

ENHANCING SCIENCE PROCESS SKILLS OF ELEMENTARY SCHOOL STUDENTS IN INDONESIA THROUGH THE INTEGRATION OF ENGINEERING DESIGN PROCESS (EDP) LEARNING MODEL BASED STEM APPROACH

MELHORAR AS COMPETÊNCIAS DE PROCESSOS CIENTÍFICOS DOS ALUNOS DO ENSINO BÁSICO NA INDONÉSIA ATRAVÉS DA INTEGRAÇÃO DA ABORDAGEM STEM BASEADA EM MODELOS DE APRENDIZAGEM DO PROCESSO DE DESIGN DE ENGENHARIA (EDP)

Article received on: 8/18/2025

Article accepted on: 11/17/2025

Astri Sutisnawati*

Universitas Negeri Jakarta (UNJ), South Jakarta, Indonesia

Orcid: <https://orcid.org/0000-0003-0737-7081>

astrisutisnawati@ummi.ac.id

Yuli Rahmawati*

Universitas Negeri Jakarta (UNJ), South Jakarta, Indonesia

Orcid: <https://orcid.org/0000-0002-1603-3320>

yrahmawati@unj.ac.id

Mohamad Syarif Sumantri*

Universitas Negeri Jakarta (UNJ), South Jakarta, Indonesia

Orcid: <https://orcid.org/0000-0002-7354-4477>

syarifsumantri@unj.ac.id

The authors declare that there is no conflict of interest

Abstract

Amid the escalating demands of 21st century education, the development of science process skills has become a critical priority that must be fostered from an early age through pedagogical activities emphasizing inquiry, experimentation, and reflective practice. This study seeks to address this imperative by designing and empirically validating a science instructional model for Indonesian elementary students that embeds the Integration of Engineering Design Process (EDP) Learning Model Based STEM Approach. The model was developed following the Dick and Carey instructional design paradigm and progressed through four major phases, including the specification of learning objectives, the design of an EDP integrated STEM instructional model, and the implementation of both formative and summative assessments. Expert judgment indicated a very high level of alignment and suitability across content, construct, and implementation dimensions, supporting the theoretical soundness of the proposed model. Classroom trials involving teachers and students demonstrated that the integration EDP based

Resumo

Em meio às crescentes exigências da educação do século XXI, o desenvolvimento das competências do processo científico tornou-se uma prioridade crítica que deve ser fomentada desde cedo através de atividades pedagógicas que enfatizam a investigação, a experimentação e a prática reflexiva. Este estudo procura responder a este imperativo ao desenhar e validar empiricamente um modelo instrucional de ciências para alunos do ensino básico indonésios que incorpora a Abordagem STEM baseada em modelos de aprendizagem do Processo de Design de Engenharia (EDP). O modelo foi desenvolvido seguindo o paradigma de design instrucional de Dick e Carey e avançou por quatro fases principais, incluindo a especificação dos objetivos de aprendizagem, o desenho de um modelo instrucional STEM integrado pelo EDP e a implementação de avaliações formativas e sumativas. O julgamento dos peritos indicou um nível muito elevado de alinhamento e adequação entre dimensões de conteúdo, construção e implementação, apoiando a solidez teórica do modelo proposto. Ensaios em sala de aula



STEM learning model is feasible to implement and closely aligned with the demands of elementary science education. Effectiveness testing using the Independent Samples t test yielded a significance value of < 0.001 , indicating a statistically significant difference in science process skill scores between the experimental and control classes. These findings substantiate that the the Integration of Engineering Design Process (EDP) Learning Model Based STEM Approach possesses strong theoretical validity, commendable practicality, and substantial effectiveness in enhancing elementary students' science process skills. By engaging students in EDP oriented STEM activities, the model provides authentic problem solving experiences that cultivate their abilities to observe, formulate hypotheses, design investigations, analyze data, and derive evidence based conclusions in real world contexts.

Keywords: Engineering Design Process. elementary. science. STEM Approach.

envolvendo professores e alunos demonstraram que o modelo de integração de aprendizagem STEM baseado em EDP é viável de implementar e está estreitamente alinhado com as exigências da educação científica do ensino básico. Os testes de eficácia com o ttest de Amostras Independentes apresentaram um valor de significância de $< 0,001$, indicando uma diferença estatisticamente significativa nas pontuações de competências de processos científicos entre as classes experimental e de controle. Estas conclusões comprovam que a Abordagem STEM baseada em modelos de aprendizagem do Processo de Projeto de Engenharia (EDP) possui forte validade teórica, praticidade louvável e eficácia substancial no aprimoramento das competências de processos científicos dos alunos do ensino básico. Ao envolver os alunos em atividades STEM orientadas para EDP, o modelo proporciona experiências autênticas de resolução de problemas que cultivam as suas capacidades de observar, formular hipóteses, desenhar investigações, analisar dados e derivar de conclusões baseadas em evidências em contextos do mundo real.

Palavras-chave: Processo de Design de Engenharia, ensino básico, ciências, Abordagem STEM.

