Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/18273
DOI URL: http://dx.doi.org/10.21474/IJAR01/18273

RESEARCH ARTICLE

EFFECTS OF STEM LEARNING ON CRITICAL AND CREATIVE THINKING SKILLS: A META-ANALYSIS

Asrizal[1], Febrian Virijai[2], Annisa N[2] and Usmeldi[3]

1. Physics Education, Department Of Physics, Padang State University, Indonesia.
2. Magister of Physics Education, Department Of Physics, Padang State University, Indonesia.
3. Faculty of Technique, UniversitasNegeri Padang, Indonesia.

Manuscript Info

Manuscript History
Received: 05 December 2023
Final Accepted: 09 January 2024
Published: February 2024

Key words:-
STEM, Critical Thinking, Creative Thinking, Meta Analysis

Abstract

The twenty-first century is marked by increasingly sophisticated advances in science and technology. Critical thinking and creative thinking skills are skills needed in this century. In addition, STEM is also needed to practice these 21st-century skills. However, the reality in the field found that students' critical thinking and creative thinking skills are still low. The next fact is that there is still little application of STEM-integrated learning. The solution to overcome these problems is STEM-integrated learning to improve students' critical and creative thinking skills. The purpose of this study was to describe the effect size of students' critical and creative thinking skills on STEM-integrated learning. The research method used is a meta-analysis. The data collected were 20 national and international articles related to the effect of STEM learning on students' critical and creative thinking skills. The strong or weak influence of STEM learning on critical and creative thinking skills is determined by the size of the effect. The results of the meta-analysis showed that the level of education, learning models, and learning materials showed that the influence of STEM learning on students' critical and creative thinking skills was in the high category. This research provides an opportunity for future research to develop STEM-integrated learning to improve other twenty-first-century skills at every level of education, relate them to learning models, and apply them to every learning material.

Introduction:-

The twenty-first century has challenges, namely world competition in various sectors, including education. This century is characterized by advanced technology and easy access to the internet. To face the challenges of this century, the Indonesian people must be able to prepare quality people resources. The best course of action to address the problems of our century is education. Education graduates must master science and technology in order to be able to take advantage of technological sophistication (Usmeldi et al, 2017). Education is a place to prepare quality human resources.

Education is an activity that serves as a forum for transferring knowledge from teachers to students. Graduates of educational units must be competent and qualified. Educated graduates have innovative, creative and competent

Corresponding Author:- Asrizal
Address:- Jl. BaktiAbri Number 34B, Koto Tangah, Padang, West Sumatra.

abilities at the world level (Asrizal et al, 2018; Usmeldi, 2016). Learning in this century is directed toward being more perceptive to knowledge, culture, art, science, math, technology, and engineering which are all incorporated into learning (Malik, 2018). Oneof the initiatives of the Indonesian government to build education is to develop a curriculum that makes learning centered on students and integrated learning. Learning using an integrated model that balances a good example is to take a scientific approach while utilizing technology to use in this century's skills (Novitra et al, 2021). Current learning is expected to give pupils the abilities and skills they need for the twenty-first century.

These twenty-first century skills include leadership, adaptability, entrepreneurial skills, innovation, curiosity or critical thinking, and imagination or creative thinking. Twenty-first century capabilities at least apply critical-creative skills, integrate science with the real world, apply information, comunication, and technology (ICT), collaborative and communicative (Asrizal et al, 2020). Twenty-first century skills are also dominant in the areas of literacy, innovation, and high competitiveness (Grey & Morris, 2022; Orak&&İnözü, 2021). Critical thinking skills allow students to adapt to different environments to classify problems, solve problems, find solutions, find ideas, seek truth of arguments, think inductively-deductively, play an active role, and interact with other students (Klein, 2016; Sameth&Lessy, 2022). Students who have possessing critical thinking abilities facilitates problem-solving. Apart from critical thinking, creative thinking skills are also required. The capacity to think creatively is assume to enforce new ideas, while critical thinking is defined as the ability to use thinking, reasoning, analysis, synthesis, and reflection on information (Asrizal et al, 2022). People with critical thinking skills have criteria including being able to generate fresh concepts, ideas that don't yet exist in that place, find new processes that have never been done, and do something by looking at it from a different perspective (Annisa, 2022; Asrizal et al, 2023; Birgili, 2015). Creative skills can bring individuals without problems with various situations and can be trained through appropriate mastery and learning processes.

