Jurnal Pembelajaran Dan Biologi Nukleus p-ISSN: 2442-9481
Vol 11 (3): 1280 - 1300, September 2025 e-ISSN: 2685-7332

Integrating STEM Approach through a Student Worksheet to Strengthen Problem-Solving on the Excretory System Learning

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Submitted July 11 Th 2025 and Accepted August 31 Th 2025

Abstract

Background: *The 2022 PISA assessment reveals that Indonesian students demonstrate considerably weak science problem-solving abilities, achieving merely 383 points compared to the OECD's 485-point benchmark, with this deficiency particularly pronounced in biology education where learners encounter difficulties comprehending and contextualizing concepts such as the excretory system in practical scenarios.* **Methodology:** *Employing a 4D developmental framework (Define, Design, Develop, Disseminate) truncated at the Develop phase, this investigation created a STEM-integrated student worksheet designed to strengthen problem-solving competencies among eleventh-grade pupils, utilizing expert validation, stakeholder feedback surveys, and pre-post assessment protocols analyzed through percentage calculations, N-Gain coefficients, and paired-samples t-testing.* **Findings:** *The intervention demonstrated exceptional validity with 90% expert approval ratings across content and pedagogical dimensions, exhibited strong practicality reflected in 88.71% positive educator-student reception, and yielded statistically significant learning gains as evidenced by paired t-test results ($p < 0.05$) alongside a substantial N-Gain value of 0.75.* **Contribution:** *This study provides specific empirical evidence that a STEM-integrated student worksheet, developed through an adapted 4D model, effectively strengthens eleventh-grade students' science problem-solving abilities in the excretory system Learning. The results further contribute to the field by establishing this worksheet as a valid, practical, and statistically proven instructional alternative that aligns with competency-based demands and improves analytical reasoning more effectively than conventional learning materials.*

Keywords: *STEM; Student Worksheet; Excretory System; Problem Solving Skill*

https://doi.org/10.36987/jpbn.v11i3.8155

INTRODUCTION

Problem-solving skills are one of the higher-order thinking skills (HOTS) that students must master in the 21st century. This skill enables learners to think critically, creatively, and reflectively when confronting complex challenges in science and real-world contexts (Mayer, 2008). In biology learning, problem-solving skills help students deeply understand abstract concepts and relate them to real-world phenomena, such as health disorders and environmental issues (Utami et al., 2023).

However, various studies have revealed that Indonesian students' problem-solving skills remain relatively low. According to the Programme for International Student Assessment-PISA 2022 report by (OECD, 2023), Indonesian students' science problem-solving skills remain low, with an average score of 383, far below the OECD average of 485. This finding indicates that students still face difficulties in connecting scientific knowledge with real-life contexts. In biology learning, problem-solving is a higher-order cognitive process that involves analytical, critical, reflective, and creative thinking skills, allowing students to understand abstract concepts and apply them to authentic biological phenomena such as diseases, the use of health technologies, and environmental issues (Bybee, 2013). Similarly, Rizalia et al., (2024) found that high school students struggle to comprehend concepts and solve contextual questions related to the excretory system. This challenge stems predominantly from Indonesia's teacher-dominated biology instruction that prioritizes mechanical memorization over the cultivation of analytical thinking and problem-solving capabilities (Yulianto & Rahayu, 2020).

The human excretory system is one of the biological topics where this issue is most evident, as students often perceive it as abstract and complex to understand (Lisa et al., 2023). Observations at SMA Negeri 1 Dolok Batu Nanggar revealed that biology learning was still dominated by lectures and had not utilized interactive learning media. The available worksheets contained only simple exercises and did not guide students through investigative or problem-solving activities. This local finding mirrors the national issue and highlights the need for innovative learning media that are contextual, interactive, and oriented toward higher-order thinking.

Internationally, comparable educational deficiencies have been successfully mitigated through progressive pedagogical frameworks including Problem-Based Learning (PBL) and STEM (Science, Technology, Engineering, and Mathematics) methodologies, which emphasize interdisciplinary integration for addressing authentic challenges while fostering creative capacity, with global research evidence consistently demonstrating that STEM-oriented instruction substantially enhances learners' analytical reasoning and problem-solving competencies in scientific domains. (Kışoğlu, 2018; Made et al., 2022). However, in Indonesia, STEM implementation remains limited, as Syarah et al., (2021) noted that biology teachers tend to focus on content delivery rather than collaboration, creativity, and application of concepts.

This gap between the demands of 21st-century learning and current classroom practices serves as the basis for this study. The proposed solution is to develop a STEM-based Student Worksheet using the Engineering Design Process (EDP) model by Jolly (2016), which guides students through authentic problem-solving stages from defining the problem, conducting research, imagining solutions,

designing plans, building prototypes, to evaluating and revising the solutions produced. In this way, students not only understand concepts but also become skilled in applying them. Research by Oktavianto & Aghni (2022), explained that STEM-based e-Worksheets were effective in enhancing complex problem-solving skills, achieving excellent validation results (an average score of 4.4) and an N-gain increase of 0.75. Another study by Simanullang (2022) also supported that STEM-based worksheets significantly improved students' critical thinking skills. Nevertheless, there are still very few studies focusing on STEM-based worksheet development on the excretory system for high school students, even though this topic is strongly related to human health and everyday life.

