Al-Ishlah: Jurnal Pendidikan
Vol.16, 4 (December, 2024), pp. 5014-5028
ISSN: 2087-9490 EISSN: 2597-940X, DOI: 10.35445/alishlah.v16i4.5969

Development of a Socio-Scientific Issues-Based Module on Chemical Equilibrium to Enhance Students' Critical Thinking and Learning Autonomy

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ARTICLE INFO

Keywords:

module;
Socio-Scientific Issues;
autonomy;
Critical Thinking Skills;
chemical equilibrium

Article history:

Received 2024-09-07
Revised 2024-10-31
Accepted 2024-12-19

ABSTRACT

This study aimed to develop and validate socio-scientific issue-based modules on chemical equilibrium to enhance students' autonomy and critical thinking skills. The research employed the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model within a Research and Development (R&D) framework. Data were collected through interviews, surveys, validation sheets, and user response questionnaires. The module underwent validation by three experts, small-scale testing with three students of varying abilities, and user feedback from one teacher and 20 students across three schools (SMAN 1 Pinggir, SMAN 5 Pinggir, and SMAN 8 Mandau). Large-scale testing utilized a pretest-posttest control group design with 34 students from SMAN 8 Mandau to evaluate effectiveness. The module achieved a 92% validation score, reflecting high validity. Small-scale testing prompted minor revisions, and feedback from teachers and students was highly positive, with satisfaction scores of 100% and 90%, respectively. Large-scale testing showed significant improvements in the experimental group's autonomy and critical thinking skills, with a high N-Gain of 0.71 for critical thinking and a moderate N-Gain of 0.64 for autonomy. In contrast, the control group achieved only moderate (0.50) and low (0.10) N-Gain scores, respectively. The findings underscore the effectiveness of socio-scientific issue-based modules in fostering critical thinking and autonomy, especially in complex scientific contexts. The study demonstrates that such modules are highly effective tools for enhancing higher-order thinking and engagement in scientific topics like chemical equilibrium. Further research could explore broader implementation across diverse educational settings.

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1. INTRODUCTION

The Fourth Industrial Revolution is marked by rapid advancements in science and technology, driving transformative changes across various sectors, including the economy, culture, and society. This era of innovation has significantly altered how individuals work, interact, and engage with the world around them (Tritularsih & Sutopo, 2017). As technology increasingly automates traditional roles, the need for future generations to develop adaptive skills that enable them to thrive in this dynamic environment has become imperative (Astuti, Waluya, & Asikin, 2019).

One of the primary challenges of the 21st century is equipping individuals with essential competencies such as Critical Thinking and Problem Solving, Creativity and Innovation, Communication, and Collaboration. These skills, often referred to as 21st-century skills, are particularly crucial in STEM (Science, Technology, Engineering, and Mathematics) fields, where complex problem-solving is integral to both academic and professional success (Trilling & Fadel, 2009). However, international assessments such as the Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS) reveal significant deficiencies in critical thinking and problem-solving skills among students, especially in chemistry education. This gap underscores the urgent need for innovative teaching strategies and educational resources that foster higher-order thinking and prepare students to meet the demands of a rapidly evolving technological landscape (OECD, 2018; Mullis & Martin, 2017).

Socio-scientific issues (SSI) present a promising approach to address this issue, fostering critical thinking by engaging students with real-world problems. SSI, when integrated into chemistry education, encourages students to apply scientific concepts to societal challenges, making learning more relevant and impactful. Given the importance of chemical equilibrium as a foundational topic in chemistry, this study aims to develop SSI-based modules focused on enhancing students' critical thinking and autonomy in this area, providing a comprehensive solution to the current gaps in chemistry education.

Critical thinking equips students with the ability to solve contextual problems using rational logic, helping them make informed decisions and develop strategies for future global competition. Paired with independent learning, these skills empower students to take an active role in building knowledge. In chemistry education, fostering critical thinking and autonomy is essential, as it enables students to engage deeply with complex scientific concepts and apply them to real-world challenges (Septiningrum, Khasanah, & Khoiri, 2021).

