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Development of Multiple Representation-based Electronic Teaching Materials Using Guided Inquiry on Acid-Base Topic

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Abstract: This study aims to develop and determine the feasibility of multiple representation-based electronic teaching materials using a guided inquiry model on the topic of acid and base for class XI high school. The method used in this research is research and development (R & D) which was developed by Thiagarajan and known as the 4D model. The 4D model consists of four stages: define, design, develop, and disseminate. This research instrument is a questionnaire to obtain a quantitative score used to determine the feasibility of teaching materials. The study results indicate that the developed teaching materials have a very good feasibility percentage. The developed teaching materials have been corrected by expert lecturers and revised according to the input given so that a decision is obtained that the teaching materials can be used. The feasibility of teaching materials is determined based on the assessment of the chemistry teacher as a reviewer and student responses. The assessment category obtained from the review by the chemistry teacher are very good with an average assessment percentage of 86.75%. Based on the results of field trials, the student responses show that the developed teaching materials were classified as very good category with an average percentage of 83.00%. Therefore, based on the validation and field trial results, the developed electronic teaching materials are feasible for use in class XI chemistry learning on the acid-base topic.

Keywords: Acid-base topic; Electronic teaching materials; Guided inquiry; Multiple representation

Introduction

Chemistry is a scientific discipline that is not only closely related to everyday life but also includes abstract concepts. The acid-base topic is one of the chemical materials that most students consider difficult because there are abstract parts. One of these abstract parts is about ion charges which cannot be seen directly by students at the microscopic level (Ye et al., 2019). There is a need for visualization of abstract concepts and explanations of multiple representation concepts, which include macroscopic, microscopic, and symbolic representations. The macroscopic representation of acid-base material, for example, is in the form of the concept that an acid is a substance that has a sour taste and a base is a substance that has a bitter taste. Microscopic level representation can be in the form of particles in solution. The symbolic representation of acid-base material can be in the form of an ionization reaction equation in solution (Zuhroti et al., 2018). Symbolic representation is in the form of symbols and reaction equations, for example, hydrochloric acid has the symbol HCl (Wulandari et al., 2018). Students' lack of ability to translate structural formulas and understand symbolic representations of molecules affects students' ability to solve problems (Graulich, 2015). Currently, chemistry learning is more representative of the macroscopic and symbolic level, while the submicroscopic level is rarely given (Sagita et al., 2017). Students' ability to translate microscopic representations into symbolic representations is still relatively low (Gkitzia et al., 2020).

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Some students think that chemistry subjects are difficult to understand, especially those related to analytical questions involving formulas and concepts with a higher understanding in solving a problem (Faizah et al., 2013). Based on interviews conducted by Pursitasari et al. (2012), students feel they have understood the theory well but when solving exam questions, many cannot answer correctly. It indicates that students have not learned meaningfully but only memorized so that their understanding is temporary (not long-term). Students may be less trained in solving problems that involve analytical skills.

The acid-base material contains dimensions of factual, conceptual, principle and procedural knowledge (Yani et al., 2022). In studying the concept of acid-base, which consists of acid-base theory, acid-base strength, measurements, pH calculations, and acid-base reactions, students can experience misconceptions (Ningrum et al., 2022). An assignment to assess understanding and characterize how students think and reason about acid-base reactions has been developed. The results showed that students had some knowledge of macroscopic concept, but lacked understanding of microscopic conceptualization of the behavior of acid-base substances. The learning difficulties experienced by students include: 1) most of the students know the meaning of ionic dissociation of substances in an aqueous solution, but they are difficult to apply theoretical knowledge to find the possibility of ionic dissociation occurring, 2) acid-base behavior is predicted by students only based on compound formulas, because they have little empirical knowledge about the behavior of acid-base substances. Thus, students only associate the presence of H or OH in the formula of a substance with an acid or base reaction, without distinguishing between atoms (or groups of atoms) or ions, 3) students lack understanding of the meaning of subscript and superscript in polyatomic ion formulas, 4) some students cannot distinguish between ions and atoms of an element (Más et al., 2007).

