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DEVELOPMENT OF A BASIC CHEMISTRY E-BOOK ENHANCED WITH MULTIPLE REPRESENTATIONS AND STEM ACTIVITIES

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ABSTRACT

Chemistry concepts are generally abstract so they require teaching materials that visualize those abstract concepts. The aims of this study were to develop a Basic Chemistry E-Book enhanced with multiple representations and a STEM approach. This study used a research and development model modified from the ADDIE model which consists of 5 stages, namely: (1) Analysis (analysis of students' characteristics and course objectives), (2) Design (design of e-book and research instruments), (3) Develop (e-book production), (4) Implementation (expert judgement and field trials), and (5) Evaluation (the effectiveness test and revision of e-book). Research result showed that the feasibility of e-book based on the expert judgement got 93.75% as a score on the material feasibility component, 100% as a score of feasibility component and 95.40% as a score of the language and STEM component. Furthermore, the results of small-scale field trials obtained a percentage of 86% and large-scale field trials obtained a percentage of 87%. The effectiveness test of e-book got score 0,643 means e-book was effective enough for using in learning chemistry. Based on this study, e-book for Basic Chemistry Course based on multiple representations with the STEM approach is appropriate for being used in general chemistry course.

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INTRODUCTION

The main competency of science education department UIN Kiai Haji Achmad Siddiq Jember are to become a science teacher who has good control of conceptual and procedural knowledge and able to integrate their knowledge with other fields of science. Undergraduate students of science education department are required to properly master the basics of chemistry in order to be able to explain chemical materials in an integrated way with science and not causing conceptual errors to students. However, the fact is that many students who experienced difficulties in studying chemistry. Preliminary research in Basic Chemistry course showed that more than 50% students of science education department still understood chemistry concepts well. Early research also informed that students in early semesters had difficulty understanding chemical concepts as a whole (Adadan et al., 2009; Keller & Hermanns, 2024).

Problem analysis using questionnaires on students of science education department who had taken the Basic Chemistry course class of 2022/2023 showed that 60.9% of students did not understand chemical concepts both macroscopic, submicroscopic and symbolic. Students were still confused about how to visualize the combining of atoms to form molecules. Further, they had difficulty in writing balance chemical equation after doing an experiment. They could not also apply chemical concepts in real life problems. In line with the preliminary research, Anon (2018) stated that some students have difficulty understanding chemistry questions that are based on multiple representations. Students' difficulties in understanding chemical concepts in macroscopic, submicroscopic and symbolic representations are caused by students did not use representation-based teaching materials at both in high school and in higher education (Altınbaş et al., 2024; Niyomufasha et al., 2024; Pratiwi et al., 2024; Thyberg et al., 2024) .

With regard to the specific knowledge achievements contained in curriculum of science education department UIN Kiai Haji Achmad Siddiq Jember, in the field of chemistry in particular, prospective science teachers is expected to be able to solve chemistry problems conceptually and procedurally in multiple representations. The chemical concept itself is composed of three levels of chemical representation, namely at the macroscopic, submicroscopic and symbolic levels (Amiruddin et al., 2024; "The Effect of Multiple Representation-Based Learning (MRL) to Increase Students' Understanding of Chemical Bonding Concepts," 2018; Widarti, 2021). The macroscopic level is a representation of understanding concepts related to phenomena or chemical phenomena that are encountered directly. The symbolic level is a representation related to chemical phenomena such as the use of chemical formulas, mathematical formulas, reaction equations, graphs and chemical symbols. Meanwhile, the submicroscopic level is a representation relating to atoms or molecules at the particle level that cannot be seen directly (Diani et al. 2024; Niyomufasha, Ntivuguruzwa, & Mugabo 2024).

Based on researcher observation on basic chemistry class, there was no teaching material in basic chemistry course that can help students understand chemistry concepts both macroscopically, submicroscopically and symbolically. Students usually used general chemistry textbook which were difficult to be understood and couldn't explain submicroscopic and symbolic concept well. Meanwhile, chemistry contains abstract concepts which need to be explained in delivery with concrete

examples so that they are easy to be understood (Amiruddin et al., 2024; Widarti, 2021). Thus, to overcome this problem, it is necessary to have a textbook based on Multiple Representation so that prospective teachers have a complete understanding of chemical concepts and do not give rise to misconceptions (Altınbaş et al., 2024; Amiruddin et al., 2024).

An approach can be used to understand multiple representations in science is Science, Technology, Engineering, and Mathematics (STEM) approach (Arslan & Genc, 2024; Hsu et al., 2024). STEM education approach is an interdisciplinary approach to equip students with the knowledge and 21st century skills that are necessary to thrive in a rapidly evolving world driven by technological advancement (Arslan & Genc, 2024). STEM learning are able to foster critical and thinking skills, the ability to think scientifically and master technology in students (AlAli & Yousef, 2024; Dehbozorgi & Roopaei, 2024; Hwang et al., 2024). STEM learning is composed of several aspects, namely: 1) science, in the form of concepts or principles apply in universe, 2) technology, namely systems designed to make human life easier, 3) engineering in the form of procedures or problem solving framework, and 4) mathematics namely the study of numbers accompanied by logical and empirical arguments (Arslan & Genc, 2024; Deehan et al., 2024; Yalçın, 2024). The application of STEM approach supports the achievement of special knowledge science education department UIN Kiai Haji Achmad Siddiq Jember.

