Automotive Engineering Learning

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1. INTRODUCTION

Throughout the 21st century, there has been a very significant shift in the need for work competencies (Stuchlikova, 2016; Trilling & Fadel, 2012). Disruption of old jobs and their replacement with new jobs is the background for the shift in competency needs in the world of work (Schwab, 2016; Sylte, 2020; Xu et al., 2018). Vocational education as a human resource development institution certainly has a very important role in carrying out the transformation of competencies based on current needs (Malik, 2018; Pavlova, 2009). In addition, having multiple competencies is an absolute thing that must also be developed by vocational education, so that competitive opportunities in outcomes are maintained (Ackerman & Kanfer, 2020; DeSimone, 2020). The ability to think critically, problem solving, creativity is at the heart of carrying out work in the 21st century (Dwyer et al., 2014; Szabo et al., 2020; Yılmaz, 2021). In addition, communication, collaboration and digital literacy are also very much needed as a basis for developing each competency (Chai & Kong, 2017; Rizaldi et al., 2020; van Laar et al., 2019). Thus, it is very important for vocational education to develop 21st century skills in students to produce a competent workforce in the 21st century. (Ifeoma Obidile, 2018). Various steps have been taken by vocational education in spurring the growth of 21st century skills in students, one of which is by strengthening important student skills which can later stimulate the development of competence (Made Sudana et al., 2019).

Previous research has revealed a lot of low 21st century skills possessed by students. Worse, teachers as learning managers and facilitators also experience the same problem (Astuti et al., 2021; Mutohhari, Sutiman, et al., 2021). The criticality and creativity of students and teachers in creating a learning climate that is able to stimulate the growth of 21st century skills is still very low (Estriyanto et al., 2017). Likewise, the importance of communication and collaboration skills is still contrary to the achievement of these competencies (Mutohhari, Sutiman, et al., 2021). In fact, this situation is also exacerbated by the low level of maturity of teachers and students in using digital technology. Teachers and students are still not aware of the condition of digital technology in supporting 21st century skills-oriented learning (Astuti et al., 2021; Mutohhari, Sofyan, et al., 2021). These problems should be the focus of more attention for vocational education to revitalize its learning.

Data in previous studies were also confirmed directly with factual data in the field. Based on the observations of researchers in the field, it is revealed that 21st century skills are still not reflected in students. Even worse, teachers as facilitators and managers of learning also still have minimal 21st century skills. This is reflected during learning, that the transfer of knowledge still occurs in one direction, namely from teacher to student. The direct involvement of students in constructing their knowledge and skills independently is still very minimal. The impact is that students' understanding of lesson orientation is very low. The low depth and creativity of students in thinking to solve problems is the impact of these problems. In addition, the collaboration and communication of students who are less than optimal is also a crucial additional problem.

The ineffectiveness of the learning process is an important key problem that must be solved. The use of learning methods is still focused on the transfer of knowledge from teachers to students only. Likewise, the lack of interactive learning media that is able to cover the strategies applied is also a polemic in itself (Ana et al., 2020; Shrestha, 2016). Previous research reveals crucial problems that occur in the learning process. The preparation of lesson plans is the most crucial problem for teachers. Most of the teachers still use the old lesson plans, so the learning process is still using the old models, methods, media and learning resources (Nurtanto et al., 2021). This is certainly problematic because new skills await the transformation of the learning process that is able to achieve them (Made Sudana et al., 2019). Thus, it is necessary to have a learning process that is able to cover the 21st century learning process.

Project-based learning is one of the learning models that is predicted to be a model that can improve 21st century skills (Bell, 2010; Pawar et al., 2020). Analyzing the importance of problems to be solved through products is the beginning of activities that are able to grow analytical skills towards problems and their solutions (Zheng et al., 2021). In these initial activities, students can also deepen and develop their thinking to conceptualize carefully related to the products that will be produced to overcome existing problems, so that here critical thinking skills and creativity can be honed properly (Jalinus et al., 2019). Then, the production process that involves teamwork will spur students to develop ways of communicating and collaborating to produce mature products (Song, 2018). Meanwhile, all activities in project-based learning will emphasize the use of technology, media and learning resources that are effective and efficient in supporting the process (Basilotta Gómez-Pablos et al., 2017). Thus, the estuary will also foster a sense of caring and digital literacy in students, so that maturity in using digital technology is also formed by itself (Astuti et al., 2021).

It should be noted that some teachers still need training and assistance regarding how to implement project-based learning models, especially in vocational education. Previous research revealed that there are still many teachers who spend too long in implementation, but the results are not comprehensive (Mustapha et al., 2020). Currently, project-based learning is widely integrated with the Science, Technology, Engineering and Math (STEM) approach to increase its effectiveness (Hussin et al., 2019). The advantage of the STEM approach to project-based learning is that it involves several disciplines that are integrated with each other, so that it will form multicompetence in students. (Hanif et al., 2019). In addition, the integration of several multidisciplinary sciences can cover several relevant subjects to collaborate in implementing project-based learning which requires a long period of time. (Gandi et al., 2019).