1 INTRODUCTION

Science process skills are an important foundation in science education that students must master, especially in today's era of technological and information disruption. In the context of 21st century skill demands, mastery of these skills not only facilitates the understanding of scientific concepts but also encourages individuals to reason and act on scientific principles. These skills play an important role in facilitating independent learning and self-development, which are key to lifelong learning (Deta et al., 2020). In addition, the ability to solve complex problems is becoming increasingly important in the face of future challenges. Therefore, the development of science process skills among students is not only relevant, but also crucial to ensure their success in an ever-changing world.

Science process skills comprise a comprehensive set of essential competencies that enable students to engage effectively in scientific inquiry. Key skills include

systematic observation, which involves careful recording of details and patterns observed in nature, as well as accurate measurements that ensure precise quantification of data. In addition, effective classification allows the organization of information into coherent categories, facilitating a clearer analysis. Formulating hypotheses represents another important skill, as it involves generating informed predictions that guide experimental investigation. The ability to interpret data is critical, allowing individuals to draw meaningful conclusions based on empirical findings. In addition, identifying variables is essential in understanding the elements that influence the outcome of experiments. Conducting experiments serves as a fundamental component of scientific inquiry, giving individuals a direct opportunity to test their hypotheses. After the experiment, learners must articulate conclusions substantiated by the collected data, contributing to a deeper understanding of scientific principles (Herda et al., 2020). Science process skills influence learning outcomes and foster creative thinking skills, as well as the ongoing development of basic science process skills such as observing, classifying, measuring, predicting, using numbers, understanding space-time relationships, and summarizing/communicating are essential in science learning (Juhji & Nuangchalerm, 2020). Science process skills are found in the IPAS learning approach which includes the activities of observing, questioning and predicting, planning and conducting research, processing and analyzing data and information, evaluating and reflecting, and communicating results (Kemendikbud Ristek, 2020).

STEM, which stands for Science, Technology, Engineering, and Mathematics, was created with the primary goal of significantly enhancing the educational experience by systematically integrating diverse knowledge, innovative ideas, and essential skills essential to student development in today's rapidly evolving world (Tseng et al., 2013). The implementation of STEM education does more than help students to memorize abstract concepts; it also focuses on fostering a deeper understanding of concepts that are not only relevant but also applicable to their daily lives, thereby enriching their overall learning experience in a practical context. From an educational perspective, STEM can encompass a wide variety of engaging activities and hands-on experiences, but typically involves replacing thoughtful conventional teaching strategies with a more dynamic, inquiry-based, project-oriented approach that encourages active participation and critical thinking (Breiner Jonathan M. et al., 2020). In the field of STEM learning, teachers adopt roles that are fundamentally different from traditional knowledge transfer; instead, they

serve as facilitators who actively assist students in navigating the learning process, help them acquire vital skills, and guide them in discovering and understanding the intricacies of the learning process on a personal level (Zamista, 2018). STEM Through effective implementation of STEM education, students are empowered to become not only better tech-literate individuals but also innovative thinkers, inventive creators, self-learners, logical analysts, and proficient problem solvers equipped to address the complex challenges of the modern world (Stohlmann et al., 2012). To address issues related to science process skills, there is a need for a strong, student-focused learning framework. Student-focused teaching methodologies enhance the cultivation of SPS in learners by engaging them in cognitive and practical activities (Gizaw & Sota, 2023), similar to the Engineering Design Process learning model (Kline & Schindel, 2017).

The engineering design process is a comprehensive and structured framework that guides individuals through a series of different iterative steps aimed at developing a functional and effective product. Initially, this process begins with generating innovative ideas, encouraging creativity and different thinking. During this phase, participants are assigned to exchange their minds about potential solutions to specific project problems or requirements, based on their knowledge and experience. After the ideation stage, the evaluation process takes center stage. Here, individuals critically assess the feasibility, practicality, and potential impact of each proposed idea (Fattepur et al., 2016). The purpose of the Engineering Design Process Learning Model is not only to prepare students to understand lessons academically, but also to equip them with the innovation, collaboration, and problem-solving capabilities essential for future success, both in advanced education and the world of work, Metz argues that technical design is capable of improving learning outcomes, scientific literacy, and partially empowering a population that has historically been underrepresented in science and engineering (Metz et al., 2014).

Students' science process skills can be enhanced by interdisciplinary integrated teaching that combines multidisciplinary knowledge and skills. This approach, through project-based learning and STEAM education, fosters innovative thinking, problem-solving, and teamwork, ultimately enhancing students' comprehensive abilities and practical application skills (Su, 2025). STEM (Science, Technology, Engineering, and Mathematics) approaches are implemented to deal with real-world challenges through designs that focus on problem-solving processes, similar to those undertaken by

professional engineers and scientists. By making STEM learning central to educational reform, we can create a more supportive environment for students, giving them the opportunity to initiate and continue developing skills that are so important in the 21st century (Williams, 2011). STEM learning not only serves as a tool for understanding scientific concepts, but also prepares students to hone much-needed creative thinking skills in the face of global competition in this modern era. Skills such as problem solving, critical thinking, and collaboration are becoming increasingly important in the context of an ever-changing and evolving world (Becker & Kurt, 2011). Through this approach, students are encouraged to be actively involved in the learning process, encouraging them to think innovatively and apply their knowledge in real situations, so that they can become individuals who are not only prepared to face future challenges, but are also able to contribute positively to society. (Becker Kurt, 2011).