Based on these considerations, this study aims to: (1) to produce STEM-based worksheets that are content-valid and feasible to use, (2) to examine the practicality of the worksheets through limited trials involving teachers and students, and (3) to evaluate the effectiveness of the worksheets in improving students' problem-solving skills. Problem-solving skills in this study are defined based on Polya (1973) four-step model: understanding the problem, devising a plan, carrying out the plan, and evaluating the results. Through these objectives, the study is expected to make a theoretical contribution to the development of STEM-based learning media and a practical contribution to biology teachers by helping them design interactive, contextual, and higher-order thinking-oriented instruction.

METHOD

This study employs a Research and Development (R&D) approach by adapting the 4D model, namely Define, Design, Develop, and Disseminate, developed by Thiagarajan (1974).

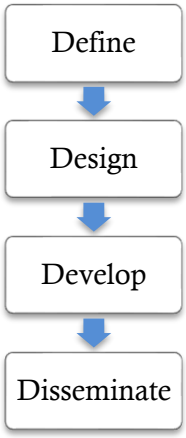


Figure 1. 4D Model Design, Source: Thiagarajan (1974)

The 4D model was chosen because it is suitable for developing instructional media, particularly STEM-based student worksheets, aimed at improving students' problem-solving skills. The stages of the 4D model include: (1) Define, which involves identifying needs and formulating problems; (2) Design, which focuses on creating a STEM-oriented Student Worksheet. It is formatted in A4 size and comprises 23 pages.

This worksheet is carefully organized to feature several key elements, including a cover page, a preface, a table of contents, core and basic competencies, user instructions, descriptions of learning materials, STEM-related learning activities, problem-solving tasks, references, and an author's biography; (3) Develop, which consists of expert validation and limited trials; and (4) Disseminate, which refers to wider implementation. Due to time and scope limitations, this development was carried out only up to the third stage, namely the Develop stage. The 4D model is considered systematic and practical for producing learning products that are valid, practical, and effective, and can be applied in classroom biology learning (Sugiyono, 2013).

Sample or Participant

The research was conducted at SMA Negeri 1 Dolok Batu Nanggar, Simalungun Regency, North Sumatra, during the first semester of the 2024/2025 academic year. The participants consisted of 30 eleventh-grade science students (grade XI IPA) and one biology teacher. The purposive sampling technique was chosen to enable the researcher to obtain more in-depth information from a group that aligns with the study's objectives (Creswell & Guetterman, 2024). The selection criteria included: (1) students who had learned the excretory system topic based on the curriculum, (2) representation of diverse academic abilities (high, medium, and low), and (3) willingness to actively participate in the research. The biology teacher acted as a collaborator during the limited trial and evaluated the practicality of the learning media. The number of 30 participants was determined according to (Sugiyono, 2013), who stated that a small-scale sample is sufficient for a preliminary stage of development research to obtain initial feedback on validity and practicality.

Instrument

The instruments used in this study were designed to measure the validity, practicality, and effectiveness of STEM-based Student Worksheets. Each dimension was measured using different but complementary instruments to evaluate the overall quality of the product.

Product validation was conducted through expert appraisal instruments administered by a single biology content specialist and one instructional media specialist, with the assessment framework constructed according to Indonesia's National Education Standards Board (Badan Standar Nasional Pendidikan, 2016) criteria encompassing four principal dimensions: (1) content suitability, (2) presentation quality, (3) linguistic appropriateness, and (4) graphic design elements, whereby each criterion was evaluated using a four-point Likert metric (1 = invalid, 2 = minimally valid, 3 = valid, 4 = highly valid), with data subsequently analyzed through percentage calculations establishing worksheets achieving ≥ 85% as demonstrating exceptional validity, while expert feedback and recommendations informed subsequent content and design refinements prior to empirical field testing.The practicality of the worksheet was measured using teacher and student response questionnaires after the limited classroom trial.

The instruments were developed based on Nieveen (1999) practicality criteria, including ease of use, clarity of instructions, time efficiency, attractiveness,

and usefulness. The teacher assessed the usability, curriculum alignment, and integration into classroom activities, while students evaluated clarity, design attractiveness, and engagement in STEM-based learning. The data were analysed descriptively using percentages, and the worksheet was categorised as very practical if the average score was ≥ 85%.

The effectiveness of the worksheet was evaluated using a problem-solving skill test comprising 10 essay items, developed according to Polya (1973) The assessment incorporated four sequential problem-solving phases: problem comprehension, strategy formulation, plan execution, and outcome evaluation, with test items subjected to content specialist validation to confirm their appropriateness and cognitive demand level, and the instrument deployed in pre-instruction and post-instruction configurations to measure learning gains. Students' scores were analysed using the Normalised Gain (N-Gain) formula by Hake (1999) to determine improvement levels: high (N-Gain ≥ 0.7), medium (0.3 ≤ N-Gain < 0.7), and low (N-Gain < 0.3). To determine the statistical significance between the pretest and posttest results, a Paired-Samples T-Test was used, which was conducted at the 0.05 significance level.

