

Designing Sustainable City: Feasibility of Gamification-Integrated STEM-Based Science Learning Tools

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Abstract – This study aims to develop and validate STEM-based learning tools integrated with Game-Based Learning themed "Sustainable City" to address the lack of student engagement in STEM education. Employing the Educational Design Research (EDR) method, this research focuses on the design and construction phase involving the development of student worksheets and teaching modules. The product feasibility was assessed by five experts through content and graphic validation using a 46-item instrument with a 4-point Likert scale. Data were analyzed using percentage analysis and Aiken's V index. The results demonstrate that the content feasibility achieved an average score of 93% (Very Valid) with an Aiken's V of 0.90, highlighting strong validity in integrating the EDP and SDGs. The graphic feasibility obtained an average score of 87% (Very Valid). However, the specific finding revealed a critical gap in the "Cover Design" indicator, which scored the lowest (75%). Overall, the STEM-EDP materials are declared academically feasible by experts, although they require graphic improvements. However, the effectiveness of these tools has not been practically tested in the field. Therefore, further development must integrate academic validity with classroom trials to ensure its positive impact on student motivation.

Keywords: Feasibility Study; Game-Based Learning; Science Learning; STEM; Sustainable City

INTRODUCTION

Integration of STEM (Science, Technology, Engineering, and Mathematics) is a strategic field crucial to the 21st century, driven by technological and industrial advancements and increasingly complex global challenges (Fadillah, 2024; Suyuti et al., 2025). STEM education is proven to foster 21st-century skills, such as critical thinking, creativity, collaboration, and communication, as well as enhance students' literacy and numeracy (Yulianti et al., 2025). In line with this, the global demand for STEM graduates continues to rise (Black et al., 2021).

However, in Indonesia, there remains a significant gap between the quantity and competence of STEM graduates and the workforce demand in related sectors (Amalina et al., 2025; Yanuar, 2024). This gap pertains not only to the quantity of graduates but also reflects low student

interest in STEM beginning at the primary and secondary education levels. Although STEM is considered essential and has been proven to offer various benefits, empirical evidence suggests that students do not yet fully perceive it as a field that is engaging, relevant, and relatable to their daily lives (Fairhurst et al., 2023). This situation indicates that the primary challenge in STEM education lies not solely in the subject matter, but also in how the STEM learning experience is designed and delivered to students.

Education plays a crucial role in fostering student interest and motivation in STEM through the design of learning experiences that are active, contextual, and oriented toward real-world problem-solving (Afriana et al., 2016; Mulyono et al., 2025). A key aspect in supporting this process is the availability of learning tools, such as teaching modules and Student worksheets,

that are pedagogically and contextually designed. Effective modules and worksheets serve not only as guides for learning activities but also as tools to foster student engagement, curiosity, and interest in learning (Padilah et al., 2024).

In the context of STEM education, STEM-based learning tools play a crucial role in integrating science, technology, engineering, and mathematics holistically, as well as developing students' higher-order thinking skills (Salsabila et al., 2024). However, STEM learning tools that are solely conceptual and procedural in nature may prove less effective if not accompanied by strategies capable of enhancing student interest and engagement. Therefore, the issue of low student interest in STEM must be a primary consideration in the development of learning tools.

The integration of game elements into learning offers a potential approach to address this issue. Games can create interactive, challenging, and goal-oriented learning experiences, thereby fostering active student engagement and enhancing intrinsic motivation (Jääskä et al., 2022). When integrated with the STEM approach, games have the potential to assist students in understanding concepts contextually, practicing problem-solving through authentic scenarios, and creating meaningful and enjoyable STEM learning experiences. The use of the 'Sustainable Cities' theme further reinforces this integration, as it represents real-world problems that are relevant to students' lives and align with sustainable development issues.

Based on the aforementioned description, this research focuses on the development of game-integrated STEM learning tools (teaching modules and worksheets) themed 'Sustainable Cities' for junior high school students, as well as testing

their feasibility in terms of content and graphic aspects based on expert assessment.

