HYDROGEN
JOURNAL OF CHEMISTRY EDUCATION
https://e-journal.undikma.ac.id/index.php/hydrogen/index

August 2026. 14(4)
e-ISSN: 2656-3061
p-ISSN: 2338-6487
pp. 849-854

Development of Chemistry Tetrahedron Mahaffy Based on Scratch Platform as Learning Media on Hydrocarbon Topics to Strengthen Systems Thinking Skills of High School Students

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Article History
Received: 16-07-2026
Revised: 14-08-2026
Published: 31-08-2026

Keywords: Scratch Learning Media; Chemistry Mahaffy Tetrahedron; Hydrocarbons; Systems Thinking.

Abstract
This development study aimed to produce and test the feasibility of interactive learning media based on the scratch platform that integrates Mahaffy's Chemistry Tetrahedron approach (macroscopic, microscopic, symbolic, and humanistic) on hydrocarbon material for grade XI high school to strengthen students' systems thinking skills. Using the 4D Thiagarajan development model (define, design, develop, and disseminate), feasibility validation was carried out by chemistry material expert, learning media expert, and chemistry teachers (usability test), while the response test involved 32 grade XI high school students. The research instruments are validation questionnaires and responses with Likert scale 1-5. The results showed that the media obtained very good ratings from teachers and obtained good categories of student responses. The Media is stated to be very suitable for use in Chemistry learning and potentially optimally supports the strengthening of systems thinking through the integration of interactive and contextual chemical representations. The media was declared very suitable for use in chemistry learning and has optimal potential to support the strengthening of systems thinking through the integration of interactive and contextual chemical representations.

How to Cite: Putra, H. F. K., & Sari, R. L. P. (2026). Development of Chemistry Tetrahedron Mahaffy Based on Scratch Platform as Learning Media on Hydrocarbon Topics to Strengthen Systems Thinking Skills of High School Students. *Hydrogen: Jurnal Kependidikan Kimia*, *14*(4), 849-854. https://doi.org/10.33394/hjkk.v14i4.21943

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INTRODUCTION

Systems thinking refers to the ability to identify components of a system, recognize relationships among components, and consider how changes in one component may influence other components and the system as a whole (Meadows, 2008). In chemistry education, this perspective is relevant because chemical concepts are represented across macroscopic, submicroscopic, symbolic, and humanistic contexts that need to be connected rather than learned independently (Johnstone, 1993; Mahaffy, 2006). However, chemistry learning may still emphasize isolated concepts and algorithmic problem solving, which can make it difficult for students to relate molecular structure, chemical properties, observable phenomena, and applications in everyday life (Nakhleh, 1992). The initial needs analysis conducted in the present development study also indicated a need for learning media that facilitates the integration of chemical representations.

This need is particularly relevant to hydrocarbon learning because students are expected to relate carbon structures, molecular representations, nomenclature, properties, reactions, and applications. A learning resource that explicitly connects these dimensions may therefore provide a more coherent learning environment for exploring relationships among chemical concepts.

Previous studies provide complementary evidence for the two main foundations of the present media. Mahaffy's Chemistry Tetrahedron provides a framework for connecting macros-

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copic, submicroscopic, symbolic, and humanistic representations, whereas Scratch provides an interactive environment for presenting visualizations, animations, and exploratory activities (Mahaffy, 2006; Maloney et al., 2010; Resnick et al., 2009). Thus, these approaches offer different but complementary functions: the Chemistry Tetrahedron organizes the representational structure of the content, while Scratch provides the digital interaction through which those representations can be explored. However, the present study focuses specifically on integrating the four represen-tations into an interactive hydrocarbon learning sequence oriented toward systems thinking. This design differs from studies that examine multiple representations or Scratch as separate instruct-ional approaches.

The gap addressed in this study is therefore not simply the use of digital technology or multiple representations individually, but the development of a single interactive learning design that links the four Chemistry Tetrahedron dimensions within hydrocarbon activities. The product was designed so that chemical phenomena can be introduced at the macroscopic level, interpreted through submicroscopic particle representations, expressed using symbolic representations, and connected to humanistic or real-life contexts. This structure is intended to provide opportunities for students to examine relationships among components of a chemical system rather than treating each representation as an isolated element.