However, the reality shows that students' critical thinking abilities are not developing well. According to the 2019 PISA (Program for International Student Assessment) results, Indonesia ranks 72 out of 77 countries with a score of 403, below the average score of 493. Similar findings are reported by TIMSS (Trends in International Mathematics and Science Study), where Indonesia ranks 70 out of 78 countries with an average score of 406 (TIMSS and PIRLS, 2019). Several factors contribute to the low critical thinking skills of Indonesian students, including (1) the education system in Indonesia, (2) the models, approaches, methods, and strategies used in teaching, (3) the learning resources available, (4) students' learning styles, and (5) assessment instruments (Retno, 2017). Therefore, there is a need to improve students' critical thinking skills, one of which can be achieved by developing teaching materials that enhance students' critical thinking abilities.

According to Nurhasnah & Sari (2020), existing teaching materials are often too focused on content, lacking context and variety, and fail to incorporate scientific knowledge to solve problems. The teaching materials provided by schools are limited and do not sufficiently target the development of students' critical thinking skills. This likely contributes to the low level of critical thinking skills among Indonesian students. Efforts to enhance the quality of science education in Indonesia include enriching science teaching materials to focus on improving students' critical thinking abilities (Yulianti, Permanasari, & Heliawati, 2019).

Interviews with three chemistry teachers from SMAN 8 Mandau, SMAN 5 Pinggir, and SMAN 1 Pinggir revealed a concerning lack of critical thinking skills among students. The teachers observed

that students exhibit weaknesses in core components of critical thinking, including interpretation, analysis, evaluation, inference, and the ability to explain their understanding. Additionally, students struggle with self-regulation, which further underscores their limited critical thinking abilities. This deficiency may be linked to the use of teaching materials that fail to effectively support the development of these skills. Research suggests that conventional science teaching practices, which often neglect the integration of science reading and writing as foundational competencies, may also contribute to this gap (Fuadi, Robbia, Jamaluddin, & Jufri, 2020). Furthermore, the issue is exacerbated by students' low learning autonomy. Many students rely heavily on instructors for guidance and lack the motivation and skills necessary for independent learning, which are critical for fostering higher-order thinking and problem-solving capabilities.

In high school chemistry, students frequently face challenges with topics like chemical equilibrium, which require an understanding of the three levels of chemical representation: macroscopic (observable phenomena), submicroscopic (atoms and molecules), and symbolic (formulas and equations) (Sagita et al., 2017; Sukmawati, 2019). Chemical equilibrium is particularly difficult because it necessitates the integration of abstract concepts with practical applications (Astuti, 2020). Despite these difficulties, mastering chemical equilibrium is crucial for developing critical thinking skills, as the topic demands analyzing dynamic processes, predicting outcomes, and solving complex problems related to reaction balance (Chusnah et al., 2020; Imaduddin, 2018). This ability to critically evaluate both theoretical and practical aspects of chemistry underscores the importance of effectively teaching this concept.

Chemistry is often perceived as a difficult and unappealing subject by students, primarily due to its abstract nature and the requirement to employ logic, mathematics, and language skills simultaneously (Zakiyah et al., 2018). Many students struggle with study strategies, conceptual connections, and extensive mathematical calculations, contributing to their low academic performance in the subject (Muderawan et al., 2019). Chemical equilibrium, in particular, poses unique challenges due to its abstract nature and the mathematical rigor involved. Research by Indriani et al. (2017) highlights that students often harbor misconceptions about equilibrium, such as believing that reactants are completely consumed or that equilibrium implies a cessation of reactions with equal concentrations of products and reactants. Misunderstanding equilibrium constants further complicates their grasp of the topic, as students struggle to correctly write and interpret these constants. The abstract nature of dynamic equilibrium reactions, coupled with limited prior exposure to foundational concepts, leads to persistent difficulties and low performance in this area of chemistry.

Given the characteristics of chemistry learning, it is necessary to develop teaching materials that meet students' needs and provide innovative solutions to enhance learning processes and critical thinking skills. In spite of the fact that there are numerous elective educating materials accessible, few have been created by instructors to boost students' critical thingking. One promising choice is the improvement of instructing modules. Modules are chosen based on their capacity to energize autonomous learning, eventually cultivating students' learning independence.