RESEARCH METHODS

This study employs the Educational Design Research (EDR) method with a mixed-methods approach. EDR was selected because this approach aims not only to test theory but also to systematically design and develop interventions. The EDR method adapts a three-phase development model, namely: (1) analysis and exploration, (2) design and construction, and (3) evaluation and reflection (Mirattanaphrai & Srikoon, 2025). This article focuses on the implementation of the second phase, namely "Design and Develop." The learning tools are developed based on STEM-Gamification as a practical solution to address complex learning problems in real-world settings (McKenney & Reeves, 2025). A mixed-methods approach was employed to obtain a more comprehensive understanding by combining qualitative data, in the form of expert feedback for improvement, and quantitative data, consisting of product validity scores (Grand-Guillaume-Perrenoud et al., 2023).

The flowchart of the research method for phase 2 (design and construct), which serves as the focus of this article, is presented in Figure 1. Figure 1 illustrates that the design and construct phase is divided into three stages: initial design development, design refinement 1, and final refinement.

In the development stage, the initial design was formulated based on the analysis and exploration results from the previous stage (EDR Phase 1). Consequently, the preliminary draft of the Student worksheets was developed in alignment with the Phase D Science Learning Outcomes relevant to the 'Sustainable Cities' content. This specifically targeted the element of scientific understanding, covering energy, physical

and chemical properties of soil, climate change, environmental conservation, and the interaction of living things with the environment in efforts to prevent and mitigate climate change. Furthermore, the process skills element was designed to encompass all aspects outlined in the

learning outcomes. The worksheet design also incorporates gamification elements, realized in the form of the 'Sustainable City' board game, which is further integrated with the STEM approach via the Engineering Design Process model, particularly during the 'Learn' stage.

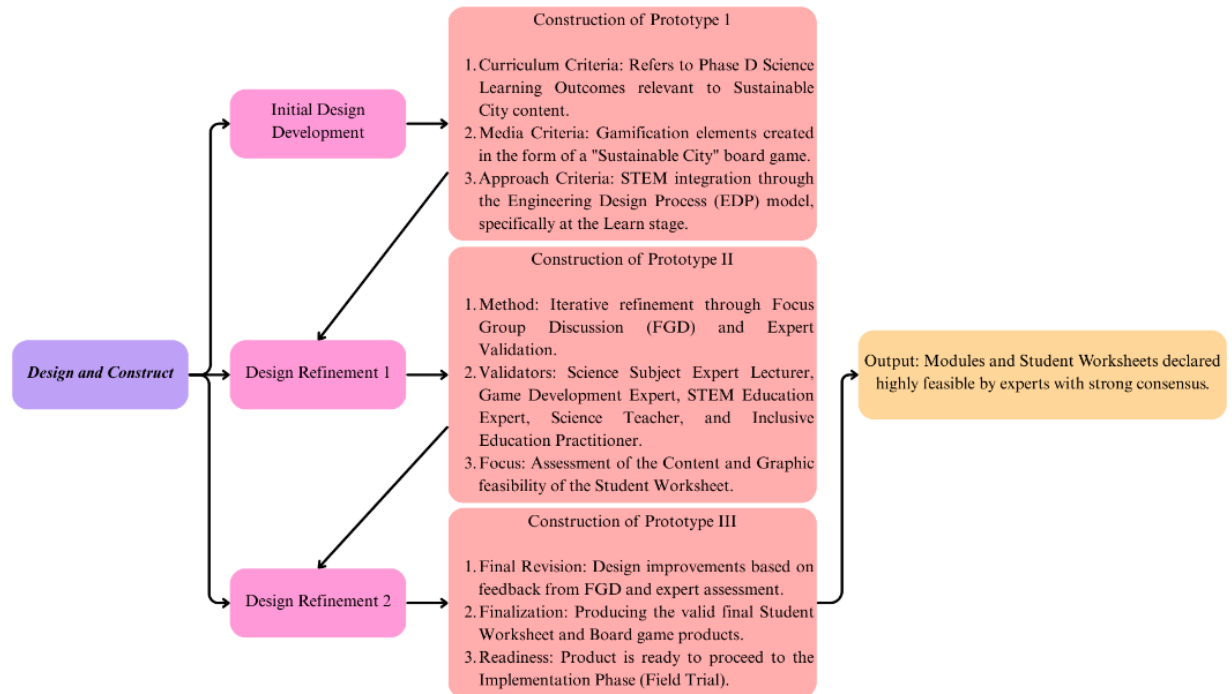


Figure 1. Research Method Flowchart

After the initial design was developed, it was then refined through repeated design improvements via Focus Group Discussions (FGD) and expert validation. This stage involved five experts selected based on their competence in their respective fields, consisting of one lecturer specializing in science, one expert in educational game development, one expert in STEM education, and two education practitioners (science teachers and inclusive education instructors) to assess the content and graphics of the student worksheet.