This research aims to address the challenges that have been identified by developing and evaluating the effectiveness of a learning model that integrates the Engineering Design Process based STEM approach,, which produces a PRODUCTIVE syntax, to improve the science process skills of elementary school students. The development of PRODUCTIVE learning models can be an effective combination in developing skills to face global challenges in the modern era as well as providing opportunities to learn science in a cross-cultural and cross-disciplinary context (Sutisnawati et al., 2025)

1.1 Research questions

Referring to the previous explanation, this study seeks to answer some of the following key questions:

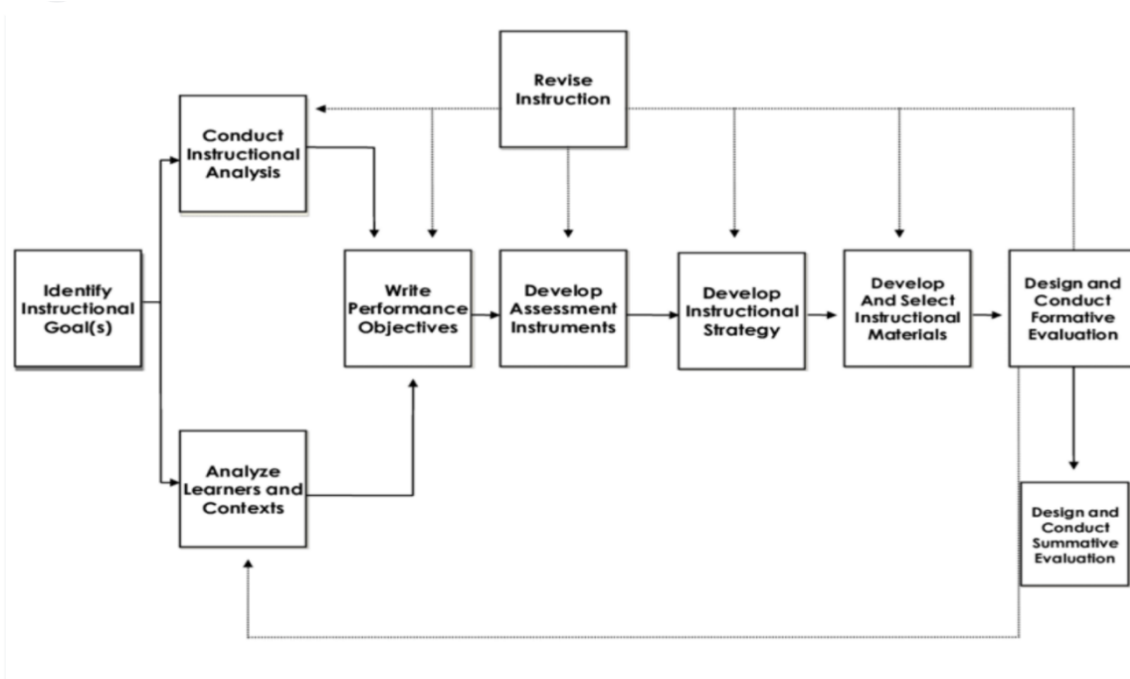
1. How was learning models developed?
2. How valid is the developed learning model?
3. How practical is the learning model when implemented?
4. How effective are those learning models in improving students' science process skills?

2 METHOD

2.1 Research design

The study uses research and development (R&D) methods with reference to Dick and Carey's model of learning system development, which emphasizes systematic interrelationships between goals, learning analysis, strategies, materials, and evaluation (Dick et al., 2001). Development procedures are tailored into several key stages, namely: (1) identification of learning objectives of science process skills; (2) instructional analysis and analysis of students' characteristics and primary school contexts in Indonesia; (3) formulation of specific learning objectives and indicators of science process skills; (4) development of science process skills assessment instruments and scientific attitudes; (5) design of learning strategies based on integration of engineering design process (EDP) learning model based STEM approach (6) development and selection of materials Teaching, teacher guide, and learning media; (7) limited trials and large group trials with formative evaluations; and (8) product revision until producing a final learning device worthy of use. The field implementation phase concludes with a summative evaluation to test the effectiveness integration of engineering design process (EDP) learning model based STEM approach in improving students' science process skills through the design of pseudo-experiments with pre- and post-treatment measurements.

Figure 1
Research Design



The research process carried out is clearly visualized in Figure 1, which illustrates the integration between qualitative and quantitative methods throughout the entire research phase. In the initial phase, i.e. needs analysis and learning goal setting, qualitative approaches are prioritized through the use of in-depth interviews, review of relevant documents, as well as data triangulation involving various parties, including students, teachers, and principals. This method aims to dig into a deeper understanding of the context and needs that exist in the field. The information and insights gained from this process then become a solid foundation for formulating conceptual designs as well as frameworks of learning models that are effective and responsive to learners' needs. Thus, the study focuses not only on numbers and statistics, but also on the experiences and perspectives of all stakeholders involved.