To ensure reliability, all validation and response instruments were tested using Cronbach's Alpha, with $\alpha \geq 0.70$ indicating high reliability (Arikunto, 2013). Therefore, all research instruments were deemed valid and reliable for the comprehensive evaluation of the STEM-based Student Worksheet.

Data collection

Data were collected during the second semester of the 2024/2025 academic year at SMA Negeri 1 Dolok Batu Nanggar through several stages of the 4D development model. Various instruments were used, including teacher interview sheets, expert validation sheets, teacher and student response questionnaires, classroom observation sheets, and problem-solving skill tests. All data were collected systematically to assess validity, practicality, and effectiveness as the main quality criteria of the developed product.

Procedure

This investigation employed by Thiagarajan (1974), 4D developmental framework comprising Define, Design, Develop, and Disseminate phases, though temporal and operational constraints necessitated research termination at the Develop stage, with each phase executed systematically to generate a STEM-integrated Student Worksheet demonstrating validity, practicality, and efficacy in advancing students' problem-solving competencies.

Define Stage

During this phase, needs assessment was executed through educator interviews and classroom observations to diagnose prevailing instructional challenges and determine students' requirements for pedagogical materials. Additionally, curriculum analysis, student characteristics analysis, and concept mapping of the

excretory system topic were carried out. The results of this analysis served as the foundation for formulating learning objectives and designing the content of the STEM-based worksheet.

Design Stage

This stage involved developing the initial draft of the STEM-based worksheet by integrating the Engineering Design Process (EDP) syntax by Jolly (2016), which includes identifying problems, imagining possible solutions, planning, creating, testing, and improving solutions. The EDP approach emphasises learning through iterative problem-solving and design-based inquiry, making it suitable for developing STEM-oriented learning materials.

At this stage, research instruments such as validation sheets, teacher and student response questionnaires, and problem-solving test instruments were also prepared to assess the product's quality. The validation sheets were designed to evaluate the content, presentation, language, and graphical aspects of the worksheet. The teacher and student questionnaires assessed the practicality of the worksheet in terms of clarity, usefulness, and engagement, while the problem-solving test measured students' abilities across four indicators adapted from Polya (1973), scuh as understanding the problem, planning a solution, implementing the strategy, and evaluating the results. The worksheet design was created using Canva to produce an attractive, communicative, and visually engaging layout aligned with students' learning characteristics.

Develop Stage

During this stage, the product underwent validation by a material expert, a media expert, and an educational practitioner to assess content accuracy, language clarity, design quality, and the integration of STEM elements. Revisions were made based on the experts' feedback before conducting a limited trial involving 30 students of Class XI-3 at SMA Negeri 1 Dolok Batu Nanggar. The pilot implementation sought to collect data regarding the worksheet's practicality and efficacy through educator and learner feedback instruments alongside problem-solving competency assessment outcomes.

Disseminate Stage

The dissemination stage encompassed a constrained implementation involving a single cohort of 30 students to assess the STEM-integrated worksheet's capacity for enhancing learners' problem-solving proficiencies, with data acquisition utilizing educator and student response surveys complemented by problem-solving competency test results to ascertain the product's practicality and effectiveness, though the investigation remained limited to small-scale piloting attributable to temporal restrictions and did not advance to broader dissemination.

Data analysis

The acquired data underwent descriptive quantitative analysis to furnish objective characterization of the STEM-based worksheet's validity, feasibility, and effectiveness, with data subsequently processed through computational procedures utilizing Formula 1, while worksheet validity was evaluated by two validators comprising a biology specialist and an instructional media specialist. Each expert evaluated the worksheets using a validation sheet that included four main aspects adapted from the National Education Standards Board (Badan Standar Nasional Pendidikan, 2016), i.e : (1) content feasibility, including concept accuracy, material completeness, and curriculum relevance; (2) presentation feasibility, including clarity of instructions, organization, and coherence; (3) language feasibility, covering readability, accuracy of scientific terms, and sentence effectiveness; and (4) graphical feasibility, including layout, illustration, and color balance. The validation scores were analyzed using a percentage formula by Cahaya et al., (2024) and categorized according to Riduwan (2018) such as: very valid (81–100%), valid (61–80%), reasonably valid (41–60%), and not valid (<41%), as shown in Table 1. The worksheet was considered feasible for use if it achieved ≥ 81% with minor or no revision.

$$\text{Percentage} = \left(\frac{\text{Total Score Obtained}}{\text{Maximum Score}}\right) \times 100\% \quad \text{..... (1)}$$

Table 1. Validity Assessment Criteria by Riduwan (2018)

Percentage (%)	Validity Category	Information
81 – 100%	Very Valid	Feasible to use without revision
61 – 80%	Valid	Feasible to use with minor revisions
41 – 60%	Fairly Valid	Needs revision before use
< 41%	Not Valid	Not feasible to use

The practicality of the worksheets was evaluated through teacher and student response questionnaires. Teachers assessed usability, implementation feasibility, clarity, and integration with classroom learning, while students assessed attractiveness, readability, and ease of understanding. The practicality criteria were based on Nieveen (1999), and the results were analyzed as percentages into four categories: very practical, practical, reasonably practical, and less valuable, as shown in Table 2. The worksheet was considered very practical if the average score was ≥ 85%.