Automotive engineering is one of the expertise programs in vocational education that needs to be focused on implementing project-based learning with a STEM approach (Liang, 2012; Wakid et al., 2020). The lack of research in this field and the low 21st century skills of automotive engineering students are important reasons for the need to implement this model in automotive engineering (Mustapha et al., 2020). In addition, the complexity in achieving the competencies and the limited time allocation in the expertise program support the implementation of the model (Ayyakkannu, 2018). Based on these important issues, this study aims to test the effectiveness of project-based learning with a STEM approach to improve 21st century skills which include problem solving, critical thinking, creativity, communication, collaboration, and digital literacy.

2. METHODS

This research is a quasi-experimental research by adopting the Nonequivalent Control Group Design (Thyer, 2012). The study involved vocational education students in an automotive engineering expertise program in Yogyakarta Province. The study used a quantitative data approach with orientation to the collected data and then analyzed using a t-test with 4 different methods to measure the effectiveness of the project-based learning model with a STEM approach. Data on all variables were collected through the observation method used for direct observation in the field. The research is carried out simultaneously with related subjects in the period from early November to the end of December 2021.

This study involved students of class XII in vocational education in the Province of Yogyakarta-Indonesia. Class XII students are selected based on the criteria that the class is a class that has mastered the basics required in subjects in the automotive expertise program.

Due to the large number of vocational educations in Yogyakarta Province and the limitations of research during the COVID-19 pandemic, a sample was taken using a simple random sampling technique. Sampling results obtained a research sample of 214 students, which were allocated in the experimental class as many as 108 students and the control class as many as 106 students

Data was collected using the observation method to measure the level of problem-solving skills, critical thinking, creativity, collaboration, communication and digital literacy in students. The research instrument used an observation sheet with 4 assessment criteria, namely Excellent (E), Good (G), Poor (P) and Very Poor (VP). The main points of the statement of 21st century skills on the observation sheet are arranged based on the variables and indicators adopted from the experts. The grid of instruments used to measure 21st century skills shown in Table 1.

Table 1. Grids of Research Instrument

Learning Skills	Indicators	Item	References
Creativity	Creative thinking	4	(Lankshear & Knobel, 2008; Trilling & Fadel, 2012)
	Creative in collaborating	3	
	Implementing innovation	3	
Critical thinking	Effective reasoning	3	
	Systemic thinking	3	
	Complex assessment	2	
	Quality of decision making	2	
Problem-solving	The quality of the problem	3	
	Complexity of ways	3	
	Solution analysis skills	4	
Communication	Clarity of verbal articulation	1	
	Effectiveness in listening	1	
	Clarity of purpose of communicating	1	
	The use of ICT in communicating	2	
Collaboration	Flexible compromises	1	
	Collaborative work responsibilities	2	
	Work effectively with diversity	2	
Digital literacy	Efficiency of use	3	
	Effectiveness of use	3	
	Understanding of purpose & benefits	2	
	Understanding of digital ethics	2	

Instrument validation was carried out using content validation by asking for expert opinion and using product moment correlation calculations to measure the validity of the observation sheet items. The reliability test was carried out using the formula from Cronbach's alpha to determine the level of consistency of the observation sheets. The results of the validation of the expert opinion stated that the pre-test and post-test instruments had high validity. Descriptive qualitative and inferential statistical analysis were used to analyze the collected data. Descriptive qualitative is used to describe the concept of implementing project-based learning with STEM (PjBL-STEM) approach in automotive engineering. Data analysis with inferential statistics in this study used inferential statistics paired sample t test and independent sample t test.

3. RESULTS AND DISCUSSION

Result

Implementation of PjBL-STEM

In general, the implementation of PjBL-STEM is the same as project-based learning in general, namely learning begins by analysing problems and asking important questions. However, it is this, the integration of STEM into focus for nature with project-based learning processes. STEM will function to obtain multi-competence obtained by students and provide time efficiency for the application of various disciplines. STEM will enter into learning to be involved in their respective disciplines in collaborating on compiling and completing products. The concept of project-based learning with a STEM approach refers to the basic concept that refers to the production of a product as the output of the learning process (Hawari & Noor, 2020). Each activity must produce a product, whether a product in the form of a design, concept analysis, or finished product. Details of the learning process with the PjBL-STEM model are presented in Table 2.