During the field implementation phase, two schools participated in the study, involving a total of 120 students divided into two groups, namely the experimental group and the control group. Each group consisted of 30 students per school, which ensured that there was a clear comparison between the two approaches tested. Each student is given a uniform learning device, as well as an evaluation instrument designed to measure the effectiveness of the applied methods. These instruments include pre-tests to assess students' initial knowledge, post-tests to evaluate their understanding after interventions,

and worksheets designed to support the learning process. Each phase of this experiment produced significant quantitative data, mainly in the form of scores from the pre-test and post-test, as well as measurements of the practicality of the applied methods. In addition, qualitative data is also collected through student feedback, direct observations during the learning process, and in-depth group discussions. The process of analyzing these two types of data is very important, as it allows researchers to build a final model that is not only based on empirical evidence, but also takes into account student input and experience. Thus, the resulting model becomes more contextually relevant and has a solid basis in effective pedagogical practice. This ensures that the approach adopted is not only in accordance with the theory, but can also be applied in a real way in the student's learning environment.

2.2 Research subject

Field implementation of the study was conducted in two different primary schools, with each school numbering 60 students. The students were divided into two groups: an experimental group that used a PRODUCTIVE learning model and a control group that applied conventional learning methods. This division is designed to provide a clear comparison between the effectiveness of the two learning approaches. Although the trial participants were different at each stage, all students involved in the study had comparable characteristics. They were fifth graders with relatively similar early science process skills. It is important to ensure that the observed differences in research results can be attributed directly to the applied learning methods, rather than due to other variables that may affect student learning outcomes. Thus, this research seeks to make a significant contribution to the development of more effective learning methods at the primary education level.

2.3 Instruments

The instruments used in the study include measurements of validity, practicality, and effectiveness, with a particular focus on developing students' science process skills at the elementary school level. The process of formulating and developing learning objectives is carried out with a qualitative approach, which includes document analysis,

in-depth interviews, and triangulation of data from various sources in the school. This approach aims to gain a holistic understanding of learning needs and contexts.

Validity is the first aspect to be evaluated, where an expert validation rubric is applied to assess the design of the student's learning model and worksheet. The rubric is designed to evaluate the various components of the learning model, including the content presented and its relevance to Engineering Design Process (EDP) theory as well as Science, Technology, Engineering, and Mathematics (STEM). For student worksheets, the validation rubric is divided into three main categories: content validation, language validation, and media validation. This validity measurement process was carried out using a 5-point Likert scale, which allowed for a more structured and systematic assessment.

The practicality of the developed learning model was evaluated through user responses, which were collected through questionnaires filled out by students and teachers during the field trial and implementation phases. This level of practicality is measured based on user responses regarding several aspects, including the usefulness of the PRODUCTIVE learning model, its ease of use, and the level of satisfaction and enjoyment felt during the teaching learning process. Analysis of this data was also carried out using a 5-point Likert scale, giving a clear picture of user perception. The effectiveness of learning models is measured through pre- and post-test methods, which focus on science process skill indicators. The instrument is designed to measure seven essential indicators of science process skills: observing, questioning, hypothesizing, predicting, investigating, interpreting, and communicating findings (Harlen, 1999). With this comprehensive approach, it is hoped to obtain valid and reliable data on the effectiveness of learning models in improving students' science process skills.

2.4 Data analysis

In determining the degree of practicality of a method or tool, assessment is carried out by comparing scores obtained from student and teacher feedback against the maximum possible achievable score. Results from this comparison were then classified into five levels: “impractical” categories for scores between 0 to 20, “less practical” for scores of 21 to 40, “reasonably practical” for scores of 41 to 60, “practical” for scores of 61 to 80, and “very practical” for scores reaching 81 to 100 (Novitra, 2021). In the context of science process skills, scores are calculated by comparing the results of each student

to the maximum achievable score. Furthermore, to evaluate student progress, the difference between pre-test and post-test scores is used to determine gain scores. These gain values are then classified into five categories: “decrease” for values below -1.00, “no improvement” for values equal to 0.00, “low” for values between 0.00 and 0.30, “moderate” for values between 0.30 to 0.70, and “high” for values ranging from 0.70 to 1.00 (Sukarelawan et al., 2024).

To assess the effectiveness of the PRODUCTIVE model in improving science process skills, an independent t-test was performed on the gain value. The test aims to compare the improvement in ability between students in the experimental class and the control class. Before the analysis is performed, it is important to ensure the equivalence of initial ability between the two groups by using an independent t-test. If the results of the pretest show that there are no significant differences between the two groups, then the analysis can be continued to identify differences in the increase in critical thinking ability, which is carried out on the basis of the t-test of the gain value obtained.

