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Integration of STEM Project-Based Learning into 21st Century Learning and Innovation Skills (4Cs) in Vocational Education Using SEM Model Analysis

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ABSTRACT

Students in the twenty-first century must demonstrate competence and competitiveness, but the current issue is a lack of creativity or creative and innovative problem-solving skills. The integration of project based learning (PjBL) with Science, Technology, Engineering, and Mathematics (STEM) is the solution to this problem. The purpose of this study was to ascertain the relationships between the variables affecting STEM Project Based Learning and to investigate 21st Century Learning and Innovation Skills including critical thinking or problem solving, creativity, collaboration and communication (4Cs). The research method used was quantitative. The subjects of this study were vocational high school students majoring in software engineering with a population of 1043 people and a sample of 283 students. Data was collected by distributing questionnaires to everyone. The questionnaire is structured as a semi-open questionnaire, with the exception of questions/statements about the respondent's name. There are four possible responses to each closed question/statement object: Rate 4 if it's very good and 1 if it's very bad. The quantitative analysis employed the Structural Equation Model (SEM) technique to analyze responses to a semi questionnaire submitted via Google Form. The study's findings indicated that while there was a correlation between STEM Project Based Learning and 4Cs competencies, communication skills were less effective in STEM Project Based Learning learning due to a variety of influencing factors. To improve students' communication skills, the author recommends that the school provide increased motivation to ensure that communication skills are acquired properly.

Keywords: Project based learning, STEM, 21st century learning and innovation skills (4Cs)

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1. INTRODUCTION

Education innovation is critical to the country's economic prosperity in the twenty-first century (Fayomi et al., 2019). The most rational strategy for stimulating educational innovation and increasing student productivity in the twenty-first century is to strengthen and develop student skills through integrated disciplines (Rayna & Striukova, 2021). 21st century learning is education that prepares generation for a world in which rapid technological advancements affect all facets of life, including the teaching and learning process (Osman & Marimuthu, 2010). 21st century learning can be incorporated into Vocational High School learning innovations. Learning in the twenty-first century is characterized by creative thinking, communication, collaboration, and critical thinking (Musa et al., 2012).

Issue that students frequently face when learning in class, both face-to-face and online, is that they rarely compose significant points from the learning material's content (Polat & Aydın, 2020). As a result, students' critical thinking abilities are limited, and their memory is confined to the material they receive. According to the study's findings, the study's findings indicate that a deficiency in critical thinking abilities in the classroom has resulted in very few opportunities for students to succeed. Critical thinking skills are important for learning because they allow students to make decisions what must be done and believed in order to solve problems, identify problem relationships, and develop creative solutions that are appropriate,

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systematic, and potentially structured in order to solve them (Tang et al., 2020). Along with critical thinking abilities in order to succeed, students must be able to solve problems (Marsono, Bella Cornelia Tjiptady, 2021). The ability to solve problems serves as a learning practice in which students discover appropriate and creative ways to accomplish goals through group collaboration and gain an understanding of contemporary global issues (Burkholder et al., 2021).

Collaboration and communication skills are also necessary for 21st century learning. According to research findings, teachers in schools have not conducted an objective assessment of students' collaboration and communication skills. Students will engage in activities that promote critical thinking, creativity, collaboration, and communication through active learning. To develop collaboration and communication skills in students, measures must be taken to implement a learning model that promotes 21st century skills, namely the project-based learning model, or PJBL (Chu et al., 2011). The PjBL model is an innovative approach to education that emphasizes project-based learning in construct student knowledge (Parrado-Martínez & Sánchez-Andújar, 2020). PjBL can be applied across a variety of fields (Cocota et al., 2015). A benefit of PjBL is that the learning model can generate outputs (Guzmán et al., 2016). The model is appropriate for students in elementary school through university (Donnelly, 2010). Essentially, PjBL enables students to collaborate on conceptual understanding, the application of prior knowledge, and skill acquisition. Additionally, PjBL allows teachers to incorporate multiple disciplines into their projects, one of which is STEM integration (Capraro & Slough, 2013a). If students receive project-based learning that is integrated with STEM, they will benefit from increased ability, increased achievement, the ability to collaborate effectively, the ability to solve real problems and motivate students, and the ability to meet the needs of students with diverse skills and learning(Lin & Tsai, 2016).

(John, 2015) has ranked project-based learning first among the 10 qualities of learning and teaching in the 21st century, citing it as primary means by which those characteristics are fulfilled. He describes the method as practical, collaborative, transdisciplinary, real-time, adaptable, student-centered, and real-world. (Lucie, 2017) PjBL is students identify real-world problems and seek solutions, gaining knowledge and skills through extended periods of work on topics or challenges of interest. (Kulprasutidilok, 2015) the learning outcomes of university students majoring in health management technology were evaluated using project-based learning, and it was discovered that students performed better, were able to arrange projects at a very high level, and were really satisfied with it. (Deejring, 2017) In his research findings, he discovered that the experimental group who studied via PjBL produced better learning outcomes and creative thinking than the control group.

In PjBL, students can comprehend concepts through the creation of products, whereas in STEM, there is a design and redesign process (engineering design process) that encourages students to create their best products. STEM integration can have a beneficial effect on learning, particularly in terms of improving student achievement in the fields of technology and science (Becker & Park, 2011). STEM project-based learning can be implemented teacher based on preparation, implementation, presentation, assessment, and correction (Lou et al., 2017). Using a STEM education strategy and a collection of project-based course templates (Tseng et al., 2013). Engineering design ideas are combined with science curricula in STEM project-based learning, which encourages real-world application. Evauation of the effectiveness of STEM project based learning, numerous studies have been carried out, including ones that looked at problem-solving abilities (Hanif et al., 2019). STEM curriculum on direct current electricity was used to investigate the students' Problem Solving Skills (Apriyani et al., 2019). The STEM development and validation research is based on previously carried educational content (Gustiani, 2017). The existence of instruments is one factor that contributes to PjBL learning model with STEM integration. Essentially, learning success is more valuable than hands-on experience. Through the use of tools, students can gain hands-on experience with PjBL and STEM integration. Visual programming is one of the tools that have been developed to make STEM and PjBL education more interesting and relevant. At Vocational High School majoring visual programming, emphasis is placed on developing software engineering competencies, specifically in the areas of web programming and mobile devices.

Web programming and mobile devices are among the fundamental subjects of vocational competence in Vocational High School. This subject is covered in the fundamental lessons of eleventh greader's Information and Communication Technology expertise program. The web programming material covered in eleventh greade semester 2 two corresponds to the syllabus for web programming and mobile devices. The Web and Mobile Programming Vocational High School's Fundamental Competencies range from web application technology concepts to mobile application connectivity. The researchers assume that after receiving training through the Continuing Professional Development program STEM Learning Approach, teachers in Vocational High School already have the provision to integrate project-based learning with STEM. Therefore, The researchers want to know how learning integration affects students in Vocational High School, particularly software engineering skills. Genuine behavior in completing tasks and solving various problems professionally demonstrates critical thinking behavior and working collaboratively and communicating with one another to produce and develop innovative ways or results that are distinct from existing products or services. As a result, this research is deemed critical in order to enhance the quality of graduate students at Vocational High School.

1.1. Statement of the Problem

The issue is that graduates of vocational high schools are still deemed insufficient. One example is students' lack of creativity or creative, and innovative thinking skills when solving a problem. This can result in widespread unemployment and a reduction of vocational students' career prospects in the business or industry world (Blinova et al., 2015). Indonesia is ranked

72nd out of 77 countries in the Program for International Student Assessment (PISA) ranking that measures the importance of reading competence. It is ranked 72nd out of 78 countries in terms of mathematics scores. While Science is ranked 70th out of 78 countries in terms of its value. This value has remained relatively stable over the last 10-15 year s(OECD, 2021).