The literature identifies a number of challenges that hinder the practical application of and research on STEM education. This obstacle include the absence of unified STEM framework, the need for more comprehensive teacher training, and the development of new material and research to analyze their impact (Portillo-Blanco et al., 2024). Several researches in STEM fields have been conducted to overcome those obstacles. STEM researches in higher education have been conducted in many ways. Previous studies showed a significant increase in research activity related to STEM from 2013 to 2024 (Portillo-Blanco et al., 2024; Yeung et al., 2024). STEM implemented in a Transport Phenomena course at the undergraduate level to understand Heat Transfer by incorporating elements of STEM education (Zárate-Navarro et al., 2024). In line with previous research, STEM research was conducted in mathematics master's degree course, resulted that teacher's self-efficacy in teaching STEM subject after completing the course was increasing (Zhumabay et al., 2024).

Developing STEM based teaching materials was also researched in many fields of education. An integrated module education website with virtual experiments using PhET could improve critical thinking skills on thermochemistry learning materials (Pertiwi et al., 2024). Sum et al. (2024) created artificial intelligence to enhance the quality of STEM education by developing microcontroller based kits and Cortes (2024) also developed video game dynamics applied into STEM subjects. Based on previous researches, there were many researches in developing STEM learning materials. Nevertheless, development of STEM learning materials enrich with multiple representations is still lacking. Novelty of this research was the combination of using multiple representations and STEM approach to build contextual basic chemistry e-book. Based on descriptions, research formula of this research were how to develop Basic Chemistry e-book enhanced with Multiple Representations and a Science, Technology, Engineering, and Mathematics (STEM) approach and how to describe the result of the effectiveness of e-book in order to overcome problems in learning Basic Chemistry course in science education department UIN Kiai Haji Achmad Siddiq Jember.

METHOD

Research Participants

Population of this research was student of science education department class 2022/2023 as a total of 76 students. Sample of this research was taken by using

random sampling form science 1, science 2, and science 3 class. There were 3 regular class in science education department class of 2022/2023 which had same initial abilities so that sample was taken randomly from 3 classes. This research used science class 1 and 2 which has an equal initial abilities based on pretest score. Number of samples were 10 students for small field trial and 30 students for large field trial. Sample for effectiveness tests of e-book, namely science 1 class as much 13 students and science 2 as much 13 students was chosen because it has the same initial abilities.

Research Design and Procedures

This research is categorized as research and development (R&D). The development model used was ADDIE model which consists of 5 stages, namely Analysis, Design, Develop, Implementation and Evaluation Phase (Branch, 2009). The research and development procedures for e-book based on multiple representations with STEM approach follow the research systematics described below:

In analysis phase of ADDIE model, an analysis of the Basic Chemistry course was carried out to find the materials that would be compiled in electronic textbooks (e-books). Apart from that, a literature study was also carried out regarding the availability of learning resources/ references needed in Basic Chemistry learning process. Furthermore, analysis of students' characteristics was also conducted to understand students learning style and cognitive level (Sum et al., 2024). The e-book initial concept then was prepared accordance with curriculum analysis has been carried out. The e-book draft was based on references obtained, but added with multiple representations using a STEM approach. Then design of research instruments for e-books were also created in the design phase before conducting expert judgement, field trials and the effectiveness of e-book.

Basic chemistry e-book and research instruments were developed during the development phase. Research instruments consisted of expert judgement (validation), field trials questionnaires (Deehan et al., 2024; Dehbozorgi & Roopaei, 2024), and the effectiveness test of e-book. Basic chemistry e-book was then validated by material expert, textbook design expert and STEM education expert. Revision of e-book from expert judgement resulted a second draft of e-book.

The e-book second draft brought to field trials in the implementation phase which consisted of small-scale and large-scale field trial. Field trials conducted on science education department student of 2022/2023 class. The small scale response test was carried out on 10 students with the aim of knowing the readability of the e-book being developed, while the large scale response test was carried out on 30 students with the aim of knowing the level of attractiveness and readability of e-book being developed. After undergoing students' response, the evaluation phase was done, the effectiveness test of e-book has been carried out on 13 students of science 1 as experiment class and 13 students of science 2 as control class. Revisions on e-book then was done based on expert judgement and field trials. Then, students' who have studied by using Basic Chemistry e-book was given pre and post-test to compare students learning outcome before and after learning. The result of students' learning outcome became a reference for the last revision of e-book.

