Enhancing physics students’ creative thinking skills using CBL model implemented in STEM in vocational school

N Putri, D Rusdiana, and I R Suwarma
Departemen Pendidikan Fisika, Universitas Pendidikan Indonesia, Jl. Dr.Setiabudi No. 229, Bandung 40154, Indonesia
*Corresponding author’s email: novianaputri@gmail.com

Abstract. The main goal of this study is to present examples and results of the implementation of the Challenge Based Learning (CBL) model implemented STEM education in Indonesia. This study integrates the steps of the CBL model and the dimensions of STEM education. The research method used in this study is a quantitative method with a type of quasi-experimental research design. The research subjects consisted of 23 first-grade students’ in vocational schools. The instrument used in this study is an essay test consisting of 4 questions creative thinking skills with indicators according to Torrance namely fluency, flexibility and originality. Data was analyzed using normalized gain values, Shapiro-Wilk Test, non-parametric and Cohen tests with SPSS 20.00 at a significant level of 0.05. As a result of the study, it was found that there were differences in students' creative thinking skills after being treated by the CBL model which was implemented with STEM education. The level of achievement of students’ creative thinking skills in the post-test is higher than the pre-test. This research shows that the application of the CBL model implemented STEM education is effective in enhancing creative thinking skills and in the most significant order in improving indicators of flexibility, fluency and originality.

1. Introduction
Three 21st century knowledge skills that must exist in education are life and career skills, learning and innovation skills and information media and technology skills. These three skills are summarized in a 21st century rainbow knowledge skills scheme. One of the skills in learning and innovation skills is creativity and innovation. [1] Creative thinking is an important skill mastered because it can facilitate students' understanding needs in the long term [2, 3] and can provide facilities for achieving educational goals [4] Results of interviews researchers in physics teachers and students related to carrying out classroom learning show that, the learning process carried out still prioritizes the study of theories and has not trained the processing of student skills in the study of physical content in depth. The learning process that continues is still using the lecture method, demonstration, verification practice and mathematical problem solving. The orientation of students in learning material physics is only limited to being able to solve physics content questions in a quick and easy way. The gap between the learning process that occurs in the field with the demands of 21st century competency can have an impact on the students’ low creative thinking skills.

Creative thinking skills are abilities or talents in students who must be trained so they can improve their skills. The low level of creative thinking skills occurs because creative thinking education has not been grown and handled according to the correct procedure [5]. Students' creativity can be developed
through teaching strategies [6]. Effective and relevant teaching and learning strategies are necessary to develop students' creative thinking skills. Effective and relevant teaching and learning strategies can be done through innovative models, strategies, methods, and learning approaches.

The CBL model is a learning model that combines three learning models namely problem based learning, project based learning, and contextual learning [7]. CBL implementation studies in six schools throughout the United States, showed that 90% of teachers stated that there were significant changes in 12 key skills in learning (leadership, creativity, media literacy, problem solving, critical thinking, flexibility, and adaptability), 70% of teachers stated the application of the CBL model can improve the skills of 21st century skills, more than 90% of teachers stated that they can make learning time more effective, more than 75% of teachers stated that they were able to improve material mastery and student involvement in learning [8], collaborative students' in learning [9], CBL model via cloud technology and social media for enhancing information management skills [10], CBL with engineering design processes (EDP) have positive effects on student outcomes, students' attitudes, and students' knowledge [11], increase motivation [12], effective in increasing creativity and innovation student's [13].

Referring previous research, the application of the CBL model has been combined with certain things and proven to have an impact on some 21st century skills and other competencies. In order to achieve the 21st century physics goals, this paper suggests STEM education as an alternative approach for learning innovation of CBL model. The essence of STEM education is to prepare for the 21st century workforce with STEM education and related activities so that students' can take what they learn in the classroom or laboratory in the real world [14], STEM education lessons, students are provided many opportunities to develop their thinking skills (metacognitive skills, critical and creative thinking) [15]. Morrison explains the several benefits of STEM education including making students' better problem solvers, innovators, inventors, self-reliant, logical thinkers, and technologically literate [16].

Research related to the application of STEM education in learning shows that students' achievement on integrated concepts of STEM literacy show large effect sizes [17], effective on learning and achievement of learning objectives [18], creative problem solving solutions in students' and the development of future innovators [19], increasing creativity and problem solving [20, 21]. prepare students' to develop the skills needed in the demands of 21st century education [22], improve innovation and students’ learning outcomes [23], improve metacognitive skills and students' interest in science lessons [15], improvement of students' STEM literacies [24] and ability understanding concepts [25], scientific inquiry and discovery the biological contents [26].

