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Development of 'CrossChemistry Games': A web-based educational game on organic chemistry topics

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ABSTRACT

This research aims to develop the *CrossChemistry Games* educational game as a learning medium for Organic Chemistry material and to determine the feasibility and response of students to the CrossChemistry Games. This type of research is Research and Development (R&D) research using the ADDIE development model, which consists of the Analysis, Design, Development, Implementation, and Evaluation stages. In this study, only the Analysis, Design, and Development stages were carried out. The subjects of this research were 36 students in grade 11 at Wardaya High School. The feasibility test of learning media refers to the validation results of media and material experts. The research results showed that the results of the validation test for the CrossChemistry Games learning media met the valid criteria with a validity value of 82%, and students' responses to the CrossChemistry Games learning media met the very good criteria with a value of 87%. This research has important implications for increasing the use of learning media in chemistry learning at Wardaya High School. The use of learning media combined with technology will support education in the 5.0 era and can increase student involvement, facilitate understanding of chemical concepts, and improve thinking and problem-solving skills. It is recommended that technology-based learning media be integrated into broader chemistry learning strategies.

Keywords: organic chemistry, crossword, learning media, educational game

1. INTRODUCTION

As the development of 4.0 industry to 5.0 society, proper preparation is required from individuals, groups, the general public, and even academics (Asnawati et al., 2023). All sectors must be prepared to face and wisely, intelligently, accurately, and appropriately utilize technology according to its intended purpose. The development of technology has given rise to many benefits in various fields, such as education. In the digital era, education has experienced many significant changes in technology-based usage (Permana et al., 2024). The education system is expected to adapt to the Society 5.0 era, aiming to prepare a new generation to embrace the upcoming revolution from an educational perspective (Mega, 2022).

The world of education must quickly adapt to the current situation and utilize technology for the development of learning. Generation Z is familiar with gadgets, smartphones, and games. It is known that children generally like games; moreover, Generation Z likes something creative, practical, and exciting, within a variety of activities, including learning activities. Therefore, the use of technology in the form of learning media or educational games is well-suited for learning media towards the current digital generation (Oktavia, 2022).

The interviews with students from SMA Wardaya indicated that the learning process included lectures, practice questions, and educational games. Students tend to become uninterested while studying and working on practice questions. Students show greater engagement in the learning process when educational games are incorporated, as these tools support the completion of tasks and enhance understanding, especially in terms of memorization. Students need educational games at various intervals in the learning process, which is filled with material and schoolwork. Students can study more enjoyably, thereby enhancing their understanding of the material provided by teachers.

Integrating technology into the classroom may improve student involvement and facilitate independent learning. Online learning platforms, educational applications, and interactive software provide opportunities to present material dynamically and support diverse learning styles. Findings from this research provide valuable insight for the development of technology-based learning strategies, and at the same time provide the basics for perfecting the education policy that integrates technology as a supporting learning tool (Norpin et al., 2024).

Educational games are an innovation in the learning medium that involves students in the learning process and enables them to engage more enjoyably in practice exercises and critical thinking. This study tool helps students create a meaningful learning space and stimulates student development through a joyous learning experience. This style of learning enhances students' interest and motivation, thereby fostering a sense of curiosity that encourages a deeper exploration of the material beyond the initial scope (Winatha & Setiawan, 2020).

Recent research highlights that game-based learning (GBL) in chemistry education has been proven to significantly enhances students' conceptual understanding and learning motivation. A systematic review of 57 studies, all indexed in Scopus, found that the use of educational games supports both hands-on and minds-on learning, enabling students to engage in active and deeper learning (Chans & Portuguez Castro, 2021). In the context of learning media development, studies such as Oktadio and Pardede (2024) show that the development of interactive multimedia learning media based on educational games in chemistry topics, such as the colloid system for Grade XI, produced excellent results: a mastery learning percentage of 92.44%, student interest of 87.33%, and student activity of 88.11%.

Therefore, research was conducted to develop learning media in the form of *CrossChemistry,* an educational web-based game on organic chemistry materials. *CrossChemistry* is a crossword puzzle game developed using the application website Wordwall, with organic chemistry material as the learning medium. The use of Wordwall in this research was built upon a previous study by Akbar and Hadi (2023) that showed improvement in students' analytical skills, which in turn led to an increase in learning outcomes when using the application Wordwall. The characteristics of *CrossChemistry* guide students to be active in lessons because they participate as players. This aligns with the strategy of learning organic chemistry, which involves memorization, making it easier for students to recall the material. Learning that

is done in enjoyable ways tends to be more meaningful and lasts longer in students' memories. Enjoyable, interactive lessons increase students' learning motivation, which is expected to lead to improved learning outcomes.

