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Green Solver Card Game: Needs Analysis and Design for Green Chemistry Learning

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ABSTRACT

This research is driven by the instructional saturation and passive learning environment observed in green chemistry education at SMAN 8 Samarinda. The study aims to conduct a needs analysis and design an interactive learning medium called the *Green Solver* card game to increase student engagement and conceptual understanding. Using the Research and Development (R&D) approach with the ADDIE model, this research is specifically limited to the analysis and design stages. The subjects involved in this preliminary study were 1 chemistry teacher and 189 tenth-grade students as the primary data sources. The analysis stage, conducted through interviews and questionnaires, revealed that 76.2% of students found existing static media uninteresting, while 92.1% expressed a strong preference for the integration of game-based learning. In the design stage, the *Green Solver* card game was developed by adapting the "Truth or Dare" social mechanism into two strategic components: Theory cards and Action cards. Theory cards serve as retrieval practice tools to strengthen conceptual memory, whereas Action cards incorporate gamified challenges and environmental problem-solving tasks to alleviate learning anxiety and promote social collaboration. The resulting design includes a comprehensive guidebook, a tiered scoring system (5-40 points), and visual elements optimized for cognitive processing through dual coding. This study successfully produced a prototype blueprint that offers a holistic solution to transform classroom dynamics from passive to active learning.

A. INTRODUCTION

Chemistry is often considered a challenging subject for students due to the nature of the material, which includes macroscopic, sub-microscopic, and symbolic representations. This complexity requires visualization skills and a deep conceptual understanding, rather than mere memorization (Kapici, 2023; Petillion & McNeil, 2020). One crucial topic in the modern curriculum is green chemistry, which emphasizes the principles of sustainability and environmental preservation. Although highly relevant to everyday life, this material is often presented in a theoretical and textual manner, making it difficult for students to grasp its essence and urgency (Zuin et al., 2021). A literature review by Chen et al. (2020) confirms that in order to build authentic sustainability awareness, green chemistry learning must integrate collaborative methods and problem-based learning.

The success of science education highly depends on student engagement, both cognitively and emotionally (Alhadabi, 2021; Rahmadhea, 2024). However, maintaining optimal student interest and attention remains one of the main challenges in chemistry education (Solntsev et al., 2022; Waruwu & Sitinjak, 2022). Based on observations at

SMAN 8 Samarinda, green chemistry learning has generally been supported by the use of presentation media such as PowerPoint or Canva slides. Although visually appealing, this one-way presentation format often limits active interaction among students. This aligns with the findings of Deslauriers et al. (2019), which indicate that less interactive learning can create an illusion of understanding, where students feel they comprehend the material even though their actual achievement is low. This lack of dynamic interaction also risks reducing focus and triggering academic boredom (Pekrun et al., 2017). Therefore, there is a prominent urgency to introduce a variety of interactive learning media capable of transforming classroom dynamics to be more lively and engaging.

One approach proven effective in increasing student engagement and 21st-century skills is Game-Based Learning (GBL) (Qian & Clark, 2016). Systematic literature reviews confirm that educational games, particularly physical games such as tabletop or card games, remain highly relevant due to their superiority in promoting direct face-to-face interaction, motivating students, and training social collaboration skills (da Silva et al., 2025; Sailer & Homner, 2020). Various previous studies have implemented this concept; for instance, Miller et al. (2019) developed a strategy card game called *Green Machine* to help students understand systems thinking concepts in green chemistry. Similarly, Li and He (2023) demonstrated the effectiveness of the *Card Lab* educational game in supporting chemistry laboratory learning. More recently, Tursyngozhayev et al. (2024) also demonstrated that implementing the *Compound Chain* card game significantly enhanced students' understanding of chemical nomenclature. These previous studies establish the state of the art that serves as the foundation for developing the instructional media innovation in this study.

Although the use of card games in chemistry has been widely researched, there remains a prominent research gap regarding the lack of media that utilize familiar social game approaches to simultaneously address cognitive and affective issues (such as learning anxiety). To fill this gap, this study offers novelty by developing the *Green Solver* card game, which adapts the mechanics of the popular social game "Truth or Dare" into an educational context. Unlike previous media, *Green Solver* modifies this mechanism into 'Theory' cards to test students' conceptual memory, and 'Action' cards to provide a recreational atmosphere that trains students' courage to collaborate without anxiety (Zainuddin et al., 2020). Through this innovation, green chemistry material is no longer viewed as mere memorization, but rather as a problem-solving challenge to be resolved collaboratively. Therefore, the research objective of this study is to conduct a needs analysis and to design a prototype of an interactive learning medium, the *Green Solver* card game, to enhance student engagement and conceptual understanding.