This study wants to prove new innovations in learning CBL models that are implemented with STEM education at the vocational level. The basic consideration of the application of STEM education in vocational schools is because the Indonesian vocational curriculum requires practice to be more than theory, which is 70% practice and 30% theory. Learning carried out in vocational high schools must teach and develop work skills to students through productive program learning activities [27]. This certainly corresponds to the scientific practice and engineering practice dimensions of STEM education. So that it can support and achieve learning standards that have been set at the vocational schools.

2. Method
The research method was used in this study is a quantitative method with quasi-experimental research design[28]. The research includes single group pre-test/post-test design. The subjects of the research consist of 23 students’ at 10th grade of one in vocational school. As for the sample in this study were selected using cluster random sampling technique. In this study the application of the CBL model implemented in STEM education for enhancing creative thinking skills was integrated into instructional design and worksheet.
2.1 Improving of Instructional Design
The improving of Instructional design consist of three phases namely: (1) Engage Phase, this phase is an exploration of experience that has been encountered in everyday life through questions and defining problems related to the context to be studied and determining a project challenge related to dynamic electrical material. STEM dimension in this phase is Asking questions and defining problems. (2) Investigate Phase, this phase is an effort to identify questions through analysis of findings from project activities and efforts to formulate ideas to solve the most appropriate problems from the project challenges given. STEM dimension in this phase is Developing and using models, planning and carrying out investigations, Analyzing and interpreting data, Using mathematics and computational thinking. (3) Act Phase, this phase is an effort to formulate and develop ideas from the study of science, present ideas as an effort to reflect the results of the study, and evaluate the ideas of the project that has been done. STEM dimension in this phase is constructing explanations and designing solutions, engaging in argument from evidence, obtaining, evaluating, and communicating information.

2.2 Improving of Worksheet
The improving of Worksheet consist of eight steps namely: (1) Asking questions and defining problems, Students’ are trained to ask questions and define a problem based on experience and observation of a phenomenon to formulate, improve and evaluate a discussion so that it can be empirically tested using models and simulations; (2) Developing and Using Models, Students’ are trained to develop and use a model or method based on provisional predictions related to certain variables. (3) Planning and Carrying Out Investigations, Students are trained to plan and conduct investigations to develop and revise the previously formulated model; (4) Analyzing and Interpreting Data, Students’ are trained to analyze scientific findings through detailed statistical analysis using tools, technology, or models (computing, mathematics) to provide valid scientific explanations and can be used in determining an accurate design solution; (5) Using Mathematics and Computational Thinking, Students’ are trained to solve science problems and techniques using mathematical analysis that can be used to analyze and model findings data; (6) Constructing Explanations and Designing Solutions, Students’ are trained to propose solutions as product engineering and provide complex explanations of solutions that are proposed as forms of scientific products; (7) Engaging from Evidence, Students’ are trained to form conclusions related to scientific principles and theories quantitatively or qualitatively about the relationship between variables from the results of scientific products; (8) Obtaining, Evaluating, and Communicating Information, Students’ are trained to communicate the results of scientific products to evaluate the validity, reliability, and synthesis of ideas, models, designs that arise from various perspectives.

2.3 Data Collection Tool
The essay test in this study was analyzed using the scoring rubric of creative thinking skills [28]. Students’ given twice test of creative thinking skill for pretest and posttest with same instrument. The essay test in this study was analyzed using the scoring rubric of creative thinking skills [29]. The instrument creative thinking skill test was validated by three expert judgement and tested. The results of the juice expert explained that the instrument can be used to measure creative thinking skills. The result used Pearson moment product correlation, shows instrument content validity ratio is was 0.70. The result of instrument reliability show that coefficient alpha Cronbach’s was 0.72.

2.4 Data Analysis
After doing the pretest, treatment and posttest data the ability of students’ creative thinking skill in the analysis used normalized gain (\( g \)), Shapiro-Wilk Test, non-parametric test and Cohen’s with SPSS 20.00 program at .05 significant levels. To test for singular differences from improving creative thinking skills, data was processed with IBM Statistics SPSS 20 software at a significant level of 0.05. To test the impact of implementing the CBL model implemented in STEM education using the Cohens
size effect (d) for single groups by reducing the average posttest score with the average pretest score and dividing it by the standard deviation.

3. Result and Discussion
The data analysis of creative thinking skill improvement among the students’ is classified based on indicators fluency, flexibility and originality. The difference of the creative thinking skill improvement between the class applying the CBL model implemented in STEM education can be seen in Table 1.