Table 2. PjBL-STEM Implementation Process

PjBL-STEM Syntax	Knowedge Discipline	Learning Process
Important questions about problems	Science, technology, and engineering	- Observing and analyzing problems based on facts in the field and in the literature abaout automotive problems - Discuss and formulate problems - Determine the product type
Planning and scheduling activities	Science	- Planning product work - Scheduling in the completion process - Looking for materials to design products
Carry out the project work process and monitoring	Science Technology Engineering Math	- Develop existing technology through products - Perform product engineering according to the theme - Perform calculation of material specifications needed for product manufacture
Assessments and evaluations	Science, Technology, Engineering, and Math	- Assessing the product - Carry out evaluations and final checks on product design, manufacturing processes, and calculation processes

Base on Table 2 the implementation of the automotive engineering expertise program, lessons are carried out in four meetings. Automotive electrical maintenance subjects, physics, chemistry, mathematics, entrepreneurship collaborate in organizing project-based learning with a STEM approach. Learning at the first meeting begins with observation and problem analysis, both in the field and through analysis of literature sources that are currently a trend. In this activity, students are trained in the scientific process to conduct small research and inculcate the scientific process in them. Processing subjects in science, technology and engineering, such as physics, chemistry, and automotive electrical maintenance are integrated. Students are directed to analyse the problems that often occur in automotive and are often complained by customers related to the automotive electrical system. In the first meeting, the products produced were identification and formulation of problems related to the importance of safety in motorized vehicles and the price of electrical components that were less affordable in the lower middle class. Students then make a list of what should be the focus of the project as a problem-solving solution by referring to the results of field observations which are strengthened through literature analysis. Analytical abilities, critical thinking, communication, collaboration, and students' creativity in finding important problems to be solved became the focus of teacher assessors in the first assessment.

After the students produce a product in the form of an analysis of the problems that occur, then the two students together with the teacher meet to plan and schedule to complete the project as a problem-solving innovation. Students together with all teachers of related subjects, namely automotive electrical maintenance subjects, physics, chemistry, mathematics, entrepreneurship provide an explanation of what activities will be carried out next. The teacher explains to students regarding the initial description of the product design process, product manufacture, product specifications to be measured and calculated, and product sales and marketing analysis. After that, the students together with the teacher do the scheduling and technical processes that will be carried out next. In the second meeting, students also designed product designs using computer applications. Students also perform mathematical calculations related to the measurement of the required components according to the required specifications. The products designed by students include vehicle safety touch sensors, vehicle charging system regulators & rectifiers, electronic control systems for motorcycle ignition systems and automatic flashers. The examples of the process in making the resulting design are show in Figure 1 and Figure 2. Students' communication, collaboration, and creativity skills in designing and designing products became the focus of the teacher assessors at the second meeting.

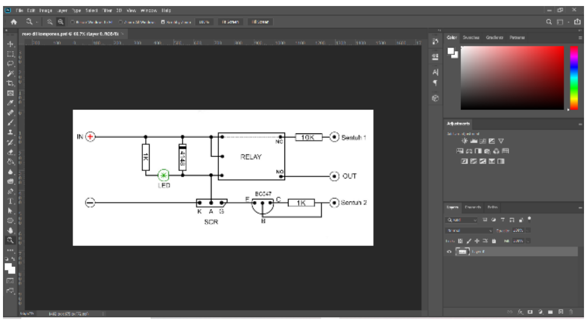

Figure 1. Sample Design 1

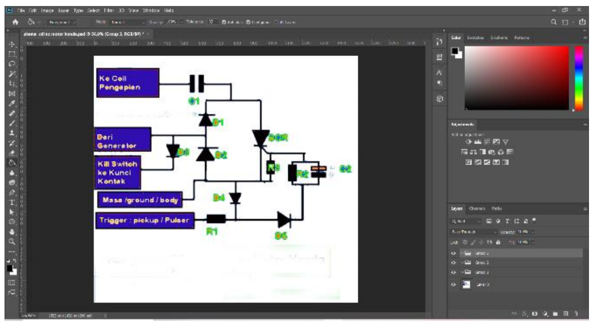

Figure 2. Sample Design 2

After the design and product design are completed, the next meeting students make projects according to their respective designs. The project is made in groups, with a focus on making components on vehicles in the form of vehicle safety touch sensors, regulators & rectifiers for vehicle charging systems, electronic control systems for motorcycle ignition systems and automatic flashers. The products produced by students are standardized according to the specifications of each product, because the calculation and measurement of the requirements for the specifications of the materials for manufacture have been carried out. An example of the resulting raw product is shown in Figure 3 and Figure 4. Critical thinking skills, communication, collaboration, and students' creativity in working on projects are the focus of the teacher assessors in the third assessment.

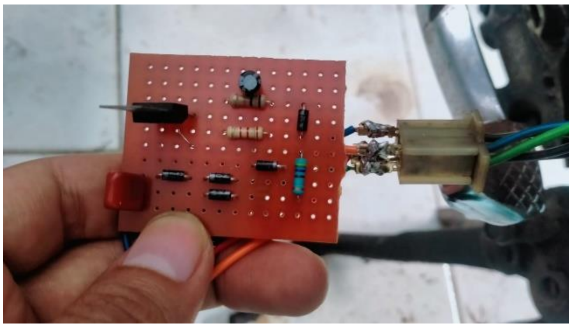

Figure 3. Example of Product 1

Figure 4. Example of Product 2

After the product is finished, then at the last meeting the teacher provides an understanding of entrepreneurship to market the products that have been produced. Market analysis, SWOT analysis is conveyed and strengthened to students regarding products that have been successfully completed. In this meeting, each group also presented and discussed the products produced together to get input and improvements. After that, all teachers make a final assessment of the product produced and evaluate and reflect together with students as well. Analytical abilities, critical thinking, communication, collaboration, student creativity and product results are the focus of teacher assessors in the final assessment.