2. METHOD

This type of study falls under the category of Research & Development (R&D), carried out during the odd semester of the 2023/2024 academic year. Both the development and testing processes were conducted at Wardaya High School, Grade XI, in the academic year 2023/2024. The subjects in this research were 36 students from classes XI-1 and XI-2.

The study used the ADDIE development model, which consists of five stages: Analyze, Design, Development, Implementation, and Evaluation. However, this study only used three stages: analysis, design, and development.

The tools used for data collection in this research were a media expert validation sheet, a material expert validation sheet, and a student response questionnaire. Expert material validation was performed by Mr. Badrus Syamsi, M.Pd. as a chemistry teacher at Wardaya School and Mrs. Luthfia Ulva Irmita, M.Pd., a chemistry education lecturer at UIN Syarif Hidayatullah Jakarta, who validated the organic chemistry material for the Cambridge curriculum at the senior high school level, and The media validation was conducted by Mr. Jaya Mitra and Mr. Kevin Muharyman, a digital marketing and IT staff member at SMA Wardaya, who evaluated the design aspects of CrossChemistry Games. The validity assessment of the learning media, CrossChemistry, was conducted by an expert validator using an instrument designed on a Likert scale. A Likert scale was used to determine the individual assessment of an object. The Likert scale scores are presented in Table 1.

Table 1. Likert Scale Scores

Category	Score
SA (Strongly Agree)	4
A (Agree)	3
D (Disagree)	2
SD (Strongly Disagree)	1

To analyze the data from the validity questionnaire and student responses, the following formula was used:

$$PS = (F / N) \times 100\%$$

Where,
PS: Percentage response
F: Total score test
N: Maximum score

After calculating the percentage, the results were categorized based on the criteria adapted from Sugiyono (2018) or other relevant standards (Paulus et al., 2023). This will help in effectively interpreting the validity and data of student responses.

The interpretation of the score validity and the score of student responses based on the criteria given is as follows in Table 2:

Table 2. Percentage and Criteria of Validity

Percentage	Criteria
86%-100%	Highly Feasible
76%-85%	Feasible
60%-75%	Moderately Feasible
55%-59%	Less Feasible
<54%	Not Feasible

3. RESULT AND DISCUSSION

This study involves research and development that aims to determine the validation and students' responses towards *CrossChemistry* as a medium for learning organic chemistry. *CrossChemistry* is a crossword puzzle developed in a wordwall web-based application on organic chemistry as a learning medium. This medium is categorized as a form of Game-Based Learning (GBL), as it integrates elements of gameplay into the learning process, thereby enhancing student engagement, motivation, and overall learning experience (Plass et al., 2015). Unlike general applications such as Kahoot or standard Wordwall-based activities, CrossChemistry Games are tailored to the context of organic chemistry by adapting the crossword puzzle format. This approach not only assesses short-term recall but also requires students to interconnect concepts, terminology, and chemical representations more comprehensively. Consequently, it promotes higher-order thinking skills, such as analysis and problem-solving, which are not fully supported by rapid-response quiz platforms such as Kahoot (Rahim & Ali Mohammed, 2024). Furthermore, the use of interactive crossword puzzles enables the personalization of learning materials according to curricular needs and classroom context, offering advantages over more generic applications. The integration of GBL through CrossChemistry Games aligns with prior research indicating that contextualized game-based learning media can enhance conceptual understanding while fostering students' intrinsic motivation (Hamari et al., 2019).

The research was conducted starting from the analysis stage of the study. During this phase, it was concluded that the data obtained show how education at Wardaya High School is usually done by lectures, discussions, practice questions, and quizzes. Unfortunately, having an ordinary class and tests has led students to feel bored in class. Participation and engagement are more significant when students are able to practice in the form of games; therefore, they become more enthusiastic and are able to understand the materials better. Drawing on the results of the needs analysis, it is evident that students at Wardaya High School need instruments to be used for their learning process, making it more interesting and understandable. Additionally, organic chemistry often requires memorization, which makes learning more tedious. Therefore, this *CrossChemistry* for organic chemistry is established, where advanced topics are more enjoyable and can be understood more easily.