Table 2. Practicality Criteria by Nieveen (1999)

Percentage (%)	Practicality Category
81 – 100%	Very Practical
61 – 80%	Practical
41 – 60%	Fairly Practical
< 41%	Not Practical

The effectiveness of the worksheets was determined from students' pretest and posttest scores on problem-solving skills, which consisted of ten essay items developed according to Polya (1973) problem-solving stages. The gain in students' scores was analysed using the Normalised Gain (N-Gain) by Hake (1999) found on Formula 2, In addition, a paired-samples t-test was conducted to assess the significance of the difference between the pretest and posttest scores. The analysis was performed using IBM SPSS Statistics version 26 with a significance level (α) of 0.05. A p-value of <0.05 indicated a significant difference, meaning that the developed worksheet was effective in enhancing students' problem-solving ability. The N-Gain values obtained were then categorized according to Hake's classification in Table 3.

$$\text{N Gain (\%)} = \frac{(\text{Post-test Score} - \text{Pre-test Score})}{(\text{Maximun Score} - \text{Pre-test Score})} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Table 3. N Gain Criteria by Hake (1999)

***Gain* Value (g)**	**Effectiveness Category**
$g \geq 0,7$	High
$0,3 \leq g < 0,7$	Medium
$g < 0,3$	Low

RESULT AND DISCUSSION

Result Clear Parameters

This study examines STEM-based worksheets focused on the excretory system for senior high school students in grade XI, to enhance their problem-solving abilities. The development process utilized the 4D model, limited to the Develop stage, which incorporated the steps of the STEM approach through the engineering design process. This involved defining problems, conducting research, brainstorming solutions, planning, building prototypes, and evaluating and revising the proposed solutions.

The results demonstrated that implementing STEM-based worksheets had a positive impact on three key parameters: validity, practicality, and effectiveness. The validity assessment results indicated that the worksheets achieved an average score of 95.5 % from the material expert and 90.9 % from the media expert, which fall into the "very valid" category (Riduwan, 2018). This shows that the developed worksheets were feasible to use without significant revision.

Regarding practicality, the teacher response received a score of 95 %, while the student response scored 88.7 %, both categorised as "very practical" (Nieveen, 1999). These findings indicate that the worksheets are easy to use, visually engaging, and suitable for integration into classroom learning.

Regarding effectiveness, students' problem-solving skills improved significantly, as reflected in the increase in their mean score from 43.58 in the pretest to 86.58 in the posttest. The N-Gain index of 0.75 indicates an improvement in the high category (Hake, 1999), validating that STEM-based worksheets successfully improved students' problem-solving abilities. Statistical analysis using a paired sample t-test obtained t = -22.447 (df = 29, p = 0.000 < 0.05) to determine the significance of

the increase, confirming a highly significant difference between the initial and final measurements.

Comprehensively, the research data demonstrates that the developed STEM-based worksheets meet highly valid, highly practical, and highly effective standards, indicating their potential in improving learning outcomes and developing analytical and problem-solving skills in high school students.

Define Stage

The Define stage was carried out to identify the initial needs in developing a STEM-based Student Worksheet on the excretory system material. This needs analysis comprises five main components: front-end analysis, learner analysis, concept analysis, task analysis, and specifying instructional objectives.

The results of the front-end analysis at SMA Negeri 1 Dolok Batu Nanggar and interviews with the biology teacher revealed that classroom learning was still dominated by lecture-based instruction and textbook use. About 78% of students (23 out of 30) reported that the excretory system topic was challenging to understand due to its abstract nature and lack of real-life context. The teacher also mentioned that students' motivation was relatively low, as reflected in their average biology test score of 63.4, below the school's minimum mastery criterion (KKM) of 75. These findings indicate that the biology learning process still n eeds contextual and inquiry-oriented materials to enhance students' understanding and engagement. This situation aligns with previous studies by Rizalia et al., (2024) and Juleha et al., (2019), who found that teacher-centred biology learning tends to reduce student participation and limit opportunities to develop higher-order thinking skills.

Further analysis of students' learning characteristics showed that they preferred visual and experimental approaches that connect abstract biological concepts to everyday experiences. They expressed greater interest in hands-on experiments and tasks involving simple technological design, stating that such activities help them better understand biological processes. The teacher confirmed that students' analytical and problem-solving skills remained low, particularly in identifying causes and proposing solutions for excretory system disorders. This finding is consistent with the work of Lisa et al., (2023) and Annisa (2022), who emphasised that contextual and visual-based learning strategies can improve conceptual understanding and learning motivation in science education.