The novelty of this study lies in the design of a Scratch-based learning sequence that operationalizes Mahaffy's four representations in hydrocarbon learning. The product combines (1) macroscopic phenomena or real-life contexts, (2) submicroscopic molecular representations and animations, (3) symbolic representations such as formulas and chemical nomenclature, and (4) humanistic contexts related to the use and implications of hydrocarbons. These represen-tations are incorporated into interactive questions and activities that require students to relate information across representations. Because the present study evaluates product feasibility and user responses rather than learning gains, the contribution is framed as the development of a systems-thinking-oriented learning artifact, not as evidence that the media increases systems-thinking ability.

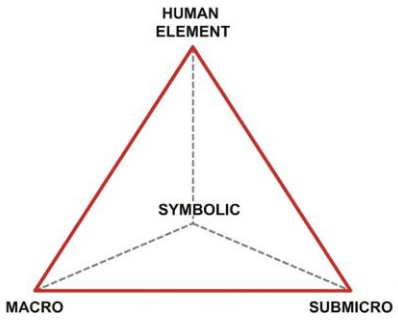


Figure 1. Chemistry Tetrahedron Mahaffy

This approach emphasizes the interrelationships between the four representations, enabling students to understand chemical concepts holistically and meaningfully. Abduli et al. (2015) asserted that systems thinking skills in chemistry can develop if students are able to see the relationships between various levels of representation and integrate them in solving contextual problems.

Accordingly, this study addresses two research questions: (1) What are the characteristics of the Scratch-based learning media integrating Mahaffy's Chemistry Tetrahedron for hydrocarbon learning? and (2) How feasible is the developed media and how do Grade XI students respond to its use? The objectives are to describe the characteristics of the developed media and to determine its feasibility and student responses. The systems-thinking orientation is treated as a design feature of the media; direct improvement in systems-thinking ability was not measured in this study.

METHOD

Research Design

This study employed Research and Development (R&D) using an adaptation of the 4D model proposed by Thiagarajan, Semmel, and Semmel (1974), consisting of define, design, develop, and disseminate stages. In this study, the disseminate stage was limited to a small-scale user trial; therefore, the study did not constitute broad dissemination. The adaptation was used to obtain formative evidence of product feasibility and student response within the scope of the development study. (Sari et al., 2019).

Research Procedure

Define Stage

The define stage aimed to identify development needs through an initial analysis of learning problems, student characteristics, and hydrocarbon content. The analysis indicated that

students needed support for integrating chemical representations, providing a rationale for multi-representational learning media. (Johnstone, 1993; Nakhleh, 1992).

Design Stage

The design stage produced the learning flow, content structure, navigation scheme, and interactive activities for the Scratch-based media. The four Chemistry Tetrahedron representations were embedded across the learning sequence: macroscopic phenomena and contexts, submicroscopic molecular representations and animations, symbolic formulas and nomenclature, and humanistic applications or implications of hydrocarbons. Interactive questions were designed to prompt students to relate information across these representations. (Resnick et al., 2009).

Develop Stage

The develop stage involved expert review, practitioner assessment, and iterative product revision. The manuscript should report the exact number and qualifications of each expert and teacher rater and five chemistry teachers as practitioner raters, if this is the confirmed study design. Feedback from each review stage was used to revise content, language, presentation, interaction, and product characteristics before the student trial. (Abduli et al., 2015).

Disseminate Stage

The disseminate stage was implemented in a limited form through a trial involving 32 Grade XI high school students. The trial was intended to obtain student responses to the developed media. Because the study did not involve broad dissemination, this stage should be understood as a limited dissemination/user trial rather than evidence of effectiveness. (Wilson et al., 2013).

Research Subjects and Variables

The research subjects included the product being developed and its users. The product in question was a Scratch-based learning media integrated with Chemistry Tetrahedron on hydrocarbons. The user subjects consisted of chemistry teachers who served as validators at the testing stage and students from class XI as respondents at the disseminate. The selection of subjects is based on relevance to the implementation of chemistry learning at the high school level. The research variables are focused on the feasibility and quality of the media, which include the following aspects: (1) feasibility of content/material, (2) systems thinking and integration of Chemistry Tetrahedron, (3) feasibility of presentation, (4) language, (5) characteristics and ease of use.