According to the circumstances in the field, implementation of 21st century learning has not shown a significant assessment. Yusri (2018) turns out that in schools many students have difficulty thinking critically because these students never communicate in terms of expressing opinions and these students rarely write or take notes on the material presented by the teacher. Research Alcantara, et al (2017) and Utami, et al. (2017) the lack of critical thinking skills results in very few opportunities for students to succeed. (Windari, 2014) stated that students are very difficult to solve problems because they are unfamiliar with problem solving given by the teacher. This condition makes students' problem solving abilities low (Mawaddah & Anisah, 2015; Widodo & Kartikasari, 2017). The creative abilities students must have are not well supported in schools, where creative thinking is not developed by teachers in most lessons (Prakoso & Suwarma, 2016). It is also said that the ability to think creatively is still low or very low, especially in the field of education (Lubis, 2015; Subali & Mariyam, 2013) Although many teachers have measured creative thinking skills, the creative thinking skills understood by teachers are different from the creative thinking skills that need to be developed. be measured. Collaboration skills are very important to be applied in schools in order for students to work together in different groups as an orientation in the world of work. (noviana, 2019) states that in schools, teachers do not conduct objective assessments to measure collaboration and communication skills because teachers do not conduct evaluations due to the lack of examples of these skills assessment tools.

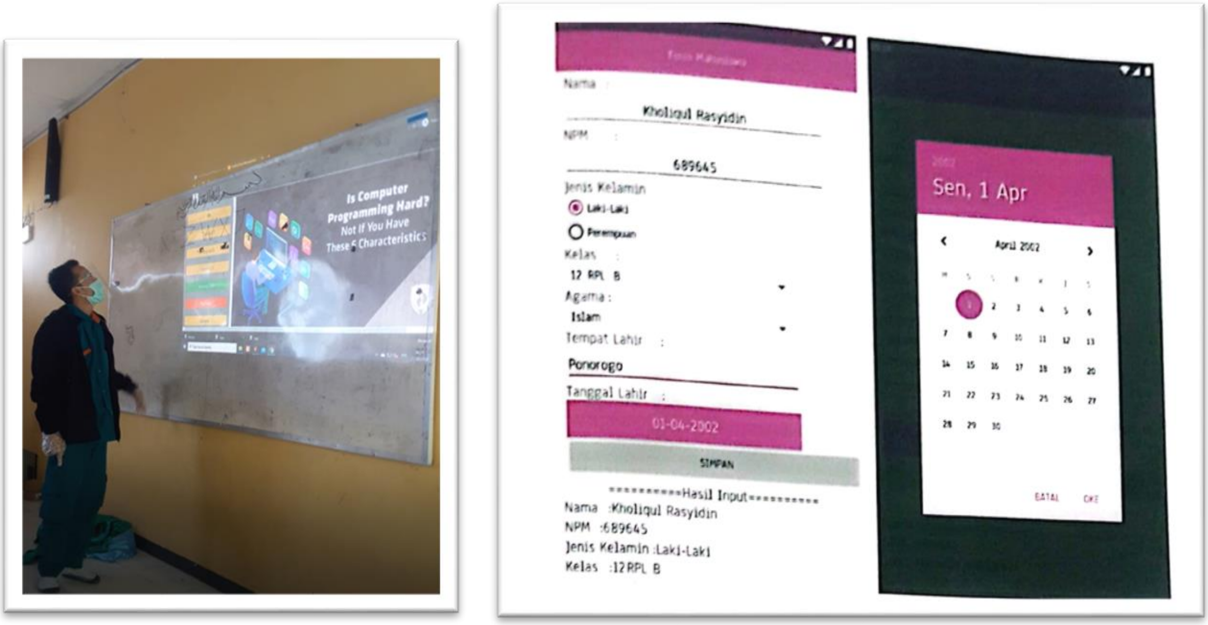

Figure 1. Students explain the project results in front of the class and project assignments made by students

If teachers use active and creative pedagogy with student participation, assessment of teamwork and communication skills can be applied. Active learning teaches creativity, communication, critical thinking or problem solving, and collaboration. Maximum effort in learning activities should be made so that students can develop collaboration and communication skills. This can be applied by using learning models that help students' collaboration and communication skills. Implementing a learning model that promotes creative thinking skills is one way to address these issues in accordance with the curriculum being used (Mangala & Rani, 2010). The most effective learning model is one that incorporates STEM project-based learning because can help develop their capacity for creative thinking, communication, problem solving or critical thinking and collaboration. Students will building skills in critical thinking, reviewing research, problem solving creatively, and synthesizing information in consequence of the STEM project based learning process.

1.2. Purpose of the Study

Numerous studies described in the paragraph above have examined STEM Project Based Learning's impact on 21 century skill, but none have examined the factors that most strongly influence 21 century skill in software engineering majors at vocational high schools. As a result, this study seeks to close existing research gaps by examining the following research questions: 1) the effectiveness of the STEM Project-Based Learning model to foster critical thinking or problem solving in software engineering vocational skills, 2) the effectiveness of the STEM Project Based Learning model to build communication skills in software engineering vocational skills, 3) the effectiveness of the STEM Project Based Learning model to enhance skills collaboration in software engineering vocational skills, 4) The STEM Project Based Learning model is successful developing creative abilities in software engineering skills vocational schools, 5) the relationship between the factors that influence STEM Project based learning on 21 century skill students.

2. METHODOLOGY

This research design was quantitative by using Structural equation model (SEM) analysis. This research was conducted to determine the indicators of STEM Project Based Learning that have the highest to lowest effect on problem solving or critical thinking skills, collaboration, communication and creativity in RPL Expertise Vocational Schools. The research population is all SMK students in East Java with A-accredited Software Engineering competency who take web programming and mobile devices. Determination of the sample is done proportionally. So with a student population of 1486 people, 283 students were taken with an average age of 16-17 years. Data collection techniques used semi-questionnaires to measure problem solving or critical thinking skills, collaboration, communication and creativity and STEM Project Based Learning specifically the google form, There were four scales on the instrument, particularly: very good, good, poor, and very poor.

The research data was obtained during one semester of learning. Prior to data collection, the school gave permission to conduct research. Students were given an explanation by the teacher to fill in the quesioner sheet through the google form sheet. This quesioner sheet was given during online learning and given time to fill in before the online learning ends, after the data was obtained it was then analyzed using SPSS 22.0 and Amos. Structural equation modeling analysis was conducted to analyze the relationship between the factors that influence STEM Project Based Learning, creativity, problem solving or critical thinking, communication, and collaboration as 21 century and innovation skills.

The validity test uses the Pearson Correlation technique to measure whether the variable is valid or not. Based on the results of testing the validity of the research instrument, it is known that all question items on the STEM project based learning, critical thinking, collaboration, communication, and creative variables have item correlation coefficient values > table correlation values. The conclusion of the statement on the variable is able to measure the variable and is declared valid.

Table 1.
Validity Test of Variable

Variable	Indicator	Correlation Coefficient Values
STEM Project Based Learning	indicators of apperception and given a concrete example of mobile device programming at the beginning of the introduction to learning (X11)	0.888
	indicators of group work division and dividing modules as well as guiding how to fill them out (X12)	0.904
	indicators guiding students to make observations in the surrounding environment related to mobile device programming (X13)	0.900
	indicators guides students in analyzing problems and finding solutions in their surroundings related to mobile device programming (X14)	0.746
	indicators guiding students in designing mobile programming projects (X15)	0.913
	indicators guides students in setting the timeline, deadlines, and project assessment criteria (X16)	0.830
	indicators facilitates students to present project designs (X17)	0.849
	indicators guiding students when they make steps that are not in accordance with the project (X18)	0.803
	student monitoring indicators in the project making process (X19)	0.862
	student assignment indicator to report the progress of the project that has been made (X110)	0.806
	indicators assessing student products adapted to mobile programming learning (X111)	0.852
	student assignment indicator to report the progress of the project that has been made (X112)	0.806
	indicators assessing student products adapted to mobile programming learning (X113)	0.852
problem solving or critical thinking	understanding indicators when the teacher gives apperception (Y11)	0.874
	understanding indicator when the teacher explains the module material (Y12)	0.887
	understanding indicators when the teacher gives a video tutorial (Y13)	0.861
	student response indicators after the teacher gave the module material (Y14)	0.837
	student response indicators after the teacher gave the video tutorial material (Y15)	0.859
	explains individually how to get the results of the work given by the teacher (Y16)	0.937
	indicator to make conclusions based on the learning that has been given (Y17)	0.841
	indicator to recognize and explain the part of the problem given by the teacher (Y18)	0.801
	indicators to identify various solutions (Y19)	0.899

collaboration	responsibility and productivity indicators (Y21)	0.850
	responsive action indicator to the surrounding conditions (Y22)	0.821
	indicator of cooperation between friends (Y23)	0.842
	indicator of working productively (Y24)	0.886
	indicator showing respect between friends (Y25)	0.930
communication	indicators involved in conversation and discussion (Y31)	0.801
	indicator to deliver an oral presentation (Y32)	0.820
	indicators of communicating in various environments (Y33)	0.851
	receptive communication indicators: listening, reading, seeing (Y34)	0.953
	indicators for differentiating the intent of speech (Y35)	0.714
	indicators using communication strategy (Y36)	0.790
	indicators to communicate clearly for a purpose (Y37)	0.795
creativity	indicators for designing initial mobile-based programming project ideas (Y41)	0.873
	indicators for designing a mobile-based programming final project (Y42)	0.871
	indicators to develop mobile applications (Y43)	0.853
	of indicators of openness and courage to explore problems (Y44)	0.749
	the indicator having curiosity (Y45)	0.812
	the fluency indicator (Y46)	0.902
	elaboration indicator (Y47)	0.857
	the flexibility indicator (Y48)	0.919
	divergent indicator (Y49)	0.869
	risk-taking indicator (Y410)	0.908
	relationship indicator with other indicators (Y411)	0.805