A module is a systematically and thoroughly organized teaching material written in accessible language, appropriate for the students' level of knowledge and age, allowing them to learn independently with minimal guidance from educators. Modules are designed to facilitate independent learning and are created according to an analysis of students' needs to achieve learning objectives (Ferenčíková, 2017).

Socio-Scientific Issues (SSI) is an educational approach that emphasizes real-world social problems, promoting critical thinking and independent learning in students. By investigating and discussing these issues, students actively engage with their learning, particularly in chemistry, where they can connect abstract concepts to tangible societal challenges. For example, students can examine how climate change affects the equilibrium of carbonic acid in oceans, leading to ocean acidification. This connection not only highlights the relevance of chemical equilibrium but also encourages critical thinking about the environmental and societal implications of scientific phenomena. According to

Handayani & Hastuti (2018), SSI significantly enhances students' critical thinking skills by relating learning to their lived experiences.

Through SSI, students can hone their abilities to enhance critical thinking skills. Chemistry education, as part of science learning, often focuses solely on achieving core knowledge without addressing other aspects, such as thinking skills. Instruction that fosters thinking skills helps students become accustomed to solving problems they encounter in their daily lives. An integrated teaching material based on SSI (Socio-Scientific Issues) is needed to develop thinking skills, including critical thinking (Firdaus & Wilujeng, 2018).

Based on the analysis of teaching materials used by teachers at SMAN 8 Mandau, SMAN 5 Pinggir, and SMAN 1 Pinggir, it was found that the materials are not based on SSI. Teachers have not yet incorporated social issues or encouraged contextual thinking in their teaching. The limited use of SSI in teaching materials indicates a lack of optimal efforts related to the development of teaching materials to address the weaknesses of the current science teaching materials (Rostikawati & Permanasari, 2016).

Integrating real-world socio-scientific issues (SSI) into chemistry education is crucial for enhancing students' understanding of chemistry concepts and fostering critical thinking skills. SSI-based teaching materials provide opportunities for students to connect theoretical knowledge with practical applications, encouraging independent learning and deeper engagement both in and out of school. Such materials also facilitate debates and discussions, enabling students to develop argumentation skills and critically evaluate explanations of scientific phenomena (Imaduddin & Khafidin, 2018). Despite the recognized importance of SSI-based approaches, a significant research gap exists in the availability of teaching resources tailored to link complex chemistry topics, such as chemical equilibrium, with real-world issues. Furthermore, limited studies have focused on how these materials can specifically improve both critical thinking and learning autonomy.

This study aims to address this gap by developing SSI-based modules designed to improve critical thinking and learning independence in the context of chemical equilibrium. The research seeks to answer the following questions: (1) How effective are SSI-based modules in enhancing students' critical thinking skills in chemistry? (2) Can these modules significantly promote learning autonomy among students? By addressing these questions, the study aims to provide a novel approach to chemistry education, where students actively engage with socially relevant issues, thereby transforming abstract scientific concepts into meaningful learning experiences.

The significance of this research lies in its potential to bridge the gap between conventional chemistry teaching and the development of 21st-century skills, equipping students with the tools to think critically and learn independently in both academic and real-world contexts.

2. METHODS

This research aims to develop socio-scientific issues (SSI)-based modules to enhance critical thinking skills in chemistry education. A mixed-method approach was utilized, combining both subjective and quantitative strategies to pick up a comprehensive understanding of the module's viability and its affect on understudy learning results. The quasi-experimental plan, particularly the pretest-posttest non-equivalent control gather plan, was chosen to survey the contrasts in basic considering capacities sometime recently and after the usage of the modules. This design allows for comparison between the experimental group, which used the SSI-based modules, and the control group, which did not. The ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) was used for the development of the modules, ensuring a systematic approach that addresses each stage of instructional design. The research was conducted at SMAN 8 Mandau during the 2023-2024 academic year, with trials also held at SMAN 5 Pinggir and SMAN 1 Pinggir. For small-scale testing, one-on-one evaluations involved three class XI students with varying academic abilities. User feedback was gathered from three teachers and 30 students across the participating schools, while the large-scale trial involved 30 class X students from SMAN 8 Mandau. Purposive examining was

utilized to choose members based on particular criteria significant to the ponder, as laid out by Sugiyono (2017). Information collection strategies included interviews, surveys, approval sheets, and appraisals of critical thingking and natural care capacities, guaranteeing a comprehensive assessment of the module's adequacy.