Twenty-first century learning is a technique of transferring understanding from coach to student with the student at the center of learning. Learning in the twenty-first century is based on the principles of student-centered, collaborative, connected to real life, and purposeful and learning is prepared physically, mentally, and socially (Asrizal et al, 2018; Gunadi et al, 2022). One variation of learning that is sufficient to hone students' critical skills and creative thinking are STEM learning (Science, Technology, Engineering, and Math). Integrated learning based on ICT (Technology, Information, and Communication) can enhance students' development of twenty-first century skills (Asrizal et al, 2022). The goal of STEM education is to foster conceptual learning, critical-creative skills, aid pupils in developing their capacity to contribute to the economy and expand employment Astawan et al, 2023). STEM learning greatly facilitates students' skills in developing critical-creative thinking skills.

STEM learning is integrated learning that incorporates the fields of science, engineering, technology, and math which have complex structures and various forms in learning and practice (Gao, 2020). STEM learning is an integrated learning that has the goal of encouraging authentic, active, holistic and meaningful learning in accordance with twenty-first century learning (Yurnetti et al, 2020). The learning process connects human interaction with humans or human interaction with the natural surroundings. The way students interact seen from various disciplines can train both analytical and creative thinking abilities as well as create an innovation. STEM is an integrated learning that is quite effective at enhancing one's capacity for critical and original thought. STEM facilitates students in the learning process and practice. There are at least three senses that help expedite the learning process, namely the senses of hearing, touch, and sight (Akbari et al, 2018; Rabiat, 2017). Learning that involves many senses can build more student knowledge and the learning process is more focused on students.

However, seen from the actual field circumstances there are some gaps. The first real condition is that students still have poor critical and creative thinking abilities. The second real condition is that STEM learning has not been widely implemented in schools, both junior and senior high schools (Mawrni&Sani, 2020; Nungrum et al, 2022; Sugmagati et al, 2020; Rohman et al, 2021). The third real condition is that there is still little meta-analytic research that describes the impact of STEM integrated improving pupils' capacity for critical and creative thought. Seeing the gap between ideal conditions and real conditions, it is necessary to do research to explain the results of STEM integrated improving pupils' capacity for critical and creative thought. The results of this study can also be developed for further research related to STEM learning and twenty-first century skills.

To find out the effectiveness and how big of an impact STEM education has on students' ability to think critically and creatively, researchers conducted a meta-analysis of 20 research journals. The objective of this meta-analysis is

to explain how STEM has an impact on critical-creative abilities. These journals discuss the influence of STEM learning on the capacity for critical and inventive thought in pupils. There is a need for research to see how much influence STEM learning has. Researchers in reviewing this meta-analysis measure the effect size or the magnitude of the influence of STEM learning on critical and creative thinking skills. This is the focus of this meta-analysis. The researcher also analyzed each journal and grouped them based on students' twenty-first century skills, educational level, learning model used, and related learning materials.

Method:-

The research conducted is included in literature review research, one of which is meta-analysis. Meta-analysis is a statistical analysis in the form of quantitative data from individual research and combined to obtain conclusions (Aslikhah, 2015). The meta-analysis presented is an illustration of the size of the effects of STEM affecting students' critical and creative thinking skills. The meta-analysis steps carried out in this study consist of several stages.First, it collected 20 national and international articles related to the impact of STEM on students' critical thinking skills. Second, perform data analysis using the effect size formula. Third, grouping literature based on moderator variables, namely based on education levels, learning models, and learning materials. Fourth, publish research results to the public.

The variables in this study consist of three variables. The first independent variable is STEM-based learning. Second, the dependent variables are critical thinking skills and creative thinking. Third, moderator variables are based on education level, educational model, and learning material. This research data was obtained from reputable national and international articles.

