Journal of Education and e-Learning Research
Vol. 10, No. 3, 578-584, 2023
ISSN(E) 2410-9991 / ISSN(P) 2518-0169
DOI: 10.20448/jeelr.v10i3.4987

Integration of STEAM and ESD: Improving the understanding of fluid concepts and creativity

Nur Khoiri[1] ✉
Fenny Roshayanti[2]
Rezki Widarti[3]


(✉ Corresponding Author)

[1,2,3]*Department of Science Education, Graduate School, Universitas PGRI Semarang, Semarang, Indonesia.*
[1]*Email: nurkhoiri@upgris.ac.id*
[2]*Email: fennyroshayanti@upgris.ac.id*
[3]*Email: rezki.widarti.79@gmail.com*

Abstract

The aim of this study was to develop a learning model that integrated ESD-oriented STEAM with fluid ideas to produce ESD-oriented STEAM-based learning. This study employs the Borg and Gall model which is simplified into three steps. The effectiveness and documentation were evaluated using questionnaires for experts and educational practitioners, observation sheets for student creativity and pre- and post-test sheets. The data analysis involves both quantitative and qualitative methods. The findings demonstrated the characteristics of STEAM-based physics learning tools including increased creativity and student learning outcomes. Analyzing how ESD-focused STEAM-based learning resources are used in the developed fluid material yields beneficial results. Student learning outcomes increased in the moderate category. The average score for student creativity was 86.12% in the very good category showing that the usage of learning resources including worksheets based on STEAM subjects and ESD was successful in enhancing creativity and student learning outcomes. This study has implications for improving student interest in physics education. The findings of this study can also be used to advise curriculum designers to incorporate this model for physics teachers to use while instructing physics in their courses.

Keywords: Creativity, ESD, Learning devices, Learning outcomes, STEAM.

Citation | Khoiri, N., Roshayanti, F., & Widarti, R. (2023). Integration of STEAM and ESD: Improving the understanding of fluid concepts and creativity. *Journal of Education and E-Learning Research, 10*(3), 578–584. 10.20448/jeelr.v10i3.4987
History:
Received: 25 May 2023
Revised: 10 August 2023
Accepted: 31 August 2023
Published: 12 September 2023

Publisher: Asian Online Journal Publishing Group

Funding: This research is supported by Universitas PGRI Semarang, Indonesia (Grant number: 061/SKK/LPPM/HIBAH GB/XI/2022).
Institutional Review Board Statement: The Ethical Committee of the Universitas PGRI Semarang, Indonesia has granted approval for this study on 9 August 2022 (Ref. No. 212/LPPM/UPGRIS/VIII/2022).
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

Contents

1. Introduction **579**
2. Method **580**
3. Results and Discussion **581**
4. Conclusion **583**
References **583**

Contribution of this paper to the literature
This work advances STEAM education by combining STEAM and ESD to foster creativity and comprehension. The evolving learning model incorporates ESD-oriented STEAM concepts and provides fluid ESD-oriented STEAM-based learning that is reliable, useful and efficient. It advises the curriculum designer to include this model for physics teachers while teaching physics in their classrooms.

1. Introduction

Education plays a crucial role in enabling students to develop the views and strive towards a sustainable future necessary to address the world's complex challenges. Segera (2015) states that complex issues must be solved with a multidisciplinary and multidimensional approach. According to Rahmawati, Roshayanti, Nugroho and Hayat (2021), problem-solving with a multidisciplinary and multidimensional approach can be integrated with Education for Sustainable Development (ESD). Education for Sustainable Development (ESD) also known as lifelong learning aims to educate and involve people in activities that will promote physical activity, creativity, problem-solving abilities, scientific and social literacy and a commitment to individual and collective responsibility (Agusti, Wijaya, & Tarigan, 2019). Education for Sustainable Development (ESD) instills thoughts about the needs of the present generation without neglecting future generations (Wijayanti, Roshayanti, Farikhah, Khoiri, & Siswanto, 2021).