Research Instruments

Data collection technique used were questionnaire and test technique. Instruments used were: (1) expert judgement questionnaire and (2) field trial questionnaires and (3) essay test. The expert judgement questionnaire was adapted from Badan Standar Nasional Pendidikan or The National Education Standard Agency of Indonesia. Pertiwi et al. (2024) arranged from 4 indicators, namely content suitability indicator, presentation suitability indicator, language suitability, and STEM existence indicator. It consisted of 26 statement items with details 8 statements for content suitability indicators, 7 statements for presentation suitability indicators, 6 statements for language suitability indicators, and 5 statements for STEM existence indicators. The expert judgement questionnaire used in this study was in the form of a checklist with scoring on each

aspect using a 1-5 Likert scale. The criteria for each rating scale used are as follows:

Table 1. Criteria For Each Rating Scale

Criteria	Score
Very Good	4
Good	3
Enough	2
Not Enough	1

Based on Table 1, expert would gave score from 1 to 4 for each criteria based on Basic Chemistry e-book. The expert judgement questionnaire was validated by expert before being used. Test of reliability showed that r table score for 26 items of expert judgement statements was 0.824. It showed the reliability of expert judjement statements was good.

Student response questionnaire which was adapted from Ministry of Education and Culture (2017) which arranged from 3 indicators, namely content suitability, presentation suitability, and language suitability indicators. It consisted of 15 statement items with details 7 statements for content suitability indicators, 5 statements for presentation suitability indicators, and 3 statements for language suitability indicators. Students' questionnaire used 1 to 5 likert scale from very valid, valid, quite valid, not valid to very not valid criteria. While the validity audience of e-book had score 1 to 5 from very interesting, interesting, quite interesting, not interesting, and very not interesting. The expert judgement questionnaire was validated by expert before being used. Test of reliability showed that r table score for 15 items of students' response statements was 0.856. It showed the reliability of expert judgement statements was good.

The research method used must be written in accordance with the scientific way, that is, rational, empirical and systematic. The scientific method contains the type and design of research, the operational definition of research variables, the population and sample of research (for inferential research) or the subject and object of research (for non-inferential research), research instruments and data collection techniques, and data analysis techniques.

RESULT AND DISCUSSION

Result of e-book development describes based on ADDIE model as explained as follows.

Analysis

Need assesment has been carried out before developing basic chemistry e-book. Need assessment of e-book developing consisted of curriculum analysis, student characteristic analysis, and resource analysis. Curriculum analysis was carried out by examining the curriculum used before developing e-book. Based on analysis of curriculum, several basic competencies should be mastered by students in Basic Chemistry course were to explain the classification and changes in matter, as well as the laws relating to matter and chemical reactions; to understand reaction dynamics (rate) and thermodynamics in relation to chemical reactions; to explain the concept of acid-base solutions and calculating the pH of solutions, and be able to calculate the concentration of acid and base solutions; to describe the concepts of reaction rates, redox reactions and electrochemistry; and explain hydrocarbon compounds, the reactions involved in them and their uses in everyday life (Petrucci, 2011). Those basic competencies used as a reference to determine the materials in e-book.

Furthermore, analysis of student characteristics was also carried out to determine student character both in intellectual and language aspects. In intellectual terms, science education are generally aged 18-19 years, so they had the ability to think abstractly and have a high level of language understanding. This was because their language skills were supported by the references used during lectures. Based on need assessment, student learning style was 62% audio visual so that students

need a learning media which could cover their learning style. Resource analysis showed that each class in science education department had sufficient facility for example there are an LCD and monitor in each class which could support the use of e-book in a Basic Chemistry class.

Design

Researchers made a draft of e-book and research instruments in this phase. Draft of Basic Chemistry E-book enrich with multiple representation and STEM consisted of an introduction, instructions for using e-book, table of contents, and learning outcomes. The content design contains materials, experimental designs, STEM activities, and various book features such as virtual laboratory, let's think and team work to enhance multiple representation. The closing draft contains a bibliography.

The research instrument consisted of expert judgement questionnaire, student response questionnaire, and essay test for students. Expert judgement questionnaire consisted of 26 statement items with details 8 statements for content suitability indicators, 7 statements for presentation suitability indicators, 6 statements for language suitability indicators, and 5 statements for STEM existence indicators. Student response questionnaire consisted of 15 statement items with details 7 statements for content suitability indicators, 5 statements for presentation suitability indicators, and 3 statements for language suitability indicators. Essay test used to determine students learning outcome in evaluation phase.

Develop

Basic Chemistry e-book enhance with multiple representations and STEM activites can be accessed at the following link: https://online.fliphtml5.com/orjiv/inks/.

Learning activities which support multiple representations were one of the core part of e-book. E-book is designed to guide student to understood chemical concepts. Each material began with a page containing illustrations and the main content of that section. In between explanations of the material there was a learning activity called "Virtual Laboratory" which guides students to simulate practicums or experiments, as illustrated in Figure 1.