Analysis Prerequisite Test

Prerequisite analysis test was conducted to determine whether the data were normally distributed and had homogeneous variance as a requirement to perform paired sample t-test and independent sample t-test. The analysis prerequisite test contains tests for data normality and homogeneity of variance. The analysis prerequisite test was carried out using SPSS V 21 software. The results of the data normality test are shown in Table 3.

Table 3. Normality Test Result

Variable	Pre-test p Value		Decision	Post-test p Value		Decision
	Experiment	Control		Experiment	Control	
Problem-solving	0.215	0.119	Normal	0.184	0.262	Normal
Critical thinking	0.402	0.118	Normal	0.167	0.089	Normal
Creativity	0.168	0.123	Normal	0.190	0.062	Normal
Communication	0.277	0.091	Normal	0.200	0.217	Normal
Collaboration	0.065	0.117	Normal	0.110	0.202	Normal
Digital literacy	0.281	0.108	Normal	0.314	0.264	Normal

Based on Table 3 the data normality test using the Kolmogorov Smirnov formula, the significance value in each class was greater than 0.050 at a significance level of 5%, so it can be concluded that the data is normally distributed. After the data is known to be normally distributed, then the homogeneity of variance test is then carried out. Based on the results of the homogeneity of variance test, it is known that the significance value for all variables is greater than 0.050 at a significance level of 5%, so it can be concluded that the variance of the experimental class posttest data and control class posttest data on the 21st century skills variables is the same or homogeneous. The results of the homogeneity test are shown in Table 4.

Table 4. Homogeneity Test Results

Variabel	Df1	Df2	Sig	Dec.
Problem-solving	1	212	0.155	Homogeneous
Critical thinking	1	212	0.167	Homogeneous
Creativity	1	212	0.132	Homogeneous
Communication	1	212	0.200	Homogeneous
Collaboration	1	212	0.181	Homogeneous
Digital literacy	1	212	0.267	Homogeneous

The Effectiveness of PjBL-STEM in Improving Students' 21st Century Skills

Before testing the effectiveness of PjBL-STEM in improving students' 21st century skills using statistical inferential t-tests, first a balance test was conducted between students' 21st century skills in the pretest of both classes. Equilibrium test aims to ensure that the initial abilities of students in the control class and the experimental class are commensurate, so that an effectiveness test can be carried out. Independent sample t-test was used to test the equivalence of skills possessed in the experimental and control classes. Based on the equilibrium test, a significance value of above 0.05 was obtained, so that the pretest scores for the 21st century ability in the two classes were stated to be balanced. The details of the equilibrium test between the experimental and control pre-test values is show in Table 5.

Table 5. Initial Ability Test Result

Variabel	Esperiment		Control		t Value	Sig	Decision
	Df	Mean	Df	Mean			
Problem-solving	106	21.84	104	21.10	1.108	0.254	Balanced
Critical thinking	106	20.08	104	20.64	1.012	0.288	Balanced
Creativity	106	18.62	104	19.12	1.121	0.237	Balanced
Communication	106	9.16	104	9.00	0.902	0.325	Balanced
Collaboration	106	9.08	104	9.86	1.120	0.231	Balanced
Digital literacy	106	21.16	104	21.00	0.983	0.307	Balanced

After the initial ability test was carried out, the next step was to give the project-based learning model treatment with a STEM approach to the experimental class and the control class using the original learning model. The treatment and control process was carried out in 4 face-to-face online meetings. PjBL-STEM in subjects in the automotive department is carried out with outputs in the form of products made from automotive components, namely vehicle safety touch sensors, electronic ignition control systems, vehicle charging system regulators & rectifiers, and automatic flashers. The teacher's role is as a facilitator and guide of project implementation from beginning to end. Meanwhile, students carry out the process of making projects independently under the guidance and supervision of online teachers. After the treatment and control processes were completed, a final assessment (posttest) was carried out in one full meeting and paired sample t-test and independent sample t-test were carried out. The results of the paired sample t-test are shown in Table 6.

Table 6. Paired Sample t-Test Result

Variable	Pre. – Post. Experiment			Pre. – Post Control		
	Mean Diff.	t Value	Sig	Mean Diff.	t Value	Sig
Problem-solving	-15.664	-10.184	0.000	-6.002	-4.058	0.000
Critical thinking	-12.972	-8.629	0.000	-4.025	-3.141	0.000

Variable	Pre. – Post. Experiment			Pre. – Post Control		
	Mean Diff.	t Value	Sig	Mean Diff.	t Value	Sig
Creativity	-12.618	-8.402	0.000	-4.020	-3.122	0.001
Communication	-8.014	-6.586	0.000	-3.388	-2.184	0.012
Collaboration	-7.139	-5.078	0.000	-3.352	-2.037	0.024
Digital literacy	-14.981	-9.294	0.000	-4.322	-3.703	0.000

Based on Table 6 results of the paired sample t test, the significance value in the experimental pretest-posttest pair across all skills was 0.000 (p <0.05), it can be concluded that there was a significant increase in students' 21st century skills after receiving treatment from the implementation of project-based learning models with STEM approach, so the first hypothesis is supported. After knowing the significant increase between the paired samples (experimental pretest - experimental posttest), then an independent sample t-test was carried out to find out the average difference between the experimental class posttest and control class posttest as presented in Table 7.