The conceptual analysis in this stage focused on the human excretory system, including the structure and functions of the kidneys, lungs, liver, and skin, as well as the physiological mechanisms and disorders associated with them. These concepts were connected to daily health practices such as maintaining hydration and nutrition to prevent kidney stones or liver disease. This aligns with the Merdeka Curriculum Learning Outcomes, which emphasise mastery of biological concepts and the ability to apply them to solve real-world problems. According to Saragih et al., (2025), integrating STEM-based learning in biology helps bridge abstract concepts and authentic life contexts, making it a suitable framework for topics such as the human excretory system.

To align with STEM principles, the worksheet's learning tasks were designed to encourage students to connect biological theory with practical investigation and simple engineering applications. In the worksheet, students conducted a simple laboratory experiment to analyse simulated urine samples for protein and glucose content using the Biuret and Benedict tests. They were asked to design their own experiment using readily available materials, such as egg white solution as a protein substitute and glucose solution as a sugar substitute, and to observe colour changes as indicators of biochemical reactions. Students interpreted the results based on their understanding of kidney filtration and reabsorption mechanisms. Through this process, they applied the steps of the Engineering Design Process (EDP) outlined by Jolly (2016), including identifying problems, designing and testing solutions, and evaluating outcomes while developing critical and problem-solving skills. This activity is supported by Županec & Radulovi (2022), who reported that simple biochemical experiments in STEM learning increase student engagement and help them visualise abstract biological concepts.

The learning objectives were formulated in accordance with Regulation No. 37 of 2018 issued by the Ministry of Education and Culture, focusing on the enhancement of higher-order thinking and problem-solving abilities. The objectives of the developed worksheet include: (1) explaining the structure and function of human excretory organs; (2) analysing disorders of the excretory system and their treatments; and (3) designing simple technology-based solutions to detect disorders in the excretory system. Overall, the findings from this stage reveal a clear, evidence-based need to develop STEM-based worksheets that are contextual, engaging, and effective in improving students' problem-solving skills in the human excretory system.

Design Stage

The Design Stage focused on developing the initial draft of the STEM-based Student Worksheet on the human excretory system. At this stage, the learning activities were designed by integrating the Engineering Design Process (EDP) by Jolly (2016) as the main framework. The EDP syntax consists of six iterative steps: identifying problems, imagining possible solutions, planning, creating, testing, and improving. This process was adopted to foster students' critical and creative thinking through systematic, reflective, design-based learning.

In the "Define the Problem" stage, students were introduced to contextual cases such as changes in urine color that could indicate excretory disorders. This activity trained students to identify and analyze problems in real-world contexts. During the "Research" and "Imagine" stages, students conducted simple laboratory experiments using Biuret and Benedict tests to detect protein and glucose in synthetic urine samples. These experiments required students to observe chemical color changes as data for problem analysis and solution development.

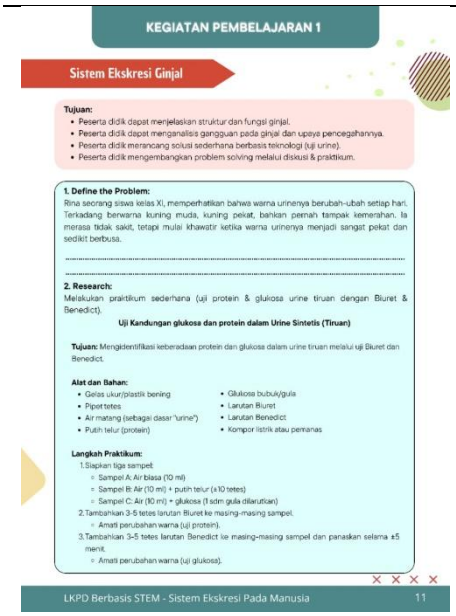
The "Plan" and "Create" stages guided students to design a strategy and develop a simple prototype of a urine color sensor using readily available materials, which was then tested in the "Test, Evaluate, and Redesign" stages. Here, students assessed the accuracy of their designs, identified weaknesses, and made improvements. Finally, in the "Communicate" stage, they discussed their findings, presented their

conclusions, and collaboratively reflected on the problem-solving process, as shown in Table 4. These activities align with the ideas of Wendell & Rogers (2013), who stated that engineering-design-based science activities improve students' systematic reasoning and conceptual understanding.

Before implementation, an initial design evaluation was conducted through expert validation to assess the product's feasibility and quality, including content, presentation, and graphical design. The validation involved a biology materials expert and a learning media expert, who assessed the worksheet using a Likert scale across four significant aspects: content feasibility, presentation, language, and graphical design (Badan Standar Nasional Pendidikan, 2016).

Media experts' assessments show that STEM-based worksheets received an average score of 90.90% in the "highly valid" category. According to media experts, the layout and structure of the worksheets are attractive and consistent with the STEM framework, although there are some suggestions for improvement to make them more exploratory and consistent in integrating problem-solving aspects.The proposed revisions included: (1) ensuring consistency between the title ("STEM-Based Worksheet") and the internal content, which previously appeared more conventional; (2) adding more specific instructions that direct students to identify problems and apply the STEM approach in solving them; (3) shortening the textual material so it functions as a guide rather than a handout, focusing on key points and problem-solving activities; (4) adding more contextual problem cases beyond urine discoloration, such as disorders in the liver, skin, and lungs; (5) strengthening the Polya (1973) problem-solving stages (understanding the problem, planning, implementing, and evaluating solutions); and (6) converting lengthy descriptive texts into infographics, tables, and mind maps to enhance visual appeal and readability.