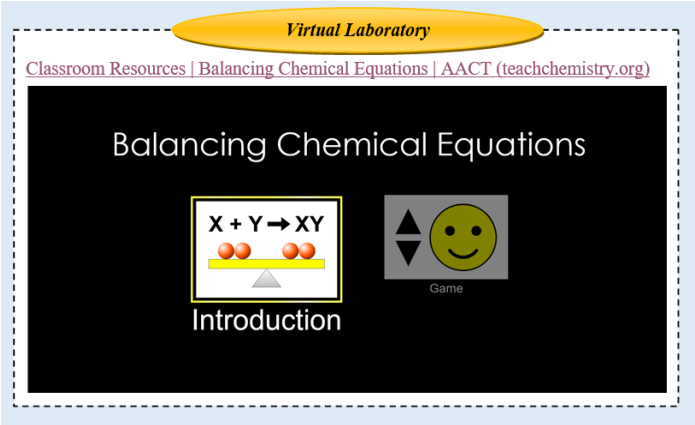

Figure 1. Virtual Laboratory in Basic Chemistry E-book

Based on Figure 1, students learned how to balance chemical equation by looking at visual image of atoms and made a balance chemical equation using virtual laboratory. This way would help students to visualize how atoms combine to form new molecules. The presence of virtual laboratory would make it easier for students to understand submicroscopic and symbolic aspect as they easily made balance chemical equation. In line with this research, (Guentulle et al., 2024; Pertiwi et al., 2024) also confirmed that multiple representation based chemistry book should contain material simulation which able to guide students to understand symbolic and submicroscopic aspect.

This Basic Chemistry e-book was also developed with a STEM approach so that this book has features to support STEM,

namely "Science-Engineering-Technology Aspects" which invite students to integrate chemical (science) concepts with engineering and mathematical calculations. STEM activities in e-book was shown by Figure 2(a)

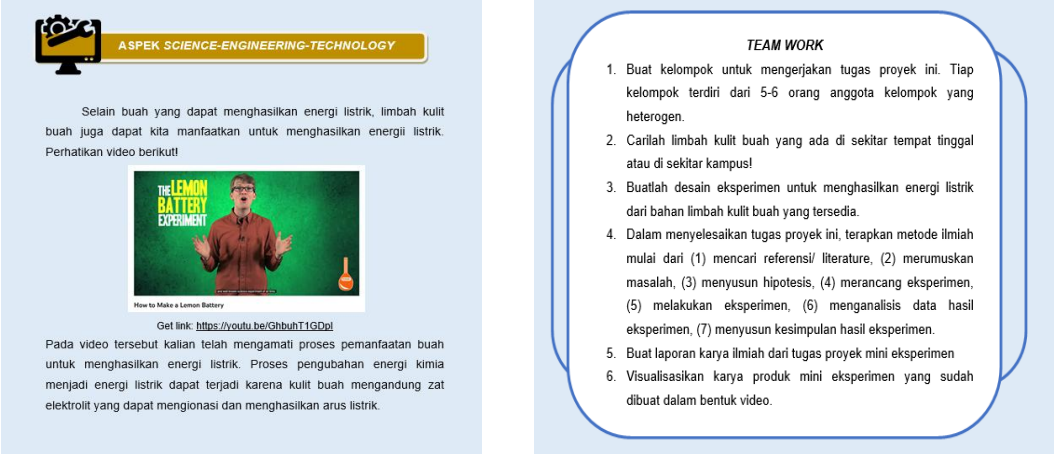

Figure 2. (a) STEM Aspect in Basic Chemistry E-Book (b) STEM activities for students

Based Figure 2(a), students were stimulated to proceed fruit peel to become energy resource. By making an experimental design to convert fruit peel into an energy source, students would apply chemical concepts to solve problems that were integrated with engineering (designing solutions to solve problems). Then, students would also learn to calculate how much fruit peel waste to turn on an LED light so that learning was integrated with mathematics. Dominguez et al. (2023) stated that the core activity of STEM involves a real-world experiment where student attempt to solve problems. STEM activities would encourage students to solve problems systematically from searching literatures, formulate research questions, formulate hypothesis, made an experimental design analyze data of experiments to made a conclusion of experiment or investigation. All stages that students go trough in solving problem formed design-oriented thinking in student. This would increase 21st century skills of students including critical thinking, creativity, collaboration, communication, information and media literacy, productivity and social skills (Derevyanchuk et al., 2024; Faculty of Education, SIMAD University, Mogadishu, Somalia et al., 2024).

E-book was then subjected to an expert to determine the level of validity of e-book. Product validation consists of validation from material experts, textbook design experts for learning, STEM education and linguistics experts, as contained in Table 2.

Table 2. Validation Result

Validator	Result	Criteria
Material Expert	93,75%	Very valid
Textbook Design Expert	100,00%	Very valid
STEM education Expert	95,40%	Very valid
Expert judgement rate =	**96,38%**	Very valid

Based on expert judgement result above, e-book got overall score 96,38%. The validation score from material expert showed that the presentation of the material in Basic Chemistry e-book was in accordance with learning outcomes, needs and characteristics of students. In addition, the assignments in e-book involved project

assignments integrated with engineering and technology aspects in STEM approach by applying the chemistry concepts that have been taught. E-book design (writing and letter layout, sentence and paragraph layout, image layout and color selection) was also meets the standards. Apart from that, the presentation of chemistry concepts in e-book was coherent and the completeness of e-book feature was up to standard. Besides that, the language used in e-book (including terms) was easy to be understood and the existence of STEM aspects in e-books were also very clearly visible in the material presented.

Implementation

Basic chemistry e-books based on multiple representations with STEM approach was tested in small-scale and large-scale field trials. Small-scale field trials were carried out on 10 students, while large-scale field trials were carried out on 30 students of science education department class of 2022/2023. The trials were carried out using a questionnaire instrument for student responses to e-book, as contained in Table 3.