The data analysis technique used in this study is the quantitative analysis technique. Data analysis was carried out using several formulations of effect sizes. The formula used (Becker & Park, 2011), namely:

Effect size one group

$$ES = \frac{\bar{X}_{post} - \bar{X}_{pre}}{SD_{pre}}$$

This effect size formula is used for research that only uses one class as the experimental class. The research was conducted in two tests, namely pretest and posttest. Prior to treatment, students were given an initial test. After being given treatment, students are tested again as a final test and determine how much influence the use of STEM learning has on critical thinking skills.

Effect size two groups posttest only

$$ES = \frac{\bar{X}_E - \bar{X}_C}{SD_C}$$

The two groups posttest only effect size formula is a formula for calculating the effect size in research that examines two classes. The first class is treatment is given to the experimental class, while the second class is the control or comparison class that is not treated. However, what was tested was only on the posttest. After the experimental class is given treatment, both classes will be tested as a final test.

Effect size two groups pretest and posttest

$$ES = \frac{(\bar{X}_{post} - \bar{X}_{pre})_E - (\bar{X}_{post} - \bar{X}_{pre})_C}{\frac{SD_{preC} - SD_{preE} - SD_{postE}}{3}}$$

This formula is almost the same as the previous formula, which is carried out in two classes. However, this formula is for research that tests both classes with pretest and posttest. The first test administered to the two classes was a posttest, especially to the experimental class and the control class. Following the treatment administered to the experimental class, both classes were tested again as a posttest test.

Effect size using-count

$$ES = t\sqrt{\frac{1}{n_E} + \frac{1}{n_C}}$$

The current effect size formula is used for studies that calculate t-counts. The formula is quite simple. The research used in two groups, namely there is a control class and there is an experimental class.

The effect size or effect size that has been obtained can be identified according to the category, namely 0 ES 0.2 including the low category, 0.2 ES 0.8 including the medium category effect size, and ES 0.8 including the effect size high category (Cohen, 1988). We can see the impact of STEM education in developing creative thinking skills from this category.

Result and Discussion:-

Researchers have collected several research and journals that cover the STEM education's impact on twenty-first century skills, namely critical and creative skills. Researchers took journals from reputable national and international journals. The journals that have been collected were published from 2018 to 2021. The journals studied can be seen in Table 1.

Table 1:- Journal Article Code.

Code	Education Level	Effect Size
J1	Senior High School (SHS)	0.06
J2	Senior High School (SHS)	2.20
J3	Junior High School (JHS)	1.48
J4	Senior High School (SHS)	0.97
J5	Junior High School (JHS)	3.34
J6	Senior High School (SHS)	0.81
J7	Senior High School (SHS)	0.32
J8	Senior High School (SHS)	1.42
J9	Junior High School (JHS)	3.09
J10	Senior High School (SHS)	0.97
J11	Senior High School (SHS)	1.03
J12	Junior High School (JHS)	1.18
J13	Junior High School (JHS)	1.11
J14	Junior High School (JHS)	1.58
J15	Junior High School (JHS)	1.82
J16	Senior High School (SHS)	3.60
J17	Junior High School (JHS)	0.97
J18	Senior High School (SHS)	2.14
J19	Senior High School (SHS)	0.96
J20	Senior High School (SHS)	0.33

The collected journals were analyzed and classified into several sections. The goal is to see an overview of the size of the effect and how big the influence of STEM is. The classification is based on critical and creative abilities at each stage of education, learning models, and learning resources. The size of the influence as the graphic explanation provided shows by the researcher. Of the 20 studies on average, It demonstrates the impact of STEM-integrated education on students' critical and creative skills.

This first graphic image is an illustration of the extent to which STEM has an influence on students' twenty-first century abilities by education level. The twenty-first century skills are critical-thinking and creative-thinking abilities of students. Below are examples of how STEM instruction affects students' critical thinking and creative thinking at various grade levels. Value of the effect size can be seen in Figure 1.