ESD provides students with the knowledge, skills, values and attitudes to process information, make decisions and take actions that promote economic sustainability, social justice and the environment for both the present and the future. ESD is the key to achieve the Sustainable Development Goals (SDGs) by providing broad and innovative insights about the global environment such as SO_2 concentration in the environment (Ruhiat et al., 2016), pollution (Ruhiat, Wibowo, & Oktarisa, 2017) and forming understandings, attitudes and values relevant to social, economic and environmental life (Novidsa, Purwianingsih, & Riandi, 2020). Physics is a field where ESD-focused learning debriefing may be used. Physics is both a process and a product. Process means the procedure for discovering physical products (facts, concepts, principles, theories or laws) that is carried out through scientific steps (Hanna, Sutarto, & Harijanto, 2017; Khoiri, Riyadi, Kaltsum, Hindarto, & Rusilawati, 2017). Physics instruction is primarily theoretical and informative which results in a lack of support for and instruction in developing students' skills, values and attitudes that reflect concern for and responsibility for the environment making it difficult to meet learning objectives. STEAM is a learning content that uses five sciences, namely science, technology, engineering, art and mathematics related to one another as a problem-solving pattern (Septiani & Kasih, 2021). STEAM is used to focus on understanding the integrated nature of the disciplines of science, technology, engineering, the arts and mathematics and their importance in children's long-term academic success, economic well-being (Quigley & Herro, 2016) and societal development (Wahyuningsih et al., 2019).

The increasing implementation of science and technology has both positive and negative impacts on various fields. Various disasters or ecological damage occurred as a result of the improper application of science, causing financial loss and human casualties. Education for Sustainable Development (ESD) is a shared responsibility to pay attention to environmental sustainability. Therefore, researchers aim to prepare students not only for STEAM-based learning but also for efficiently overcoming obstacles in a society that values cooperation. The implementation of ESD-focused instruction in schools is crucial. Therefore, education is an essential component of sustainable development. According to Hidayah and Ami (2021), sustainable development is a development that can meet current needs without reducing the capacity or ability of the next generation to meet their own needs.

The goal of learning about fluid physics cannot be completely achieved since students still require help comprehending the idea. Students are not involved in the learning process. They only become part of the object of learning. Increased student participation in fluid learning and comprehensive learning is achieved through the STEAM procedure. Nurfadilah and Siswanto (2020) stated that STEAM is contextual learning.

STEAM learning trains students to think about finding solutions to existing problems by creating their ideas with the latest technology. STEAM learning can bridge concepts that are still abstract mathematically into science, technology, engineering and art. STEAM learning fosters students' creativity in creating a fun learning tool (Lestari, 2021). According to Suryaningsih, Nisa, Muslim, and Aldiansyah (2022), students responded positively or cooperated with the use of STEAM-PjBL in chemistry learning. Sustainable development is a development that meets the needs of the current generation without compromising the needs of future generations to maintain environmental quality and pay attention to aspects of environmental benefits and environmental sustainability. This paradigm has been implemented through ESD in education. The concept of ESD has three main areas of sustainable development: economic, environmental and societal with culture as its main dimension. ESD's philosophy is primarily interdisciplinary. This is in line with the recommendation of the National Science Teachers Association that science educators must be equipped to develop thematic, integrated and interdisciplinary sciences. Science learning is no longer limited to one discipline but must be linked to other disciplines. Using learning models makes the learning atmosphere monotonous and sometimes even boring. This limits the ability of students to discover and try new things. In response to these problems, a project-based learning model is offered which can improve student learning outcomes (Datu, Qadar, & Junus, 2020). The PjBL model is a learning model that provides opportunities for teachers to manage learning in class by involving project work. Project work contains complex assignments based on problems given to students as a first step in gathering and integrating new knowledge based on their experiences in real activities. It requires students to carry out design and investigative activities, solve problems, make decisions and provide opportunities for students to work independently or in groups (Khoiri, Marinia, & Kurniawan, 2016). The result of the project work includes written reports, presentations or recommendations. Assessment of project tasks is carried out from the planning process, working on project assignments to the final project results (Mulyadi, 2015).

The STEAM approach encourages students to explore all their abilities. The potential for implementing ESD-oriented STEAM can be done through fluid learning by providing projects. Project-based learning has the potential to make learning experiences more exciting and meaningful and improve scientific performance (Novianto, Masykuri, & Sukarmin, 2018). In addition, it also requires students to understand fluid learning by observing phenomena that occur in the surrounding environment using developing technology so that students can find concepts and the results of the project are presented by paying attention to ethical and aesthetic values as art and displaying other forms (material form with mathematical manifestations). It is necessary to conduct a study on Science, Technology and Engineering Art Mathematics (STEAM) with an Education for Sustainable Development (ESD) orientation to increase creativity and student learning outcomes.