3 RESULTS

The results section provides a comprehensive analysis of the four research questions outlined earlier. Each question is discussed in detail, highlighting the methodology used, the data collected, and the implications of the findings. This thorough examination not only clarifies the importance of the research but also illustrates how the results contribute to the wider field of study.

3.1 Development of the PRODUCTIVE learning model

The development of the learning model known as PRODUCTIVE begins with a fundamental step, that is, the determination of instructional objectives. This process is carried out carefully through the analysis of the needs, performance and characteristics of the students. Various methods are used to obtain accurate and comprehensive data, including surveys, document analysis, live observations, as well as focused group discussions (FGD). Through this approach, educators can better understand students' specific contexts and needs, which in turn influence the development of learning models. Based on the results of an in-depth analysis of student characteristics and performance,

the critical thinking indicators to be reinforced through this learning model include a number of important skills. Such indicators include the ability to identify problems, systematically collect and analyze data, assess emerging dominant concepts, evaluate existing arguments, draw logical conclusions, as well as conduct reflections on thought processes and results achieved. These instructional goals serve as strategic guidelines in designing learning syntax. This is in line with the views of Inch & Tudor (2015), who emphasize the importance of the science process skill cycle in designing effective approaches to meet the need for improving science process skills among students. The next stage in the development of this model is to create an appropriate instrument to measure the achievement of the established instructional objectives. This process is followed by the integration of Engineering Design Process (EDP) and Science, Technology, Engineering, and Mathematics (STEM) based learning experiences aimed at encouraging critical thinking among students. From this integration, learning principles and a syntax are generated consisting of four stages, which are abbreviated as PRODUCTIVE: Problem Engagement, Design, Prototyping, and Testing and Evaluation. This learning model resulting from the merger of EDP and STEM came to be known as PRODUCTIVE. This complex and structured integration process is summarized in table 1, which provides a clear picture of the steps taken as well as the relationships between the components in the learning model. Thus, the PRODUCTIVE model serves not only as a tool for learning, but also as a framework that supports the development of students' critical and creative thinking skills in the face of real-world challenges.

Table 1
Integration EDP in STEM

EDP (Wind et al., 2017)	Concept STEM (Roehrig et al., 2021)	Science process skills (Harlen & Jelly, 1990)	Integration STEM-KPS	EDP-Basis Theory	Of	PRODUCTIVE Learning Model
1. Problem Definition 2. Problem Understanding	Focus on real-world problems	Observing	The process of identifying real-world problems that must be solved.	John Dewey's problem-solving theory		Problem Engagement: 1. Emphasizes that deep problem solving and understanding is the main step before finding a solution 2. Emphasizing decision-making is the selection of certain behavioral alternatives (behaviors) from two or more existing alternatives
1. Problem Understanding, 2. Problem Definition	Centrality of engineering	Observing and Questioning	The activity of finding and asking questions about observations and formulating questions from various sources uses the role of engineering to solve existing problems.	George R. Terry's Theory of Summary Results:		
1. Conceptual Design 2. Concept Evaluation	Context integration	Hypothesizing, Predicting	Propose consistent explanations to allow solutions to problems at the conceptual level.	Contextual Research Theory in the development of Vygotsky innovations:		Design 1. Research must integrate contextual integration so that the solutions developed are relevant and applicable in the real world. 2. The process of combining concepts and knowledge from different disciplines science to achieve holistic understanding, solve complex problems, and come up with innovative solutions.
1. Concept Evaluation 2. Concept Evaluation	Content integration	Hypothesizing, Predicting	Make suggestions about future events and analyze the integration of content across disciplines based on observations	Interdisciplinary Theory		
Prototyping	STEM practices	Investigating	Creating prototypes in the form of planning and conducting experiments by combining STEM practices.	Theory Pahl and Beitz		Prototyping, is a critical step in the engineering and science design process, where prototypes are used to test concepts, collect data, and refine designs.
Testing	Twenty-first century skills	Investigating, Interpreting	Interpret results and test prototypes to see if the design meets the requirements and constraints by prioritizing 21st century skills.	Experiential Learning Theory According to David Kolb:		Testing and Evaluation : 1. Testing is conducted through hands-on activities that stimulate participants to apply 21st century skills, solve real problems, and reflect on the process.
Iteration	Informing students about STEM careers	Communicating	Review the tested prototype to communicate the results in the learning.	EDP theory according to Wind et al., 2017 which states that Iteration		2. Evaluation and iteration characterize engineering design processes in which various stages can be frequently updated and revisited as new knowledge of the

EDP (Wind et al., 2017)	Concept STEM (Roehrig et al., 2021)	Science process skills (Harlen & Jelly, 1990)	Integration STEM-KPS	EDP-Basis Theory	Of PRODUCTIVE Learning Model	proposed problem or solution is acquired.
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3.2 Validity of PRODUCTIVE learning model

The PRODUCTIVE learning model undergoes a rigorous validation process conducted by a panel of four instructional design experts, referred to as the Validator (Va). This evaluation uses a specific assessment rubric adapted to the learning model, ensuring that the PRODUCTIVE framework meets the established pedagogical standards. In parallel, the student worksheets associated with the model received validation from a broader group of nine experts. These experts use three different types of grading rubrics, carefully designed to evaluate the various dimensions of a worksheet, including content accuracy, language clarity, and media effectiveness. Each of the three assessment rubrics is scrutinized by a trio of experts, facilitating a comprehensive evaluation process. This collaborative validation involves in-depth discussion and detailed written assessment, enabling a thorough examination of the material. The validation process continues on an iterative basis until the validator reaches a consensus, finally declaring the developed product as valid and effective for educational use. The findings from this validation analysis of the PRODUCTIVE learning model are summarized in Table 2, which provides a detailed overview of assessment results and expert feedback.