Data collection was conducted using validation sheets filled out by experts to assess product suitability. The validation sheets were compiled using a four-point Likert scale, with a rating range from 1 (Very Unsuitable) to 4 (Very Suitable). The

selection of an even scale without a neutral option was done intentionally to minimize central tendency bias, which is the tendency of respondents to choose a safe value in the middle, so that respondents are encouraged to give more decisive assessments in the direction of agree or disagree (Kankaraš & Capecchi, 2025). The validation sheet also contains open-ended questions about suggestions for improvement from experts for refining the student worksheet design.

The validation sheet consists of 46 statements covering aspects of content and graphic feasibility. Content feasibility is broken down into indicators of necessity, novelty, material coverage, design accuracy, timeliness, contextuality, and legal compliance. Graphic feasibility covers

indicators of student worksheet size, cover design, and content design.

Qualitative data analysis was applied to the input, criticism, and suggestions provided by validators through questionnaires. The analysis technique used refers to an interactive model that includes three main stages, namely data reduction by sorting and selecting relevant comments for product improvement, data presentation by grouping input based on content and graphics, and drawing conclusions or verification by determining the necessary revisions to the learning device prototype (Miles et al., 2018).

Quantitative analysis was performed to process the assessment scores obtained from the expert validation sheet. The data were analyzed using the suitability percentage technique to determine the general suitability category of the product. The suitability percentage was calculated by comparing the score obtained with the maximum score that could be achieved, then converted into a percentage using Equation (1),

$$\text{Value (\%)} = \frac{\sum x}{\sum x_i} \times 100\% \quad (1)$$

where $\sum x$ is the sum of the scores obtained from the validators, and $\sum x_i$ is the ideal maximum score. The percentage results are then converted into eligibility categories using the scale in Table 1 (Qin et al., 2024).

Table 1. Validity Criteria

Value (%)	Criteria
$0 < x \leq 20$	Very Unfeasible
$20 < x \leq 40$	Unfeasible
$40 < x \leq 60$	Moderately Feasible
$60 < x \leq 80$	Feasible
$80 < x \leq 100$	Very Feasible

Furthermore, to specifically assess content validity and measure the level of inter-rater agreement for each instrument

item, Aiken's V index was employed. This index is calculated using Equation (2),

$$V = \frac{\sum s}{n(c - 1)} \quad (2)$$

where V is the item validity index, s is the score assigned by the validator minus the lowest score in the rating category ($r - l_o$), n is the number of validators, and c is the number of rating categories. The value of V ranges from 0 to 1. Based on the established interpretation criteria, an item is considered to have high validity if $V > 0,80$ (Putri et al., 2025).

RESULTS AND DISCUSSION

The developed product, consisting of gamification-integrated STEM-EDP Student worksheets and teaching module, has undergone validation by five experts. The validation data were categorized into two primary aspects: content feasibility (subject matter substance) and graphic feasibility (media design).

Results

The content feasibility assessment was conducted using an instrument comprising 18 items designed to measure seven essential indicators. Based on quantitative data analysis, the learning tools achieved the 'Very Feasible' category across all assessment indicators. A summary of the average scores and Aiken's V validity indices is presented in Table 2.