2. Method

The research used the development method as an ESD-oriented STEAM learning model to increase creativity and the learning outcomes of fluid concepts. According to Borg and Gall (2003), there are ten development steps: introduction, design, initial product development, initial trial, revision, main trial, product revision, operational trial, final revision, dissemination and distribution. The preliminary study is the initial or preparatory stage in research and development. This stage consists of three steps: The first is a literature study to study the concept. Concepts or theories relating to the product or model to be developed. In addition, at this stage, a study of research results that are relevant to the research to be carried out. The second is a field survey which collects data directly in the field to measure the need for the product to be developed. The third is the preparation of the initial product or draft model. Model development is carried out based on field findings, literature studies, problem analysis and the implementation of learning as a basis for the formulation of learning programs. The learning program is in the form of an ESD-oriented STEAM-based learning program in PjBL. Furthermore, program validation was carried out by discussing the program draft with teachers and people who were assessed as having the ability to ESD-oriented STEAM-based learning in PjBL. Program validation is carried out to determine the feasibility of the program that has been formulated. The program revision is used as a basis for revising or improving the program that has been made so that the learning program is considered feasible to be implemented in the following research stage. The model test is the stage of testing the efficacy of the model or product being developed. Efficacy testing is usually done by comparing the products developed with those commonly used in schools. In this stage, tests are carried out on the products or models prepared in the preliminary study stage. The test was carried out in two steps: a limited field test and a wider field test. The trial implementation and the number of data sources sampled are the things that differentiate between the two tests. According to Borg and Gall (2003), not all R&D steps are carried out in the research and development of ESD-oriented STEAM-based learning on this fluid material; only the restricted product testing stage at step six is completed.

2.1. Data Collection Process

Data collection is done in several ways such as through unstructured interviews. Interview techniques were used to gather data about practitioners' opinions of the developed learning tools. A questionnaire is a data collection technique that gives respondents a set of questions or written statements to answer (Sugiyono, 2013). The questionnaire method was used to gather data about the practicality of the developed learning tools. Next, a description evaluation is performed to evaluate student learning results.

2.2. Data Analysis Techniques

Validity is reviewed from the content and construct. Content validity includes the model developed based on the curriculum and the theory underlying the learning model described. Meanwhile, construct validity consists of a model component that does not conflict with other models. The model syntax leads to achieving goals, social systems, reaction principles and support systems that support the developed learning syntax. Analysis of data validity by finding the average of each validator. Each statement in the validation sheet uses the invalid (In), quite valid (QV), valid (V) and very valid (VV) options. Each choice is scored 1, 2, 3 and 4. There are 16 statement items that the validator must fill in. We obtained a minimum score of 16 and a maximum score of 64. From the minimum and maximum scores, the validity criteria of ESD-oriented STEAM-based learning were determined using invalid, quite valid, valid and very valid intervals. The criteria for the validity of STEAM-based learning are obtained in Table 1.

Table 1. Criteria for the validity of ESD-oriented STEAM-based learning.

Score	Criteria of validity
53-64	Very valid
41-52	Valid
29-40	Quite valid
16-28	Invalid

Meanwhile, the final score from the validator is obtained and the percentage is then calculated as shown in Table 2 to determine the validity of the curriculum, lesson plans, STEM modules and worksheet instructional materials.

Table 2. Learning device validation criteria.

Achievements	Criteria of validity
85.01% - 100.00%	Very valid
70.01% - 85.00%	Valid
50.01% - 70.00%	Quite valid
01.00% - 50.00%	Invalid

The practicality of learning data was obtained from the practical validation of learning tools carried out by experts and teacher responses. The final result from the validation is used to calculate the percentage to determine the validity of the curriculum, lesson plans, STEM modules and worksheet learning resources.

Table 3. Criteria for the level of practicality.