Table 3. Validation Result

	Physical Presentation	Content Quality Language	STEM aspects
Small Scale	86%	86%	87%
Large Scale	86%	86%	89%

Evaluation

There were some revisions done for Basic Chemistry e-book based on expert judgement and field trials. The first revision was about several experimental design in e-book did not include tools and materials so that researchers added tools and materials on experimental design in e-book, as illustrated in Figure 3(a) and 3(b). The second revision was virtual laboratory was added by initial questions to stimulates students' curiosity, as illustrated in Figure 4(a) and 4(b).

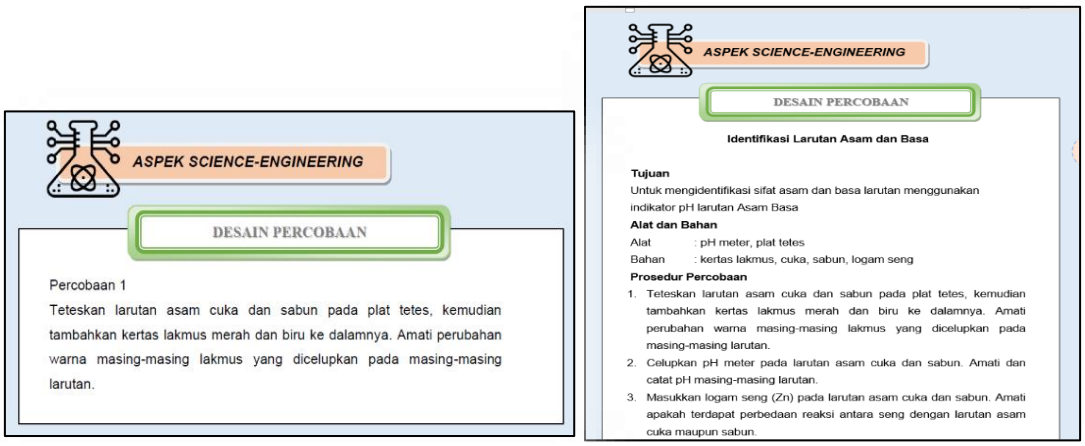

Figure 3. (a) Before revision: there was no tool and material (b) After revision: there are tools and materials in experimental design of e-book.

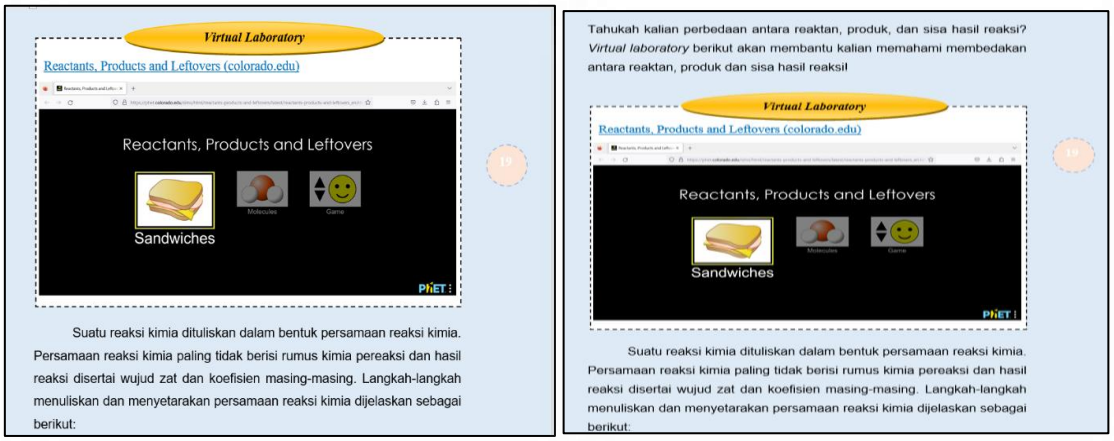

Figure 4. (a) Before revision: there was no initial question in virtual laboratory activity (b) After revision: there is an initial question in virtual laboratory activity.

Based on the results obtained from qualitative student responses, the e-book really helps students to increase their interest for learning basic chemistry and enrich their knowledge with a lot of literacy. This opinion was in line with previous research that STEM based Basic Chemistry E-book could enrich students' literacy and improve their critical thinking skill. Students' gave their opinion about chemistry e-book, that were: (1) e-book was fun to be used because it contained virtual laboratories so students could also understand chemistry concepts after doing the simulation; (2) e-book consisted of questions as exercises for training students understanding about all materials; (3) viewed from a visual perspective, the appearance of e-book was very attractive and was not make students feel bored and monotonous, there were colorful images which also motivate students to learn; and (4) e-book very helped students to instill a love of studying chemistry.