Problems that arise when students study acid-base chemistry material include difficulties in understanding how acid-base reactions occur and understanding the principles of various acid-base theories. For example, in Lewis's acid-base theory, students must be able to explain why a reaction occurs by describing the reaction with an arrow, so that students are able to articulate the meaning of the arrow and the reason why electron transfer occurs (Cooper et al. 2016). Students' inability to visualize particles, connect macroscopic and microscopic representations makes students bored so that students only tend to memorize the material (Li & Arshad, 2014). Students face difficulties when they have to connect all levels of representation (macroscopic, microscopic, and symbolic). Students find it difficult to understand the microscopic level if they are not given proper explanations and visual methodology (Santos & Arroio, 2016). Teachers must integrate all levels of multiple representations to optimize students' conceptual understanding, one of which is using multiple representation-based teaching materials.

Students in the learning process do not only rely on the knowledge transfer from the teacher but can also be supported by finding knowledge independently. Students can independently study subject matter supported by textbooks and teaching materials. Thus, through the use of effective teaching materials, students will be able to store knowledge in long-term memory (Pursitasari et al., 2020). Teachers commonly use printed books and student worksheets as teaching materials that have not been able to develop students' critical thinking skills optimally (Gazali et al., 2019). Multiple representations need to be applied in online learning modules to facilitate students' understanding of abstract scientific concepts and phenomena. Representations are presented through static graphics, photos or diagrams, animations and simulations, videos, and textual forms such as information, inquiry questions, instructions, and others. Students who take part in the inquiry process of studying a concept at the microscopic level can identify the interaction between the dynamic properties of molecules and atoms. However, some students find it challenging to explore and engage independently with learning modules when research is applied by open inquiry (Mamun et al., 2020). Therefore, an instructional guide (guided) in inquiry learning is needed.

Teaching materials can be developed with learning models, one of which is the guided inquiry model. Inappropriate teaching methods can lead to several misconceptions about students' understanding. The guided inquiry method is based on constructivism using learner-centered activities. Guided inquiry teaching provides an enlightening experience that offers opportunities for inquiry and discussion (Vlassi & Karaliota, 2013). Inquiry learning is included in a group of information processing models which play a role in helping students to find information, construct concepts, and test a hypothesis (Joyce et al., 2016). The important points of inquiry-based learning are students can think about questions and express opinions. Students' active participation in activities, answering questions, and discussions makes a positive contribution to the development of critical thinking levels (Duran & Dökme, 2016). Research by Bunterm et al. (2014) showed that students who applied guided inquiry experienced greater improvements in aspects of science content knowledge and science process skills when compared to structured inquiry.

Based on the results of interviews with chemistry teachers at SMA Negeri 11 Yogyakarta when conducting observations at the school, information was obtained that the teaching materials used were printed teaching materials. It was found that some students were reluctant to ask questions when they did not understand the material or tended to be passive. In previous lessons, the teacher had not implemented the guided inquiry learning model in the implementation of learning acid-base material. Habellia et al. (2019) states that compared to electronic teaching materials, printed teaching materials have several limitations, including the information contained in printed teaching materials is only information that has been written and cannot be accessed freely, only students who have books can use it, so it is less effective. Meanwhile, learning in the 21st century requires teaching materials that can facilitate students to take advantage of advances in information technology that are available and can be accessed freely without the limitations of space and time. Teaching materials can be developed in the electronic form to provide convenience (practical) for students to be accessed via an Android-based smartphone or a laptop. Furthermore, Komikesari et al. (2020) states that one of the applications used to compile electronic teaching materials is Flip PDF Professional. Flip PDF Professional is different from other PDF application programs. Flip PDF Professional can combine the material in pdf files with images, animations and learning videos. Learning media products using Flip PDF Professional apply technology so that they can be accessed using a laptop, computer, or smartphone. Thus, students can use the media independently.

Based on this description, the use of teaching materials that contain multiple representations in chemistry subjects is still rarely developed, especially in acid-base materials which require multiple representations to visualize abstract concepts. Therefore, it is necessary to develop electronic teaching materials based on multiple representations with guided inquiry models on acid-base material. Practical integration of technology such as Flip PDF Professional is needed in operating electronic teaching materials so that the material message can be visualized well. The development of electronic teaching materials is an effort to overcome the limitations of printed teaching materials. In addition, presenting material that involves multiple representations in guided inquiry syntax helps students understand chemical concepts.

Method

This study uses an R&D development model adopted from Thiagarajan or the 4D model. The four stages of development of the 4D model are define, design, develop, and disseminate (Thiagarajan et al., 1974). The define stage includes front-end analysis, student analysis, task analysis, concept analysis, and goal specification. The design stage includes the preparation of teaching materials, media selection, format selection, and initial design. The development stage includes the expert validation stage and development test. The dissemination stage through diffusion by presenting the development results. The flow chart of this research is presented in Figure 1.