Achievements	Criteria of practicality
85.01% - 100.00%	Very practical
70.01% - 85.00%	Practical
50.01% - 70.00%	Less practical
01.00% - 50.00%	Not practical

2.3. Effectiveness

Data analysis is used to determine the effectiveness of ESD-oriented STEAM-based learning tools for creativity and student learning outcomes. The data were obtained from the students' pre-and post-test results. A student must score at least 75 on an achievement test in order to be considered successful in terms of learning outcomes. The criteria for assessing scientific literacy abilities and learning outcomes are shown in Table 4.

Table 4. Criteria for evaluating the effectiveness.

N-Gain	Category
$G > 0.7$	High
$0.3 \leq g \leq 0.7$	Moderate
$G < 0.3$	Low

3. Results and Discussion

3.1. ESD-Integrated STEAM- Based Device Validity

Practitioner validation results are obtained from the total score in Table 5.

Table 5. Summary of practitioner validation results

Product	Achievement	Category
Syllabus	92 %	Very valid
Lesson plans	94 %	Very valid
Modules	91 %	Very valid
Worksheet	91 %	Very valid

The average score in the validation tests conducted by practitioners of lesson plans for the ten aspects of content standards, core competencies, basic competencies, materials, PjBL activities, Grade Point Average (GPA), assessment of learning outcomes, time allocation, learning resources and language is 92% which is considered to be very worthwhile. The average validation of learning tools from 10 respondents among educational practitioners with the acquisition of presentation results from each learning device is as follows: The syllabus has a validation value of 92% and the category is very valid and feasible to use without revision. The lesson plan has a validation percentage of 94% and the category is very valid and suitable for use without revision. The e-module has 91% and the category is very valid and suitable for use. The worksheet has a percentage of 91%, the category is very valid and feasible to use.

The learning tools developed include a syllabus, lesson plans, worksheets and modules. The learning model used is Project Based Learning (PjBL). The material in the teaching module is ESD-oriented STEAM-based fluid dynamics. The average expert validation results on the ESD-oriented STEAM-based syllabus reached 93% in the very feasible category. The aspects assessed include core and basic competencies, learning activities, indicators, assessments, time allocation and learning resources, materials or tools. This is in accordance with Nirwana (2018) which states that a syllabus is a learning plan for a particular subject or group of subjects or themes that includes competency standards, basic competencies, subject matter or learning, learning activities, indicators, assessments, allocations of time and learning resources, materials and tools. The syllabus is an elaboration of competency standards and basic competencies into subject matter or learning, learning activities and competency achievement indicators for assessment (Zulhanif, 2018).

The results of the validation of the lesson plan in this study were carried out to assess aspects of the formulation of learning objectives, content consisting of lesson plan systematics, learning model syntax, material suitability, learning scenarios, evaluation instruments, language and time. This is in accordance with the Government Regulation of the Republic of Indonesia Number 19 of 2005 concerning National Education Standards Article 20: "Planning the learning process includes syllabus and learning implementation plans that contain at least learning objectives, teaching materials, teaching methods, learning resources and assessment of learning outcomes" (Faridah, 2019).

The average of the lesson plan validation results reached 81% and educational practitioners got 94% in the feasible or valid category. In addition to assessing feasibility, experts also provide suggestions and comments to improve and revise the products that have been developed. More suggestions and comments on aspects of STEAM and ESD should be raised in learning. It should be noted that learning physics is not limited to the knowledge that must be understood by students. This is in accordance with the opinion of Hanna et al. (2017) that physics is both a process and a product. Process means the procedure for discovering physical products (facts, concepts, principles, theories, or laws) carried out through scientific steps.

The ESD-oriented STEAM-based worksheet that has been developed gets a validation value of 78% from experts in the feasible category and 91% from practitioners in the very feasible category. The worksheet's questions are accompanied by illustrations that serve as prompts for students to find solutions. This is consistent with Kurniawaty (2022) description of 21st-century learning in a variety of contexts which states that solving various unusual problems in both traditional and creative ways, identifying and asking important questions that clarify various points of perspective and producing better solutions. The worksheets were created with growing concern for the environment, sustainable learning and the next generation in mind. The STEAM model in the worksheet demands creativity. This is in accordance with the opinion (Septiani & Kasih, 2021) which states that the STEAM model is a combination that can support children to be more creative and independent.

The learning tools developed will be beneficial for physics teachers to make physics more interesting for students in their classroom. So, this study is very important to implement.