Table 2. Summary of Content Feasibility Validation Results

Indicator	Average Score (%)	Aiken's V Value	Category
Needs	97.5	0.96	Highly Valid
Novelty	85.0	0.80	Valid
Content Coverage	93.3	0.91	Highly Valid
Design Accuracy	93.3	0.91	Highly Valid
Currency	91.6	0.88	Highly Valid

Indicator	Average Score (%)	Aiken's V Value	Category
Legal Compliance	97.5	0.96	Highly Valid
Overall Average	93.0	0.90	Highly Valid

Referring to Table 2, it is evident that the content validity exhibits high consistency. Indicators related to relevance, such as Needs and Contextuality, obtained the highest expert agreement indices. Overall, Aiken's V value of 0.90 confirms that the developed 'Sustainable Cities' material meets stringent content validity standards without requiring revision regarding its substance. However, experts suggested including a gameplay tutorial video and simplifying the game rules presented in the student worksheets. These suggestions have been addressed by simplifying the rules and adding a tutorial video, as illustrated in Figure 2.



Figure 2. Tutorial Video Display





In contrast to the content aspect, which received exceptionally high ratings, the validation results for the graphic aspect revealed data variations that serve as a critical note for the developers. The detailed score breakdown is presented in Table 3.

Table 3. Summary of Graphic Feasibility Validation Result

Indicator	Average Score (%)	Aiken's V Value	Category
Size	95	0.93	Highly Valid
Cover Design	75	0.67	Valid
Content Design	90.5	0.87	Highly Valid
Overall Average	87	0.83	Highly Valid

The assessment of graphic aspects focused on three main visual components: physical size, cover design, and content design. Based on Table 3, the 'Worksheet Physical Size' and 'Content Design' indicators fell within the 'Highly Valid' category, with scores exceeding 90%. The 'Size' indicator achieved the highest score, demonstrating that the developed worksheet dimensions are appropriate (neither too large nor too small). Although the 'Cover Design' indicator was categorized as valid, it received the lowest score among all indicators. Consequently, this assessment served as the basis for improving the cover design to ensure the graphics are more visually appealing and accurately represent the worksheet's content.

Table 4. Validator Feedback and Recommendations

Comments and Feedback	Display Before Revision	Revision	Display After Revision
<p>Balance the colors, elements, and functionality of the cover. Ensure the graphic design is relevant to the content, specifically regarding the harmony and coherence of colors, background, and font sizes. Furthermore, incorporate elements from the game cards, depictions of a sustainable city, and icons representing junior high school students</p>		<p>The cover design revision focused on color harmonization, layout, and typography to enhance readability. Additionally, visual elements such as game card illustrations, sustainable city icons, and junior high school student characters were incorporated to reinforce the design's relevance to the subject matter and the target audience</p>	
<p>Adjust the board game display to include complete game components and utilize bright colors to attract student attention. Furthermore, the current visual design feels too 'rural'; it should be modified to better represent an 'urban' environment</p>		<p>Revisions to the board game interface involved transforming the background illustrations from a rural aesthetic to an urban setting to better align with the 'Sustainable Cities' topic. Additionally, the color palette was updated using brighter hues to capture student interest, and the visual game components were refined to ensure completeness</p>	

Comments and Feedback

Display Before Revision

Revision

Display After Revision

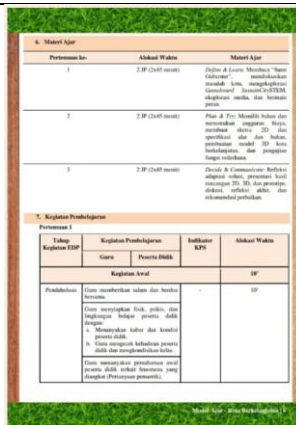
Simplify game components and rules to enhance student comprehension, and include a game tutorial video



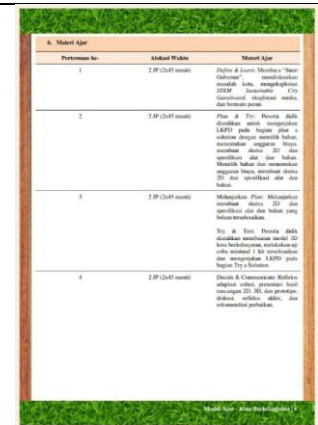
Instructions and game components were simplified to minimize confusion, and a tutorial video was added to ensure the gameplay flow is easily followed by students