B. METHODS

This research employs a Research and Development (R&D) approach by adapting the ADDIE development model (Branch, 2009). This model was chosen because its systematic structure has proven effective in developing physical game-based learning media (tabletop games) to ensure alignment between pedagogical objectives and game mechanics (Chin & Heng, 2024). Although the ADDIE model consists of five stages (Analysis, Design, Development, Implementation, and Evaluation), this study is specifically limited to the Analysis and Design stages. This limitation was imposed to focus the research on constructing the conceptual framework, conducting a needs analysis, and designing a mature prototype of the *Green Solver Card* media before proceeding to the physical production and field-testing stages. The research was conducted at SMA Negeri

8 Samarinda, with the preliminary study subjects involving 1 chemistry teacher and 189 tenth-grade students as primary data sources.

Data collection was conducted using several instruments: structured interview guidelines to explore learning problems, document analysis sheets to examine Learning Outcomes, and a student needs analysis questionnaire. Data analysis was performed using mixed descriptive techniques. The data from interviews and document analysis were analyzed using qualitative descriptive methods by reducing the data and presenting it narratively to justify the media design. Meanwhile, the data from the student needs analysis questionnaire were analyzed using quantitative descriptive methods through percentage calculations to measure the students' level of interest and need for game-based media.

The research procedure was carried out through two systematic stages. The first stage, Analysis, aimed to gather foundational information as a basis for development. Activities at this stage included: (1) needs analysis through teacher interviews and distributing questionnaires to 189 students to map learning obstacles, (2) curriculum analysis to formulate question indicators for *Theory* cards and types of challenges for *Action* cards, and (3) analysis of student characteristics to adjust the visual style of the media. The second stage, Design, is where the analysis results are transformed into product specifications. The main activities at this stage included developing the game flow adapted from *Truth or Dare*, designing a tiered scoring system, selecting visual elements (colors, typography, and illustrations), and drafting supporting materials such as a game guidebook. The final output of this method is a blueprint design of the *Green Solver* card game, ready for validation and production in subsequent studies.

C. RESULT AND DISCUSSION

1. Result

Analysis Stage

The analysis stage was conducted to identify the root causes of the problems in green chemistry learning at SMAN 8 Samarinda. Based on the results of observations and interviews with the chemistry teacher, it was identified that the delivery of material still heavily relied on static presentation media (slide-based). This condition created a passive learning environment and triggered high instructional saturation among students.

This diagnosis is reinforced by empirical data obtained from a needs analysis questionnaire distributed to 189 tenth-grade students. The questionnaire results showed that 76.2% of students rated the currently used instructional media as lacking cognitive challenge and tending to be boring. Conversely, there was a highly significant enthusiasm, with 92.1% of students expressing a strong interest in the integration of game-based learning media to break the classroom monotony. Furthermore, 87.3% of students agreed that the development of new, more interactive media was urgently needed. The detailed percentage of student responses can be seen in Table 1.

Table 1. Distribution of Student Needs Analysis Responses

No	Question Indicators	Positive Response (Agree & Strongly Agree)(%)	Interpretation
1	The media is currently uninteresting	76,2%	The problem was identified.
2	Interest in game-based media	92,1%	High Potential
3	Agree with the development of Green Solver media	87,3%	Urgent Needs

Design Stage

Responding to the findings in the analysis stage, this study designed the prototype specifications for a card game medium named *Green Solver*. This medium was designed by adapting the social mechanics of the *Truth or Dare* game into an educational context.

Physically, the *Green Solver* cards are designed in a portable size (6 x 9 cm) to be practical for use in various group discussion formations, both inside and outside the classroom. The visual design is dominated by the color green to reinforce the identity of the green chemistry material, and it employs consistent color coding as a signaling principle to make it easier for students to process visual information (Schneider et al., 2018). As the main supporting tool, this medium is equipped with a comprehensive guidebook containing Learning Outcomes, Learning Objectives, a Concept Map, and standard rules of play to minimize confusion when students play independently (Figure 1).

