

Inquiry-Integrated STEM on Electronic Student Worksheet: An Effort to Stimulate Creative Thinking and Collaborative Skills

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ABSTRACT

This study aims to determine the practicality of developing an inquiry-based STEM-integrated electronic student worksheet to stimulate creative thinking and collaborative skills in kinetic gas theory. The electronic student worksheet was created using a development and research model adopted by Borg and Gall, and it was limited to seven steps. Data collection techniques involved direct observation, questionnaires, and surveys. The findings from this study indicate that the inquiry-based STEM-integrated electronic student worksheet is practical for learners to use in enhancing their creative thinking and collaborative skills on kinetic gas theory. Furthermore, the tests' results categorized it as highly practical, suggesting that this electronic student worksheet can be used as teaching material to further train learners' creative thinking and collaborative skills in kinetic gas theory.

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INTRODUCTION

Mastering 21st-century skills, such as creative thinking and collaboration, has become increasingly important. Creative thinking is vital for students as it helps generate ideas for solving problems they encounter (Izzah et al., 2023; Khoiri et al., 2023; Lucas et al., 2013; Rosidah et al., 2019). Collaborative skills are necessary to ensure a complementary teaching and learning process where learners can support and enhance each other's learning experiences (Ekeh, 2023; Hesse et al., 2015; Johnson & Johnson, 2014; Phommanichan & Cuong, 2023).

However, the reality shows that students' creative and collaborative thinking skills are relatively low. An international survey by the Organisation for Economic Co-operation and Development (OECD) also found that only about 28% of students achieve higher collaborative competency (OECD, 2019).

Based on the pre-research results on 198 high school students in Lampung, Indonesia, 89.9% had difficulties during physics learning sessions. The problems were triggered by the students' difficulty understanding the material the teachers presented. The available learning resources were insufficient to help students understand the material. The monotonous teaching methods also bored students, resulting in a passive learning attitude and an inability to develop creative thinking during physics lessons. A study by Starko (2018) shows that students often do not get enough opportunities to practice and develop creative thinking in conventional classroom contexts. To address these issues, innovative teaching methods, such as project-based and collaborative learning, have proven significant in enhancing students' creative thinking (Deria et al., 2023; Illahi et al., 2022) and collaborative skills (Khoiri et al.,

2023; Sawyer, 2017). The findings indicate the need for a more dynamic and interactive teaching approach to facilitate the development of these essential skills.

Student worksheets are an important tool in the learning process that, if well-developed, can enhance creative and collaborative skills because they encourage learners to be active in group learning processes (Lestari et al., 2023; Nurhayati et al., 2022; Syamsuddin et al., 2023). Learners are also encouraged to sharpen their understanding and ideas in finding joint solutions to existing problems.

Besides providing teaching materials such as student worksheets, adopting an effective learning model or approach is also crucial in enhancing students' creative and collaborative skills. One approach that has proven effective is the inquiry approach (Adhiriyanthi et al., 2021; Ulandari et al., 2019). This approach enriches the content delivered through student worksheets and changes how students interact with the material, promoting a more profound and interactive learning experience. By implementing the inquiry approach, students are invited to be passive recipients of information and active seekers of knowledge (Kusmaryono & Setiawati, 2013). It encourages them to formulate questions, conduct explorations, and research. Thus, students can explore, try new ideas, think critically and creatively about the topics or concepts they learn (Prince & Felder, 2006), and build their understanding through collaboration and discussions with their peers. As a result, students gain knowledge and develop essential skills such as teamwork, problem-solving, and adaptability (Hmelo-Silver et al., 2007). Therefore, integrating the inquiry learning model and quality student worksheets can create an optimal intellectual and social growth environment.

Furthermore, the importance of STEM is emphasized. The relevance of STEM (Science, Technology, Engineering, and Mathematics) in education is becoming

increasingly relevant in today's era of globalization and technological advancement because STEM education provides the essential knowledge and skills base for various critical and innovative future career fields (Fathoni et al., 2020; Mulyani, 2019; Villa et al., 2023). With a focus on science, technology, engineering, and mathematics, STEM education prepares students to face complex real-world challenges, promoting critical thinking and developing effective problem-solving capabilities (Çiftçi & Topçu, 2023; Nungu et al., 2023; Subali et al., 2023). Additionally, the STEM approach supports interdisciplinary integration that strengthens conceptual and applicative understanding, helping students to understand and implement their knowledge more effectively and creatively (Thovawira et al., 2021).