Table 1. Scores, Pretest, Posttest and N-Gain Score Data for Each Aspect

| Indicators of Creative Thinking Skills | Average Score | Criteria |
|--------------------------------------|---------------|----------|
|                                      | Pretest | Posttest | N-Gain |
| Fluency                              | 2.74    | 10.04    | 0.78    | High    |
| Flexibility                          | 1.78    | 10.04    | 0.80    | High    |
| Originality                          | 2.09    | 7.13     | 0.49    | Medium  |

Table 1 shows that the application of the CBL model implemented in STEM education in sequence can increase indicators of flexibility, fluency and originality. The analysis shows that there are significant differences in the improvement of creative thinking skills between before and after the applying the CBL model implemented in STEM education. The effectiveness of the application of the CBL model implemented in STEM education to improve creative thinking skills in learning can be determined by statistical test analysis and effect size. The results of the effect size analysis of creative thinking skills can be seen in Table 2.

Table 2. Results of the Effect Size Analysis for Each Aspect of Creative Thinking Skills

| Indicators of Creative Thinking Skills | Score  | SD     | dcohen | Criteria |
|--------------------------------------|--------|--------|--------|----------|
|                                      | Pretest| Posttest|        |
| Fluency                              | 0.09   | 0.20   | 0.153  | 1.30     | High     |
| Flexibility                          | 0.08   | 0.17   | 0.131  | 1.52     | High     |
| Originality                          | 0.18   | 0.15   | 0.166  | 1.02     | High     |

Table 2 shows that the application of the CBL model implemented in STEM education in a sequential manner has a large impact in increasing indicators of flexibility, fluency and originality. Other research also explains the integrated concepts of STEM literacy showed science achievement presented a medium effect size while the technology achievement showed a large one [17] and was effective in increasing innovation and student learning outcomes [23]. Improving creative thinking skills by applying the CBL model implemented in STEM is indicated because of the assignment of project tasks. STEM education enhances student learning experiences through application of general principles and practices. When incorporated properly, it should inspire creativity, inquisitive thinking, and teamwork [19]. An important aspect of improving metacognitive skills is knowledge, intelligence, experience, and practice [15]. Giving students the project task has the potential to make students creative in research, such as planning, designing and reflecting on learning outcomes in different cases. post-project requires students to be able to think fluency, flexibility, and originality.

3.1. Pre-project Phase
In the pre-project activities students are given challenges in the form of analyzing the phenomena presented in the real problem which in essence they are assigned to make energy-efficient home prototypes by designing scaling rooms and houses, formulating tools and materials needed and designing simple electrical installation designs. The three core points will challenge students to submit a lot of formulation of ideas or ideas (Fluency), provide various ideas for solving problems from other
disciplined perspectives (Flexibility) and formulate a complete prototype design with unique and different from other groups (Originality).

3.2. Project Phase
In the prototype project activities students will be faced with various phenomena or constraints on workmanship. Where in responding to this, students will be challenged to be able to submit many ideas to address the phenomena or constraints found (Fluency), provide various ideas and arguments when finding new phenomena or in solving problems in terms of the perspective of other scientific disciplines (Flexibility), propose ideas or different ideas in addressing phenomena or constraints found and constructing a prototype design uniquely and differently from other groups (Originality).

3.3. Post-project Phase
In post-project activities or students will be challenged to analyze shortcomings, strengths and development of ideas from those who have been applied during the project. Where in formulating these things students are required to identify processes that have been carried out in a manner that can propose many ideas related to shortcomings, strengths and the development of other ideas (Fluency), identify shortcomings, strengths and develop ideas related to solving problems faced in terms of other scientific disciplines (Flexibility), propose different ideas or ideas in identifying flaws, strengths and developing ideas from other groups (Originality).

4. Conclusion
As a result of the research, it was found that there were significant differences in the improvement of creative thinking skills between before and after using CBL Model implemented in STEM Education. The level of achievement of students' creative thinking skills on the post-test is higher than the pre-test. This study shows that the application of the CBL model implemented in STEM Education is effective in enhancing creative thinking skills and in the most significant order in increasing indicators of flexibility, fluency and originality.