Instruments and Data Collection

The research instrument was a questionnaire compiled using a Likert scale. The validation questionnaire was used for expert assessment by chemistry lecturers to assess the product's feasibility. In addition, a feasibility and usability test questionnaire was used by chemistry teachers to assess the quality and usefulness of the media in learning. A student response questionnaire was used during the limited trial phase to determine students' perceptions of the use of the developed media.

Data Analysis Technique

Data were analyzed descriptively. For each assessment aspect, the mean score was calculated as the sum of the item scores divided by the number of raters and/or relevant observations. The mean scores were then compared with the ideal assessment criteria. For the five-category ideal-score classification, Xi denotes the ideal mean and SDi denotes the ideal standard deviation. The category boundaries were applied consistently across instruments with different maximum scores.

Table 1. Ideal Assessment

Interval	Category
Score > Chi + 1.8 SDi	Very Good/High
Xi + 0.6 SDi < Score ≤ Xi + 1.8 SDi	Good/High
Xi - 0.6 SDi < Score ≤ Xi + 0.6 SDi	Sufficient/ Moderate
Xi - 1.8 SDi < Score ≤ Xi - 0.6 SDi	Less/Low
Score ≤ Chi - 1.8 SDi	Very Low/Low

Note: Xi is the ideal mean and SDi is the ideal standard deviation.

RESULTS AND DISCUSSIONS

Result

The study produced a Scratch-based learning media integrating Mahaffy's Chemistry Tetrahedron for hydrocarbon learning. The product contains learning materials, interactive activities, questions, animations, and contextual elements that connect macroscopic, submicroscopic, symbolic, and humanistic representations. The results reported below concern product feasibility and user responses; no direct pretest–posttest measurement of systems-thinking ability was conducted.

The teacher assessment showed that the developed media was rated very good across all assessed aspects. This result provides evidence of positive practitioner judgment regarding the content, systems-thinking-oriented design, language, presentation, and product characteristics, rather than evidence of learning effectiveness.

Table 2. Results of Media Feasibility Test by Teachers

Evaluation Aspects	Average Score	Maximum Score	Category
Content Eligibility	24,8	25	Very good
Systems Thinking	24,8	25	Very good
Linguistics	25,0	25	Very good
Presentation	24,6	25	Very good
Product Characteristics	24,85	25	Very good
Overall Mean	24,81	25	Very good

The high scores across the assessed aspects indicate that the media met the specified feasibility criteria according to teacher ratings. The product design was based on multiple representations, including macroscopic, submicroscopic, symbolic, and humanistic dimensions, consistent with the Chemistry Tetrahedron framework (Mahaffy, 2006). The present data support the feasibility of this design from the teachers' perspective; they do not directly demonstrate increased knowledge construction or reduced partial understanding.

The student response results are presented in Table 3. All assessed aspects were categorized as good, indicating positive student responses to the material, systems-thinking-oriented design, language, appearance, and product characteristics. These responses should be interpreted as perceptions of the media rather than evidence of improvement in students' systems-thinking ability.

Table 3. Students' Responses toward the Learning Media

Evaluation Aspects	Average Score	Maximum Score	Category
Material	20,40	25	Good
Systems Thinking	20,53	25	Good
Linguistics	11,75	15	Good
Appearance	16,67	20	Good
Product Characteristics	20,44	25	Good
Overall Mean	17,96	22	Good

The student questionnaire results were in the good category across all assessed aspects. The findings indicate positive acceptance of the developed media in the limited trial. Explanations involving cognitive load or digital literacy are treated here only as possible theoretical considerations because these variables were not directly measured in the present study. Therefore, the results should not be interpreted as evidence of media effectiveness on learning outcomes.

Based on the assessment criteria, the developed learning media received a very good rating from teachers and a good response from students. These findings support the feasibility and acceptability of the product within the scope of the development and limited user trial.

Discussion

The findings indicate that the Scratch-based Chemistry Tetrahedron media provides a feasible alternative for presenting hydrocarbon concepts through multiple representations. This interpretation is consistent with Mahaffy's (2006) emphasis on connecting humanistic and chemical dimensions and with research on multiple representations in chemistry education (Gilbert & Treagust, 2009; Taber, 2013). The contribution demonstrated by the present study is the integration of these representational dimensions into an interactive Scratch environment; the study does not establish an effect on learning outcomes.