Table 4. Worksheet presentation, STEM activities & problem-solving indicators

Worksheet Presentation	STEM Activities & Problem Solving Indicators
	At the Define the Problem stage, students are introduced to a real-life case in which changes in urine color indicate possible disorders in the excretory system. This activity helps them identify the problem and recognize its potential causes. At the Research stage, students conduct simple experiments using Biuret and Benedict tests to analyze the presence of protein and glucose in synthetic urine. This process enables students to gather data and information as a basis for problem-solving. During the Imagine and Plan stages, students are encouraged to design strategies by generating ideas

Worksheet Presentation	STEM Activities & Problem Solving Indicators
	for a prototype of a simple urine color sensor and planning the required tools and procedures. At the Create stage, they implement the strategy by constructing the prototype and testing it using the prepared samples. The subsequent Test & Evaluate and Redesign stages allow students to evaluate the solution by analyzing the test results, identifying weaknesses, and improving the prototype to make it more effective. Finally, at the Communicate stage, students present and discuss their findings, thereby reinforcing reflective and collaborative thinking.

Meanwhile, a Biology materials expert showed that the STEM-based worksheet on the human excretory system received a 100 % score in the "very valid" category. The materials expert stated that the materials were already accurate and aligned with the curriculum. However, suggested adding links to supporting instructional videos to enrich the learning experience and help students visualize abstract biological processes. All expert suggestions were incorporated during the design revision phase. The revised worksheet is more concise, visually appealing, and interactive, emphasizing problem-solving through the integration of science, technology, engineering, and mathematics.

Thus, the design stage resulted in a STEM-based Student Worksheet that is valid in both content and media, systematically integrating the EDP steps into meaningful, contextual learning activities aimed at improving students' analytical, creative, and problem-solving skills in the human excretory system.

Develop Stage

The development process of STEM-based Student Worksheets was carried out through stages of validation and limited-scale trial implementation.The validation involved one subject matter expert and one media expert to assess aspects such as content relevance, conceptual accuracy, language clarity, and the quality of the worksheet's appearance. The validation results showed that the worksheet received an average score of 48 from the subject matter expert, with a percentage of 100 % (very valid), and a score of 40 from the media expert, with a rate of 90.90 % (also considered very valid). These findings suggest that the developed worksheet is highly valid and feasible for use in learning. However, the validators also provided constructive feedback, such as adjusting illustrations to be more contextual and improving the activity instructions, which were then used as the basis for revising the worksheet.

Table 5. Results of Validation Test by Media Expert

Assessment Aspect	Score Obtained	Maximum Score	Percentage (%)	Criteria
Graphics	18	20	90	Very Valid
Presentation	22	22	100	Very Valid
Total	40	44	90.90	Very Valid

Table 6. Results of Validation Test by Material Expert

Assessment Aspect	Score Obtained	Maximum Score	Percentage (%)	Criteria
Content	43	48	89.58	Very Valid
Presentation	4	4	100	Very Valid
Total	48	48	100	Very Valid

Once the worksheet was validated, it underwent a limited trial with 30 eleventh-grade high school students and a biology teacher. The teacher provided feedback that indicated a practicality percentage of 95%, placing it in the convenient category. Meanwhile, the students' average satisfaction rate was 88.71%, also classified as convenient. This high level of practicality shows that the worksheet is user-friendly for both teachers and students, considering factors such as engagement, content relevance, and clarity of language, as outlined in Table 7.

Table 7. Results of Practicality Test by Teacher

Assessment Aspect	Score Obtained	Maximum Score	Percentage (%)	Criteria
Interest	8	8	100	Very Practical
Material	10	12	83.33	Very Practical
Language	4	4	100	Very Practical
Appearance/Format	16	16	100	Very Practical

Total	38	40	95	Very Practical

The STEM-integrated worksheet's efficacy in strengthening problem-solving competencies concerning the excretory system among eleventh-grade learners was assessed through pre-instruction and post-instruction evaluations, each comprising 10 essay items, with trial outcomes revealing substantial learning enhancement as demonstrated by markedly elevated posttest means relative to pretest baselines, producing an N-Gain coefficient presented in Table 8, while statistical significance of score differentials was determined via Paired-Samples T-Test analysis yielding highly significant findings documented in Table 9.

These findings align with the view of Vazquez et al., (2017), who stated that practical teaching materials enable teachers to focus more on active learning strategies, such as collaboration. Farahita et al., (2024) also emphasized that practical learning media can enhance student engagement. An attractive design has been proven to motivate students to participate actively, while contextual material appropriate to the cognitive level facilitates understanding, and communicative language improves group work (Firmansyah et al., 2021). This statement is consistent with Yakop et al., (2024), who asserted that ease of use is a key factor in determining the practicality of a teaching material. Thus, the STEM-based worksheets that have been developed meet the criteria of validity, practicality, and effectiveness in improving students' problem-solving skills in the topic of the excretory system.