5. References
[1] Trilling B, Fadel C 2009 21st Century Skills: Learn. for Life in Our Times (San Francisco: John Wiley & Sons)
[2] Canel A N 2015 A Program Based on the Guilford Model that Enhances Creativity and Creative Psychological Counseling International Journal of Health Administration and Education Congress (Sanitas Magisterium) 2 pp.5-29
[3] Batey M 2014 Creating meaningful brands: How brands evolve from labels on products to icons of meaning The definitive book of branding 22-41
[4] Hosseini A S 2014 The effect of creativity model for creativity development in teachers. International Journal of Information and Education Technology 4 2 p.138
[5] Zhou C 2105 Teaching engineering students’ creativity: A review of applied strategies Journal on Efficiency and Responsibility in Education and Science 5 2 pp.99-114
[6] Satriawan M, Liliiasari S, Setiawan W 2019 Journal of Physics: Conference Series 1157 3 p.032044
[7] Nichols M, Cator K and Torres M 2016 Challenge Based Learner User Guide. Redwood City (CA: Digital Promise) pp.24-36
[8] Johnson L and Brown S 2011 Challenge based learning: The report from the implementation project (Austin, Texas: The New Media Consortium)
[9] Luis C E and Marrero A M 2013 Real object mapping technologies applied to marine engineering learning process within a CBL methodology Procedia Computer Science 25 pp.:406-10
[10] Yoosomboon S and Wannapiroon P 2015 Development of a challenge based learning model via cloud technology and social media for enhancing information management skills *Procedia-Social and Behavioral Sciences* 174 pp.2102-7

[11] Gaskins W 2015 Student understanding of the engineering design process using challenge based learning age 26 1

[12] Gaskins WB, Johnson J, Maltbie C and Kukreti A 2015 Changing the learning environment in the college of engineering and applied science using challenge based learning *International Journal of Engineering Pedagogy (iJEP)* 5 pp.33-41

[13] Yang Z, Zhou Y, Chung JW, Tang Q, Jiang L, Wong TK 2018 Challenge Based Learning nurtures creative thinking: An evaluative study *Nurse education today* 71 pp.40-7

[14] Ejiwale J A 2013 Barriers to successful implementation of STEM education *Journal of Education and Learning* 7 2 pp.63-74

[15] Anwari I, Yamada S, Unno M, Saito T, Suwarma I, Mutakinati L, Kumano Y 2015 Implementation of authentic learning and assessment through stem education approach to improve students’ metacognitive skills *K-12 STEM Education* 3 pp.23-36

[16] Stohlmann M, Moore T J and Roehrig G H 2012 Considerations for teaching integrated STEM education *Journal of Pre-College Engineering Education Research (J-PEER)* 2 1 p.4

[17] Becker K and Park K 2011 Effects of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A preliminary meta-analysis *Journal of STEM Education: Innovations & Research* 12

[18] Borchers A, El-Sayed T L, Hoff C 2012 Bringing environmental sustainability to undergraduate engineering education: Experiences in an inter-disciplinary course *Journal of STEM Education* 13 2 p.22

[19] Roberts A 2012 A justification for STEM education *Technology and engineering teacher* 718 pp.1-4

[20] Morrison J 2006 Attributes of STEM education: The student, the school, the classroom *TIES (Teaching Institute for Excellence in STEM)* 20

[21] Furner J M and Kumar D D 2007 The mathematics and science integration argument: a stand for teacher education *Eurasia journal of mathematics, science & technology education* 3 3

[22] Sanders M 2009 Integrative STEM education: primer *The Technology Teacher* 68 4 pp.20-6

[23] Ceylan S and Ozdilek Z 2015 Improving a sample lesson plan for secondary science courses within the STEM education *Procedia-Social and Behavioral Sciences* 177 pp.223-8

[24] Tati T, Firman H, Riandi R 2017 Journal of Physics: Conference *895* 1 p.012157

[25] Kaniawati DS, Kaniawati I, Suwarma I R 2017 Implementation of STEM Education in Learning Cycle 5E to Improve Concept Understanding On Direct Current Concept *Atlantis Press*

[26] Osman K, Hiong LC, Vebrianto 2013 21st century biology: an interdisciplinary approach of biology, technology, engineering and mathematics education *Procedia-Social and Behavioral Sciences* 102 pp.88-94

[27] Syah IU, Sumirat U, Purnawan P 2017 Pencapaian Kompetensi Siswa SMK dalam Praktik Bekerja dengan Mesin Bubut *Journal of Mechanical Engineering Education* 4 1 pp.66-73

[28] Fraenkel JR, Wallen NE, Hyun HH 2011 How to design and evaluate research in education (New York: McGraw-Hill)

[29] Torrance E P, Safter H T 1999 *Making the Creative Leap and Beyond* (NewYork:CreativeEducation Foundation Press)

**Acknowledgments**

The authors would like to acknowledge the support provided by SMK N 1 Lembang, Bandung Indonesia who have provided research facilities, without which research cannot be carried out.