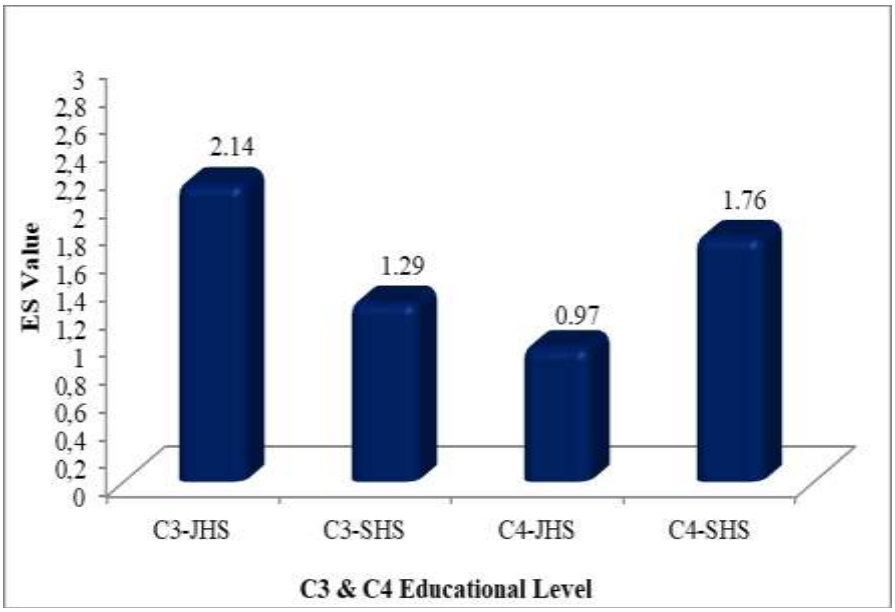

Figure 1:- ES scores of C3 and C4 for each level of education.

Researchers classified effect sizes based on students' skills and educational level. These data are C3-JHS (Critical Skills-Junior Hight School) is the average size of STEM education exposure to the critical thinking skills of junior high school students, C3-SHS (Critical Skills-Senior Hight School) is the average size of the influence of STEM on the critical skills of high school students, C4-JHS (Creative Skills-Junior Hight School) is the average measure of the influence of STEM on creative thinking skills of junior high school students, and C4-SHS (Critical Skills-Senior Hight School) is the average measure the influence of STEM on the creative skills of high school students. The results of the effect size description that has been calculated as the average show that both students' skills and levels are in the high category. This is seen in the value of effect size, which is 2.41; 1.29; 0.9; and 1.79. In journals obtained by researchers for critical skills at the junior high school average value field level is higher than the effect sizes at other levels. The lower effect size is on junior high school creative skills.

The second picture describes the effect size description or how the influence of STEM learning that is integrated with the model for learning critical skills of students. Learning with which learning model is most suitable for practicing critical and creative skills can be seen in the picture. Figure 2 below displays the typical findings of the effect size values.

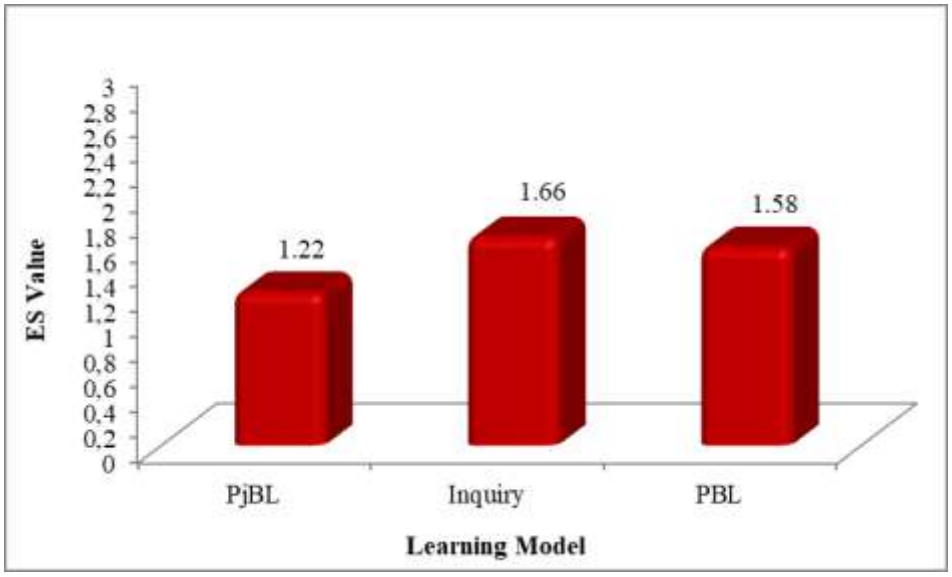

Figure 2:- ES value of each learning model.