The next stage was creating the design, which involved drafting a media that could fulfill the needs of students in Wardaya High School by selecting the type of game and deciding on which application to use. The game chosen is a crossword puzzle that contains topics on organic chemistry and is constructed in the wordwall web application. Another additional step is arranging practice exercises based on the content module of the lesson. Moreover, the outline is made, where 14 questions for across and down are listed in the *CrossChemistry*.

Proceeding to the next stage, *CrossChemistry* is built. All questions and their answer keys are input into the wordwall web application. The final product will then undergo a validity test. The validity of CrossChemistry Games was assessed by two content experts and two media experts using a five-point Likert scale. The validation focused on the material's accuracy, curriculum relevance, clarity, design layout, and technical feasibility. The results are summarized in Table 3.

Table 3. Validation Result

No	Validator	Percentage (%)	Category
1	Validator I	80.4	Feasible
2	Validator II	84.6	Feasible
3	Validator III	82.5	Feasible
4	Validator IV	80.5	Feasible
	Average	**82**	**Feasible**

As presented in Table 3, the validation scores from all four experts ranged from 80.4% to 84.6%, with an overall mean of 82%, which falls within the feasible category. This indicates that the product meets the minimum validity criteria and can be further developed for classroom implementation. To provide

clearer interpretation, the distribution of scores is also presented in Figure 1.

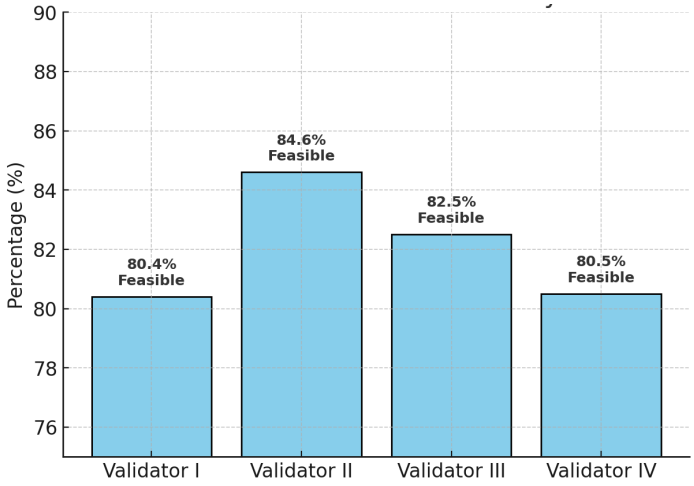

Figure 1. the validation scores

The figure confirms that the validators' assessments were relatively consistent, with only slight variation between raters. All experts agreed that CrossChemistry Games is a valid and feasible medium, while also suggesting minor improvements in layout and user navigation for future refinement. The suggestions from the validators are presented in table.

Table 4 . Suggestions and Improvement Measures

No	Suggestions	Revision
1	Several organic chemistry terms need to be adjusted to those used in the most recent curriculum.	To update terms and definitions in the questions based on textbooks and the most recent curriculum.
2	The questions should ideally include a variety of difficulty levels.	Add questions with a variety of difficulty levels, ranging from easy to challenging, to accommodate the potential of all students.
3	Colors for the background and letters require more clarity to improve readability.	Change color combinations to ones with better contrast and that are comfortable in the eye.
4	Guidelines for usage are still insufficiently detailed.	Add instructions for usage that are clear and efficient in the opening page of the game.
5	Requires addition of illustrations or images related to the material of organic chemistry.	Difficult to provide illustrations of organic structures.
6	The leaderboard should be provided with information of time played and final score.	Improving the leaderboard feature to completely display completion time and score.
7	The transition animations in the game are too rapid.	Adjust the animation duration to improve visual comfort without hindering students' concentration.

CrossChemistry is a crossword puzzle game developed using the WordWall web application, designed as an interactive learning medium for organic chemistry. To play this game, students must first access a link provided by the teacher. Before starting, students are asked to input a name as the game won't be able to start without one. After entering, students may pick a row of squares to answer, whether it be diagonal or horizontal, based on what they desire. Answers are directly typed into the provided column, and if they're correct, letters in each square will be automatically filled. On the other hand, if they answered wrong, "lives" of the player will be deducted. The game includes a time limit, therefore pushing students to think quickly and accurately. By the end of the session, the leaderboard will display the ranks of the winners or the time required to finish the game, which can be seen by both students and the teacher. This feature not only triggers competitiveness, but also provides immediate feedback on students' achievement

in learning organic chemistry.