Integrating STEM into education through materials like student worksheets enriches the curriculum. It prepares students with the deep understanding and skills needed to succeed in an increasingly technology-based and science-oriented world. Therefore, integrating the Inquiry model into electronic student worksheets helps students better understand concepts and ideas and also helps them develop important creative thinking and collaborative skills essential for success in the 21st century.

In the past five years, research on the development of student worksheets has shown a significant trend towards integrating technology and innovative learning approaches. Research that highlights how digital and interactive student worksheets, including multimedia and interactive elements like videos and quizzes, can enhance student engagement and motivation (Novita et al., 2021; Petters, 2021; Subekti & Prahmana, 2021; Suparwati et al., 2023). Inquiry-based learning approaches, as explored by Wale & Bishaw (2020), have proven effective in enhancing students' critical thinking abilities, while the integration of STEM elements in student worksheets, researched by Kusumaningtias

& Ningsih (2022) and Fakhruddin et al. (2021), supports the practical application of scientific and mathematical concepts. Furthermore, Qothrunnada et al. (2023) show that student worksheets designed for collaboration and creativity can substantially develop students' social and creative skills. Although there has been much research on student worksheet development, this research focuses on the sufficiency and essential interactivity in supporting a dynamic learning process and stimulating student interest in topics such as kinetic gas theory, both online and offline.

Therefore, this research focuses on developing an interactive student worksheet and implementing online and offline (electronic-student worksheets) based on inquiry and integrated with a STEM

approach to kinetic gas theory. The purpose of these interactive, inquiry-based student worksheets is to facilitate more active learning, where students not only receive information passively but also engage in exploring and discovering STEM concepts through activities designed to enhance creativity and collaboration. Therefore, the developed student worksheet is expected to be more effective in enhancing students' creative thinking abilities and the ability to work collaboratively.

METHODS

This study employs the Research and Development (R&D) method (Borg & Gall, 1989). The R&D steps utilized are adopted from Borg and Gall, limited to 7 steps (see Figure 1).