Reliability testing using Cronbach's Alpha technique. According to the test of Cronbach's alpha criteria 0.6 so that the questionnaire shows reliable or consistent results for the variables it measures.

Table 2.
Reliability Test of Variable

Variable	***Cronbach Alpha***	***Cut Off***	**Keterangan**
STEM Project Based Learning	0.967	0.6	Reliabel
Problem solving or critical thinking	0,956	0.6	Reliabel
Collaboration	0,917	0.6	Reliabel
Communication	0,916	0.6	Reliabel
Creativity	0,964	0.6	Reliabel

Based on the research instrument reliability test results in the table, Cronbach's Alpha value is > 0.6. Therefore, the questions are declared to be reliable or consistent in measuring these variables, it will be used as a data collection tool in this study.

Multivariate analysis in this research used Structural Equation Modeling (SEM) with prerequisite tests normality, linearity, and multicollinearity. SEM is a technique for building and testing statistical models in the form of causal models. SEM is a mixed technique that includes factor analysis, path analysis and regression.

3. FINDINGS

The findings indicate that there are several indicators measuring the STEM Project Based Learnıng variable spelled out identified in Table 3.

Table 3.
Loading Factor STEM Project Based Learning

Variable	**Indicator**	**Loading Factor**
STEM Project Based Learnıng	indicators of apperception and given a concrete example of mobile device programming at the beginning of the introduction to learning (X11)	0.905
	indicators of group work division and dividing modules as well as guiding how to fill them out (X12)	0.874
	indicators guiding students to make observations in the surrounding environment related to mobile device programming (X13)	0.861
	indicators guides students in analyzing problems and finding solutions in their surroundings related to mobile device programming (X14)	0.739
	indicators guiding students in designing mobile programming projects (X15)	0.863
	indicators guides students in setting the timeline, deadlines, and project assessment criteria (X16)	0.854

	indicators facilitates students to present project designs (X17)	0.790
	indicators guiding students when they make steps that are not in accordance with the project (X18)	0.854
	student monitoring indicators in the project making process (X19)	0.882
	student assignment indicator to report the progress of the project that has been made (X110)	0.788
	indicators assessing student products adapted to mobile programming learning (X111)	0.860
	student assignment indicator to report the progress of the project that has been made (X112)	0.783
	indicators assessing student products adapted to mobile programming learning (X113)	0.851

The contribution of indicators of apperception and given a concrete example of mobile device programming at the beginning of the introduction to learning (X11) to measure the STEM Project Based Learning variable is 90.5%. The contribution of indicators of group work division and dividing modules as well as guiding how to fill them out (X12) to measure the STEM Project Based Learning variable is 87.4%. The contribution of indicators guiding students to make observations in the surrounding environment related to mobile device programming (X13) to measure the STEM Project Based Learning variable is 86.1%. The contribution of indicators guides students in analyzing problems and finding solutions in their surroundings related to mobile device programming (X14) to measure the STEM Project Based Learning variable by 73.9%. The contribution of indicators guiding students in designing mobile programming projects (X15) to measure the STEM Project Based Learning variable is 86.3%. The contribution of indicators guides students in setting the timeline, deadlines, and project assessment criteria (X16) to measure the STEM Project Based Learning variable by 85.4%. The contribution of indicators facilitates students to present project designs (X17) to measure the STEM Project Based Learning variable by 79.0%. The contribution of indicators guiding students when they make steps that are not in accordance with the project (X18) to measure the STEM Project Based Learning variable is 85.4%. the contribution of student monitoring indicators in the project making process (X19) to measure the STEM Project Based Learning variable is 88.2%. the contribution of the student assignment indicator to report the progress of the project that has been made (X110) to measure the STEM Project Based Learning variable is 78.8%. the contribution of indicators assessing student products adapted to mobile programming learning (X111) to measure the STEM Project Based Learning variable is 86.0%. the contribution of the student assignment indicator to report the progress of the project that has been made (X112) to measure the STEM Project Based Learning variable is 78.3%. The contribution of indicators assessing student products adapted to mobile programming learning (X113) to measure the STEM Project Based Learning variable is 85.1%.

The loading factor value of the perception indicator and given a concrete example of mobile device programming at the beginning of the introduction to learning (X11) is 0.905, as indicated in the table above. This means diversity of STEM Project Based Learnıng variables represented by perception indicators, with a concrete example of mobile device programming at the start of the introduction to learning (X11) at 90.5 %. In other words, the apperception indicator and a concrete example of mobile device programming at the start of the introduction to learning (X11) contribute 90.5 % to measuring the STEM Project Based Learnıng variable. This indicates that the indicator of evaluating student products adapted to mobile device programming learning (X11) is the most important indicator for measuring the STEM Project Based Learnıng variable. Additionally, Table 4 contains the indicators for measuring critical thinking variables.

Table 4.
Critical Thinking Loading Factor

Variable	Indicator	Loading Factor
Critical Thinking	understanding indicators when the teacher gives apperception (Y11)	0.925
	understanding indicator when the teacher explains the module material (Y12)	0.928
	understanding indicators when the teacher gives a video tutorial (Y13)	0.914
	student response indicators after the teacher gave the module material (Y14)	0.719
	student response indicators after the teacher gave the video tutorial material (Y15)	0.710
	explains individually how to get the results of the work given by the teacher (Y16)	0.767
	indicator to make conclusions based on the learning that has been given (Y17)	0.738
	indicator to recognize and explain the part of the problem given by the teacher (Y18)	0.755
	indicators to identify various solutions (Y19)	0.752

The contribution of understanding indicators when the teacher gives apperception (Y11) to measure critical thinking variables is 92.5%. the contribution of the understanding indicator when the teacher explains the module material (Y12) to measure the critical thinking variable is 92.8%. the contribution of understanding indicators when the teacher gives a video tutorial (Y13) to measure the critical thinking variable is 91.4%. the contribution of the student response indicators after the teacher gave the module material (Y14) to measure the critical thinking variable was 71.9%. the contribution of the student response indicators after the teacher gave the video tutorial material (Y15) to measure the critical thinking variable was 71.0%. contribution indicator explains individually how to get the results of the work given by the teacher (Y16) to measure the critical thinking variable by 76.7%. the contribution of the indicator to make conclusions based on the learning that has been given (Y17) to measure the critical thinking variable is 73.8%. the contribution of the indicator to recognize and explain the part of the problem given by the teacher (Y18) to measure the critical thinking variable is 75.5%. the contribution of indicators to identify various solutions (Y19) to measure critical thinking variables is 75.2%.

The value of the loading factor indicator of understanding when the teacher explains the module material (Y12) is 0.928. This means that the diversity of critical thinking variables can be represented by indicators of comprehension (Y12) of 92.8 percent when the teacher explains the module material. In other words, the understanding indicator contributes 92.8 percent to the measurement of critical thinking variables when the teacher explains the module material (Y12). Additionally, the critical thinking variable measurement model indicates that when the teacher explains the module material (Y12), the indicator of comprehension has the highest loading value of 0.928. This means that the indicator of comprehension when the teacher explains the module material (Y12) is the most influential indicator when it comes to assessing critical thinking variables. Additionally, Table 5 contains indicators for assessing collaboration variables.