Table 2*Result of Validation Model by Expert*

Assessment Aspect	Score				Average	%
	Va1	Va2	Va3	Va4		
Learning Model Focus						
	20	19	17	20	19	13,8 %
Syntax	29	29	29	32	29,75	21,6 %
Model Reaction Principle	20	17	17	19	18,25	13,2 %
Model Social Systems	30	28	24	28	27,5	19,9 %
Model Support System						
	15	15	12	15	14,25	10,4 %
Instructional and Companion						
Impacts	25	24	23	24	24	17,4 %
Model Rationality	5	5	5	5	5	3,6 %
Total Score	129	122	115	128	551	
Criteria					91,8%	Very Valid

The validation results show that the PRODUCTIVE learning model has been classified as highly valid, underscoring its remarkable suitability for integration into the educational process. This assessment highlights a robust model design, which is effectively aligned with contemporary pedagogical standards and practices. Validation scores are significantly supported by three main factors: the theoretical foundation of the model, the components that make up the learning framework, and the support system that improves its implementation. Each of these elements plays an important role in asserting the effectiveness and applicability of the model in real-world educational settings. Table 3 provides a comprehensive overview of expert validation results regarding material content, language proficiency, and media used in student worksheets.

Table 3*Result of Validation Student Worksheet by Expert*

Assessment Aspect	Validity	
	Overall Average (%)	Criteria
Content	96,6	Very Valid
Language	83,2	Very Valid
Media	94,5	Very Valid

Notably, the validity of this worksheet received very high ratings, especially in the language field, which garnered the highest score among the evaluated criteria. These results reinforce the idea that the learning model and accompanying worksheet have been carefully crafted to meet established eligibility standards, positioning them for successful application in the educational environment. Furthermore, these findings underscore a

strong theoretical foundation supporting the development of PRODUCTIVE learning models. This solid foundation not only enhances the credibility of the model but also ensures that it is well equipped to facilitate an effective learning experience for students. Overall, the validation results confirm that the PRODUCTIVE learning model and its related materials are ready for implementation, promising to enrich the learning journey for educators and learners.

3.3 Practically of PRODUCTIVE learning model

The next stage in the study was to conduct an in-depth evaluation of the practicality of student learning models and worksheets, conducted through assessments by science teachers at the primary school level. The results of the analysis presented in Table 4 show that both learning tools are in the category of highly practical and effective.

Table 4

Practicality Result According to The Teachers

PRODUCTIVE Learning Model	%
Relevance of the material to Learning Outcomes	13,63
Clarity of Material	33,6
Relevance of the material to the Learning Objectives	12,72
Clarity of learning resources	8,18
Facilitating Science Process Skills	26,26
Total Score	94,5
Criteria	Very Valid

In aspects of usability, ease of application, and level of satisfaction, each of the learning tools managed to achieve impressive scores, with all scores being above 94,5%. Usability, in this case, records the highest average, signifying that this tool is not only relevant but also highly beneficial to the learning process. Student worksheets also demonstrate a high level of practicality, especially in terms of the content presented, the use of appropriate language, and the level of user satisfaction. The material aspect, in particular, earned the highest score, reflecting the suitability of the content with the competencies and needs of the student. Overall, the results of this evaluation show that the learning tools that have been developed not only meet the validity criteria, but are also very feasible and easy to apply in the context of science learning that integrates engineering design processes (EDP) with STEM approaches. Furthermore, the results of

the practicality of the worksheet based on the PRODUCTIVE learning model according to the students' view indicate that all aspects assessed are in the category of "very high." Although the ease aspect receives the lowest score, this does not reflect the difficulty in the overall learning process, but rather more to the challenges students face in finding creative ideas. Overall, the data obtained showed that students gave a very positive reaction to the PRODUCTIVE learning model-based worksheet. This assessment covers a variety of aspects, including content, usability, ease, and satisfaction levels. These findings confirm that appropriate and strategic instructional design can significantly improve student engagement as well as their cognitive outcomes, as revealed in research by Krajcik & Delen (2016) and Swandi et al. (2025).