The learning model is very important to be considered by the teacher. Choosing a learning model can improve study results of students and some skills. Learning models that are suitable for integrated with STEM education can help pupils develop their critical and creative skill abilities. STEM integrated learning works well. In Figure 2 it can be seen that the learning models that are often integrated with STEM learning are PjBL, inquiry learning, and PBL. From several journals, the commonprice of the impact size of the integrated STEM learning model on students' critical and creative skills was obtained. The PjBL, inquiry, and PBL learning models show that this model is suitable for integration with STEM learning and has an effect on creative and critical skills.

Researchers also grouped the description of the effect size into learning materials. Researchers collected journals and grouped them based on material related to the STEM effect on the critical and creative abilities of pupils. As for the materials that have been obtained by researchers, it showsin the description in Figure 3 below.

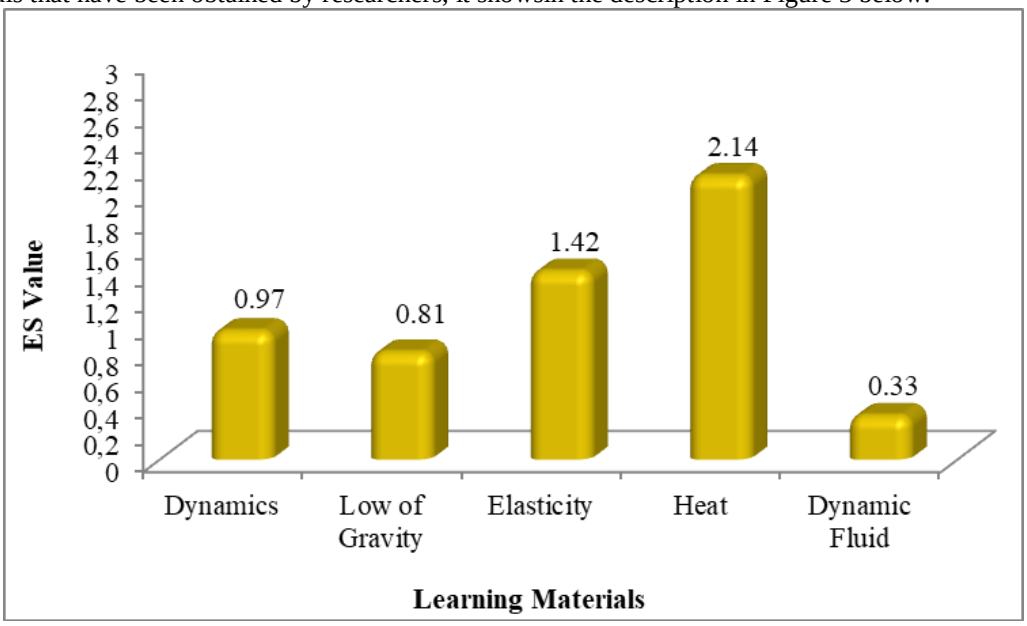

Figure 3:- ES value of each learning material.

STEM is learning that combines four disciplines. A teacher and researcher must be able to distinguish which learning materials can be integrated with STEM. In STEM learning, not all learning materials can be integrated. Learning materials that can be made integrated, such as STEM learning, are adapted to basic competencies in subjects. The results of the meta-analysis related to learning materials turned out to be 4 materials included in the high category, namely rotational dynamics, the law of gravity, elasticity, and heat. This means that the four materials affect STEM learning on students' critical and creative skills. Meanwhile, dynamic fluid material has moderate influence. This could be because the research had less impact on critical and creative skills. However, for the overall average meta-analysis of STEM learning on students' critical and creative skills, it has a high effect.