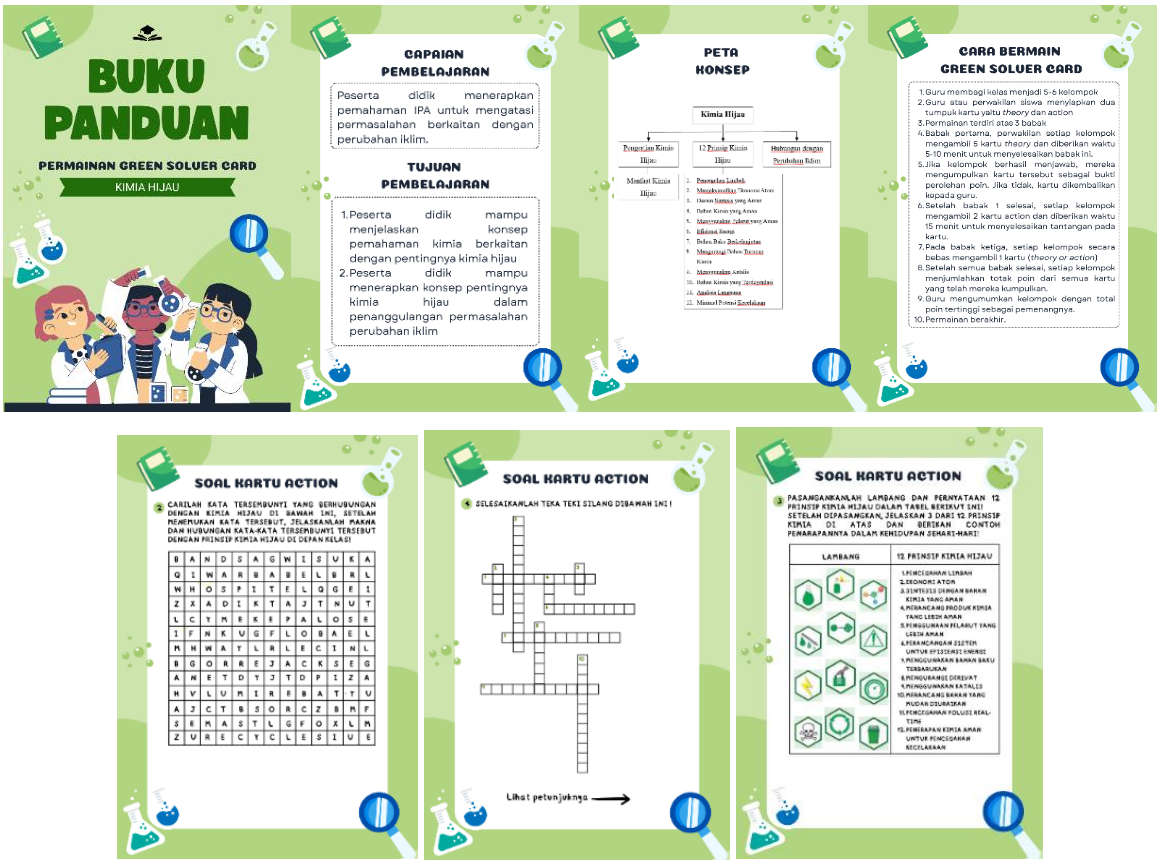

Figure 1. Green solver game guidebook

The core structure of the *Green Solver* game is divided into two complementary card components, namely Theory cards and Action cards. The Theory cards are an adaptation of the "Truth" mechanism and contain concise conceptual questions related to green chemistry material (Figure 2). Complementing this, the Action cards serve as an adaptation of the "Dare" mechanism, featuring various challenges such as crossword puzzles, hidden word searches, and matching pictures with statements. In addition to these game-based activities, the Action cards also include problem-solving tasks related to environmental issues (Figure 3).