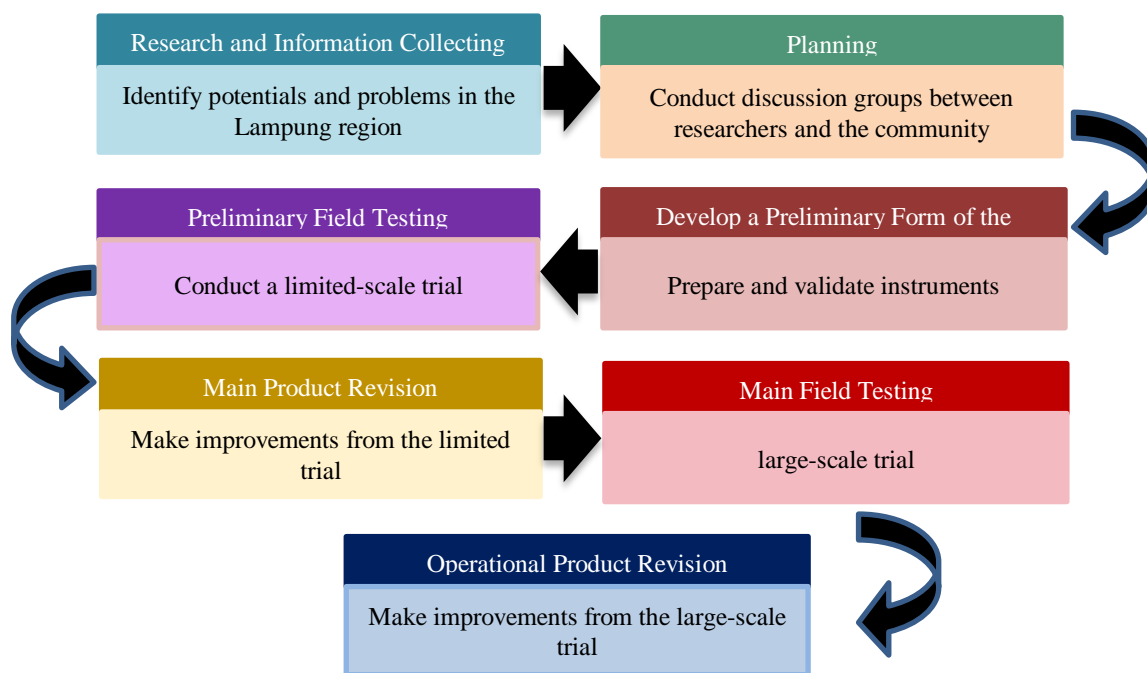


Figure 1. Stages of Borg and Gall Research and Development

In the first stage, a literature study on the problem under investigation and needs analysis are conducted to formulate the research framework. The second stage involves planning. This stage includes preparing a research plan related to the problem, setting objectives for each stage, designing the research steps, and conducting a feasibility study if possible/necessary. The

third stage involves development. The electronic student worksheet was developed using ISpring software and is accessible online and offline. After the product had been developed, a validation test was conducted. Following the validation process, the next step was conducting an initial field trial on a limited scale. Based on the results of the limited-scale trial, revisions were made to the

initial product. After the improvements were made, a large-scale trial was conducted. The subsequent stage involved making further improvements based on the results of the

large-scale trial, resulting in the final product. The design of the electronic student worksheet can be seen in Table 1.

Table 1. Inquiry-Based Electronic Student Worksheet Design with STEM Approach

No	Section	Description
1	Cover	<ul style="list-style-type: none"> a. The front cover will be colourful. It is dominated by blue and yellow. The image presented on the cover is adjusted to the kinetic theory of gas. b. The title is at the top left. c. The author's name will be listed at the bottom left. In the centre, there is a Start button to enter the menu.
2	Menu	The menu section has six buttons to access other features in the electronic student worksheet. The menu includes Preface, Instructions for Use, KI (Core Competence) and KD (Basic Competence), Topics, Reading Materials, and Evaluation.
3	Preface	This page contains a preface composed of praise and gratitude, describing the benefits of electronic student worksheets for readers and the author's gratitude to all those who have helped make them.
4	Instructions for Use	This page contains instructions for using electronic student worksheets and features in electronic student worksheets.
5	Core and Basic Competencies	This page contains core competencies and basic competence that have been adjusted to the syllabus.
6	Topic	<p>There are three topics: Ideal Gas and Boyle's Law, Charles' Law, and Gay-Lussac's Law. With the activity stages, namely:</p> <ul style="list-style-type: none"> a. Orientation, showing the phenomena of the laws of gas kinetic theory and presenting the problem. b. Conceptualization, providing theory-based questions based on the phenomena presented in videos to generate hypotheses about the problem. c. Investigation, conducting experiments or experiments d. Conclusion: Make conclusions from the results of the investigation. e. Discussion, communicating and reflecting on learning activities.
7	Reading Material	This page contains reading materials that can be used as additional information to deepen the material.
8	Evaluation	Consists of Quiz in the form of multiple-choice and description questions to test student competence.
9	Bibliography	Contains references in making electronic student worksheets

In this study, data sources were derived from primary data. Non-test instruments were used as the instruments. Data collection techniques included 1) observation or direct monitoring. Through this technique, researchers collected the necessary data, especially to provide a general overview of the object under study, while also serving as

a means for further study. 2) Questionnaires. Through this technique, the researchers collected data on participants' responses. 3) Library Research. Library research was necessary to provide theoretical and conceptual references and a "framework" for the entire study process, from planning and data collection to data analysis. The criteria

for average analysis used by expert validators and the interpretation of the practicality level of the electronic student worksheet can be seen in Tables 2 and 3.

Table 2. Validation Criteria

No	Achievement Rate (%)	Criteria
1	$75 < V \leq 100$	Highly Valid
2	$50 < V \leq 75$	Valid
3	$25 < V \leq 50$	Less Valid
4	$0 < V \leq 25$	Invalid

Table 3. Practical Interpretation

No	Achievement Rate (%)	Criteria
1	$80 < P \leq 100$	Excellent
2	$60 < P \leq 80$	High
3	$40 < P \leq 60$	Moderate
4	$20 < P \leq 40$	Low
5	$0 \leq P \leq 20$	Poor

RESULTS AND DISCUSSION

This study utilized the electronic student worksheet developed using the iSpring application. Once the product was finalized, it was tested by three expert validators in media & design and material & construction. The product validation test results are presented in Table 4.