Game Walkthrough: (1) Students enter the game web through link given https://wordwall.net/play/75948/113/695; (2) Students input their name before starting the game, the game will not proceed, unless the information is provided; (3) Students are able to choose which boxes to be answered, whether horizontally or vertically; (4) Students type the answer in the answer box; (5) If the answer is correct, the boxes on the grid will fill up with the constituent letters of the answer; (6) This game has a time limit; (7) After the game is concluded, a leaderboard will show the ranking of the winners and time need to answer the questions respectively; (8) Both students and teachers will be able to see the leaderboard at the end of the game. See Figure 2.

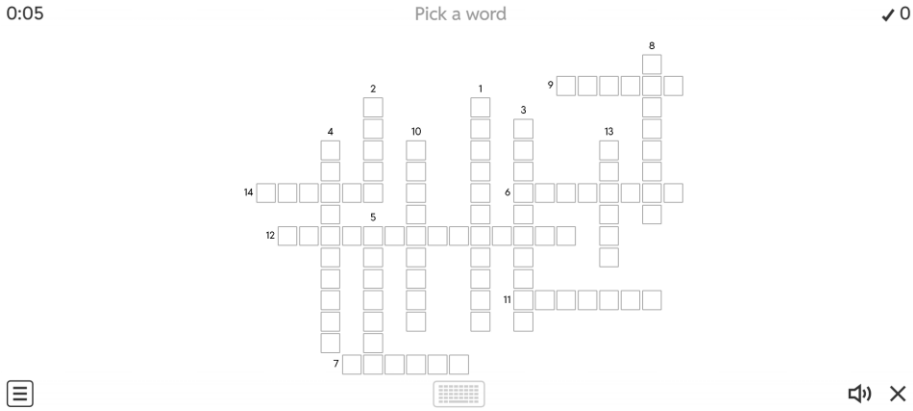

Figure 2. CrossChemistry Games

The questions in *CrossChemistry Games:* (1) Chemical compound containing carbon and hydrogen; (2) Formed in the reaction between an alcohol and carboxylic acid; (3) The group determines the main chemical properties of an organic compound; (4) Compounds that have the same functional group and similar chemical properties; (5) The simple alcohol; (6) Breaking down long chained hydrocarbons; (7) Hydrocarbon with one or more double bonds; (8) Bond formed between atoms when atoms share electrons to fill the outer shell of electrons; (9) Element that has the capacity to share four electrons; (10) Carbon chain that is filled up with the maximum number of hydrocarbons; (11) Organic compound containing a hydroxyl group; (12) Small molecules joining together to form much longer molecules; (13) Hydrocarbon which containing only single bond; (14) Chemical with the same molecular formula but different arrangement of atoms

When *CrossChemistry* is used in the learning process, students are able to play a game whilst still learning organic chemistry. In *CrossChemistry*, students are able to practice by answering crossword puzzle questions related to organic chemistry material. Students who have utilized *CrossChemistry* have shown an increase in ability to memorise and answer questions regarding organic chemistry. 87% of student responses fall into the category of "really good". Based on the survey, it can be stated, students enjoyed using *CrossChemistry*, as it increases interest in learning and is user-friendly. This is in accordance with the study conducted by (Rahayu & Dasna, 2022), which states that the implementation of educational games in the learning process enhances students' interest in various subjects. Furthermore, this finding is supported by evidence from systematic reviews indicating that game-based learning (GBL) in chemistry can improve motivation, conceptual understanding, and overall mood during study (Byusa et al., 2022).