Table 5.
Collaboration Loading Factor

Variable	Indicator	Loading Factor
Collaboration	responsibility and productivity indicators (Y21)	0.832
	responsive action indicator to the surrounding conditions (Y22)	0.810
	indicator of cooperation between friends (Y23)	0.852
	indicator of working productively (Y24)	0.796
	indicator showing respect between friends (Y25)	0.843

The contribution of responsibility and productivity indicators (Y21) to measure the collaboration variable is 83.2%. the contribution of the responsive action indicator to the surrounding conditions (Y22) to measure the collaboration variable is 81.0%. The contribution of the indicator of cooperation between friends (Y23) to measure the collaboration variable is 85.2%. The contribution of the indicator of working productively (Y24) to measure the collaboration variable is 79.6%. The contribution of the indicator showing respect between friends (Y25) to measure the collaboration variable is 84.3%.

Furthermore, the value of the loading factor indicator of the attitude of cooperation between classmates (Y23) is 0.852. This means that the diversity of collaboration variables can be represented by the indicator of cooperation between classmates (Y23) of 85.2%. In other words, the collaboration attitude indicator among friends (Y23) contributes 85.2 percent to the measurement of the collaboration variable. Additionally, the collaboration variable measurement model indicates that the indicator of cooperative attitude among classmates (Y23) has the highest loading value of 0.852. This means that the indicator of friend-to-friend cooperation (Y23) is the most influential indicator for assessing the collaboration variable. While Table 6 illustrates the indicators used to quantify communication variables.

Table 6.
Communication Loading Factor

Variable	Indicator	Loading Factor
Communication	indicators involved in conversation and discussion (Y31)	0.866
	indicator to deliver an oral presentation (Y32)	0.766
	indicators of communicating in various environments (Y33)	0.806
	Receptive communication indicators: listening, reading, seeing (Y34)	0.908
	indicators for differentiating the intent of speech (Y35)	0.721
	indicators using communication strategy (Y36)	0.811
	indicators to communicate clearly for a purpose (Y37)	0.740

The contribution of indicators involved in conversation and discussion (Y31) to measure the communication variable is 86.6%. The contribution of the indicator to deliver an oral presentation (Y32) to measure the communication variable is 76.6%. The contribution of indicators of communicating in various environments (Y33) to measure the communication variable is 80.6%. The contribution of receptive communication indicators: listening, reading, seeing (Y34) to measure the communication variable is 90.8%. The contribution of indicators for differentiating the intent of speech (Y35) to measure the communication variable is 72.1%. The contribution of indicators using communication strategy (Y36) to measure the communication variable is 81.1%. The contribution of indicators to communicate clearly for a purpose (Y37) to measure the communication variable is 74.0%.

Following that, the loading factor for the indicator of receptive communication, specifically listening, reading, and seeing (Y34), is 0.908. This means that the diversity of communication variables can be captured by 90.8 percent of receptive communication indicators, specifically listening, reading, and seeing (Y34). In other words, 90.8 percent of the communication variable is measured by receptive communication indicators such as listening, reading, and seeing (Y34). Additionally, the communication variable measurement model indicates that the indicators of receptive communication, specifically listening, reading, and seeing (Y34), have the highest loading value of 0.908. This means that indicators of receptive communication, specifically listening, reading, and seeing (Y34), are the most frequently used indicators when assessing communication variables. Additionally, Table 7 contains the indicators for measuring variables associated with creative thinking.

Table 7.
Creative Thinking Loading Factor

Variable	Indicator	Loading Factor
Creative Thinking	indicators for designing initial mobile-based programming project ideas (Y41)	0.852
	indicators for designing a mobile-based programming final project (Y42)	0.794
	indicators to develop mobile applications (Y43)	0.795
	of indicators of openness and courage to explore problems (Y44)	0.781
	the indicator having curiosity (Y45)	0.770
	the fluency indicator (Y46)	0.852
	elaboration indicator (Y47)	0.835
	the flexibility indicator (Y48)	0.833
	divergent indicator (Y49)	0.832
	risk-taking indicator (Y410)	0.843
	relationship indicator with other indicators (Y411)	0.699

The contribution of indicators for designing initial mobile-based programming project ideas (Y41) to measure creative variables is 85.2%. The contribution of indicators for designing a mobile-based programming final project (Y42) to measure creative variables is 79.4%. The contribution of indicators to develop mobile applications (Y43) to measure creative variables is 79.5%. The contribution of indicators of openness and courage to explore problems (Y44) to measure creative variables is 78.1%. The contribution of the indicator having curiosity (Y45) to measure the creative variable is 77.0%. The contribution of the fluency indicator (Y46) to measure the creative variable is 85.2%. The contribution of the elaboration indicator (Y47) to measure the creative variable is 83.5%. The contribution of the flexibility indicator (Y48) to measure creative variables is 83.3%. The contribution of the divergent indicator (Y49) to measure the creative variable is 83.2%. The contribution of the risk-taking indicator (Y410) to measure the creative variable is 84.3%. The contribution of the relationship indicator with other indicators (Y411) to measure the creative variable is 69.9%.

The loading factor indicator value for designing the initial mobile-based programming project idea (Y41) is 0.852, as determined by the measurement model above. This means that the indicator of designing an initial mobile-based programming project idea (Y41) of 85.2 percent reflects the diversity of creative variables. In other words, indicators for developing initial mobile-based programming project ideas (Y41) contribute 85.2 percent to the measurement of creative variables. Additionally, the fluency indicator (Y46) has a loading factor of 0.852. This means that the fluency indicator (Y46) of 85.2 percent can be used to represent the diversity of creative variables. In other words, the fluency indicator (Y46) contributes 85.2 percent to the measurement of creative variables. Additionally, the model for measuring creative variables indicates that the indicator for developing an initial project idea for mobile-based programming (Y41) and the fluency indicator (Y46) have the highest loading values of 0.852. This means that the indicator for developing initial project ideas for mobile-based programming (Y41) and fluency (Y46) are the most influential indicators when it comes to assessing creative variables.

Essentially, the feasibility test of ascertain whether the developed SEM model is appropriate, the SEM model is used. In SEM analysis, several test indices are used, including the probability of the Chi Square test (CMIN), Root mean square residual (RMR), Goodness-of-fit statistic (GFI), The Minimmum sampel discrepancy function (CMIN/DF), adjusted goodness-of-fit statistic (AGFI), Tucker–Lewis index (TLI), CFI (Comparative fit index), and Root mean square error of approximation (RMSEA). The chi-square test criteria (CMIN) explains that if the chi-square level of significance's probability value (alpha) is greater than zero, the SEM model is declared feasible. According to the CMIN/DF criteria, if CMIN/DF equals 2, the SEM model formed is declared feasible. According to the GFI and AGFI criteria, if the goodness of fit value is greater than 0.90, the SEM model is declared feasible. According to the TLI and CFI criteria, a SEM model is declared feasible if the goodness of fit value is greater than 0.95.(Xia & Yang, 2019). And according to the RMR criteria, if the goodness of fit value is less than 0.05, the SEM model is declared feasible. According to the RMSEA criteria, if the RMSEA value is less than 0.08, the SEM model formed is declared feasible (Kakemam et al., 2022). Table 8 summarizes the results of the feasibility test of the SEM model.

Table 8.
SEM Model Feasibility Testing

Index	Goodness of Fit	Criteria	Remark
Chi Square	3923.762 (p value = 0.000)	p value > alpha 5%	Unfit
CMIN/DF	4.170	≤ 2.00	Unfit
CFI	0.777	≥ 0.95	Unfit
TLI	0.766	≥ 0.95	Unfit
RMSEA	0.106	≤ 0.08	Unfit
RMR	0.041	≤ 0.05	Fit
GFI	0.654	≥ 0.9	Unfit
AGFI	0.620	≥ 0.9	Unfit

According to Table 8 all have criteria that do not match their cut off values, indicating that the eight indexes are not met (Awang et al., 2015). As a result, the constructed entity is deemed inappropriate (feasible). Thus, the model is modified by establishing a symmetrical relationship between variables and variables, variables and error variables, and error variables and error variables, all in accordance with the modification index's guidance. Table 9 summarizes the results of the feasibility test of the SEM model following model modification.