Table 4. Recapitulation of Average Percentage of Content and Construct Expert Validation

No	Validator	Average Validation Percentage (%)	
		Media & Design	Materials & Construction
1	Validator 1	88,15%	87,14%
2	Validator 2	97,36%	98,80%
3	Validator 3	98,68%	92,85%
Total		94,73%	92,93%

According to Table 4, the media and design aspects achieved an average percentage of 94.73% from the three validators, while the material and

construction aspects scored 92.93% based on validator assessments. The display of the electronic student worksheet after validation can be seen in Figure 2.

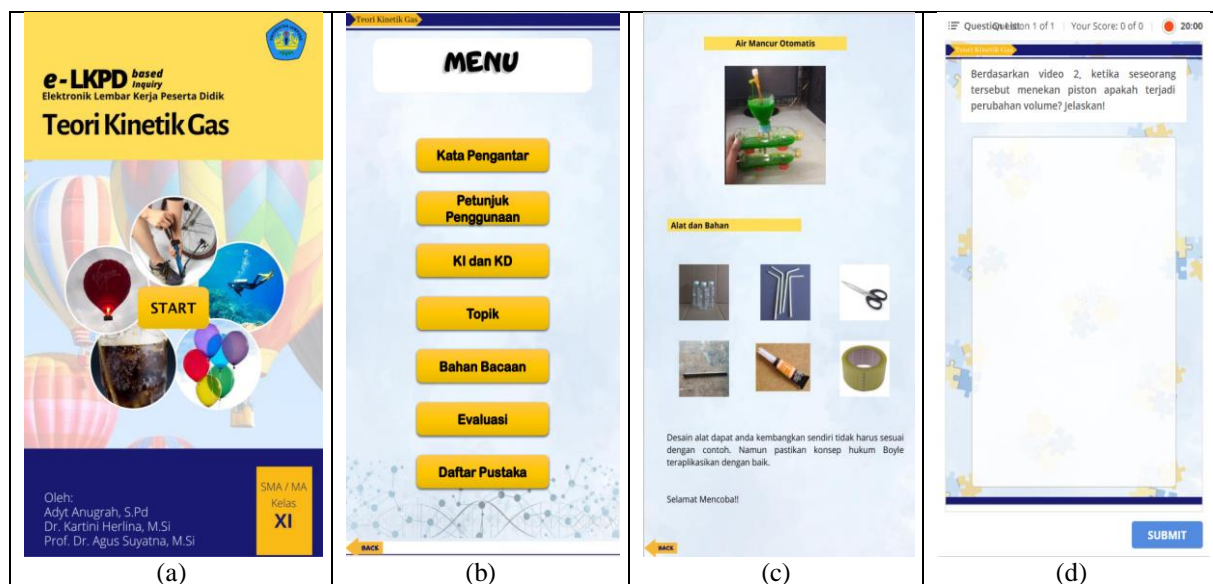


Figure 2. (a) Cover; (b) Menu; (c) Project; (d) Interactive Quiz

The validity of a product refers to the extent to which the developed electronic student worksheet is deemed suitable for

production and use. The developed electronic student worksheet operates on Android devices and includes instructions. These

instructions are intended to facilitate students' use of the product during learning sessions, aligning with the validity aspect that a product is considered suitable if instructions and information are presented clearly and understandably (Wang et al., 2004).

In terms of content, the developed electronic student worksheet focuses on the kinetic gas theory and the laws of ideal gases. The phenomena presented in the electronic student worksheet are taken from real life, thus providing relevance between theory and practical application in daily life. This relevance is intended to make it easier for students to learn the material. As shown in Figure 3, a video about the operation of a tyre pump during the orientation phase is presented. Then, a video demonstrating Boyle's law applied to a syringe is presented in the conceptualisation phase. In this phase, students are asked to formulate problems regarding Boyle's law and the relationships between variables in the phenomenon. Presenting the material in this way facilitates students' understanding of the content, aligning with the validity aspect that a suitable product must include all relevant and important content for learning (Creswell & Plano Clark, 2011). The electronic student worksheet contains activities that require students to be active learners. The inquiry basis in the electronic student worksheet, from the orientation to discussion phases, makes the activities more systematic and helps students process information, especially in fostering creative thinking abilities. This also aligns with the validity aspect of electronic student worksheets, which should include activities that actively involve students in learning (Messick, 1995).