Based on the results of a questionnaire consisting of 20 questions, students' responses to the use of *CrossChemistry* showed a strong positive tendency across various aspects, including design, ease of use, material relevance, and enhancement of learning motivation. Website Interface and Design: The majority of students comment that *CrossChemistry*'s website interface is visually appealing and comfortable to view. Interactive visual designs paired with its well structure layout provide an improved learning experience; Interest and Study Motivation: Almost all respondents praised the game for its ability to enhance interest and motivation in studying chemistry, particularly organic chemistry. In-game elements such as crosswords

and leaderboards ignited a healthy sense of competition; Ease of Learning Organic Chemistry: Students state that *CrossChemistry* has proved effective in facilitating their process of understanding organic chemistry with greater ease. Elaboration of material through interactive questions was found to be effective in increasing retention of information; Independent Learning: This game pushes students to conduct independent learning without the need of always being guided by teachers directly. This aligns with new trends in student-centered learning based education; Media Use Satisfaction: The majority of students were satisfied in using *Crosschemistry* as a learning tool. The combination of entertainment and education made the learning process light, yet meaningful; Animation and Interactiveness: Engaging and adequate animations were able to let students keep focus on material being studied; Ease in Use and Clarity of Instruction: Students rate this game highly, due to its user-friendliness and concrete instructions. This minimizes technical issues and hastens adaptation to new learning media; Relevance of Questions to the Material: All questions elaborated are relevant to the organic chemistry material being studied, hence improving conceptual understanding of materials lectured in class; Clarity of Language: Language used is clear, simple, and easy to understand, thereby preventing confusion when understanding instructions or answering questions; Intention to Reuse: Many students expressed a desire to often use *Crosschemistry* in the future as a learning tool for strengthening understanding; Complexity and Technical Support: A great majority of students find this game to be not complex and without a need for technical help. Only a few students expressed the need for guidance and technical support; Design of Features and Functionality: The available features are assessed as well-designed, functional, and supportive of achieving the learning objective; Feeling of Self-Confidence and Mastery: Students feel a surge of confidence while playing this game. The adaptation process takes place quickly, as it doesn't consume much time to understand how to play; Level of Simplicity: The majority of students believe that *CrossChemistry* is easy to use, intuitive, and is able to be played directly even by new users.

Beyond motivation, game-based learning has been widely recognized for enhancing conceptual understanding and knowledge retention. Meta-analyses in science education confirm that educational games can positively influence both cognitive and affective learning outcomes (Hu et al., 2022). In this study, CrossChemistry Games extends these benefits by requiring students not only to recall terminology but also to connect, analyze, and apply organic chemistry concepts through interactive crossword puzzles. This aligns with prior findings that educational games foster higher-order thinking skills such as analysis, synthesis, and evaluation as emphasized in Bloom's Taxonomy (Teo et al., 2025); (Crucho et al., 2025). Unlike conventional quiz-based platforms such as Kahoot or generic Wordwall activities, CrossChemistry Games integrates problem-solving and creativity into gameplay, thereby engaging students in more meaningful cognitive processing.

Furthermore, the inclusion of a leaderboard introduces an element of healthy competition, which previous gamification studies in STEM have shown to improve academic performance, though its motivational design and fairness require further consideration (Ortiz-Rojas et al., 2025). As a form of serious game, CrossChemistry Games reflects recent trends in STEM education where GBL is increasingly utilized not only to promote engagement but also to integrate emotional and experiential dimensions of learning (Tene et al., 2025). Previous studies also demonstrate that educational games can increase motivation and create enjoyable, non-repetitive learning environments that encourage active participation and critical thinking (Sakdah et al., 2021). Consistent with this, students engaging with CrossChemistry Games demonstrated positive responses and improved outcomes compared to traditional approaches, supporting findings that GBL contributes significantly to learning achievement (Kudri & Maisharoh, 2021).

4. CONCLUSION

Based on the research conducted, the validation test results showed a score of 82%, indicating that the developed learning media is considered valid enough and suitable for use. Additionally, student response questionnaires yielded a score of 87%, suggesting that students responded very positively to the CrossChemistry game. CrossChemistry can be used as an engaging learning medium for students,

particularly in memorisation, so students are not easily bored and can practice more for improved learning results.

Ethical approval
This research did not require ethical approval

Informed consent statement
Informed consent was not obtained for this study.

Author's Contributions
LUI led the conceptualization, research design, and supervision of the study, and served as the corresponding author. AZ contributed to the design and development of the *CrossChemistry* Games interface. JTL was responsible for data collection, testing, and analysis of student responses. MDPP supported the technical implementation, coding process, and validation of the game prototype.

Disclosure Statement
No potential conflict of interest was reported by the author(s).

Data availability statement
The data presented in this study are available upon request from the corresponding author for privacy reasons.

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Notes on Contributions

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