Table 9.
Model Feasibility Test After Model Modification

Index	Goodness of Fit	Criteria	Remark
Chi Square	540.936 (p value = 1.000)	p value > alpha 5%	Fit
CMIN/DF	0.727	≤ 2.00	Fit
CFI	1.000	≥ 0.95	Fit
TLI	1.020	≥ 0.95	Fit
RMSEA	0.000	≤ 0.08	Fit
RMR	0.023	≤ 0.05	Fit
GFI	0.925	≥ 0.9	Fit
AGFI	0.896	≥ 0.9	Marginal Fit

According to Table 9 indices all have criteria that match their cut off values, making the seven indices eligible. Meanwhile, the AGFI index is marginally fit. The following figure illustrates the connection between STEM Project based learning, critical thinking, collaboration, creativity, and communication of relational models and hypotheses.

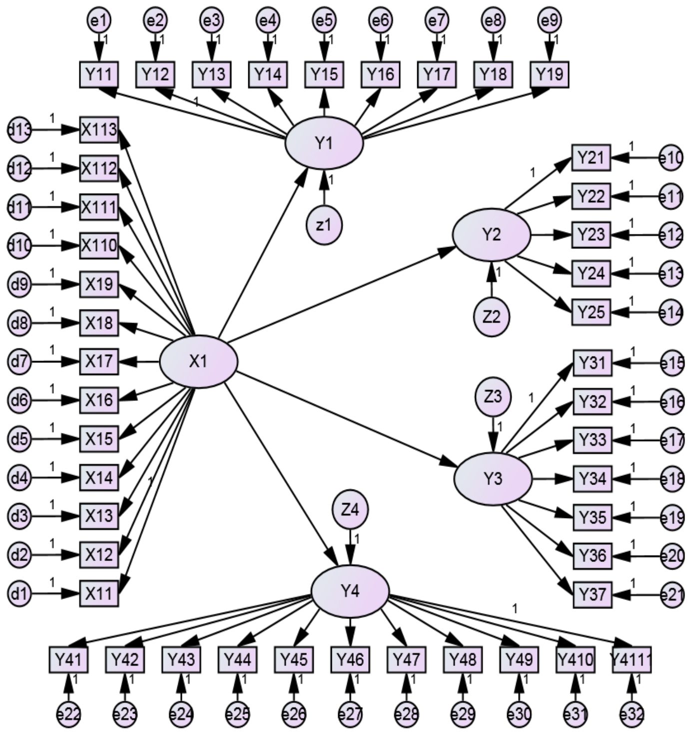

Figure 2. Relationship Between STEM Project Based Learning, Critical Thinking, Collaboration, Creativity, and Communication Relational Models and Hypotheses

The hypothesis testing of the effect of STEM Project based learning on four critical thinking skills, collaboration, communication, and creativity indicate that only communication skills obtained a p-value of 0.347, which is not significant because the p-value should be greater than the level of significance (alpha () = 5%). As a result, the null hypothesis for the endogenous variable Communication was not significantly rejected, implying that communication has no effect on the STEM Project based learning model. The analysis's findings in Table 10.

Table 10.
The Results of Effect Analysis

Exogenous	Endogenous	P	Path Coefficient
STEM Project based learning	Critical Thinking	0.010	0.158*
	Collaboration	0.016	0.151*
	Communication	0.347	0.059
	Creativity	***	0.344*

PjBL and STEM have a direct effect coefficient of 0.059 on communication skills, indicating that they have a positive but insignificant effect on communication skills. This means that the more effective PjBL and STEM are, the more likely communication skills will be improved. Although the increase is insignificant.

4. DISCUSSION AND RECOMMENDATIONS

Students learn to tackle real-world challenges and collaborate well through STEM project-based learning (Mutambara & Bayaga, 2021). The data analysis results indicate a relationship between the STEM PjBL model and problem solving or critical thinking, implying that the STEM PjBL model has an effect on the critical thinking and problem-solving skills of Software Engineering Vocational High School students in East Java. The research findings indicate that the STEM Project Based Learning model improves problem solving abilities or critical thinking students, indicating to educators STEM Project Based Learnıng may help students build strong grasp of the material being taught. Additionally, students can analyze the difficulties inherent in learning. Then students are able to propose solutions to problems and defend them with supporting and reinforcing arguments. This is in accordance with the claim that effective STEM project based learnıng can enhance abilities (Zhang et al., 2016). The descriptive analysis of the data on developing critical thinking skills revealed that students' abilities at all levels were classified as high or medium. These findings demonstrate the application STEM Project Based Learning can assist students in developing their abilities to comprehend material concepts, rather than simply memorize them. Thus, students can develop their own knowledge in order to solve problems and seek out alternative solutions (Lecorchick et al., 2020). STEM applications are integrated into scientific learning in order to provide chances for students to put their knowledge to finish issues as a method of problem solving. STEM in its entirety enables students to acquire knowledge and critical thinking skills. Each of these facets enables students to approach problems in a much more comprehensive manner.

STEM Project Based Learning plays an important role in the advancement of community economy, agriculture, technology, and national security (Egarievwe, 2015). The STEM Project Based Learning program prepares the next generation of learners, technologists, mathematicians and engineers to meet real-world requirements of the 21st century. Basically, Through productivity, social change and innovation in the global economy. Future leaders will come from the younger generation to capable of managing people and allocating limited global resources (McGunagle & Zizka, 2018). (Dasgupta et al., 2019) Engineering design, scientific research, mathematical inference, and technological aptitude are typically involved in project design activities, which can be considered cross-disciplinary projects. By incorporating engineering design into K-12 classrooms, recommend problem placement techniques by “posing authentic problems” and giving access to “authentic practices”(Strobel et al., 2013) and can train students to be able to complete complex projects (Chiu et al., 2013). The step in preparing STEM Project Based Learning students to be capable of becoming potential agents of change is to learn to put the three pillars' theoretical knowledge: economics, environment, and society into practice. (Zizka et al., 2021).

The findings indicated a correlation between STEM Project Based Learning and 21st Century Learning and Innovation Skills, but communication skills were less effective in STEM Project Based Learning learning due to a variety of influencing factors. One of the reasons for students' lack of communication skills is their fear of approaching the teacher (Bray et al., 2020). Thus, students are more likely to seek answers from alternative sources such as textbooks when they do not understand a concept and do not feel comfortable asking the teacher (Harris & Hua, 2015). To improve communication skills, the Vocational High School must provide increased motivation to students in order for communication skills to be acquired properly (Placklé et al., 2018). Collaboration between students and teachers is another way to improve communication skills. The interaction that occurs will result in active learning, in which students will attempt to acquire their own knowledge through the use of their communication skills with the assistance of the teacher, who will act as a facilitator (Alfarah, 2013). As a result, teachers must be able to develop their abilities and skills in order to effectively teach and learn (Van Nuland et al., 2010). Essentially, the existence of STEM project based learnıng enables students to be invited to take part meaningful learning in order to comprehend a concept. Students are invited to investigate through a project activity, which engages them in the process. This enhances students' capacity for communication, critical thinking, and build higher order thinking skills (Eltanahy et al., 2020). Essentially, STEM Project Based Learning teaches how to explain image of an event that enables a person to communicate, classify ideas, and generate ideas from an image or event that occurs. STEM Project Based Learnıng also provide challenges and motivation for students, as they enable students to develop effective communication skills, enabling them to effectively absorb all of the information conveyed by the teacher (Breiner et al., 2012)(Gale et al., 2020).

(Mutambara & Bayaga, 2021) says STEM Project Based Learning aims to teach students how to collaborate and solve real-world problems. Findings (Ismayani, 2016) that STEM-PjBL learning is successful at enhancing students' critical-thinking abilities. Opinion (Afriana et al., 2016) states that the application of STEM which is integrated with learning with a scientific approach can provide opportunities for students to apply knowledge to issues/problems as a form of problem solving. In line with the opinion(Sumarni et al., 2019) which says that every aspect of STEM equips students in gaining knowledge and critical thinking skills. Each of these aspects helps students solve problems much more comprehensively. (Johansson, 2018) demonstrates that students' critical thinking skills are still lacking, even if teachers try to hone critical thinking skills at school, the results are even worse than before. (Kristensson, 2018) Explains the importance of teaching students to think critically in the classroom to improve their study skills and general knowledge.(Gupta & Ahmad, 2018) argue that critical thinking is an ability that aims to provide training to apply learning strategies that are applied in the classroom. This illustrates that weak critical thinking skills are not only owned by Indonesian students, so that further investigation is needed with the correct critical thinking skills indicators.