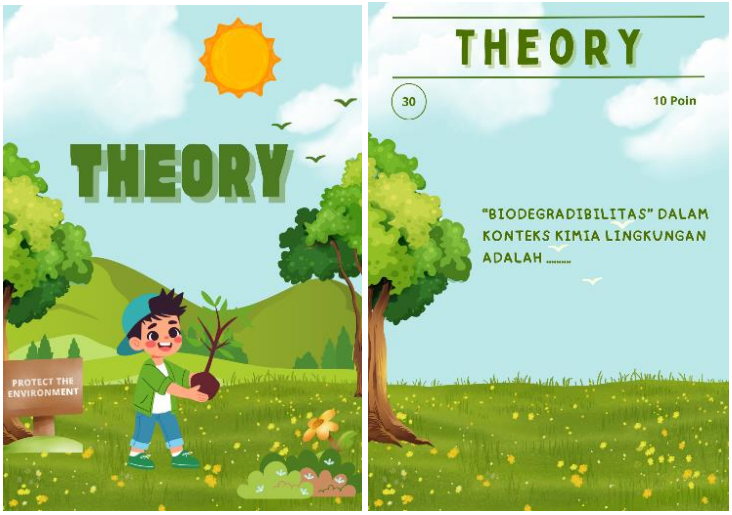

Figure 2. Theory card

Figure 3. Action card

To encourage a healthy competitive climate among students, this game implements a tiered scoring system. The acquired points are displayed at the top of each card. Each Theory card is worth 5 to 10 points. Meanwhile, the Action cards are given a much higher score weighting, namely 20 to 40 points.

2. Discussion

Retrieval Practice and Dual Coding

The Theory card component in *Green Solver* is not merely designed as an evaluation tool, but rather as a learning instrument based on retrieval practice. Based on neuroscience studies, forcing students to actively recall conceptual memory

through questions (adapting the "Truth" mechanism) is far more effective in strengthening long-term memory pathways compared to passive learning methods such as re-reading textbooks (Agarwal et al., 2021). Furthermore, presenting the material in the form of a single concise question per card implements the chunking principle. This strategy theoretically prevents cognitive overload, which students often experience when faced with text-dense chemistry materials (Rey et al., 2019). In terms of visual design, the integration of text and illustrations on the Theory cards is supported by Dual Coding Theory (Mayer, 2017). This theory asserts that processing information simultaneously through two different cognitive channels (verbal and visual) expands students' working memory capacity. Additionally, student interaction while answering these cards enables the provision of immediate feedback, a crucial element in preventing the early formation of misconceptions (Belova & Zowada, 2020).

Alleviating Learning Anxiety through Affective Gamification

To balance the cognitive load of the Theory cards, the Action cards (adapting the "Dare" mechanism) were developed as an affective gamification strategy. The performative challenges and problem-solving tasks on these cards serve a crucial function in alleviating learning anxiety toward chemistry, a subject often perceived as intimidating by students (Licorish et al., 2018). The use of light gamification elements, such as crossword puzzles, has proven effective as an enjoyable material revision tool, thereby improving the mastery of scientific terminology without triggering excessive stress (Pearson, 2020). Furthermore, from the perspective of Self-Determination Theory (SDT), the social interaction, laughter, and collaboration that emerge when students complete the Action challenges directly fulfill their basic psychological need for social connectedness, or relatedness (Sailer et al., 2017). Fulfilling this need is a core pillar that fosters students' intrinsic motivation to remain engaged in learning.

The Effectiveness of Physical Media and Social Dynamics

The decision to maintain a physical game format (tabletop game) rather than a digital one is also grounded in strong theoretical arguments. Manipulating real objects (such as holding and shuffling cards) provides a tactile experience that sensory stimulates students, helping them focus more deeply on the content compared to staring at digital screens (Kaufman & Flanagan, 2016). This physical card format naturally facilitates face-to-face interaction that encourages negotiation and collaboration; this social element is considered more effective in training students' scientific communication skills than digital games, which tend to be solitary (Veldkamp et al., 2020). By adapting the highly familiar *Truth or Dare* mechanism, *Green Solver* successfully lowers students' psychological barriers to participation (Triboni & Weber, 2018). Overall, the integration of these two types of cards demonstrates that *Green Solver* is not merely an entertainment medium, but rather a holistic pedagogical approach that equitably targets both cognitive development and the reduction of students' affective anxiety (Zainuddin et al., 2020).

D. CONCLUSION AND SUGGESTIONS

1. Conclusion

   Based on the research results from the analysis and design stages, it can be concluded that there is a high urgency (92.1% of students) for interactive and engaging chemistry learning media. As a solution, this study successfully designed a prototype of the *Green Solver* card game, which adapts the *Truth or Dare* mechanics into the context of green chemistry. The media design formulates two main components: *Theory* cards designed to strengthen students' cognitive engagement through retrieval practice, and *Action* cards that function as affective gamification to alleviate learning anxiety. This prototype is conceptually and visually ready as a holistic learning medium.

2. Suggestions

   Considering that this research is limited to the design stage, it is suggested that future studies conduct a validity test on the *Green Solver* prototype involving subject matter experts and media experts. Once validated, field testing (the implementation stage) is highly recommended to empirically measure the card game's effectiveness in improving cognitive learning outcomes and reducing students' science anxiety levels in an actual classroom setting.

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