3.2. Practicality of ESD-Integrated STEAM-based Devices

Assessment of the practicality of ESD-integrated STEAM-based learning devices on fluid material by observing the implementation of learning using ESD-oriented STEAM modules and worksheets in the experimental class. Data on the results of the implementation of the learning process were obtained from one observer using the learning implementation sheet. Data from observations of the implementation of the learning process using ESD-oriented STEAM-based learning tools with the PjBL learning model is given in Table 6.

Table 6. Observation data on the implementation of learning

No	Observed aspect	Meeting						Score	Score max	Percentage (%)
		1	2	3	4	5	6			
1.	Introduction	4	4	3	4	4	4	23	24	96%
2.	Core activities									
	Phase 1	4	3	3	4	4	3	21	24	88%
	Phase 2	3	4	4	4	4	3	22	24	92%
	Phase 3	4	4	3	4	3	4	22	24	92%
	Phase 4	4	4	3	4	4	4	23	24	96%
	Phase 5	3	4	3	3	4	4	21	24	88%
	Phase 6	4	3	3	3	4	4	21	24	88%
3.	Closing	4	4	3	4	4	4	23	24	96%
% Average										92%
Criteria		Very good								

According to Table 6, the findings of observations on the learning process using PjBL-based teaching materials with ESD-oriented STEAM content obtained a percentage of 92% in each observed aspect, including preliminary aspects, core activities (Phase 1, 2, 3, 4, 5 and 6) and closing. The average practicality score is 92%. So, it is in the very good category.

Observation was conducted on the implementation of learning using ESD-oriented STEAM-based modules and worksheets in the experimental class. The implementation of the plans that the teacher has made in the form of lesson plans has been carried out according to the procedures and objectives. This is in accordance with the opinion of Mulyasa (2007) that the lesson plan describes the procedure and arrangement of learning to achieve a set of basic competencies in the content standards that have been described in the syllabus. The scope of the lesson plan includes basic competencies consisting of one or several indicators for meeting.

Researchers also found the worksheet practical in observing the implementation of the learning process. The developed worksheet is different from the worksheet previously used by students. The ESD-oriented STEAM-based worksheet is practical because it contains learning evaluations related to ESD aspects and the way of working on student activities associated with STEAM aspects. This is in accordance with the opinion of Pawestri and Zulfiati (2020) which states that worksheets are learning resources in the form of assignment sheets, instructions for carrying out tasks and learning evaluations that must be done by students and are made according to the basic competencies that must be achieved.

The practicality of the learning tools developed by physics teachers is good.

3.3. Effectiveness of ESD-Integrated STEAM- Based Devices

The effectiveness of the developed ESD-oriented STEAM-based learning tools increases students' creativity and their cognitive learning outcomes. Improved learning outcomes were obtained from the N-Gain calculation of pre-and post-test scores.

The recapitulation results of the N-Gain score show an increase in the ability of the average control class learning outcomes to be in a low category with an average N-Gain of 0.13. Two students got moderate N-Gain scores while 34 got low N-Gain scores. In addition to the control class, pre- and post-tests were also carried out for the experimental class. The results of the recapitulation of the N-Gain scores of one of the schools in Demak, Indonesia and the students in the experimental class showed an increase in the average learning outcomes in the medium category and an average N-Gain of 0.57. A total of eight students got a high N-Gain score and 28 got a moderate N-Gain score.

Observation sheets for measuring student creativity are also included in assessing the effectiveness of ESD-oriented STEAM-based fluid learning devices. The observation sheet consists of three aspects. The first is the project design for fluid concept materials to show tools and materials for product manufacture and to make products. The second is the implementation of the project which consists of difficulties faced by students regarding product tools and materials and product manufacture. The third is quality (project results) including the suitability of the product with the material whether the function of the product is clear and correct and the ability to show product aesthetics.

Based on the recapitulation results, the average student creativity reached 86.12% which was very good. These results are given in Figure 1.