Scratch as a visual platform allows learners to build knowledge through active exploration, which is in line with the principles of constructivism (Resnick et al., 2009). From a multimedia theory perspective, the combination of text, images, and animation in media can enhance information processing through visual and verbal channels simultaneously (Mayer, 2009).

The systems-thinking orientation of the media is reflected in activities that ask students to relate the four Chemistry Tetrahedron representations. However, because no direct systems-thinking test, performance rubric, or pretest–posttest comparison was administered, the present study cannot conclude that students' systems-thinking skills increased. The results only indicate that the media was designed to support systems-thinking-oriented learning and that students responded positively to the corresponding aspect of the questionnaire.

Compared with earlier work that has addressed multiple representations or Scratch

separately, the present product combines both within one hydrocarbon learning sequence. Its distinctive feature is the explicit linkage of macroscopic, submicroscopic, symbolic, and humanistic information within interactive questions and activities. The empirical contribution demonstrated in this study is therefore the development of the product and its positive feasibility and user-response ratings, rather than evidence of superior learning effectiveness.

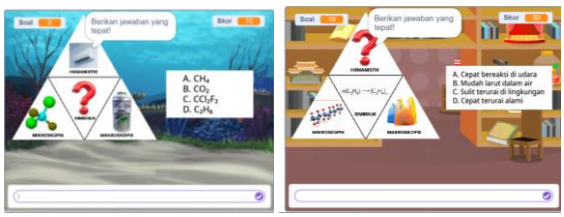


Figure 2. Mahaffy Tetrahedron Chemistry Questions

The Chemistry Tetrahedron-based questions were designed to place macroscopic, submicroscopic, symbolic, and humanistic information in a connected learning context. For example, a real-life hydrocarbon phenomenon can be linked to a particle-level explanation, a chemical formula or nomenclature, and an application or implication. This design operationalizes the intended systems-thinking orientation by asking learners to consider relationships among different representations.

The interactive questions and visual features provide opportunities for learners to explore relationships among representations. The product therefore functions as both a learning and assessment medium. However, the present study only examined feasibility and user response; claims about increased interest, active participation, conceptual understanding, or systems-thinking improvement require direct outcome measures in future research.

Several limitations should be considered. First, the student trial involved only 32 Grade XI students, limiting the generalizability of the response findings. Second, the results were based primarily on questionnaire perceptions and did not include a comparison group or direct measurement of learning outcomes. Third, systems-thinking ability was not assessed through a validated performance instrument or pretest–posttest design. Future studies should therefore examine the effectiveness of the media with larger samples, comparison groups, and validated systems-thinking measures.

Overall, the study developed a Scratch-based Chemistry Tetrahedron learning media for hydrocarbon learning and obtained very good teacher ratings and good student responses. These findings support the feasibility and acceptability of the developed media. The systems-thinking orientation is a characteristic of the product, but its effect on students' systems-thinking ability remains to be tested empirically.

CONCLUSION

The Scratch-based learning media integrating Mahaffy's Chemistry Tetrahedron was developed for hydrocarbon learning with macroscopic, submicroscopic, symbolic, and humanistic representations. The product contains learning materials, interactive activities, questions, animations, and contextual elements. Its systems-thinking orientation is embedded in activities that connect information across the four representations; however, systems-thinking improvement was not directly measured in this study.

Teacher assessment produced a very good category across all assessed aspects, with an overall mean score of 24.81 out of 25. These results indicate very good practitioner ratings of the developed learning media. The 32-student response test produced a good category across all assessed aspects, with an overall reported mean of 17.96 out of 22. This corresponds to approximately 81.6% when calculated directly as 17.96/22 × 100. Therefore, the previously reported value of 79.9% should be removed unless the raw-data calculation confirms that percentage. The student data support positive response to the media, but do not demonstrate increased systems-thinking ability.

RECOMMENDATION

Future research should extend the media to other chemistry topics and examine its effectiveness through a stronger experimental design. In particular, subsequent studies should use a validated systems-thinking instrument, pretest–posttest measurement, and a comparison group to determine whether the media actually improves systems-thinking ability. Larger and more diverse samples should also be used to examine generalizability and the influence of

implementation conditions such as digital literacy and technological infrastructure.

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