Dissemination Stage

The Dissemination Stage involved limited implementation of the STEM-based Student Worksheet on the excretory system as a preliminary trial to evaluate its effectiveness following validation and revision. The trial was conducted in Class XI-3 of SMA Negeri 1 Dolok Batu Nanggar with a small group of students as participants. The aim was to determine the impact of the developed worksheet on students' problem-solving abilities in biology learning.

The quantitative data were collected using a pretest–posttest design with 10 essay-type problem-solving questions. The research findings show an increase in the average score from 43.58 on the pretest to 86.58 on the posttest, with an N-Gain value of 0.75, which, based on Hake (1999) criteria, is classified as high, as shown in Table 8 and Figure 2. To verify the statistical significance of this improvement, a Paired-Samples T-test was conducted at the 0.05 significance level. The results of the Paired Sample t-test showed that the mean pretest score of 43.58 increased to 86.58 in the posttest, with a mean difference of 43.00. The test yielded $t = -22.447$ ($df = 29$) with a p value (Sig.2-tailed) = 0.000. With $p < 0.05$ and t value > t table (2.045), it is evident that there is a significant difference between the pretest and posttest scores. These results are shown in Table 9. This finding indicates that implementing a STEM-based student worksheet significantly improves students' problem-solving skills in excretory system material.

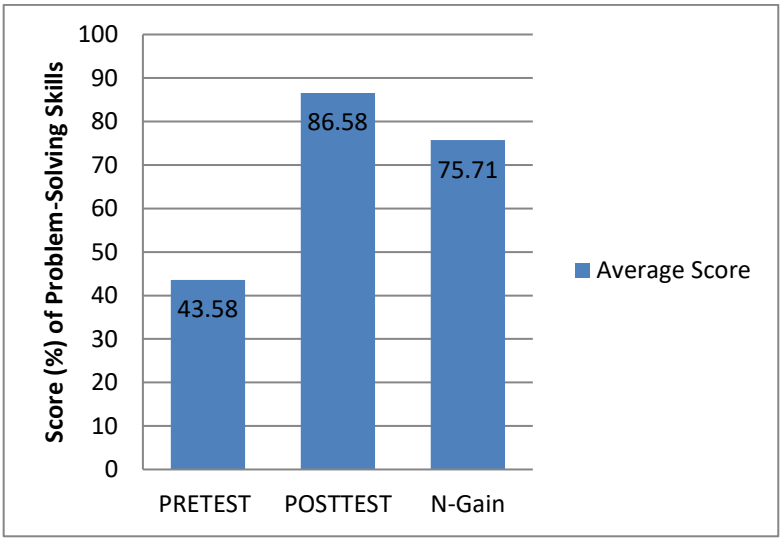


Figure 2. Diagram of Students' Problem-Solving Skills

Table 8. Average Scores of Pretest, Posttest, and N-Gain

Pretest	Posttest	N-Gain	Category
43,58	86,58	0,75	High

Tabel 9. Paired Samples Test

Pair	condition	Mean	Std. Deviation	t	df	Sig. (2-tailed)
1	Pretest-Posttest	-43.00	10.49	-22.447	29	.000

In addition, qualitative observations during classroom implementation revealed notable improvements in students' learning behaviors. Students were more active in asking questions, engaging in discussions, and collaborating during experimental and design-based tasks. They demonstrated greater initiative in identifying problems, proposing alternative solutions, and evaluating their findings systematically using the STEM framework. These behavioral changes reflect improved critical thinking, collaboration, and self-regulated learning as emphasized in STEM education principles (Bybee, 2013).

Overall, the combination of quantitative test results and qualitative observations suggests that the developed STEM-based worksheet is efficacious in improving students' understanding of the excretory system, enabling them to analyze biological problems scientifically and propose creative technological solutions through structured problem-solving activities.

Feasibility of STEM-Based Worksheet in Improving Students' Problem-Solving Skills on the Excretory System Material

The STEM-based Student Worksheet is an innovative printed teaching material designed to integrate four disciplines within the framework of the Engineering Design Process (EDP) by Jolly (2016), aiming to create an active, solution-oriented,

and contextual learning experience. The EDP syntax emphasizes systematic thinking stages, starting with identifying problems, imagining possible solutions, designing, creating, testing, and making improvements, as well as communicating (Jolly, 2016). Each of these stages has been integrated into the worksheet through case analysis activities, group discussions, simple experiments, and problem-solving tasks. Thus, this worksheet not only presents information but also trains students' higher-order thinking skills.

The feasibility aspect of the worksheet is evident from the results of expert validation, with a score of 100% (very valid) from the material expert and 90.90% (very valid) from the media expert, as shown in Tables 4 and 5. This validation confirms that the worksheet aligns with the basic competencies, indicators, and the accuracy of the excretory system concepts, while also meeting the standards of readability, design attractiveness, and ease of use. In line with Nieveen (1999), a valid learning tool must fulfill content, construct, and appearance validity.