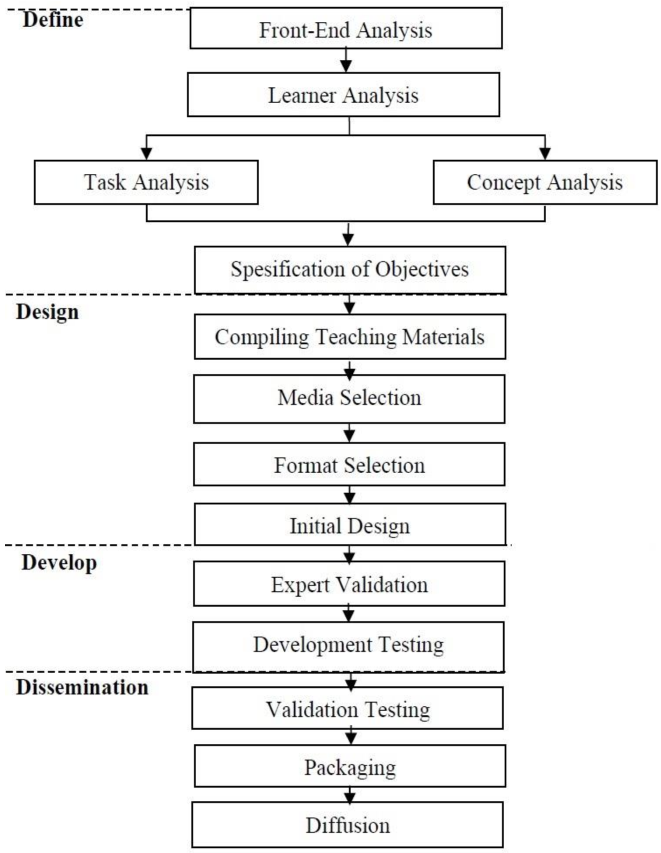

Figure 1. Flow chart of research

This study aims to develop and determine the feasibility of multiple representation-based electronic teaching materials with a guided inquiry model on an acid-base topic. The research subjects in the development trial were one experimental class and one control class from 11^{th} grade students at SMAN 11 Yogyakarta. The sampling technique at the trial stage was carried out by simple random sampling. The instrument in this study used a questionnaire to obtain product input data and a quantitative score as the value of the feasibility of the teaching materials. The data analysis technique used is a simple quantitative descriptive analysis technique. Data were obtained through teaching materials correction results by expert lecturers as correctors, assessments by four chemistry teachers as reviewers and from student responses.

The assessment instrument is made for expert lecturers, chemistry teachers, and students. The rating scale uses a Likert scale from 1 to 4, with a maximum score of 4 and a minimum score of 1. Each score is formulated into a rating scale category as shown in Table 1 (Werdiningsih et al., 2019).

Table 1. The Likert Scales

Score	Criteria
4	Very good
3	Good
2	Less
1	Very Less

The score obtained from the questionnaire data is then calculated using the following equation 1.

$$Validity\ percentage = \frac{score\ gained}{maximum\ score}\ x\ 100\% \quad (1)$$

The criteria for the percentage of conformity are shown in Table 2 (Nasrudin et al., 2018).

Table 2. The Criteria of Validity Percentage

Percentage (%)	Criteria
81 - 100	Very good
61 - 80	Good
41 - 60	Enough
21 - 40	Low
0 - 20	Very Low

Result and Discussion

The development of electronic teaching materials in this study through several stages. The defined stage determines the identification and analysis of the fundamental problems faced by teachers in the implementation of chemistry learning on acid-base materials. The analysis of students was carried out through observation to identify the characteristics of students relevant to the design of the developed teaching materials. The task analysis and concept analysis were carried out by reviewing the 2013 curriculum syllabus to formulate the primary abilities students would master in learning and the main concepts to be taught. Furthermore, the specification of the formulation of learning objectives is carried out. The design stage formulates the preparation of teaching material instruments and refers to the learning objectives. The design stage includes compiling the format of teaching materials, making covers, introductions, image and video layout design, then content of teaching materials. The media used to develop electronic teaching materials is Flip PDF Professional. The output of the design stage is the initial design product. The development stage validates the draft of teaching materials by two expert lecturers as correctors and four teachers as reviewers. Revision of teaching materials is carried out based on input from expert lecturers and chemistry teachers. Perdana et al. (2017) states that product revisions based on validation by experts and suggestions or input from teacher reviewers were needed to improve the material and design of teaching materials.