The screenshot shows a digital worksheet interface. At the top, it says 'Teori Kinetik Gas' and 'Topik 1 Gas Ideal dan Hukum Boyle'. The 'Orientasi' section contains text about Boyle's Law and a video thumbnail for 'Video 1.1. Hukum Boyle' showing a bicycle pump. The 'Konseptualisasi' section contains text asking for questions based on a video and a thumbnail for 'Video 1.2. Aplikasi hukum Boyle pada syringe' showing a hand using a syringe. Navigation arrows for 'BACK' and 'NEXT' are at the bottom.

Figure 3. Boyle's Law Phenomenon in Daily Life at the Worksheet's Conceptualization Phase

Based on the validity test results of the electronic student worksheet, reviewed from two aspects—media & design and material & construction—it was found that the average percentage from the three experts was 94.73%, placing it in the excellent category. The results indicated that the inquiry-based STEM integrated electronic student worksheet was suitable for use, particularly from the media and design aspect. The suitability of the electronic student worksheet from the media and design aspect is based on the needs of learners, thus aiding them in understanding the material of kinetic gas theory. This statement aligns with Sasaki & Sudarwanto (2021), who noted that one aspect of a product's validity should be reviewed from the developed media and design aspect. Attractive media and design can provide indirect stimulus to learners. Good media and design should focus on aesthetics and how these elements contribute

to the learning process. The design and media must be developed considering learners' understanding, engagement, and motivation. Thus, the product's validity in this context does not solely depend on the content or material but also on how learners deliver and receive the content.

Material and construction validity, as presented in Table 4 based on the assessment of three validators, obtained an average percentage of 92.93%, placing it in the excellent category. It shows that the inquiry-based electronic student worksheet with a STEM approach is suitable for use.

The concept of material and construction validity refers to the extent to which the material can measure what it is supposed to measure and whether the underlying constructs or concepts of the material are clear and consistent (Trochim, 2006; Ananda et al., 2017). In the context of an inquiry-based electronic student worksheet with a STEM approach, the material effectively facilitates inquiry-based learning within the STEM disciplines, and the underlying concepts have been developed and presented clearly and consistently.

According to research by Chatterji (2003), material and construction validity is an important factor in developing and assessing

learning instruments. This research also supports the assessment findings that materials with high validity tend to be more effective in supporting the teaching-learning process.

Based on the validity percentages, the inquiry-based electronic student worksheet with a STEM approach has been developed considering the principles of inquiry-based learning and the STEM approach. This fact aligns with research by Marshall & Horton (2011), which found that learning materials that integrate inquiry and STEM can enhance student engagement and understanding in STEM disciplines. Based on these results, it is confirmed that the developed electronic student worksheet is valid and ready for practical testing.

The practicality test involved analyzing the readability of the electronic student worksheet, the feasibility of learning implementation using the electronic student worksheet, and the student's responses. The readability questionnaire, which consisted of 11 statements, was distributed to the students. The feasibility analysis involved four observed aspects, and the student response consisted of 35 statements. The results of each analysis can be seen in Table 5.

Table 5. Practicality Test Results

No	Assessment Aspect	Percentage	Category
1	Readability	82,82%	Excellent
2	Learner Response	87,45%	Excellent
3	Applicability	91,30%	Excellent
	Average	87,86%	Excellent

According to Table 5, the average percentages for readability analysis, student response, and feasibility were 82.82%, 87.45%, and 91.30%, respectively. These results yield an overall average of 87.86%, indicating that the inquiry-based electronic student worksheet based on the practicality test can be considered excellent.