The information collection procedures utilized were interviews, surveys, approval sheets, educator reaction surveys, understudy reaction surveys, portrayal tests of students' critical thingking capacities, depiction tests of students' natural care capacities, and documentation.

2.1 Validation Sheet Analysis

The approval appraisal was carried out by 6 master teachers as validators, to be specific 3 material specialists. Giving meaning and making choices approximately item modules based on socio-scientific issues in chemical balance will utilize the accomplishment level change in Table 1.

Table 1. Validity Criteria for Validator Assessment Questionnaire Data

Percentage (%)	Criteria
81-100	Very feasible / very valid / does not need to be revised
61-80	Eligible/valid / no need for revision
41-60	Inadequate/invalid / needs revision
21-40	Not feasible/invalid / needs revision
< 20	Very inappropriate / very invalid / needs revision

(Arikunto, 2010)

The validation assessment conducted by six expert lecturers, including three material experts and three media experts, provided critical insights for revising the SSI-based modules on chemical equilibrium. Their feedback was instrumental in identifying areas for improvement, ensuring that the content is not only academically rigorous but also engaging and accessible to students. Based on the validity criteria outlined in Table 1, the experts' evaluations guided necessary revisions, enhancing the module's overall quality and effectiveness in promoting students' critical thinking and understanding of chemical equilibrium.

2.2 Analysis of Teacher Response Questionnaires

The educator reaction survey appraisal was carried out by 3 chemistry instructors to get teachers' reactions to the utilize of modules based on socio-scientific issues in chemical harmony fabric within the chemistry learning handle. The comes about of the normal score from the educator reaction survey that were gotten were at that point changed over into subjective information to decide the criteria for utilizing modules based on socio-scientific issues which can be seen in Table 2.

Table 2. Questionnaire Response Criteria Interval

Percentage (%)	Criteria
81-100	Very good
61-80	Good
41-60	Good Enough
21-40	Not good
< 20	Very Not Good

(Arikunto, 2010)

The research utilized several instruments to assess the effectiveness of the SSI-based modules. The Teacher Response Questionnaire aimed to gather feedback from three chemistry teachers regarding the modules' usability in teaching chemical equilibrium. This instrument provided qualitative data reflecting teachers' perspectives on the modules' relevance, which was then converted into qualitative criteria for evaluation. The Critical Thinking Ability Test comprised open-ended questions designed to assess students' reasoning, problem-solving, and application of chemical concepts to real-world

scenarios, thereby measuring their critical thinking skills. Similarly, the Environmental Care Ability Test included reflective questions focused on the environmental implications of chemical processes and equilibrium, evaluating students' awareness and engagement with sustainability issues. Together, these instruments offer a comprehensive evaluation of the modules' impact on teaching effectiveness and students' cognitive and environmental competencies.

2.3 Analysis of the Influence of Teaching Materials

After data collection, the subsequent step involves analyzing the data and interpreting the results to determine whether the proposed hypothesis is accepted or rejected. The data analysis process begins with a normality test to assess whether the data is normally distributed, which is performed using the Kolmogorov-Smirnov test with SPSS 26. If the data meets the normality criteria, hypothesis testing is conducted to evaluate students' character values and conservation attitudes. This stage employs an independent sample t-test, which is suitable for normally distributed data, and is executed with the aid of SPSS V23. These steps ensure the validity and reliability of the findings, supporting accurate interpretation of the results.