The findings (Capraro & Slough, 2013b) (Isaacson et al., 2020) say that The most important tool for achieving a goal or desire is effective communication. The findings (Suranti et al., 2017) which says that STEM-based PjBL makes students master the concept of explaining the picture of an event that makes a person with the capacity to communicate, organize thoughts, derive ideas from images, or explain events. In opinion (Sularmi et al., 2018) which states that STEM-based PjBL also provides challenges and motivation for students, because it is able to train students to communicate well so that they can capture all the information conveyed by the teacher.

Subsequent analysis demonstrates that STEM Project Based Learning model influences collaboration abilities. This means that STEM Project Based Learning model influences students collaboration ability in Software Engineering Skills Vocational Schools in East Java. The research demonstrates that learning the STEM Project Based Learning model can help students develop responsibility and the ability to work in teams. Additionally, students are able to work productively and with a strong work ethic in the workplace. This is reinforced by the statement that the PJBL learning model stresses contextual learning through challenging tasks including letting students organize lessons, work together on projects, and eventually produce something (Saiden, 2017).

Essentially, creative thinking is another factor affecting STEM Project Based Learnıng, referring of abilities and soft skills generate novel solutions to existing problems (Belbase et al., 2021). Creative thinking skills are techniques for approaching problems in novel and creative ways, assessing them with appropriate tools, and developing plans. Student effectiveness levels can be measured by students' design ideas, creative production, openness and courage to explore problems, curiosity about mobile programming knowledge, fluency, elaboration, flexibility, divergent thinking, risk taking, and relationships with others, with students being the most creative when collaborating with others. The findings indicated a connection between the STEM Project Based Learning model and creative abilities. STEM Project Based Learning model influences creative ability in Software Engineering Skills Vocational Schools in East Java. The STEM Project Based Learning model help to build innovative problem solving strategies. Additionally, students demonstrate the courage to propose solutions to a problem. Overall, the STEM Project Based Learning model has a number of advantages. Student activity in project-based learning is tailored to the 21st century's challenges. Thus, STEM Project Based Learnıng learning help to develop their creative thinking abilities. Understanding such concepts enables students to develop the ability to converse online and generate new and unique ideas (Gale et al., 2020).

The findings (Jauhariyyah et al., 2017) say PjBL is emphasized on complex activities like providing opportunities for students explore learning activity plans, completing collaborative projects, and good creating products. The perception serves to support this. (Lutfi et al., 2017) which also states that implementing the Project Based Learning STEM learning model has an effect on increasing collaboration skills and student creativity. This is consistent with the assumption (Doski Yance et al., 2013) which states that the application of the PjBL learning model has a major effect on the ability to collaborate and student learning outcomes both from the cognitive, affective, and psychomotor aspects. (Tang et al., 2020) claimed that creative thinking is the process of coming up with new ideas and employing soft talents to solve any difficulties that may be there. Creative thinking involves a variety of techniques for approaching issues in novel ways and developing innovative solutions. This is reinforced by the opinion (Nur, 2017) hich says that STEM Project Based Learning help to improve their creative thinking skills. Learning concepts like this can allow students to learn to discuss online and come up with new and original ideas. in line with the opinion (Riyanti, 2020) who said that the e-learning-based STEM Project Based Learning tool may improve students' creative thinking skills.

Recommendation

On the basis of the research findings, the following recommendations are made. In order to effectively implement the STEM Project Based Learningmodel, all teachers must constantly encourage students to enhance their communication abilities by inviting them to communicate both in and out of the classroom, thereby establishing a positive relationship between students and teachers and ensuring that students' ability to communicate has been ingrained since elementary school. Along with teachers, school principals must assist students in improving their communication skills by hosting seminars or workshops on effective communication.

The findings of this study indicate that the influence of the STEM Project Based Learning model on communication skills is in the poor category. Researchers hope that with results like this, productive, adaptive, and normative teachers must always provide examples and practices of how to communicate well directly or using electronic media. In addition, teachers must make learning plans and tools that support STEM project based learning tailored to the characteristics of their students so that their academic abilities also increase and have an impact on the future after graduation. Researchers hope for further research, there are other learning models that have not been studied, for example PjBL with the STEAM approach. Point A here is art, so the researcher recommends the next researcher to compare the model that has been studied by the researcher with other learning methods on the ability 21st Century Learning and Innovation Skills student.

Research and Publication Ethics Statement

Researchers observe all ethical principles and rules in data collection, analysis and reporting.

Contribution Rates of Authors to the Article

The author contributed to the creation of this article. This research study resulted from a doctoral dissertation, which was defended by the first author at Universitas Negeri Malang, under the supervision of the second, third, and fourth authors. So that all authors contribute in the preparation to the creation of the article.

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5. REFERENCES

Afriana, J., Permanasari, A., & Fitriani, A. (2016). Penerapan project based learning terintegrasi STEM untuk meningkatkan literasi sains siswa ditinjau dari gender. *Jurnal Inovasi Pendidikan IPA*, *2*(2), 202. https://doi.org/10.21831/jipi.v2i2.8561

Alcantara, E. C., Marie, J., & Bacsa, P. (2017). Critical Thinking and Problem Solving Skills in Mathematics of Grade-7 Public Secondary Students. *Asia Pacific Journal of Multidisciplinary Research*, *5*(4).

Alfarah, Y. F. (2013). Communication Skills among Gifted Students in Jordan. *Gifted and Talented International*, *28*(1–2), 255–262. https://doi.org/10.1080/15332276.2013.11678420

Awang, Z., Afthanorhan, W. M. A. W., & Asri, M. A. M. (2015). Parametric and Non Parametric Approach in Structural Equation Modeling (SEM): The Application of Bootstrapping. *Modern Applied Science*, *9*(9), p58. https://doi.org/10.5539/MAS.V9N9P58

Becker, K., & Park, K. (2011). Effects of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A preliminary meta-analysis. In *Journal of STEM Education* (Vol. 12, Issue 5). https://www.jstem.org/jstem/index.php/JSTEM/article/view/1509

Belbase, S., Mainali, B. R., Kasemsukpipat, W., Tairab, H., Gochoo, M., & Jarrah, A. (2021). At the dawn of science, technology, engineering, arts, and mathematics (STEAM) education: prospects, priorities, processes, and problems. *International Journal of Mathematical Education in Science and Technology*. https://doi.org/10.1080/0020739X.2021.1922943

Blinova, T., Bylina, S., & Rusanovskiy, V. (2015). Vocational Education in the System of Determinants of Reducing Youth Unemployment: Interregional Comparisons. *Procedia - Social and Behavioral Sciences*, *214*, 526–534. https://doi.org/10.1016/j.sbspro.2015.11.756

Bray, A., Byrne, P., & O'Kelly, M. (2020). A Short Instrument for Measuring Students' Confidence with 'Key Skills'' (SICKS): Development, Validation and Initial Results.' *Thinking Skills and Creativity*, *37*, 100700. https://doi.org/10.1016/j.tsc.2020.100700

Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, C. M. (2012). What Is STEM? A Discussion About Conceptions of STEM in Education and Partnerships. *School Science and Mathematics*, *112*(1), 3–11. https://doi.org/10.1111/j.1949-8594.2011.00109.x

Burkholder, E., Hwang, L., & Wieman, C. (2021). Evaluating the problem-solving skills of graduating chemical engineering students. *Education for Chemical Engineers*, *34*, 68–77. https://doi.org/10.1016/j.ece.2020.11.006

Capraro, R. M., & Slough, S. W. (2013a). Why PBL? why STEM? why now? an introduction to STEM project-based learning: An integrated science, technology, engineering, and mathematics (STEM) approach. In *STEM Project-Based Learning an Integrated Science, Technology, Engineering, and Mathematics (STEM) Approach* (pp. 1–5). Sense Publishers. https://doi.org/10.1007/978-94-6209-143-6_1

Capraro, R. M., & Slough, Scott. W. (2013b). Why PBL? Why STEM? Why now? an Introduction to STEM Project-Based Learning. In *STEM Project-Based Learning* (pp. 1–5). SensePublishers. https://doi.org/10.1007/978-94-6209-143-6_1