The practicality of the developed inquiry-based electronic student worksheet refers to the extent to which the electronic student

worksheet can be used effectively and efficiently in classroom practice. The practicality comprises readability, feasibility, and student response. The electronic student worksheet readability analysis achieved an average percentage of 82.82% (excellent category). Generally, a high readability score indicates that the target audience clearly writes and understands the material. This development study shows that students can easily read, understand, and follow the

instructions or information presented in the electronic student worksheet. This aligns with Klare (1984), who noted that easily readable materials are more effective in supporting the learning process, as students can focus on understanding the content rather than trying to decipher how the material is presented. Another study by McNamara et al. (2014) also shows that readability has a significant relationship with comprehension and information retention. In other words, easily readable materials tend to be more easily understood and remembered by the readers.

The readability analysis results of the electronic student worksheet in this study indicate that the material has been developed with consideration for students' ease of reading and understanding. This aligns with research by Schriver (1989), which found that good design and writing of materials can enhance readers' comprehension and information retention.

The feasibility of the electronic student worksheet in learning includes activities using the developed inquiry-based electronic student worksheet. Each stage within the electronic student worksheet was implemented and achieved an average feasibility percentage of 91.30%, categorized as Excellent. The learning activities using the inquiry-based electronic student worksheet with a STEM approach allow students to understand the learning material. In these lessons, the electronic student worksheet helps students creatively comprehend phenomena in kinetic gas theory. Features included in the developed electronic student worksheets, such as images, videos, and virtual laboratories, enhance students' curiosity, prompting them to explore the material further.

The features used in the inquiry-based electronic student worksheet using the STEM approach were developed to align with previous studies, such as the effective use of educational videos for helping students understand physics concepts (Pertiwi et al., 2017). Proper inquiry training enhances

problem-solving skills in physics learning (Herlina et al., 2016). Using animations in physics education also aids students in understanding physics concepts (Parastiwi et al., 2018). Additionally, the inquiry-based electronic student worksheet using the STEM approach is practical as teachers only need to distribute a link, and students can access the application using mobile smartphones, thus overcoming the limitations of learning time. This proves the theory of technology-enhancing learning, where using smartphones or laptops has successfully improved education quality, transforming learning mechanisms into innovative and modern ones (Nagy, 2018; Wakefield et al., 2018). According to Nurulsari et al. (2017), the positive interaction between students, teachers, and teaching materials influences the implementation of a very high-percentage social system. The active role of students is evident in their enthusiasm for discussions, conducting experiments, and enhancing performance in problem-solving.

Learning using the inquiry-based electronic student worksheet, the student response results received a positive response of 87.45%, categorized as very good, as shown in Table 5. A positive response indicates that the developed electronic student worksheet product is practical. From the feedback of students and teachers, the electronic student worksheet is easy to use, and the instructions and content presented are clear. Access to the electronic student worksheet is straightforward because it can be installed on each student's device. The electronic student worksheet also contains a Virtual Laboratory, videos, and interactive quizzes easily accessible by students. Based on the readability, feasibility, and student response results, the developed electronic student worksheet product is practical. The theory supports that factors contributing to a product's practicality include comprehensibility, ease of use, time and efficiency, affordability, content relevance, and interactivity contained in the product (Hattie, 2009; Nielsen, 2012).

The positive response to the inquiry-based electronic student worksheet demonstrates that the combination of the inquiry-learning approach and the use of technology in education can effectively enhance student learning outcomes. The higher the student response to using learning media, the higher the learning outcomes achieved (Khotimah et al., 2018). When students provide good feedback from the beginning to the end of the learning process, it makes it easier for them to understand the material provided by the teacher due to the positive feelings experienced by the students.

CONCLUSION AND SUGGESTION

Based on the results of the research and discussion, it can be concluded that the electronic student worksheet based on inquiry integrated with STEM meets the feasibility criteria, which are: a) Validity, indicating that the electronic student worksheet is highly suitable in terms of content and construct, with an average percentage of 94.73% for content aspect and 92.93% for construct aspect. b) Practicality, as demonstrated by an average readability percentage of 82.82% with a high criterion, implementation feasibility of 91.30% with an excellent criterion, and a positive response from the students at 87.45% towards the electronic student worksheet. However, further research is needed to determine how much this inquiry-based STEM-integrated electronic student worksheet can stimulate creative thinking and collaborative skills. Therefore, the suggestion for future researchers is to implement the product in classroom teaching and learning activities.

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