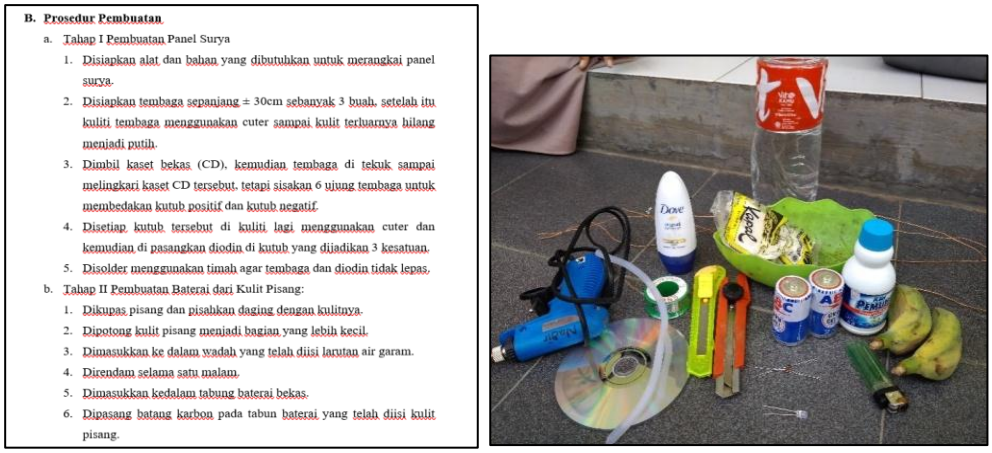

Figure 5. (a) Experimental design made by a group of students in STEM activities (b) Utilization of banana peel as an alternative energy

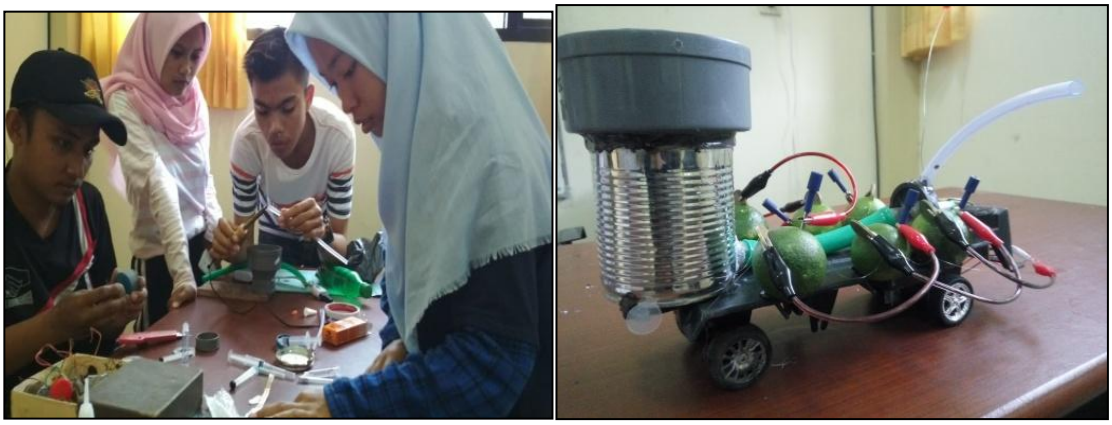

Figure 6. (a) Students work in group in STEM activities (b) Using of lemon as a source of energy

The Effectiveness Test of E-Book

The effectiveness test of e-book was done in Basic Chemistry class. Students used Basic Chemistry E-book enhance with multiple representation and STEM during the learning. STEM activities of students shown in figure. Based on figure 5(a) and 5(b), students made an experimental design for solving real problem to produce alternative energy by using banana peel. They created solar panels as an alternative source of energy from banana peel by using chemistry concept. (Yalçın, 2024) stated that an experimental design made by students would be a way of design-oriented thinking in STEM learning.

While figure 6(a) and 6(b) explained that the different group create plant watering robot by using lemon as source of energy. They work in a group so that they can discuss how to design the plant watering robot from waste. This activity will trigger students' critical and reflective thinking (Hwang et al., 2024; Pertiwi et al., 2024). This research in line with previous research conducted by (AlAli and Yousef 2024; Hwang et al. 2024; Zárate-Navarro et al. 2024) which stated by students activity increasing by applying STEM in science learning.

Table 4. N-gain Score of experiment and control class

Class	Pre Test Mean	Post Test Mean	N-gain score	Criteria
Experiment	31,2	75,2	0,643	Moderate
Control	30,7	49,8	0,274	Low

Students worked on pretest and posttest questions after doing basic chemistry learning. The N-gain score got from pretest and posttest showed by Table 4. Based on Table 4, experiment class got score 0,643 means the using of e-book in chemistry learning had moderate criteria or e-book was effective enough for using in chemistry learning.

Control class got score 0,274 for N-gain because they did not use e-book during basic chemistry course. Besides that, the increasing of average value of pre test and post test in experiment class was higher than the control one. It means that the absence of e-book in chemistry class was not effective for learning. It can be concluded that the using of e-book was effective for using in basic chemistry learning.

CONCLUSION

This study developed a Basic Chemistry E-book based on multiple representations using STEM which could be used for learning materials of Basic or General Chemistry Course in higher education. Research result showed the validity of Basic Chemistry E-book was very

valid. Moreover, the results of field trials of e-book were for 86,33% small-scale and 87,67% large-scale field trials. The effectiveness test of e-book got N-gain score 0,643 meant that e-book was effective to be used in science learning. The presence of this e-book would be a good alternative learning source for science education students. It could happen since there were STEM based learningactivity, video, and virtual laboratory which could help students to understand chemical concepts clearly, whether macroscopic, microscopic or symbolic representation.