Chiu, J. L., Malcolm, P. T., Hecht, D., DeJaegher, C. J., Pan, E. A., Bradley, M., & Burghardt, M. D. (2013). WISEngineering: Supporting precollege engineering design and mathematical understanding. *Computers & Education*, *67*, 142–155. https://doi.org/10.1016/j.compedu.2013.03.009

Chu, S. K. W., Tse, S. K., & Chow, K. (2011). Using collaborative teaching and inquiry project-based learning to help primary school students develop information literacy and information skills. *Library and Information Science Research*, *33*(2), 132–143. https://doi.org/10.1016/j.lisr.2010.07.017

Cocota, J. A. N., D'Angelo, T., & De Barros Monteiro, P. M. (2015). A Project-Based Learning Experience in the Teaching of Robotics. *Revista Iberoamericana de Tecnologias Del Aprendizaje*, *10*(4), 302–309. https://doi.org/10.1109/RITA.2015.2486458

Dasgupta, C., Magana, A. J., & Vieira, C. (2019). Investigating the affordances of a CAD enabled learning environment for promoting integrated STEM learning. *Computers & Education*, *129*, 122–142. https://doi.org/10.1016/j.compedu.2018.10.014

Deejring, K. (2017). Knowledge management model to develop creative thinking for higher education with project based learning. *Turkish Online Journal of Educational Technology*, *2017*(November Special Issue INTE).

Donnelly, R. (2010). Interaction analysis in a "Learning by Doing" problem-based professional development context. *Computers and Education*, *55*(3), 1357–1366. https://doi.org/10.1016/j.compedu.2010.06.010

Doski Yance, R., Ramli, E., & Fatni Mufit, dan. (2013). Pengaruh Penerapan Model Project Based Learnıng (Pbl) Terhadap Hasıl Belajar Fısıka Sıswa Kelas Xı Ipa Sma Negerı 1 Batıpuh Kabupaten Tanah Datar. *Pıllar Of Physıcs Educatıon*, *1*(1), 48–54. https://doi.org/10.24036/490171074

Egarievwe, S. U. (2015). Vertical Education Enhancement – A Model for Enhancing STEM Education and Research. *Procedia - Social and Behavioral Sciences*, *177*, 336–344. https://doi.org/10.1016/j.sbspro.2015.02.354

Eltanahy, M., Forawi, S., & Mansour, N. (2020). Incorporating Entrepreneurial Practices into STEM Education: Development of Interdisciplinary E-STEM Model in High School in the United Arab Emirates. *Thinking Skills and Creativity*, *37*, 100697. https://doi.org/10.1016/j.tsc.2020.100697

Fayomi, O. O., Fayomi, O. S. I., Atiba, O. E., & Ayuba, A. U. (2019). Failure of the 21st century researchers in solving national economic menace: A necessity. *Energy Procedia*, *157*, 428–434. https://doi.org/10.1016/j.egypro.2018.11.207

Gale, J., Alemdar, M., Lingle, J., & Newton, S. (2020). Exploring critical components of an integrated STEM curriculum: an application of the innovation implementation framework. *International Journal of STEM Education*, *7*(1), 1–17. https://doi.org/10.1186/s40594-020-0204-1

Gupta, S., & Ahmad, I. (2018). Strategies to promote critical thinking in learners. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*.

Gustiani, I. (2017). Development and validation of science, technology, engineering and mathematics (STEM) based instructional material. In *AIP Conference Proceedings* (Vol. 1848). https://doi.org/10.1063/1.4983969

Guzmán, E., García, I., Guerrero, E., & Pacheco, C. (2016). A tool for supporting the design of DC-DC converters through FPGA-based experiments. *IEEE Latin America Transactions*, *14*(1), 289–296. https://doi.org/10.1109/TLA.2016.7430091

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

Harris, A., & Hua, Z. (2015). Communication is key: A study of the development of communication key skills in China. *English in Education*, *49*(2), 167–187. https://doi.org/10.1111/eie.12069

Isaacson, S., Friedlander, L., Meged, C., Havivi, S., Cohen-Zada, A. L., Ronay, I., Blumberg, D. G., & Maman, S. (2020). She Space: A multi-disciplinary, project-based learning program for high school girls. *Acta Astronautica*, *168*, 155–163. https://doi.org/10.1016/j.actaastro.2019.12.005

Ismayani, A. (2016). Pengaruh Penerapan Stem Project-Based Learnıng Terhadap Kreatıvıtas Matematıs Sıswa Smk. *Indonesian Digital Journal of Mathematics and Education*, *3*. http://idealmathedu.p4tkmatematika.org

Jauhariyyah, F. R., Suwono, H., & Ibrohim. (2017). Science, Technology, Engineering and Mathematics Project Based Learning (STEM-PjBL) pada Pembelajaran Sains. *Prosiding Seminar Pendidikan IPA Pascasarjana UM*, *2*.

Johansson, M. (2018). *Argue for Criticality The Potential of Argumentation and Critical Thinking in the English Subject in Swedish Upper-Secondary School*. http://urn.kb.se/resolve?urn=urn:nbn:se:oru:diva-68822

John, S. (2015). *10 Hallmarks of 21st Century Teaching and Learning | Edutopia*. https://www.edutopia.org/discussion/10-hallmarks-21st-century-teaching-and-learning

Kakemam, E., Navvabi, E., Albelbeisi, A. H., Saeedikia, F., Rouhi, A., & Majidi, S. (2022). Psychometric properties of the Persian version of Depression Anxiety Stress Scale-21 Items (DASS-21) in a sample of health professionals: a cross-sectional study. *BMC Health Services Research*, *22*(1), 1–9. https://doi.org/10.1186/S12913-022-07514-4/TABLES/5

Kristensson, M. (2018). *Critical Thinking in the Classroom Using Fiction and the Topic of Global Warming to Develop Critical Thinking Skills*.

Kulprasutidilok, A. (2015). *Project-based Learning in Home Health Care of First Aids, Home Health Care Emergency System for Technology of Health Management Students Level 2*.

Lecorchick, D., Papadopoulos, J., & Tabor, L. (2020). Engineering education through an international collaboration: A framework. *Procedia Computer Science*, *172*, 838–842. https://doi.org/10.1016/j.procs.2020.05.120

Lin, J. W., & Tsai, C. W. (2016). The impact of an online project-based learning environment with group awareness support on students with different self-regulation levels: An extended-period experiment. *Computers and Education*, *99*, 28–38. https://doi.org/10.1016/j.compedu.2016.04.005

Lou, S. J., Chou, Y. C., Shih, R. C., & Chung, C. C. (2017). A study of creativity in CaC 2 steamship-derived STEM project-based learning. *Eurasia Journal of Mathematics, Science and Technology Education*, *13*(6). https://doi.org/10.12973/EURASIA.2017.01231A

Lubis, T. (2015). *Penerapan Strategi Penugasan Proyek untuk Mengetahui Peningkatan Penguasaan Konsep dan Profil Kemampuan Berpikir Kreatif Siswa SMP*.

Lucie, R. (2017). *What is project-based learning? 15 PBL ideas fit for your classroom - BookWidgets*. https://www.bookwidgets.com/blog/2017/06/what-is-project-based-learning-15-pbl-ideas-fit-for-your-classroom

Lutfi, Ismail, & Azis, A. A. (2017). Pengaruh Project Based Learning Terintegrasi Stem Terhadap Literasi Sains , Kreativitas dan Hasil Belajar Peserta Didik. *Prosiding Seminar Nasioanal Biologi Dan Pembelajarannya*.

Mangala, S., & Rani, E. (2010). Need and Importance of Soft Skills in Students. *Journal of Literature, Culture and Media Studies*, *2*(3).