The results of this meta-analysis found that there was a significant influence between STEM integrated learning on students' critical-creative thinking skills. The limitation of this meta-analysis research is that it only measures the influence of the effect size of critical-creative thinking skills, while there are other twenty-first century skills. Then the results of this meta-analysis focus on STEM integrated learning. It is hoped that future research will be able to describe the effect of the integrated learning model on other twenty-first century skills. The results of this study can also be used as a basis that it is necessary to develop models and teaching materials related to STEM integrated learning with creative-critical thinking skills.

Conclusion:-

From the results of the meta-analysis study, it was concluded that STEM learning is based on creative and critical thinking skills in this study. First, the effect of STEM integrated learning on students' critical and creative thinking abilities at every level of education is included in the high influential category. Second, the influence of STEM integrated learning on students' critical and creative thinking abilities in each learning model has a high influence. Third, the influence of STEM integrated learning on students' critical and creative thinking skills in each learning

material has a high influence. The results of this research provide an opportunity to develop STEM integrated learning with students' critical-creative skills.

Reference:-

1. Usmeldi, Amini, R., &Trisna, S. (2017). The Development of Research-Based Learning Model with Science, Environment, Technology, and Society Approaches to Improve Critical Thinking of Students, JurnalPendidikan IPA Indonesia, 6 (2), 318-325.
2. Asrizal, A,,Amran, A., Ananda, A., &Festiyed, F. (2018). Effectiveness of Adaptive Contextual Learning Model of Integrated Science by Integrating Digital Age Literacy on Grade VIII Students, IOP Conf. Series: Materials Science and Engineering.
3. Usmeldi. (2016). The Development of Research-Based Physics Learning Model with Scientific Approach to Develop Students' Scientific Processing Skill, Jurnal Pendidikan IPA Indonesia, 5 (1), 134-139.
4. Malik, R. S. (2018). Educational challenges in 21st century and sustainable development. Journal of Sustainable Development Education and Research, 2(1), 9-20.
5. Novitra, F.,Festiyed, F., Yogandri, Y., &Asrizal, A. (2021). Development of Online-based Inquiry Learning Model to Improve 21st-Century Skills of Physics Students in Senior High School: Eurasia Journal of Mathematics, Science and Technology Education, 17 (9): 1-20.
6. Asrizal, A., Desnita, D., Darvina, Y. 2020. Need Analysis to Develop Electronic Enrichment Book of Physics Based on Contextual Teaching and Environmental Potential. IOP Conf. Series: Journal of Physics: Conf. Series 1481 (2020) 012123.
7. Grey, S., & Morris, P. (2022). Capturing the spark: PISA, twenty-first century skills and the reconstruction of creativity. Globalisation, Societies and Education, 1-16.
8. Orak, S. D., & İnözü, J. (2021). Teachers' Awareness and Actual Practices of 21st Century Learning and Innovation Skills. International Online Journal of Education and Teaching, 8(2), 975-997.
9. Sameth, L., & Lessy, D. (2022). Students Critical Thinking Skills Through Project-Based Learning Models in Solving Pythagoras Theorem Problems. Indo-MathEdu Intellectuals Journal, 3(1), 51-66.
10. Klein, E. (2016). Developing Minds, In Developing Minds. London: Routledge.
11. Asrizal, A.,Mardiana, V., Novitra, V., &Festiyed, F. (2022). Physics Electronic Teaching Material-Integrated STEM Education to Promote 21st-Century Skills, Cypriot Journal of Educational Sciences, 17 (8), 2899-2914.
12. Annisa, N. (2022, July). Effects of STEM-based learning materials on knowledge and literacy of students in science and physics learning: a meta-analysis. In Journal of Physics: Conference Series (Vol. 2309, No. 1, p. 012063). IOP Publishing
13. Asrizal, A., Annisa, N., Festiyed, F., Ashel, H., & Amnah, R. (2023). STEM-integrated physics digital teaching material to develop conceptual understanding and new literacy of students. Eurasia Journal of Mathematics, Science and Technology Education, 19(7), em2289.
14. Birgili, B., (2015). Creative and Critical Thinking Skills in Problem-based Learning Environments, Journal of Gifted Education and Creativity, 2(2), 71-80.
15. Asrizal, A., Amran, A., Ananda, A., Festiyed, F., & Sumarmin, R., (2018). The Development of Integrated Science Instructional Materials to Improve Students' Digital Literacy in Scientific Approach, Jurnal Pendidikan IPA Indonesia, 7(4), 442–450.
16. Gunadi, G., Haryono, H., & Purwanti, E. (2022). The Analysis of 21st Century Learning Implementation and Competency Achievement of Junior High School Students in 3T Regions. Innovative Journal of Curriculum and Educational Technology, 11(1), 10-18.
17. Asrizal, A., Yurnetti, Y., & Usman, E.A. (2022). ICT Thematic Science Teaching Material With 5E Learning Cycle Model To Develop Students' 21st-Century Skills, Jurnal Pendidikan IPA Indonesia, 11 (1), 61-72
18. Astawan, I. G., Suarjana, I. M., Werang, B. R., Asaloei, S. I., Sianturi, M., & Elele, E. C. (2023). STEM-Based Scientific Learning and Its Impact on Students' Critical and Creative Thinking Skills: An Empirical Study. Jurnal Pendidikan IPA Indonesia, 12(3), 482-492.
19. Gao, X., Li, P., Shen, J., & Sun, H. (2020). Reviewing Assesment of Student Learning in Interdisciplinary STEM Education. International Journal of STEM Education, 7(24), 1-14.
20. Yurnetti, Y., Asrizal, A., &Murtiani, M. (2020). Need Analysis to Develop Science Learning Material Based on Thematic Teaching by Integrating the New Literacy. IOP Conf. Series: Journal of Physics: Conf. Series 1481 (2020) 012122
21. Akbari, S., Kurnia, N. S., Anggraeni, D. S., & Sri, M. H. (2018). Design of Teaching and Learning Materials Based on the Values of Local Heroic Struggle in Sukoharjo. International Journal of Multicultural and Multireligious Understanding, 5(6), 28-33.