Alignment of teaching materials with the designed number of sessions



Teaching materials were adjusted to align with the designed number of sessions



Discussion

The discussion begins with an overview of the developed product, comprised of STEM-based Student Worksheets integrated with gamification on the topic of "Sustainable Cities." The worksheets are presented in 24 pages and structured around the six stages of the EDP: Define, Learn, Plan, Try, Decide, and Communicate. The integration of game elements is specifically featured in the 'Learn' stage, where students utilize the "SustainCity" board game to explore scientific concepts and environmental challenges interactively. Meanwhile, the STEM approach is predominantly embedded in the 'Plan' and 'Try' stages, facilitating students in applying engineering design and mathematical calculations to construct solvable city prototypes.

The content validation results, indicating an average score of 93% with an Aiken's V index of 0.90 (Table 2), provide empirical evidence that the developed learning tools possess a highly robust content structure. This figure reflects not only scientific conceptual accuracy but also the successful integration of subject matter within the STEM-EDP framework. This high level of validity can be analyzed in depth through three key theoretical dimensions: contextual, pedagogical, and curricular urgency.

The maximum score achieved on the 'Contextuality' indicator (95%) underscores that the selection of the 'Sustainable City' topic is highly relevant to current global issues. The validators assessed that this material successfully bridges abstract scientific concepts with real-world societal

problems. The Sustainable City topic incorporated into the worksheets aligns with the Sustainable Development Goals (SDGs), specifically SDG 11 (Sustainable Cities and Communities). By integrating SDG issues into the Student worksheets, this product not only enhances cognitive skills but also cultivates scientific literacy and environmental awareness, which are vital components of modern science education (Nurwulandari & Rofiq, 2021).

The exceptionally high validity of the 'Design Accuracy' indicator (95%) demonstrates that the integration of the EDP model within the student worksheets is pedagogically effective. The learning phases are systematically structured, ranging from Define, Learn, Plan, Try, Decide, to Communicate, reflecting the principles of constructivist learning. Specifically, the 'Plan' and 'Try' stages facilitate students in constructing their own knowledge through the activities of designing and testing engineering solutions. This aligns with previous research findings suggesting that the EDP approach provides effective cognitive scaffolding, enabling students to develop Higher Order Thinking Skills (HOTS) and complex problem-solving abilities (Dila et al., 2024; Sapphira et al., 2023)

The high scores on the 'Needs' and 'Novelty' indicators indicate that this product successfully fills the existing gap in STEM learning tools. The tool offers novelty by combining scientific rigor with gamification dynamics, designed to stimulate 21st-century skills, commonly known as the 4Cs (Critical Thinking, Creativity, Collaboration, and Communication). This integration of gamification and the STEM approach provides significant added value in creating an immersive learning experience. Such synergy enables game elements, including challenges, competition, and

instant feedback to reinforce the EDP stages, allowing students to practice 21st-century skills in a more natural and profound manner (Cheng & Weatherly, 2025). Furthermore, the use of game mechanics in STEM content theoretically enhances students' intrinsic motivation by providing a safe learning environment for trial-and-error, which constitutes the core of the engineering process (Harwi, 2025). Thus, the use of this interactive media is proven to be more effective in sustaining student attention and academic performance compared to conventional learning methods, which tend to be static.

The score disparity between content quality (93%) and cover design (75%) indicates that academic validity alone is insufficient to guarantee the success of interactive media. Initially, the cover designs (Teaching Module and LKPD) utilized a dominant wood-textured background and realistic photos placed separately within geometric frames. This resulted in a cluttered layout, low color contrast between the text and background, and vertical typography that was difficult to read. Based on validator feedback, the initial design lacked harmony between visual elements and the learning content. This disharmony can hinder students' situational interest at first glance (Mayzhurra & Hariyono, 2021).

As a corrective measure, a comprehensive transformation of the cover design was carried out by applying a cleaner and more modern vector illustration concept. The revision process focused on the use of green colors symbolizing sustainability, layout simplification, and the use of bolder typography. Additionally, relevant visual elements were added, such as sustainable city icons, game card illustrations, and junior high school student characters to create a personal atmosphere for the target audience. Psychologically, this transition from a rigid

to a dynamic design plays a crucial role in increasing student engagement (Nurwahid & Mubasiroh, 2026). The use of age-appropriate characters and visuals for students (digital natives) can reduce cognitive load and build emotional connections, thereby motivating students to explore the learning media more deeply (Raoza, 2024).