The feasibility of the worksheet is further supported by teacher responses, with a score of 95% (efficient), and student responses, with a score of 88.71% (also efficient). Teachers assessed that the activity instructions were clear, the material was contextual, and the learning flow was systematic. Students found the worksheet to be interesting, easy to understand, and well-suited to their learning characteristics. This finding is consistent with Fatikhah (2021), who stated that the readability and attractiveness of teaching materials determine their feasibility. Thus, this STEM-based worksheet has been proven to be feasible in supporting the improvement of students' problem-solving skills.

Effectiveness of STEM-Based worksheets in Improving Students' Problem-Solving Skills on the Excretory System Material

The notable enhancement in students' learning outcomes is indicative of the efficacy of the STEM-based worksheet. Based on the research findings, the average pre-test score of 43.58 increased to 86.58 in the post-test results. The N-Gain score obtained was 0.75, which is in the high category. Furthermore, a paired t-test was used to test whether the increase was statistically significant. The results indicated a t-value of -22.447 > t-table of 2.045 and p= 0.000 (< 0.05), indicating that the difference between pretest and posttest was highly significant. This confirms that the STEM-based worksheet had a strong positive effect on students' problem-solving performance. The high t-value also demonstrates that the improvement was consistent across the class, validating the product's effectiveness in fostering analytical and systematic thinking skills.

This demonstrates how well the STEM-based worksheet trains students' problem-solving abilities. Its efficacy stems from the fact that the worksheet stimulates students to observe, inquire, create, experiment, and draw conclusions in addition to acting as an information source. According to STEM principles, learning exercises are designed using real-world issues as inspiration, allowing students to make the connection between theory and practice (Bybee, 2013).

Previous studies support these findings. Made et al., (2022) demonstrated that STEM-based learning tools developed with the 4D model were able to enhance

students' problem-solving skills. Rizkika et al., (2022) reported that STEM-based worksheets improved critical thinking and problem-solving skills. Furthermore, Sarita & Wisudawati (2024) added that STEM-based learning requires students to collaborate and think creatively, which has a significant impact on their problem-solving abilities.

In addition to the cognitive aspect, the effectiveness of the worksheet is also supported by psychological factors. Attractive visualizations designed with Canva increased students' motivation, as emphasized by Becker & Jacobsen (2020), who stated that learning media with engaging designs enhances students' cognitive engagement. The communicative language used in the worksheet also facilitated the understanding of instructions and increased student participation in group work (Steegmann et al., 2016). In other words, the effectiveness of the STEM-based worksheet is determined not only by the content but also by its design, language, and the learning experience it provides.

The supporting factors for the successful implementation of the STEM-based worksheet include its attractive and communicative design, contextual materials, active student engagement, and the teacher's role as a facilitator. The use of Canva contributed to the production of visually appealing worksheets. The obstacles encountered were limited time and students' unfamiliarity with the STEM approach.

CONCLUSION

This study successfully developed a STEM-based Student Worksheet on the excretory system for Grade XI students, using the 4D development model through the development phase. Based on expert assessment and direct application in the field, this worksheet has met the standards of validity, practicality, and effectiveness. The high validity score (100 % from the materials expert and 90.90 % from the media expert) demonstrates that the worksheet's content and design were scientifically and pedagogically appropriate. The practicality results (95 % teacher response and 88.71 % student response) indicate that the worksheet was feasible and engaging for classroom use. The t-test results for paired samples showed t-value is -22.447 ($df = 29$, $p < 0.05$), indicating a significant increase in students' problem-solving abilities, with an N-Gain value of 0.75 (high category).

These findings imply that integrating the STEM approach through the Engineering Design Process (EDP) effectively promotes active, inquiry-based, and contextual learning that enhances students' analytical and creative thinking. Practically, the developed worksheet can serve as a model for teachers to design similar STEM-based materials that foster real-world problem-solving skills in biology. Academically, this research contributes to the growing body of evidence supporting the integration of STEM education into science curricula to strengthen 21st-century competencies. Future research should expand the implementation to a larger sample and explore the long-term impact of STEM-based learning on students' motivation, creativity, and conceptual understanding across various biological topics.

ACKNOWLEDGEMENTS

The author would like to express sincere gratitude to the Head of SMA Negeri 1 Dolok Batu Nanggar for granting permission to conduct the research, as well as to the Biology teacher who assisted in the limited trial, and the Grade XI-3 students who actively participated during the implementation of the study. Special thanks are also extended to the material and media expert validators for their constructive feedback.

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How To Cite This Article, with *APA style* :

Saragih, D. H., & Jayanti, U. N. A. D. (2025). Development of STEM-Based Student Worksheet to Improve Students' Problem-Solving Skills on the Excretory System Material in Grade XI Senior High School. *Jurnal Pembelajaran dan Biologi Nukleus*, *11*(3), 1280-1300. https://doi.org/10.36987/jpbn.v11i3.8155

Conflict of interest : The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions : All authors contributed to the study's conception and design. Material preparation, data collection and analysis were performed by all authors. The first draft of the manuscript was submited by [**Deva Herdina Saragih**]. All authors contributed on previous version and revisions process of the manuscript. All authors read and approved the final manuscript.