Table 7. Independent Sample t-Test Result

Variable	Mean difference	t Value	Sig.
Probem-solving	9.662	7.283	0.000
Critical thinking	8.947	6.928	0.000
Creativity	8.598	6.710	0.000
Communication	4.626	4.008	0.000
Collaboration	3.787	2.400	0.008
Digital literacy	10.659	8.002	0.000

Based on Table 7 the results of the independent sample t test, the significance value for all skills was 0.000 (p<0.05), only collaboration skills got a significance value of 0.008 but it was still smaller than the significance level (p<0.05), it can be concluded that there is a significant difference in the average 21st century skills of students between the experimental class after receiving treatment and the control class that did not receive treatment. The average value of the experimental class was significantly higher after receiving treatment in the form of implementing a project-based learning model with a STEM approach, so that the second hypothesis was supported.

Discussion

21st century skills are skills that are currently indispensable to face the challenges and opportunities that exist in it (Chalkiadaki, 2018; Trilling & Fadel, 2012). Where skills in problem solving, critical thinking, creativity, communication, collaboration, and digital literacy are the main skills that form the basis for improving current work competencies (Kergroach, 2017; Xu et al., 2018). Efforts to improve these skills become a very crucial option for human resource development institutions, especially vocational education with the essence of its work (Billett, 2011; Made Sudana et al., 2019; Pavlova, 2009). Organizing 21st century skills-oriented learning is an absolute option to be applied in vocational education (Kim et al., 2019).

Project-based learning with a STEM approach is one of the 21st century learning models that is becoming a trend to improve various important skills today (Jamaludin & Hung, 2017). The results showed that the learning model was very effective in improving 21st century skills through learning in the automotive engineering expertise program. This is evidenced by the significance value which is smaller than the 5% significance level (p<0.05) in all 21st century skills. This increase is strongly motivated by various important factors. The PjBL-STEM learning steps at the beginning which emphasize problem analytical activities are an important factor in training students in solving problems, so that students' problem solving skills will improve by themselves (Gandi et al., 2019; Sholihah & Lastariwati, 2020). Then in the analytical process, the problem will certainly stimulate students' critical thinking skills and creativity in analysing and formulating solutions to problems that exist in the real world (Pawar et al., 2020). In addition, in designing and manufacturing products, the process of depth and creativity to consider the benefits, quality and usability of the product is also an important factor in stimulating the emergence of students' critical thinking skills and creativity (Djam'An et al., 2021; Ummah et al., 2019).

Previous research has also revealed the effectiveness of project-based learning integrated with STEM approaches. Learning with this model is effective in improving problem solving skills (Zheng et al., 2021). The research strongly argues that the syntax in which there is problem-based learning is the main reason for increasing problem-solving abilities in students (Pawar et al., 2020). In addition, other studies also reveal that problem-based learning in product design and manufacture will strengthen problem analytical skills. In line with this, several other relevant studies also add that the growth of problem solving skills in it will also stimulate the growth of critical thinking skills and students' creativity in analysis and formulation of problem solutions (Gandi et al., 2019; Nilsook et al., 2021).

Project-based learning with a STEM approach will certainly involve several disciplines that make it possible to collaborate with each other in contributing to produce products. That way, it can be seen that the learning really prioritizes the teamwork process in it, so that collaboration skills can be honed well (Hussin et al., 2019). In line with this, good collaboration must have good communication in it too, so that the aftermath of increasing collaboration skills will improve communication skills as well. (Achilleos et al., 2019). Then, in the whole PjBL-STEM learning process, of course, integrating digital technology that is able to provide various relevant sources in problem analysis and solutions. That way, digital literacy can also be grown (Rizaldi et al., 2020).

Previous relevant research corroborates the results of this study, which investigated the effectiveness of project-based learning with a STEM approach in order to improve students' 21st century skills (Stehle & Peters-Burton, 2019). Several studies have revealed that learning with this model is effective in improving student collaboration processes. The need for teamwork in implementing the model is the main factor influencing the growth of initiatives to collaborate in learning (Muhammad et al., 2020). Several other studies also add that the growth of students' communication skills occurs when scientific processes and problem solving occur in learning, because basically it requires collaboration to provide depth in problem solving (Jamaludin & Hung, 2017; Nurtanto et al., 2020). In line with the development of digital technology, other studies also strengthen the results of this study. Many researchers find the effectiveness of project-based learning with the STEM approach when applied to foster digital literacy. The importance of integrating digital technology in supporting the availability of extensive learning resources to support project-based learning is the main reason digital literacy can grow well (Rizaldi et al., 2020).