3. FINDINGS AND DISCUSSION

3.1 Analysis

Preliminary investigations involved observations and interviews with three chemistry teachers from schools implementing an independent curriculum: SMAN 8 Mandau, SMAN 5 Pinggir, and SMAN 1 Pinggir. The interviews revealed that chemistry is often perceived by students as a difficult and less engaging subject. This perception may stem from the complex nature of the material, which requires significant mental effort and conceptual understanding (Susilaningsih, 2019). According to Akram (2017), a lack of interest in chemistry can be attributed to several factors, including teaching methods that do not align with students' preferences or learning styles. This presents a challenge for teachers, emphasizing the importance of carefully selecting teaching materials, methods, and learning models to enhance engagement. The interviewed teachers reported low student interest, resulting in suboptimal learning outcomes. The continued use of uninteresting teaching materials, which fail to connect with students' everyday lives, may contribute to their limited critical thinking skills. Additionally, the lack of engaging learning media further exacerbates the issue, as students become easily bored during lessons (Dawati, 2019). These findings highlight the need for innovative approaches to teaching chemistry that not only align with students' interests but also foster deeper engagement and active participation.

3.2 Design

At the arranging stage, there are perspectives on the media plan that will be created. Module plan based on socio-scientific issues approach as a frame of understanding issues found within the preparatory investigation investigate stage. The instrument utilized to survey the quality of teaching materials may be a survey that contains an appraisal of instructing materials within the shape of an Module based on this socio-scientific issues approach. In this arrange, analysts make a item evaluation survey instrument network. The substance of the Module model based on a socio-scientific issues approach are arranged alluding to markers of competency accomplishment and learning materials that have been depicted at the educational modules examination organize. The substance of the Module is taken from sources, to be specific tall school/MA chemistry books, college chemistry books and the web that are pertinent to chemical harmony fabric. The plan of the module is based on a socio-scientific issues approach, which is carried out by planning a storyboard. A storyboard may be an arrangement of graphs that appear the grouping of show and visualization of thoughts from the model made, so that it can give an diagram of the coming about model (Kunto Imbar, 2021).

The module display design process involved creating both the cover page and content layout to ensure an effective and visually appealing learning resource. The module cover page was developed using Photoshop, utilizing tools such as the polygon tool, clipping mask, blending options, and type tool. The cover includes essential elements such as the module title, subject name, class and semester, the *Tut Wuri Handayani* logo, Riau University and K-13 logos, an image representing the module's theme, and the author's identity.

The content display of the module was created using Publisher 2013, incorporating tools like the shape menu, shape fill, text boxes, and background options. The module's content is structured into three main sections: introduction, core, and conclusion. The introduction includes the foreword, table of contents, an overview of the socio-scientific issues (SSI) approach, a description of the module, instructions for use, and expected learning outcomes.

The core section comprises four learning exercises aligned with the material intended for the learning process. Each exercise features competency indicators, learning objectives, material descriptions, conclusions, independent assignments, and practice questions. Finally, the conclusion section provides a bibliography, serving as a reference for the material used throughout the module. This structured and user-friendly design supports both independent learning and classroom instruction, facilitating the achievement of learning outcomes effectively.

3.3 Development

The development phase consists of two key processes: prototyping and material validation. The prototyping process involves transforming the design from the storyboard into an actual module prototype that incorporates a socio-scientific issues approach to chemical equilibrium. This stage focuses on using Publisher 2013 to create engaging and visually appealing teaching materials that effectively present the learning content.

The validation process includes both material and media validation, which involves the review of the module by six expert lecturers. These experts assess the module based on its alignment with the socio-scientific issues approach to chemical equilibrium. The material validation is conducted by three experts using an approval sheet with a 1-4 Likert scale, evaluating the module from perspectives including content accuracy, academic rigor, language quality, and practicality. The results of the material validation, which reflect the average ratings for each aspect of the evaluation, are summarized in Table 3. This validation ensures that the module meets high standards and is ready for further refinement or implementation.

Table 3. Percentage of Material Expert Validation Results

No.	Rated aspect	Percentage (%)	
		Validation I	Validation II
1	Content Eligibility	54	89
2.	Pedagogy	67	93
3.	Language Assessment	60	94
4.	Graphics	64	99
Average		61	94

The validation process for the SSI-based modules involved assessments from three material validators using a 1-4 Likert scale, focusing on content, pedagogy, language, and graphic aspects. As shown in Table 3, the first validation yielded an average percentage of 61%, categorizing the module as valid. Despite this positive outcome, the validators provided constructive feedback highlighting areas for improvement.