The development trial in this study involved one experimental class and one control class which were carried out to determine the readability of teaching material products based on student responses. Based on the student response data, it was found that the developed teaching materials was in the very good category. In addition to containing multiple representation images, the developed teaching materials are also equipped with a video of solution testing using litmus paper and universal indicators, then an evaluation quiz. Figure 2 show the front view of teaching materials.

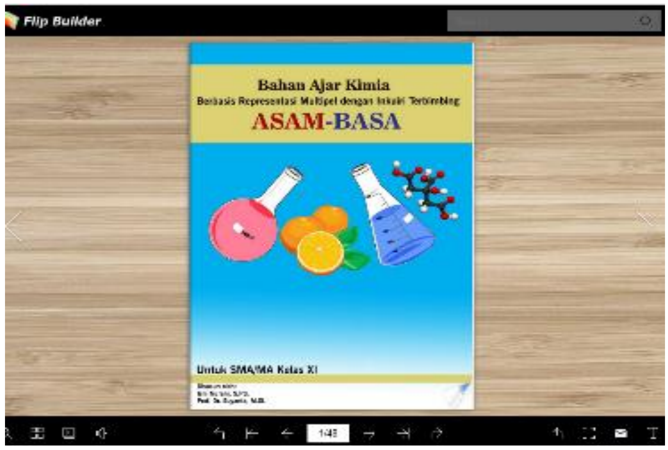

Figure 2. Front view of teaching materials

Meanwhile, illustrations of multiple representation images in teaching materials are presented in Figure 3.

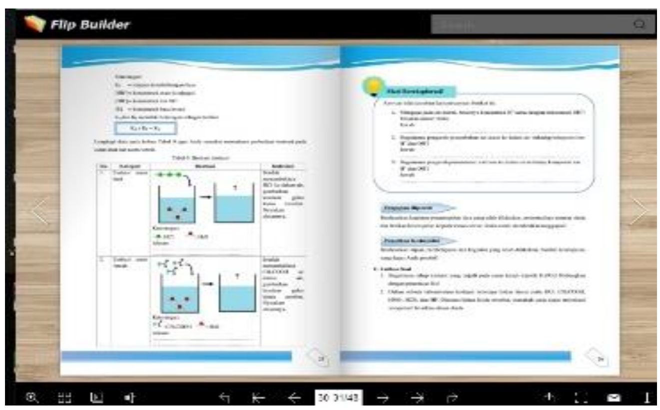

Figure 3. The display of acid- base material

In the evaluation quiz, students can directly determine whether the chosen answer is right or wrong. Figure 4 show the display of evaluation quiz.

Figure 4. The display of evaluation quiz

The display of video in teaching materials is presented in Figure 5.