4. CONCLUSION

The lack of 21st century skills in vocational education students, especially in the automotive department, is a big polemic that needs to be solved. Organizing project-based learning is a strong solution in improving 21st century skills in students. Moreover, the integration of the STEM approach allows collaboration between various disciplines at once, so that students' multi-skills can be formed as well. This study reveals the effectiveness of

PjBL-STEM learning in improving the 21st century skills of students in the automotive department, which includes problem solving skills, critical thinking, creativity, communication, collaboration, and digital literacy through an experimental process. These results become recommendations, especially in vocational education in order to improve 21st century skills which are currently an important qualification in the world of work. In addition, time efficiency by integrating various disciplines is a distinct advantage, in addition to equipping students with multi-competence.

5. REFERENCES

Achilleos, A. P., Mettouris, C., Yeratziotis, A., Papadopoulos, G. A., Pllana, S., Huber, F., Jäger, B., Leitner, P., Ocsovszky, Z., & Dinnyés, A. (2019). SciChallenge: A Social Media Aware Platform for Contest-Based STEM Education and Motivation of Young Students. *IEEE Transactions on Learning Technologies*, *12*(1), 98–111. https://doi.org/10.1109/TLT.2018.2810879.

Ackerman, P. L., & Kanfer, R. (2020). Work in the 21st century: New directions for aging and adult development. *American Psychologist*, *75*(4), 486–498. https://doi.org/10.1037/amp0000615.

Ana, A., Kustiawan, I., Ahman, E., Zakaria, S., Muktiarni, M., Dwiyanti, V., Saripudin, S., & Kahoerunnisa, I. (2020). Defining vocational teacher competencies in industry 4.0 from the perspective of policymakers. *Journal of Engineering Education Transformations*, *34*(Special Issue), 159–167. https://doi.org/10.16920/JEET/2020/V34I0/157884.

Astuti, M., Arifin, Z., Mutohhari, F., & Nurtanto, M. (2021). Competency of Digital Technology: The Maturity Levels of Teachers and Students in Vocational Education in Indonesia. *Journal of Education Technology*, *5*(2), 254–262. https://doi.org/10.23887/jet.v5i3.35108.

Ayyakkannu, A. (2018). Technical and soft skill competencies mapping at the entry level of diploma holders in mechanical and automobile engineering for auto and auto components industries. *International Journal of Mechanical and Production Engineering Research and Development*, *8*(1), 1209–1220. https://doi.org/10.24247/ijmperdfeb2018142.

Basilotta Gómez-Pablos, V., Martín del Pozo, M., & García-Valcárcel Muñoz-Repiso, A. (2017). Project-based learning (PBL) through the incorporation of digital technologies: An evaluation based on the experience of serving teachers. *Computers in Human Behavior*, *68*(1), 501–512. https://doi.org/10.1016/j.chb.2016.11.056.

Bell, S. (2010). Project-Based Learning for the 21st Century: Skills for the Future. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, *83*(2), 39–43. https://doi.org/10.1080/00098650903505415.

Billett, S. (2011). *Vocational Education: Purposes, Traditions and Prospects*. Springer. https://doi.org/10.1007/978-94-007-1954-5.

Chai, C. S., & Kong, S.-C. (2017). Professional learning for 21st century education. *Journal of Computers in Education*, *4*(1), 1–4. https://doi.org/10.1007/s40692-016-0069-y.

Chalkiadaki, A. (2018). A systematic literature review of 21st century skills and competencies in primary education. *International Journal of Instruction*, *11*(3), 1–16. https://doi.org/10.12973/iji.2018.1131a.

DeSimone, K. (2020). Beyond gender: reconceptualizing understandings of work–life balance and the extreme work model for 21st-century high-potential top earners. *Journal of Organizational Change Management*, *33*(6), 1071–1084. https://doi.org/10.1108/JOCM-02-2020-0042.

Djam'An, N., Bernard, & Sahid. (2021). Developing Students' Creativity in Building City Mathematics through Project Based Learning. *Journal of Physics: Conference Series*, *1899*(1), 267–274. https://doi.org/10.1088/1742-6596/1899/1/012147.

Dwyer, C. P., Hogan, M. J., & Stewart, I. (2014). An integrated critical thinking framework for the 21st century. *Thinking Skills and Creativity*, *12*(1), 43–52. https://doi.org/10.1016/j.tsc.2013.12.004.

Estriyanto, Y., Kersten, S., Pardjono, P., & Sofyan, H. (2017). The missing productive vocational high school teacher competency standard in the Indonesian education system. *Journal of Technical Education and Training*, *9*(1), 6–14. https://doi.org/Retrieved from https://publisher.uthm.edu.my/ojs/index.php/JTET/article/view/1499.

Gandi, A. S. K., Haryani, S., & Deni, S. (2019). The Effect of Project-Based Learning Integrated STEM Toward Critical Thinking Skill. *Journal of Primary Education*, *8*(7), 18–23. https://journal.unnes.ac.id/sju/index.php/jpe/article/view/33825.