Impact of this research on education were supply and enrich learning materials for chemistry learning in higher education. Further, the presence of STEM activities in e-book would enhance students 21st century skills. However, this study still has limitations. Firstly, the dissemination of e-book in chemistry course has not been conducted because of time and cost limitation. Secondly, virtual laboratory in e-book was not still developed by researcher but utilised science virtual laboratory which had existed. Based on the lack of this study, further study needs to be done to continue this study.

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AUTHOR CONTRIBUTIONS

Author one is responsible for conceptualization and writing the original draft;
Author two is responsible for doing validation and supervision;
Author three is responsible for editing draft;
Author four is responsible for writing and reviewing draft.

REFERENCES

Adadan, E., Irving, K. E., & Trundle, K. C. (2009). Impacts of Multi-representational Instruction on High School Students' Conceptual Understandings of the Particulate Nature of Matter. *International Journal of Science Education*, *31*(13), 1743–1775. https://doi.org/10.1080/09500690802178628

AlAli, R., & Yousef, W. (2024). Enhancing student motivation and achievement in science classrooms through STEM education. *STEM Education*, *4*(3), 183–198. https://doi.org/10.3934/steme.2024012

Altınbaş, A. A., Ertekin, E., & Solak, S. (2024). A study on multiple representation and self-efficacy perception in systems of linear equations. *International Journal of Mathematical Education in Science and Technology*, *55*(4), 976–996. https://doi.org/10.1080/0020739X.2022.2156933

Amiruddin, M., Sari, Aisyah, R., & Irwansyah, F. S. (2024). *Interactive learning multimedia based on multiple representations on acid-base solutions*. 040029. https://doi.org/10.1063/5.0206430

Arslan, H. O., & Genc, M. (2024). The STEM Education Approach for Conceptual Learning: In R. Kumar, E. T. Ong, S. Anggoro, & T. L. Toh (Eds.), *Advances in Higher Education and Professional Development* (pp. 43–73). IGI Global. https://doi.org/10.4018/979-8-3693-3699-1.ch002

Branch, R. M. (2009). Prologue. In R. M. Branch, *Instructional Design: The ADDIE Approach* (pp. 1–20). Springer US. https://doi.org/10.1007/978-0-387-09506-6_1

Cortes, A. A. (2024). Gamifing the Classroom: Bringing Videogames to Life Through Innovation in Education to Increase Student Engagement in STEM Subjects.

2024 IEEE Gaming, Entertainment, and Media Conference (GEM), 1–4. https://doi.org/10.1109/GEM61861.2024.10585581

Deehan, J., Danaia, L., Redshaw, S., Dealtry, L., Gersbach, K., & Bi, R. (2024). STEM in the classroom: A scoping review of emerging research on the integration of STEM education within Australian schools. *The Australian Educational Researcher*, *51*(5), 1–24. https://doi.org/10.1007/s13384-024-00691-7

Dehbozorgi, N., & Roopaei, M. (2024). Improving Computational Thinking Competencies in STEM Higher Education. *2024 IEEE Integrated STEM Education Conference (ISEC)*, 01–04. https://doi.org/10.1109/ISEC61299.2024.10664997

Derevyanchuk, O. V., Kovalchuk, V., Kramar, V., Kravchenko, H., Kondryuk, D., Kovalchuk, A., & Onufriichuk, B. (2024). Implementation of STEM education in the process of training of future specialists of engineering and pedagogical specialties. In O. V. Angelsky & C. Yu. Zenkova (Eds.), *Sixteenth International Conference on Correlation Optics* (p. 55). SPIE. https://doi.org/10.1117/12.3012996

DIANI, R., VIYANTI, V., LENGKANA, D., JALMO, T., DESTIANA, A., SAREGAR, A., & GANDA PUTRA (Indonesia), F. (2024). Trends, challenges, and opportunities of Multiple-Representation in Science learning: A systematic literature review. *Review of Science*, *Mathematics and ICT Education*, Forthcoming papers. https://doi.org/10.26220/REV.4657

Dominguez, A., De La Garza, J., Quezada-Espinoza, M., & Zavala, G. (2023). Integration of Physics and Mathematics in STEM Education: Use of Modeling. *Education Sciences*, *14*(1), 20. https://doi.org/10.3390/educsci14010020

Faculty of Education, SIMAD University, Mogadishu, Somalia, Abdi, A. I., Omar, A. M., Faculty of Education, SIMAD University, Mogadishu, Somalia, Mahdi, A. O., Faculty of Education, SIMAD University, Mogadishu, Somalia, Osman, M. A., Faculty of Education, SIMAD University, Mogadishu, Somalia, Asiimwe, C., & College of Education and External Studies, Makerere University, Kampala, Uganda. (2024). Assessing higher education students' perception towards their engagement in pedagogical STEM approach. *International Journal of ADVANCED AND APPLIED SCIENCES*, *11*(2), 171–179. https://doi.org/10.21833/ijaas.2024.02.018