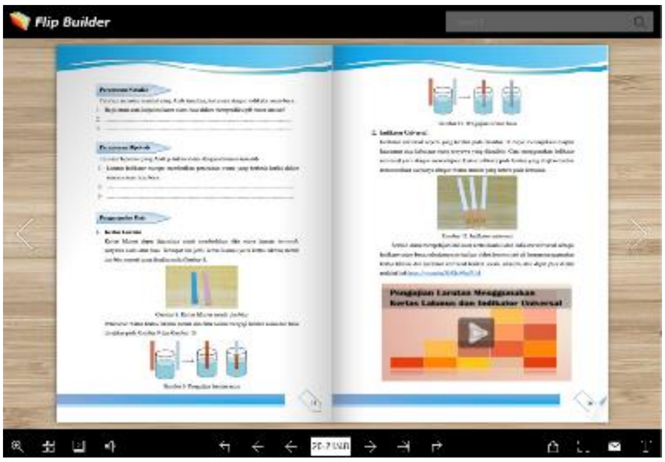

Figure 5. The display of video

The developed teaching materials in this study used a guided inquiry model. Guided inquiry emphasizes the importance of the discovery process by students. The syntax of the guided inquiry learning model consists of six stages, namely: 1) orientation, 2) problem formulation, 3) hypothesis formulation, 4) data collection, 5) result verification/hypothesis testing, and 6) conclusion (Hastuti et al., 2020). The National Education Standards Agency (BSNP) states that several feasibility indicators must meet the development of a textbook, including the feasibility of content, language, presentation, and graphics (Nursaputri et al., 2021). Two expert lecturers from the chemistry department corrected the draft of the developed teaching material product and then revised them according to the suggestions. The validation sheet consists of several aspects such as the feasibility of content, language, presentation, and graphics. After the revision, it was decided that the teaching materials could be used. The development stage is continued with review of teaching materials by four chemistry teachers. The review results by four teachers obtained an average score of 3.47 or 86.75%, a very good category. In detail, as shown in Table 3, the content feasibility aspect has an average score of 3.55 or 88.75%, which is a very good category. The language aspect has an average score of 3.35 or 83.75%, which is a very good category. The presentation aspect has an average score of 3.33 or 83.25%, which is a very good category, and the graphic aspect has an average score of 3.63 or 90.75%, which is a very good category.

Table 3. The Review Results by the Teachers

Aspects	Score Average	Percentage	Category
Content	3.55	88.75	Very good
Language	3.35	83.75	Very good
Presentation	3.33	83.25	Very good
Graphics	3.63	90.75	Very good
Average	3.47	86.75	Very good

The readability data of electronic teaching materials was obtained through the filling out of student response questionnaires by the experimental class on the field trial. The results of the field trial obtained an average score of 3.32 or 83.00%, which means very good. In detail, as shown in Table 4, the learning aspect has an average score of 3.31 or 82.75%, which is a very good category. The display aspect has an average score of 3.27 or 81.75%, which is a very good category, and the programming aspect has an average score of 3.38 or 84.50%, which is a very good category.

Table 4. The Limited Trial Results on Students

Aspects	Score Average	Percentage	Category
Learning	3.31	82.75	Very good
Display	3.27	81.75	Very good
Programming	3.38	84.50	Very good
Average	3.32	83.00	Very good

The dissemination stage is carried out with seminar presentations in a scientific forum. The results of the developed electronic teaching materials are presented. This activity is included as diffusion in the dissemination stage.

The very good response from students to the teaching materials developed is in line with research by Arini et al. (2017), which states that the electronic book media developed with Flip PDF Professional software is practical because it is equipped with interactive assignments and quizzes, and combines interactive concepts by utilizing audio-visual elements based on mobile technology so the students showed a very good response with a percentage between 84.21% to 94.74%. In addition, the research of Sriwahyuni et al. (2019) found that students are enthusiastic about learning to use electronic teaching materials made with Flip PDF

Professional software because the teaching materials are presented interestingly and not just written monotone. Becker et al. (2020) states that the positive effect of video analysis on a topic has an impact on the effectiveness of the learning process and creates an innovative learning environment. Research by Sudarsana et al. (2021) states that using electronic modules operated with Flip PDF Professional software is relatively easy and practical.

Besides being supported by the use of Flip PDF Professional media, the feasibility of these teaching materials is also influenced by applying the guided inquiry learning model. Implementation of an e-module with a guided inquiry learning model, which has several learning stages, can support students' independent learning to support the ability of students to understand chemical material (Noer et al., 2021). Hwang et al. (2021) states that students' inquiry thinking in the learning process is trained with the ability to interpret graphs which at the same time hone students' understanding in applying formulas, so that students are able to draw conclusions correctly.

Student learning interest in applying guided inquiry learning shows very good criteria because the guided inquiry learning model has a good and productive learning environment. Moreover, students actively try to find, develop curiosity, and understand the material (Putra et al., 2016; Pratono et al., 2018). Guided inquiry creates an environment that motivates students to learn by providing opportunities for students to construct meaning and develop deep understanding. In guided inquiry, students learn to distinguish between reliable and unreliable sources and choose the most appropriate for the task at hand. The existence of collaboration in guided inquiry learning allows students to try ideas, ask questions, and clarify ideas to learn from each other (Kuhlthau et al., 2007). Through guided inquiry learning, students can develop the characteristics of responding to information slowly by thinking about solutions/alternatives to problems in depth and analytically (Margunayasa et al., 2019). In line with this, Aulia (2019) states that the positive response from students showed that students were enthusiastic about guided inquiry learning, which was given guidance in its implementation.