Hanif, S., Wijaya, A. F. C., & Winarno, N. (2019). Enhancing Students' Creativity through STEM Project-Based Learning. *Journal of Science Learning*, *2*(2), 1–14. https://doi.org/10.17509/jsl.v2i2.13271.

Hawari, A. D. M., & Noor, A. I. M. (2020). Project Based Learning Pedagogical Design in STEAM Art Education. *Asian Journal of University Education*, *16*(3), 102–111. https://doi.org/10.24191/ajue.v16i3.11072.

Hussin, H., Jiea, P. Y., Rosly, R. N. R., & Omar, S. R. (2019). Integrated 21st century science, technology, engineering, mathematics (STEM) education through robotics project-based learning. *Humanities and Social Sciences Reviews*, *7*(2), 204–211. https://doi.org/10.18510/hssr.2019.7222.

Ifeoma Obidile, J. (2018). Revitalization of the Technical and Vocational Education (TVE) Programmes for Youth Empowerment in Nigeria. *International Journal of Vocational Education and Training Research*, *4*(1), 45–47. https://doi.org/10.11648/j.ijvetr.20180401.17.

Jalinus, N., Syahril, & Nabawi, R. A. (2019). A comparison of the problem-solving skills of students in pjBL versus CPjBL model: An experimental study. *Journal of Technical Education and Training*, *11*(1), 36–43. https://doi.org/10.30880/jtet.2019.11.01.005.

Jamaludin, A., & Hung, D. (2017). Problem-solving for STEM learning: navigating games as narrativized problem spaces for 21 st century competencies. *Research and Practice in Technology Enhanced Learning*, *12*(1), 1–14. https://doi.org/10.1186/s41039-016-0038-0.

Kergroach, S. (2017). Industry 4.0: New challenges and opportunities for the labour market. *Foresight and STI Governance*, *11*(4), 6–8. https://doi.org/10.17323/2500-2597.2017.4.6.8.

Kim, S., Raza, M., & Seidman, E. (2019). Improving 21st-century teaching skills: The key to effective 21st-century learners. *Research in Comparative and International Education*, *14*(1), 99–117. https://doi.org/10.1177/1745499919829214.

Lankshear, C., & Knobel, M. (2008). *Digital Literacies: Concepts, Policies and Practices*. Peter Lang Publishing, Inc.

Liang, J. S. (2012). Learning in troubleshooting of automotive braking system: A project-based teamwork approach. *British Journal of Educational Technology*, *43*(2), 331–352. https://doi.org/10.1111/j.1467-8535.2011.01182.x.

Made Sudana, I., Apriyani, D., & Nurmasitah, S. (2019). Revitalization of vocational high school roadmap to encounter the 4.0 industrial revolution. *Journal of Social Sciences Research*, *5*(2), 338–342. https://doi.org/10.32861/jssr.52.338.342.

Malik, R. S. (2018). Educational Challenges in 21st Century and Sutainable Development.

Journal of Sustainable Development Education and Research, *2*(1), 9–20. https://doi.org/10.17509/jsder.v2i1.12266.

Muhammad, N., Sudira, P., Kholifah, N., Samsudin, A., & Warju, W. (2020). Vocational Teachers' Perceptions and Perspectives in the Implementation of STEM Learning in the 21st Century. *TEM Journal*, *9*(4), 1665–1680. https://doi.org/10.18421/TEM94-46.

Mustapha, R., Sadrina, Nashir, I. M., Azman, M. N. A., & Hasnan, K. A. (2020). Assessing the implementation of the project-based learning (PJBL) in the department of mechanical engineering at a Malaysian polytechnic. *Journal of Technical Education and Training*, *12*(1 Special Issue), 100–118. https://doi.org/10.30880/jtet.2020.12.01.011.

Mutohhari, F., Sofyan, H., & Nurtanto, M. (2021). Technological Competencies: A Study on the Acceptance of Digital Technology on Vocational Teachers in Indonesia. *Proceedings of the 1st International Conference on Law, Social Science, Economics, and Education, ICLSSEE 2021*, 1–11. https://doi.org/10.4108/eai.6-3-2021.2305971.

Mutohhari, F., Sutiman, S., Nurtanto, M., Kholifah, N., & Samsudin, A. (2021). Difficulties in implementing 21st century skills competence in vocational education learning. *International Journal of Evaluation and Research in Education*, *10*(4), 1229–1236. https://doi.org/10.11591/ijere.v10i4.22028.

Nilsook, P., Chatwattana, P., & Seechaliao, T. (2021). The Project-based Learning Management Process for Vocational and Technical Education. *Higher Education Studies*, *11*(2), 20–29. https://doi.org/10.5539/hes.v11n2p20.

Nurtanto, M., Kholifah, N., Masek, A., Sudira, P., & Samsudin, A. (2021). Crucial Problems in Arranged The Lesson Plan of Vocational Teacher. *International Journal of Evaluation and Research in Education (IJERE)*, *10*(1), 345–354. https://doi.org/10.11591/ijere.v10i1.20604.