22. Rabiat, A. A. (2017). The Importance of Instructional Materials in Teaching English as Second Language. International Journal of Humanities and Social Science Invention, 6(9), 36-44.
23. Mawarni, R. & Sani, R. A. (2020). The Effect of STEM-Based Project Based Learning Model on Students' Creative Thinking Ability on Static Fluid Subject Matter in Class XI SMA Negeri 4 Tebing Tinggi T.P. 2019/2020, Journal of Physics Learning Innovation, 8 (2), 8-15.
24. Sukmagati, O. P., Yulianti, D., & Sugianto S. (2020). Development of STEM (Science, Technology, Engineering, and Mathematics) Based Student Worksheets (LKS) to Improve the Creative Thinking Skills of Junior High School Students, Unnes Physics Education Journal, 9 (1), 18-26.
25. Rohman, A., Ishafit, & Husna H. (2021). The Effect of the Application of the Steam Integrated Project Based Learning Model on Creative Thinking Judging from the Understanding of High School Student Physics Concepts on Rotational Dynamics Material, Tadulako Online Journal of Physics Education, 9 (1), 15-21.
26. Ningrum, R., Rahman, T., & Riandi. (2022). Application of STEM from Home with PjBL Model to Improve Mastery of Concepts and Creative Thinking Skills of Junior High School Students, Journal of Science Education, 6 (1), 299-307.
27. Aslikhah, N. (2015). Meta Analisis Dengan Effect Size Odds Ratio Pada Kasus Pengaruh Terapi Bheta-Bloker Untuk Pasien Gagal Jantung. Skripsi. UNY.
28. Becker, K., & Park, K. (2011). Effects of Integrative Approaches Among Science, Technology, Engineering and Mathematics (STEM) Subjects on Students' Learning: A Preliminary MetaAnalysis. Journal of STEM Education, 12 (5&6), 23-37.
29. Cohen, J. (1988). Statistical Power Analysis for The Behavior Science (2nd ed.). Hillsdale, NJ: Lawrance Earlbaum Associations.