Guentulle, V., Muñoz, R., Nussbaum, M., & Madariaga, L. (2024). How Multiple Representations Using Cyber–Physical System to Teach Rectilinear Motion Improves Learning and Creativity. *Education Sciences*, *14*(3), 293. https://doi.org/10.3390/educsci14030293

Hsu, Y.-S., Tang, K.-Y., & Lin, T.-C. (2024). Trends and Hot Topics of STEM and STEM Education: A Co-word Analysis of Literature Published in 2011–2020. *Science & Education*, *33*(4), 1069–1092. https://doi.org/10.1007/s11191-023-00419-6

Hwang, J. (Lexi), Choo, S., Morano, S., Liang, M., & Kabel, M. (2024). From Silos to Synergy in STEM Education: Promoting Interdisciplinary STEM Education to Enhance the Science Achievement of Students With Learning Disabilities. *Learning Disabilities Research & Practice*, *39*(3), 117–131. https://doi.org/10.1177/09388982241245452

Keller, D., & Hermanns, J. (2024). Development of a self-test for undergraduate chemistry students: How do students solve tasks on basic content knowledge? *Chemistry Teacher International*, *6*(1), 65–75. https://doi.org/10.1515/cti-2023-0068

Niyomufasha, T., Ntivuguruzwa, C., & Mugabo, L. R. (2024). The engineering students' use of multiple representations in mechanics problems solving at a selected public university in Rwanda. *Cogent Education*, *11*(1), 2372941. https://doi.org/10.1080/2331186X.2024.2372941

Pertiwi, N. P., Saputro, S., Yamtinah, S., & Kamari, A. (2024). ENHANCING CRITICAL THINKING SKILLS THROUGH STEM PROBLEM-BASED CONTEXTUAL LEARNING: AN INTEGRATED E-MODULE EDUCATION WEBSITE WITH VIRTUAL EXPERIMENTS. *Journal of Baltic Science Education*, *23*(4), 739–766. https://doi.org/10.33225/jbse/24.23.739

Portillo-Blanco, A., Deprez, H., De Cock, M., Guisasola, J., & Zuza, K. (2024). A Systematic Literature Review of Integrated STEM Education: Uncovering Consensus and Diversity in Principles and Characteristics. *Education Sciences*, *14*(9), 1028. https://doi.org/10.3390/educsci14091028

Pratiwi, J. K., Widarti, H. R., & Rokhim, D. A. (2024). The Use of Social Media as a Learning Media Based on Multiple Representation to Increase Student Learning Motivation: Article Review. *Orbital: The Electronic Journal of Chemistry*, 119–124. https://doi.org/10.17807/orbital.v16i2.19964

Sum, K. C., Ng, K.-H., Siu, S.-T., Chui, H.-Y., Au, C.-L., & Li, C. F. (2024). AI Assisted Microcontroller Based Kits for STEM Education. *2024 IEEE Integrated STEM Education Conference (ISEC)*, 1–4. https://doi.org/10.1109/ISEC61299.2024.10665244

The Effect of Multiple Representation-Based Learning (MRL) to Increase Students' Understanding of Chemical Bonding Concepts. (2018). *Jurnal Pendidikan IPA Indonesia*, *7*(4). https://doi.org/10.15294/jpii.v7i4.16219

Thyberg, A., Schönborn, K., & Gericke, N. (2024). Investigating students' meaning-making of multiple visual representations of epigenetics at different levels of biological organisation. *International Journal of Science Education*, *46*(14), 1405–1431. https://doi.org/10.1080/09500693.2023.2289175

Widarti, H. R. (2021). *Multiple representations in chemistry learning: A study on teachers' literacy*. 020042. https://doi.org/10.1063/5.0043360

Yalçın, V. (2024). Design-Oriented Thinking in STEM education: Exploring the Impact on Preschool Children's Twenty-First-Century Skills. *Science & Education*, *33*(4), 901–922. https://doi.org/10.1007/s11191-022-00410-7

Yeung, R. C. Y., Yeung, C. H., Sun, D., & Looi, C.-K. (2024). A systematic review of Drone integrated STEM education at secondary schools (2005–2023): Trends, pedagogies, and learning outcomes. *Computers & Education*, *212*, 104999. https://doi.org/10.1016/j.compedu.2024.104999

Zárate-Navarro, M. A., Schiavone-Valdez, S. D., Cuevas, J. E., Warren-Vega, W. M., Campos-Rodríguez, A., & Romero-Cano, L. A. (2024). STEM activities for heat transfer learning: Integrating simulation, mathematical modeling, and

experimental validation in transport phenomena education. *Education for Chemical Engineers*, S1749772824000149. https://doi.org/10.1016/j.ece.2024.06.004

Zhumabay, N., Yelemessova, Z., Balta, N., Abylkassymova, A., Bakytkazy, T., & Marynowski, R. (2024). Designing effective STEM courses: A mixed-methods study of the impact of a STEM education course on teachers' self-efficacy and course experiences. *Frontiers in Education*, *9*, 1276828. https://doi.org/10.3389/feduc.2024.1276828