Marsono, Bella Cornelia Tjiptady, Y. (2021). Model For Development Of Students 'Capability In Industry Practices In Era 4.0. *Psychology and Education Journal*, *58*(1), 3268–3275. https://doi.org/10.17762/pae.v58i1.1266

Mawaddah, S., & Anisah, H. (2015). Kemampuan Pemecahan Masalah Matematis Siswa pada Pembelajaran Matematika dengan Menggunakan Model Pembelajaran Generatif (Generative Learning) di SMP. *EDU-MAT: Jurnal Pendidikan Matematika*, *3*(2), 166–175. https://doi.org/10.20527/EDUMAT.V3I2.644

McGunagle, D., & Zizka, L. (2018). Meeting Real World Demands of the Global Economy: An Employer's Perspective. *Journal of Aviation/Aerospace Education & Research*, *27*. https://doi.org/10.15394/jaaer.2018.1738

Musa, F., Mufti, N., Latiff, R. A., & Amin, M. M. (2012). Project-based Learning (PjBL): Inculcating Soft Skills in 21st Century Workplace. *Procedia - Social and Behavioral Sciences*, *59*, 565–573. https://doi.org/10.1016/j.sbspro.2012.09.315

Mutambara, D., & Bayaga, A. (2021). Determinants of mobile learning acceptance for STEM education in rural areas. *Computers and Education*, *160*, 104010. https://doi.org/10.1016/j.compedu.2020.104010

noviana, ayu. (2019). *Pengembangan Perangkat Penılaıan Keterampılan Kolaborası Dan Komunıkası Berbasıs Project Based Learnıng. (Tesis) Oleh Ayu Noviana - PDF Download Gratis*. https://docplayer.info/183456947-Pengembangan-perangkat-penilaian-keterampilan-kolaborasi-dan-komunikasi-berbasis-project-based-learning-tesis-oleh-ayu-noviana.html

Nur, M. D. M. (2017). Pengaruh strategi pembelajaran fisika berbasis website terhadap hasil belajar pada siswa yang memiliki self- regulated learning (srl) yang berbeda. *Edcomtech Jurnal Kajian Teknologi Pendidikan*, *2*(1).

OECD. (2021). *OECD iLibrary | Science performance (PISA)*. https://www.oecd-ilibrary.org/education/science-performance-pisa/indicator/english_91952204-en

Osman, K., & Marimuthu, N. (2010). Setting new learning targets for the 21st century science education in Malaysia. *Procedia - Social and Behavioral Sciences*, *2*(2), 3737–3741. https://doi.org/10.1016/j.sbspro.2010.03.581

Parrado-Martínez, P., & Sánchez-Andújar, S. (2020). Development of competences in postgraduate studies of finance: A project-based learning (PBL) case study. *International Review of Economics Education*, *35*, 100192. https://doi.org/10.1016/j.iree.2020.100192

Placklé, I., Könings, K. D., Jacquet, W., Libotton, A., van Merriënboer, J. J. G., & Engels, N. (2018). Students embracing change towards more powerful learning environments in vocational education. *Educational Studies*, *44*(1), 26–44. https://doi.org/10.1080/03055698.2017.1331840

Polat, Ö., & Aydın, E. (2020). The effect of mind mapping on young children's critical thinking skills. *Thinking Skills and Creativity*, *38*, 100743. https://doi.org/10.1016/j.tsc.2020.100743

Prakoso, A. S., & Suwarma, I. R. (2016). *Profil Keterampilan Berpikir Kreatif Siswa pada Pembelajaran IPA Berbasis STEM*.

Rayna, T., & Striukova, L. (2021). Fostering skills for the 21st century: The role of Fab labs and makerspaces. *Technological Forecasting and Social Change*, *164*. https://doi.org/10.1016/j.techfore.2020.120391

Riyanti, R. (2020). Efektivitas Penggunaan Perangkat Pembelajaran Project Based Learning (PjBL) Terintegrasi STEM Berbasis E-Learning Untuk meningkatkan Kemampuan Berpikir Kreatif. *DWIJA CENDEKIA: Jurnal Riset Pedagogik*, *4*(2), 206. https://doi.org/10.20961/jdc.v4i2.45276

Saiden, T. (2017). Towards An Entrepreneurship And Stem Education Primary School Curriculum In Zimbabwe: A Case Study Of Bumburwi Of Gweru District. *Advances in Social Sciences Research Journal*, *4*(18), 148–159. https://doi.org/10.14738/assrj.418.3723

Strobel, J., Wang, J., Weber, N. R., & Dyehouse, M. (2013). The role of authenticity in design-based learning environments: The case of engineering education. *Computers & Education*, *64*, 143–152. https://doi.org/10.1016/j.compedu.2012.11.026

Subali, B., & Mariyam, S. (2013). Pengembangan Kreatıvıtas Keterampılan Proses Saıns Dalam Aspek Kehıdupan Organısme Pada Mata Pelajaran Ipa Sd. *Jurnal Cakrawala Pendidikan*, *3*(3). https://doi.org/10.21831/cp.v3i3.1625

Sularmi, Utomo, D. H., & Ruja, I. N. (2018). Pengaruh project-based learning terhadap kemampuan berpikir kritis. *Jurnal Pendidikan: Teori, Penelitian, Dan Pengembangan*, *3*(4).

Sumarni, W., Wijayati, N., & Supanti, S. (2019). Kemampuan Kognıtıf Dan Berpıkır Kreatıf Sıswa Melaluı Pembelajaran Berbasıs Proyek Berpendekatan STEM. *J-PEK (Jurnal Pembelajaran Kimia)*, *4*(1), 18–30. https://doi.org/10.17977/um026v4i12019p018

Suranti, N. M. Y., Gunawan, G., & Sahidu, H. (2017). Pengaruh Model Project Based Learning Berbantuan Media Virtual Terhadap Penguasaan Konsep Peserta didik pada Materi Alat-alat Optik. *Jurnal Pendidikan Fisika dan Teknologi*, *2*(2), 73. https://doi.org/10.29303/jpft.v2i2.292

Tang, T., Vezzani, V., & Eriksson, V. (2020). Developing critical thinking, collective creativity skills and problem solving through playful design jams. *Thinking Skills and Creativity*, *37*, 100696. https://doi.org/10.1016/j.tsc.2020.100696

Tseng, K. H., Chang, C. C., Lou, S. J., & Chen, W. P. (2013). Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment. *International Journal of Technology and Design Education*, *23*(1). https://doi.org/10.1007/s10798-011-9160-x

Utami, I. S., Septiyanto, R. F., Wibowo, F. C., & Suryana, A. (2017). Pengembangan STEM-A (Science, Technology, Engineering, Mathematic and Animation) Berbasis Kearifan Lokal dalam Pembelajaran Fisika. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *6*(1), 67–73. https://doi.org/10.24042/jpifalbiruni.v6i1.1581

Van Nuland, M., Thijs, G., Van Royen, P., Van den Noortgate, W., & Goedhuys, J. (2010). Vocational trainees' views and experiences regarding the learning and teaching of communication skills in general practice. *Patient Education and Counseling*, *78*(1), 65–71. https://doi.org/10.1016/j.pec.2009.05.002

Widodo, S., & Kartikasari, K. (2017). Pembelajaran Pemecahan Masalah Matematıs Sıswa Sekolah Dasar Dengan Model Creative Problem Solvıng (Cps). *PRISMA*, *6*(1), 57–65. https://doi.org/10.35194/JP.V6I1.28

Windari, F. (2014). Meningkatkan Kemampuan Pemecahan Masalah Matematika Siswa Kelas VII SMPN 8 Padang Tahun Pelajaran 2013/2014 dengan Menggunakan Strategi Pembelajaran Inkuiri. *Jurnal Pendidikan Matematika*, *3*(2).

Xia, Y., & Yang, Y. (2019). RMSEA, CFI, and TLI in structural equation modeling with ordered categorical data: The story they tell depends on the estimation methods. *Behavior Research Methods*, *51*(1). https://doi.org/10.3758/s13428-018-1055-2

Yusri, A. Y. (2018). Pengaruh Model Pembelajaran Problem Based Learnıng Terhadap Kemampuan Pemecahan Masalah Matematıka Sıswa Kelas Vıı Dı Smp Negerı Pangkajene. *Mosharafa: Jurnal Pendidikan Matematika*, *7*(1), 51–62. https://doi.org/10.31980/mosharafa.v7i1.341

Zhang, Z., Hansen, C. T., & Andersen, M. A. E. (2016). Teaching Power Electronics with a Design-Oriented, Project-Based Learning Method at the Technical University of Denmark. *IEEE Transactions on Education*, *59*(1), 32–38. https://doi.org/10.1109/TE.2015.2426674

Zizka, L., McGunagle, D. M., & Clark, P. J. (2021). Sustainability in science, technology, engineering and mathematics (STEM) programs: Authentic engagement through a community-based approach. *Journal of Cleaner Production*, *279*, 123715. https://doi.org/10.1016/j.jclepro.2020.123715