3.4 Effectiveness of PRODUCTIVE learning model

The effectiveness test is an important step to prove that research products that have gone through the validation process and are shown to be practical, are able to have a positive impact on improving learning outcomes (Afriani, 2025). This can be measured through an increase in the achievement of established competency indicators. In the context of this study, effectiveness tests were implemented at the summative evaluation stage, which served as empirical evidence regarding the product's ability to create a significant learning impact (Dick et al., 2001). The implementation of the effectiveness test was carried out at one school selected as the research site. In this process, the data obtained will be analyzed using an appropriate statistical method, that is, by calculating the gain value and performing a t-test using SPSS software version 29. Through this analysis, researchers can measure the extent to which the tested product can improve students' science process skills as well as provide a clearer picture of the effectiveness of the implemented intervention. Thus, this effectiveness test not only serves as a measuring tool, but also as a means to identify potential improvements in existing learning processes. The average gain scores of both schools can be seen in table 6.

Table 5*Comparison of Gain Values*

T-Test						
Group Statistics						
The Value of Class	N	Mean	Std. Deviation	Std. Error Mean		
Science Process Skills						
Posttest Experimental Class	30	62,70	17,891	3,283		
Posttest Control Class	30	39,40	14,124	2,579		

The Independent Samples t-test was performed to determine if there was a significant difference between students' science process skill scores in the experimental class using the Productive learning model and the control class using the conventional learning model. The Independent Samples t-test results showed that the significance value ($p < 0.001$) was less than 0.05, so that H_3 was rejected and H_2 was accepted. That is, there is a statistically significant difference between the value of science process skills in the experimental class and the control class. Based on the results of the analysis of the Independent Samples t-test, it can be concluded that there is a significant difference between the value of science process skills of students who follow learning with Productive learning models and students who follow learning with conventional learning models. At this stage, a summative evaluation is carried out with the aim of determining the level of effectiveness of the developed product. At this stage, it can also be called broad-scale implementation activities. Analysis of the effectiveness of learning is carried out using the N-Gain calculation (normalized gain), which aims to determine the degree of improvement in learning outcomes after treatment. Based on the results of the descriptive analysis in the Descriptive Statistics Table, a mean N-Gain_Score value of 0.4043 with a standard deviation of 0.25136 was obtained, as well as a minimum value of -0.19 and a maximum of 0.80. If converted into percentage form, the average value of N-Gain is 40.43%. Based on these criteria, the average N-Gain score of 0.4043 belongs to the moderate category. That is, the application of the learning model or treatment used in this study is classified as quite effective in improving the learning outcomes of learners, particularly in the skill aspect of the science process. Thus, it can be concluded that applied learning is capable of providing a significant improvement in learning outcomes, although it is still in the category of moderate effectiveness. This suggests that there is a positive influence from the use of models on the improvement of science process skills of primary school students.

4 DISCUSSION

The development of the PRODUCTIVE model in this study adopted an instructional design framework that has been shown to be effective, namely the Dick and Carey model, which is recognized as a standard in modern instructional development (Siagian, 2014). The model offers a systematic and structured approach, encompassing a series of components that interact with each other. The process begins with the establishment of clear learning objectives and in-depth analysis of student needs, continues with the development of relevant teaching materials, and ends with formative and summative evaluations to measure the effectiveness of learning. One of the main strengths of this model is its focus on student characteristics. Thus, the formulated instructional objectives are not only theoretical, but also in harmony with the real needs of the learner. The study takes a comprehensive approach taking into account participants' initial conditions, triangulating from various data sources, as well as involving validation from experts in their field. In addition, the application of field trials provides strong empirical evidence regarding the effectiveness of this model. The PRODUCTIVE model is designed as a pedagogical innovation that answers the challenges of science learning in primary schools. By integrating Engineering Design Process (EDP) based STEM approach, the model aims to stimulate students' science process skills more effectively. The comprehensive evaluation process includes testing of the model's validity, practicality, and effectiveness, which is carefully conducted to ensure that the model is feasible and ready to be implemented in a real learning context. Thus, this research not only resulted in innovations that were applicative, but also made significant methodological contributions, demonstrating how development models can be used to design solutions that fit the theoretical framework and real needs within the classroom.

Based on the validation results carried out by learning design experts, the development of productive learning models showed a very impressive average score of eligibility, which was **91.8%**. This score clearly indicates that the developed learning model not only meets, but also exceeds the eligibility standards established for the development of learning models at the primary school level. This process of assessing the feasibility of a learning design is carried out taking into account various important indicators that include learning model focus, syntax, model reaction principles, social systems that support the model, necessary support systems, as well as instructional and

accompaniment impacts. Each of these indicators plays a crucial role in determining how effective and efficient the learning model is in achieving the desired educational goals. Furthermore, the rationality of the model put forward by Joyce and Weil demonstrates its ability in meeting the demands of the modern curriculum. The current curriculum places great emphasis on the development of 21st century competencies, which include critical thinking skills, creativity, collaboration, and independence in learning (Sale, 2020). This is particularly relevant, given the challenges faced by students in the ever-evolving digital age. Productive learning models that have been developed also provide a systematic framework for teachers to design learning experiences that are not only active, but also meaningful and entirely student-centered. Thus, students not only become recipients of information, but also take an active part in the learning process, which in turn can improve their understanding and skills. In the development of this productive learning model, there are three key indicators that record the highest values, indicating that these aspects are highly effective and relevant in supporting the implementation of the proposed learning model. These indicators serve as a strong foundation for the further development and application of learning models in the educational environment, ensuring that students obtain an optimal learning experience and according to their needs.