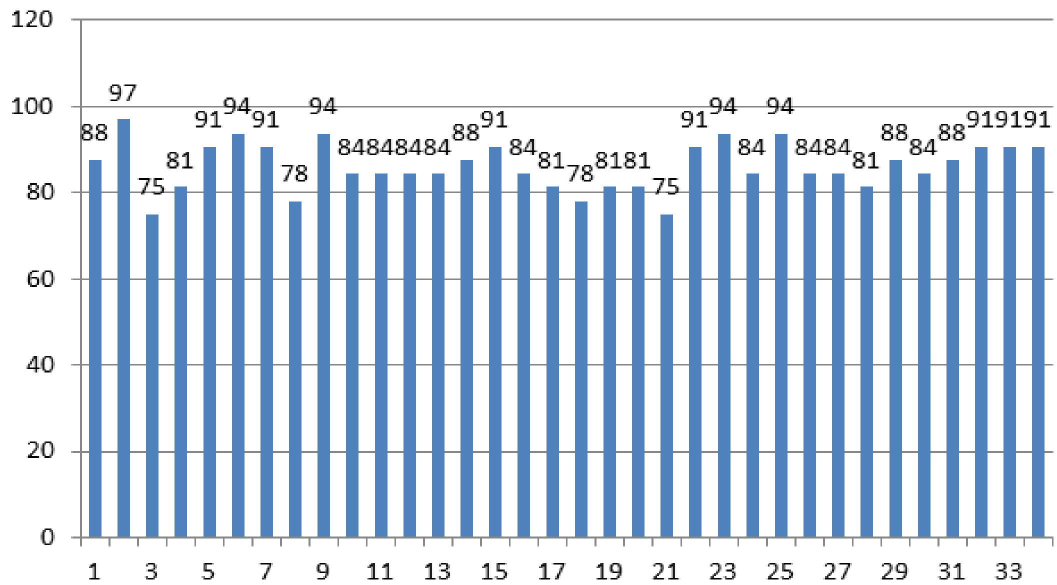

Figure 1. Student creativity percentage diagram.

Based on Figure 1, the lowest percentage of student creativity is 75% and the highest is 97%. The average reached 86.12%. Assessment of the effectiveness of ESD-oriented STEAM-based learning tools is measured based on the increase in creativity and students' cognitive learning outcomes. Improved learning outcomes were obtained from the N-Gain calculation of pre- and posttest scores.

The increase in learning outcomes in the experimental class is moderate with an average N-Gain of 0.57. A total of eight students got a high N-Gain score and 28 got a moderate N-Gain score. When compared with the control class, the average N-Gain is 0.13. A total of 2 students got moderate N-Gain scores while 34 got low N-Gain scores. This shows that ESD-oriented STEAM-based learning tools improve physics learning outcomes in a fluid material. This result proves that students have achieved their learning objectives through the learning process. According to Abdullah (2017), understanding learning outcomes is an ability children acquire after going through learning activities. Learning is the process of someone trying to obtain a relatively permanent form of behavior change. In learning activities, teachers usually set learning goals. Students who are successful in learning are those who succeed in achieving learning objectives.

Student creativity is also included in assessing the effectiveness of ESD-oriented STEAM-based fluid learning devices. Student creativity is assessed on the observation sheet which consists of three aspects: project design, implementation and project results (quality). The average creative output of the 34 students was 86.12% reaching a very good level. Creativity is built through the PjBL learning model where students carry out activities to complete projects by facing everyday problems. According to Santrock's opinion, creativity is the ability to think about something in a new and unusual way and produce a unique solution to a problem (Purwadi, Sarwanto, & Sunarno, 2016).

The results of a study by Perignat and Katz-Buonincontro (2018) about STEAM show that STEAM learning aims to develop student creativity or as a means to improve real-world problem-solving skills. Additionally, STEAM has been shown to raise interest in STEM subjects, improve the number of minority and female students pursuing STEM jobs and involve more children in these fields. In addition, STEAM also emphasizes the integration of general skill domains such as perspective-taking skills, creative skills, problem-solving skills, cross-disciplinary knowledge transfer and encouraging students to explore and provide experiences in new ways (Zubaidah, 2019).

4. Conclusion

The STEAM model integrated with ESD is very valid, has good practicality and effectively improves understanding of fluid concepts. The implications of this study are to make physics learning more interesting for students. Additionally, these results can make suggestions to curriculum developers to include this model in teaching physics in their classroom. The limitations of this study are that the model was only tried to be implemented in the physics course. Therefore, it needs to be tried in other science disciplines such as chemistry, biology and science courses.