Nurtanto, M., Pardjono, P., Widarto, W., & Ramdani, S. D. (2020). The effect of STEM-EDP in professional learning on automotive engineering competence in vocational high school. *Journal for the Education of Gifted Young Scientists*, *8*(2), 633–649. https://doi.org/10.17478/JEGYS.645047.

Pavlova, M. (2009). *Technology and Vocational Education for Sustainable Development*. Springer Science Business Media B.V.

Pawar, R., Kulkarni, S., & Patil, S. (2020). Project based learning: An innovative approach for integrating 21st century skills. *Journal of Engineering Education Transformations*, *33*(4), 58–63. https://doi.org/10.16920/jeet/2020/v33i4/139423.

Rizaldi, D. R., Nurhayati, E., & Fatimah, Z. (2020). The Correlation of Digital Literation and STEM Integration to Improve Indonesian Students' Skills in 21st Century. *International Journal of Asian Education*, *1*(2), 73–80. https://doi.org/10.46966/ijae.v1i2.36.

Schwab, K. (2016). *The Fourth Industrial Revolution*. World Economic Forum.

Sholihah, T. M., & Lastariwati, B. (2020). Problem Based Learning to Increase Competence of Critical Thinking and Problem Solving. *Journal of Education and Learning (EduLearn)*, *14*(1), 148–154. https://doi.org/10.11591/edulearn.v14i1.13772.

Shrestha, B. R. P. (2016). Vocational Education and Training Graduates: Challenges in Practical Skills to the Job Market. *International Journal of Social Sciences and Management*, *3*(3), 141–145. https://doi.org/10.3126/ijssm.v3i3.15264.

Song, Y. (2018). Improving primary students' collaborative problem solving competency in project-based science learning with productive failure instructional design in a seamless learning environment. *Educational Technology Research and Development*, *66*(4), 979–1008. https://doi.org/10.1007/s11423-018-9600-3.

Stehle, S. M., & Peters-Burton, E. E. (2019). Developing student 21st Century skills in selected exemplary inclusive STEM high schools. *International Journal of STEM Education*, *6*(1), 2. https://doi.org/10.1186/s40594-019-0192-1.

Stuchlikova, L. (2016). Challenges of Education in The 21st Century. *ICETA 2016 - 14th IEEE International Conference on Emerging ELearning Technologies and Applications, Proceedings*, 335–340. https://doi.org/10.1109/ICETA.2016.7802072.

Sylte, A. L. (2020). Predicting the future competence needs in working life: Didactical implications for VET in Norway. *International Journal for Research in Vocational Education and Training*, *7*(2), 167–192. https://doi.org/10.13152/IJRVET.7.2.3.

Szabo, Z. K., Körtesi, P., Guncaga, J., Szabo, D., & Neag, R. (2020). Examples of problem-solving strategies in mathematics education supporting the sustainability of 21st-century skills. *Sustainability (Switzerland)*, *12*(23), 1–28. https://doi.org/10.3390/su122310113.

Thyer, B. A. (2012). *Quasi-Experimental Research Design*. Oxford University Press, Inc.

Trilling, B., & Fadel, C. (2012). *21st Century Skills: Learning for Life in Our Times* (1st ed.). Calif: John Wiley And Sons Inc.

Ummah, S. K., Inam, A., & Azmi, R. D. (2019). Creating manipulatives: Improving students' creativity through project-based learning. *Journal on Mathematics Education*, *10*(1), 93–102. https://doi.org/10.22342/jme.10.1.5093.93-102.

van Laar, E., van Deursen, A. J. A. M., van Dijk, J. A. G. M., & de Haan, J. (2019). Determinants of 21st-century digital skills: A large-scale survey among working professionals. *Computers in Human Behavior*, 93–104. https://doi.org/10.1016/j.chb.2019.06.017.

Wakid, M., Usman, T., & Sulistyo, B. (2020). Project based learning model to increase the competency of automotive engineering teachers candidates. *Journal of Physics: Conference Series*, *1700*(1), 1–8. https://doi.org/10.1088/1742-6596/1700/1/012063.

Xu, M., David, J. M., & Kim, S. H. (2018). The fourth industrial revolution: Opportunities and challenges. *International Journal of Financial Research*, *9*(2), 90–95. https://doi.org/10.5430/ijfr.v9n2p90.

Yılmaz, A. (2021). The effect of technology integration in education on prospective teachers' critical and creative thinking, multidimensional 21st century skills and academic achievements. *Participatory Educational Research*, *8*(2), 163–199. https://doi.org/10.17275/per.21.35.8.2.

Zheng, Y., Xu, A., Zheng, Q., & Shieh, C. J. (2021). The practice of project-based learning to outdoor ecological education on the promotion of students' problem-solving capability. *Revista de Cercetare Si Interventie Sociala*, *73*(1), 69–80. https://doi.org/10.33788/rcis.73.5.