The practicality of this model is determined based on teacher and student responses to the PRODUCTIVE learning model and student worksheets. Practicality includes usability, ease of use, and satisfaction with learning tools, which are factors that influence success. Teacher responses indicate that the Circle and worksheet-based learning model are easy to use, useful, and teachers are satisfied and happy. Students also respond positively to the teaching tools used. These findings reinforce findings The engineering design process is a core component of engineering education, with many institutions incorporating it into their curricula to teach students practical problem-solving skills. The practicality of this learning model is strongly influenced by the responses provided by teachers and students to the learning approach known as PRODUCTIVE, as well as the accompanying worksheet. In this context, practicality includes several important aspects, such as the usefulness of the learning tool, the ease in its use, as well as the level of satisfaction felt by the users. All these factors contribute significantly to the success of the learning process. Responses from teachers show that the learning model based on the Circle method, as well as the worksheets used, are not only easy to implement, but also very useful in supporting teaching-learning activities. Teachers were

satisfied and pleased with the use of such learning tools, indicating that they found added value in the teaching process carried out. Meanwhile, students also gave a positive response to the applied teaching tools. This suggests that they feel engaged and benefit from the learning methods used. These findings are in line with the principle that the engineering design process is a core component in engineering education. Many educational institutions have integrated engineering design processes into their curricula to equip students with practical and relevant problem-solving skill (Collins et al., 2021). Thus, the application of this learning model not only increases practicality in the learning process, but also contributes to the development of students' competencies in engineering.

The results of this study show that productive learning model interventions, in addition to improving science process skills, are also able to improve creative thinking and communication skills (Aini & Aini, 2023). The findings of this study demonstrate the effectiveness of the EDP learning model in improving students' 21st century skills, especially creative thinking and communication skills. An important step in this improvement is prototype construction, in which students develop solutions to problems and present diverse prototype results. This activity plays an important role in fostering creative thinking. Training and applying the science process skills approach significantly improves elementary school students' understanding and performance in science, showing a marked improvement in their science process skills from low to high scores after implementation (Hambali, 2024). Applying scientific processes can improve elementary school students' science process skills by promoting active participation in observing, experimenting, and reasoning. This approach fosters critical thinking and problem-solving abilities, which ultimately improves their understanding and engagement in science learning activities (Leli Kartika, 2022). Thus, the productive learning model contributes to the formation of scientific thinking habits that can be applied in various contexts, which in turn will prepare students to become effective and innovative problem solvers in the future.

The effectiveness of the productive learning model can not only be measured through improved science process skill scores, but also through directly observable changes in classroom dynamics. This model directly encourages a project-based collaborative learning approach, which not only improves students' academic understanding but also develops crucial social skills. In this context, collaborative learning allows students to work together in solving challenging tasks, encouraging them

to share ideas, discuss, and give each other feedback. This process not only enriches their knowledge of the subject matter, but also processes aimed at systematically solving problems (Ghanavati et al., 2020), effective collaboration and communication and teamwork are essential for successful design results (Daly, 2014). In addition, this productive learning model also contributes to the creation of a more inclusive and dynamic learning environment.

5 CONCLUSION

The PRODUCTIVE learning model is specifically designed to meet the needs of science learning that not only focus on theoretical knowledge, but also support the improvement of essential science process skills for students. The assessments made by experts of the tools used in this model show a very high degree of validity. This includes evaluation of several aspects, such as the foundation of the underlying theory, the clear structure of the learning syntax, the appropriateness of the material taught, the clarity of the language used, as well as the quality of the media that supports the learning process.

Furthermore, the practicality of this model also earned very positive assessments from teachers. They affirm that this model is not only easy to apply in the classroom, but is also highly relevant to the learning needs faced in today's schools. The effectiveness of this PRODUCTIVE learning model is evident through a significant improvement in students' science process skills, when compared to conventional approaches commonly used. This can be seen from analysis of gain scores and t-test results that show encouraging results.

Thus, this model is well suited to be applied in the context of science education in primary schools as an innovative strategy capable of not only overcoming various existing limitations, but also strengthening students' science process skills. Findings from this study have important strategic implications for primary schools, particularly in the implementation of science learning that is contextual, interactive, and relevant to current issues faced by society. This suggests that science education is not only a transfer of knowledge, but should also actively engage students in challenging learning processes and encourage them to think critically.

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Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

How to cite this article (APA)

Rahmawati, Y., & Sumantri, M. S. ENHANCING SCIENCE PROCESS SKILLS OF ELEMENTARY SCHOOL STUDENTS IN INDONESIA THROUGH THE INTEGRATION OF ENGINEERING DESIGN PROCESS (EDP) LEARNING MODEL BASED STEM APPROACH. *Veredas Do Direito*, e223856. <https://doi.org/10.18623/rvd.v22.n7.3856>