In this research, students responded very good to the use of the electronic teaching materials developed shows that guided inquiry learning is meaningful learning. Students are given the opportunity to build concepts with guidance from the teacher. Fadhilla et al. (2021) states that the stages of hypothesis formulation and data collection are able to build students' scientific attitudes. Students are trained in their ability to classify data such as selecting, comparing, looking for differences, and finding the basis for grouping. When students feel that guided inquiry learning is meaningful, students will be motivated to learn the concepts of the material presented. Dani et al. (2021) states that implementation of guided inquiry learning can increase student motivation from the aspects of attention, relevance, confidence, and satisfaction, also increases students' creativity in solving problems. Andriani et al. (2021) states that guided inquiry-based e-modules equipped with videos, images and quizzes, which can be operated using Android, can help students increase their learning independence when understanding concepts.

Guided inquiry learning with syntax characteristic can train students' reasoning abilities. Yulianti et al. (2020) states that systematic implementation of guided inquiry learning can improve learning outcomes and students' abilities in scientific reasoning. Students' reasoning abilities can increase because in guided inquiry learning there are activity characteristics that stimulate students to actively process thinking. Sumiyarti et al. (2019) states that through guided inquiry learning, students gain learning experiences ranging from find various facts, find knowledge, and train critical thinking skills effectively. This ability becomes honed after students go through a series of guided inquiry activities from the stages of formulating problems, formulating hypotheses, collecting data, generalizing and drawing conclusions. Liana et al. (2022) states e-modules that are adapted to the characteristics and syntax of guided inquiry can help students improve critical thinking skills during the learning process.

Besides being supported by the application of the guided inquiry model, the existence of multiple representations in the presentation of material can represent abstract concepts so that students understand concepts more easily. The results of this research are in line with research by Rasmawan (2020) who developed an e-book based on multiple representations on intermolecular forces using Flip PDF software which contains images, text and dynamic visualization. The e-book developed is suitable for use and makes it easier for students to study the chemistry material. Meutia et al. (2021) states learning that applies multiple representations can effectively build concept understanding and students respond very good. Understanding of concepts is supported by content such as pictures and learning videos that connect macroscopic, microscopic, and symbolic levels. Furthermore, Kimberlin et al. (2016) states that ideas and representations of the particle level are used for a more conceptual chemical treatment. Students are involved in inquiry-based activities with varying particle matter/substance representation. Symbolic equations and particle images are used as multiple representations of chemical reactions. The use of multiple representations of chemical concepts can reduce the occurrence of misconceptions.

Learning that presents multiple representation content has a positive impact on chemistry learning. In line with research by Sunyono et al. (2018) which shows that a learning process based on multiple representations increases students' mastery of concepts. Learning with multiple representations can stimulate students to be actively involved in solving chemical problems, especially interpreting macroscopic, microscopic and symbolic phenomena. Students are given the opportunity to expand their knowledge by searching for information from the internet or textbooks, observing demonstration or animation activities, studying microscopic visual images, and understanding concepts through reasoning, thereby encouraging students' mastery of concepts.

Collaborative learning environments and teaching materials play an important role in supporting students' reasoning against a framework of macroscopic, microscopic, and symbolic relationships. Teacher facilitation through class discussions to guide students towards a more precise understanding of the relationship of these representations is necessary (Becker et al., 2015). Li et al. (2015) state that students in inquiry classes are encouraged to increase their overall understanding of chemical concepts, students can learn to relate what is observed (macroscopic), explain the particle level (microscopic), and write chemical equations (symbolic). Research by Sanchez (2021) shows that the integrated use of three representations, namely macroscopic, microscopic and symbolic representation, can led to a high extent in the understanding of concepts in chemistry. Teaching is recommended to start at the macroscopic level and introduce symbols only after the microscopic level. Furthermore, Keiner et al. (2020) states that explicit communication is needed to explain how to meaningfully link the macroscopic and microscopic levels. Microscopic changes often cannot be observed, so teachers need to focus in order to communicate accurately to students.

Conclusion

The research and development results concluded that the developed multiple representation-based electronic teaching materials have characteristics using the guided inquiry syntax at the learning stage. There are also supporting features such as video and evaluation quiz in teaching materials. The chemistry teacher review results obtained an average assessment percentage of 86.75% and from the student responses obtained an average percentage 83.00%. In conclusion, the multiple representation-based electronic teaching materials using guided inquiry are feasible, in the very good category, and acceptable for high school students to utilize as a learning medium. In the future research, a study can be conducted on the effect of using multiple representation-based electronic teaching materials on students’ concept understanding and critical thinking skills.

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Authors Contribution
All authors had real contributions in writing this manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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