References

Abdullah, B. (2017). The meaning of learning in education. *Jurnal Pendidikan Dan Pemikiran Isalm ISTIQRA, 5*(1), 94-102.

Agusti, K. A., Wijaya, A. F., & Tarigan, D. E. (2019). *Problem based learning with the ESD context to improve critical thinking skills and sustainability awareness of high school students on global warming material.* Paper presented at the Procedure of the National Physics Seminar (E-Journal).

Borg, W. R., & Gall, M. (2003). *Educational research: An introduction* (4th ed.). London: Longman Inc.

Datu, H. R., Qadar, R., & Junus, M. (2020). Application of the project based learning (PjBL) learning model to improve physics learning outcomes for class XI students of SMA Negeri 5 Samarinda. *Jurnal Literasi Pendidikan Fisika, 1*(02), 138-144. https://doi.org/10.30872/jlpf.v1i02.231

Faridah, F. (2019). Improving teacher competence in compiling syllabus and lesson plans through continuous academic supervision at Sabang 2 public middle school. *Tadabbur: Jurnal Peradaban Islam, 1*(2), 359-376.

Hanna, D., Sutarto, S., & Harijanto, A. (2017). The concept theme learning model is accompanied by media images in physics learning in high school. *Jurnal Pembelajaran Fisika, 5*(1), 23-29.

Hendriyani, M. E., Rifqiawati, I., & Usman, U. (2023). Students' creativity profile using project report through the STEM integrated project based learning model. *Jurnal Pendidikan Indonesia Gemilang, 3*(1), 68-75. https://doi.org/10.53889/jpig.v3i1.182

Hidayah, N., & Ami, M. S. (2021). Expert validation of the herbarium collection of plants used in the Tedhak Siti traditional ceremony in Jombang Regency. *Jurnal Kajian Pendidikan IPA, 1*(2), 53-61.

Khoiri, N., Marinia, A., & Kurniawan, W. (2016). The effectiveness of the PjBL learning model (Project Based Learning) on the creativity ability and learning outcomes of class XI students. *Jurnal Penelitian Pembelajaran Fisika, 7*(2), 142-146. https://doi.org/10.26877/jp2f.v7i2.1309

Khoiri, N., Riyadi, S., Kaltsum, U., Hindarto, N., & Rusilawati, A. (2017). *Teaching creative thinking skills with laboratory work*. Paper presented at the International Journal of Science and Applied Science: Conference Series.

Kurniawaty, I. (2022). Characteristics and assessment of 21st century learning. *Jurnal Basicedu, 6*(2), 4862-4868. https://doi.org/10.31004/basicedu.v5i5.1548

Lestari, S. (2021). Development of 21st century skills orientation in physics learning through spectra-Plus assisted PjBL-STEAM learning. *Ideguru: Jurnal Karya Ilmiah Guru, 6*(3), 272-279. https://doi.org/10.51169/ideguru.v6i3.243

Mulyadi, E. (2015). Application of the project based learning model to improve the physics learning performance and achievement of SMK students. *Jurnal Pendidikan Teknologi Dan Kejuruan, 22*(4), 385-395. https://doi.org/10.21831/jptk.v22i4.7836

Mulyasa, E. (2007). *Education unit level curriculum*. Bandung: PT. Remaja Rosdakarya.

Nirwana, N. (2018). Efforts to improve teacher capacity in preparing lessons in Al Mustafa Kindergarten, Jambi City. *Jurnal Literasiologi, 1*(2), 16-16. https://doi.org/10.47783/literasiologi.v1i2.34

Novianto, N. K., Masykuri, M., & Sukarmin, S. (2018). Development of a project-based learning physics module on static fluid material to increase the learning creativity of class X SMA/MA students. *Inkuiri: Jurnal Pendidikan IPA, 7*(1), 81-92. https://doi.org/10.20961/inkuiri.v7i1.19792

Novidsa, I., Purwianingsih, W., & Riandi, R. (2020). Exploring knowledge of prospective biology teacher about education for sustainable development. *Jurnal Pendidikan Biologi Indonesia, 6*(2), 317-326. https://doi.org/10.22219/jpbi.v6i2.12212