The critical role of visual design in the initial learning phase can be elucidated through the ARCS (Attention, Relevance, Confidence, Satisfaction) motivational theory (Mei et al., 2025). The cover design and interface act as an affective capture, triggering students' situational interest. Validator feedback regarding insufficient color contrast and element density in the initial design indicates the media's failure to optimally capture student attention. If this initial visual stimulus is not strong enough to spark curiosity, students' intrinsic motivation to explore deeper content challenges potentially declines, regardless of the validity of the STEM pedagogical construction within (Agustin et al., 2025; Putriningtyas & Ambarwati, 2025).

Beyond its attentional function, visual quality is also closely linked to the efficiency of information processing in the brain. Disorganized graphic displays risk increasing extraneous cognitive load, which can hinder students from absorbing core material (Çeken & Taşkın, 2022). Conversely, the application of sound multimedia design principles, such as clear typography, organized visual hierarchy, and relevant illustrations is proven to generate positive affect. According to Emotional Design theory, this condition is crucial because positive emotions facilitate smoother cognitive processes and deeper understanding during student interaction with the game (Liu & Wang, 2025).

The urgency of these visual improvements is increasingly relevant given the characteristics of contemporary junior high school students as digital natives with high visual expectations for technological products. Students accustomed to the sophisticated interfaces of commercial applications tend to be skeptical of educational media labeled as 'games' that possess a rigid visual appearance resembling conventional textbooks. This aesthetic disparity can cause cognitive dissonance, ultimately leading to low student engagement. Consequently, the 75% score on the cover design was evaluated not merely as an artistic shortcoming, but as a pedagogical obstacle that necessitated significant design revisions to ensure the product's psychological acceptance by students (Melati et al., 2025).

Although the STEM-EDP-based learning tools have overall met the 'Highly Valid' criteria in terms of substance and graphic feasibility, specific findings regarding the 'Cover Design' indicator (score 75%) demand special attention before the product is widely implemented. Based on qualitative feedback from expert validators, the recommended improvement measures do not alter the material structure, but rather focus on refining the visual interface to enhance the media's initial appeal.

Regarding technical recommendations as a follow-up to the validation (Evaluation) phase, design refinements are suggested to focus on two primary aspects. First, the improvement of contrast and visual hierarchy on the cover. The use of a brighter color palette and bolder typography is recommended to accentuate the 'game' atmosphere and distinguish it from conventional textbooks. Second, layout simplification. Overly dense graphic elements need to be reduced to minimize visual clutter, ensuring that student focus is

immediately directed toward the title and key game elements. These revisions are crucial to ensure the media functions optimally as an attentional capture mechanism before students interact with the embedded STEM content.

Policy and Development Implications: The findings of this study offer strategic implications for the future development of science learning tools. The score discrepancy between 'Content' quality (93%) and 'Cover' quality (75%) underscores that academic validity alone is insufficient to guarantee the quality of interactive learning media; a synergy with design aesthetics is required. Therefore, it is recommended that educational practitioners and curriculum developers ensure the development process of STEM learning media is not conducted linearly, focusing solely on content aspects.

CONCLUSION

Based on the research and development conducted, it can be concluded that the STEM-EDP-based science worksheet integrated with the 'SustainCity' game on the 'Sustainable City' topic are declared highly feasible for use. Expert validation results indicate that the content feasibility aspect achieved an average score of 93% (Highly Valid), while the graphic aspect obtained an average score of 87% (Highly Valid). The developed materials proved valid in integrating the EDP syntax and possess high relevance to SDGs issues. Although generally categorized as highly feasible, this study identified a critical note regarding the cover design aspect, which recorded the lowest score (75%). Therefore, it is recommended that further development prioritize visual aesthetic improvements and layout simplification to enhance the media's initial appeal. The implications of this study indicate that the success of STEM learning tools relies not solely on the validity of

scientific substance, but also requires adaptive visual packaging.

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