Nurfadilah, S., & Siswanto, J. (2020). Analysis of the ability to think creatively on the concept of polymers with the ESD-laden STEAM approach for SMA Negeri 1 Bantarbolang students. *Media Penelitian Pendidikan: Jurnal Penelitian Dalam Bidang Pendidikan Dan Pengajaran, 14*(1), 45-51. https://doi.org/10.26877/mpp.v14i1.5543

Pawestri, E., & Zulfiati, H. M. (2020). Development of student worksheets (LKPD) to accommodate student diversity in class II thematic learning at SD Muhammadiyah Danunegaran. *Trihayu: Jurnal Pendidikan Ke-SD-An, 6*(3), 903-913. https://doi.org/10.30738/trihayu.v6i3.8151

Perignat, E., & Katz-Buonincontro, J. (2018). From STEM to STEAM: Using brain-compatible strategies to integrate the arts, by David A. Sousa and Tom Pilecki. (2013). In (pp. 280). Thousand Oaks, CA: Sage.

Purwadi, S. J., Sarwanto, S., & Sunarno, W. (2016). Increased creativity and achievement in physics learning material mechanical properties of substances through Edmodo media in class X TKJ B SMK Negeri 2 Surakarta semester II of the 2013/2014 academic year. *Inkuiri, 5*(1), 45-55.

Quigley, C. F., & Herro, D. (2016). “Finding the joy in the unknown”: Implementation of STEAM teaching practices in middle school science and math classrooms. *Journal of Science Education and Technology, 25*(3), 410-426. https://doi.org/10.1007/s10956-016-9602-z

Rahmawati, S., Roshayanti, F., Nugroho, A. S., & Hayat, M. S. (2021). Potential implementation of education for sustainable development (ESD) in science learning at MTs Nahdlatul Ulama Mranggen, Demak Regency. *Journal of Education Quality, 2*(1), 15–27.

Ruhiat, Y., Sutisna, S., Hasani, A., Kuswantoro, M., Widiastuti, S., Fahrizal, R., & Wibowo, F. C. (2016). A formation model in distribution of sulfur dioxide (SO2) concentrations in cilegon city with the use of grid technique. *International Journal of Interdisciplinary Environmental Studies, 11*(3), 1-10.

Ruhiat, Y., Wibowo, F. C., & Oktarisa, Y. (2017). *Air pollutants minimalization of pollutant absorber with condensation system*. Paper presented at the In Journal of Physics: Conference Series, IOP Publishing.

Segera, N. B. (2015). Education for sustainable development (ESD) is an effort to realize environmental sustainability. *Sosio Didactic: Social Science Education Journal, 2*(1), 22–30.

Septiani, I., & Kasih, D. (2021). Implementation of the STEAM method for the independence of children aged 5-6 years at paud alpha omega school. *Jurnal Jendela Pendidikan, 1*(04), 192-199.

Sugiyono. (2013). *Qualitative and combination research methods. in Alphabet*. Bandung: Alphabet.

Suryaningsih, S., Nisa, F. A., Muslim, B., & Aldiansyah, F. (2022). Learning innovations: Students’ interest and motivation on STEAM-PjBL. *International Journal of STEM Education for Sustainability, 2*(1), 66-77. https://doi.org/10.53889/ijses.v2i1.40

Wahyuningsih, S., Pudyaningtyas, A. R., Hafidah, R., Syamsuddin, M. M., Nurjanah, N. E., & Rasmani, U. E. E. (2019). The effect of the STEAM method on the creativity of children aged 5-6 years. *Journal of Obsession: Journal of Early Childhood Education, 4*(1), 305.

Wijayanti, R., Roshayanti, F., Farikhah, I., Khoiri, N., & Siswanto, J. (2021). Analysis of physics teaching materials based on the perspective of education for sustainable development. *Educational Journal: Journal of Research Results and Literature Review in the Field of Education, Teaching and Learning, 7*(2), 340-345.

Zubaidah, S. (2019). *STEAM (Science, Technology, Engineering, Arts, and Mathematics): Learning to empower 21st century skills*. Paper presented at the National Seminar on Mathematics and Science, (September).

Zulhanif. (2018). Preparation of syllabus and learning implementation plans (RPP) to improve teacher competence through academic supervision at SDN 165 Pekanbaru. *Pigur Journal, 01*(02), 42–52.