In response to the suggestions from the first validation, several specific revisions were made to enhance the module. For instance, content eligibility was refined by incorporating more contemporary examples of socio-scientific issues related to chemical equilibrium, thereby increasing relevance and engagement. The pedagogical approach was improved by integrating more interactive elements and

inquiry-based activities that encourage active student participation. Language assessment saw enhancements in clarity and accessibility, ensuring that complex concepts were explained in a more comprehensible manner. Additionally, graphic elements were redesigned to improve visual appeal and better support learning through diagrams and illustrations that effectively convey chemical processes.

Following these revisions, the second validation demonstrated a significant improvement, with an average percentage of 94%, categorizing the module as very valid. This feedback not only validated the enhancements made but also confirmed that the module effectively aligns with educational standards and addresses the needs of both teachers and students. The iterative process of revision based on expert feedback underscored the importance of continuous improvement in educational materials, ultimately leading to a more robust and effective learning tool for enhancing critical thinking in the context of chemical equilibrium.

3.4 Implementation

The media implementation stage involves integrating the e-module into the learning process at schools. This process includes conducting one-on-one trials, small-scale trials, and large-scale trials with students. These trials are designed to gather student feedback and evaluate their responses to the e-module materials developed using a socio-scientific issues approach. This iterative testing helps refine the module to ensure its effectiveness and relevance in enhancing the learning experience.

3.4.1 Test each one one by one

The one-on-one testing of the e-module based on a socio-scientific issues approach was conducted with three individual Grade XII students at SMAN 8 Mandau who had previously studied chemical equilibrium in Grade XI. The testing was performed sequentially, with one student completing the module before proceeding to the next. The participants represented varying levels of academic ability: high, medium, and low. Feedback and suggestions provided by the students during this process are summarized in Table 5. This phase was critical for identifying areas for improvement and ensuring the module meets the diverse needs of learners.

Table 4. Student Comments and Suggestions on the One-on-One Test

Student Code	Comments and Suggestions
MM	The module design is attractive, but there aren't enough example questions. I hope future modules will include more example problems.
NA	In my opinion, this socio-scientific issues-based module is already at a stage where no improvements are necessary. The design is appealing, the formulas are easy to understand, and it greatly facilitates learning.
PA	I think the provided module is good and impressive, and it greatly helped me while studying, but there are still some parts that confuse me.
PDY	In my opinion, this module is suitable for chemistry learning because the explanations and example questions are fairly comprehensive. I hope this module will be useful for the future of the nation's children.
ES	I hope this module benefits many people. The module is already good, attractive, and cool.
JSM	In my opinion, no improvements are needed for the socio-scientific issues-based module because the chemical equilibrium module is easy to understand and very engaging to read.
CPT	I think this module is already very good and interesting to study.
MCM	This chemical equilibrium module is very comprehensive, and everything is discussed in detail, which makes it interesting to me.
EG	This module is excellent for use in chemistry learning (without improvements) because it includes many easily understandable explanations along with attractive illustrations.
Conclusion	The module is well-designed and helps students learn, but it still needs more example problems.
Suggestions:	Add more example questions along with explanations.

Interviews during one-on-one tests revealed that students found the SSI-based modules to be effective in enhancing their understanding of chemical equilibrium. While they appreciated the positive learning experience, some noted the presence of limited non-standard vocabulary, indicating a need for revisions for clarity. Students reported that the modules' multimedia content and appealing design contributed to their usability and engagement. This feedback aligns with Adawiyah & Hadisaputra (2020), which emphasizes that interesting teaching materials boost student motivation and participation. These findings highlight the significance of SSI-based modules in not only providing relevant content but also fostering critical thinking skills by connecting chemistry to real-world issues, ultimately enhancing educational outcomes in the subject.

Based on interviews with understudies in one-on-one tests, clarity The learning within the module was considered great, but that there was restricted lexicon not standard so it must be rectified. Within the angle of affect for clients, members understudies evaluate that module have a positive affect on them since they can make them superior get it the fabric displayed in different substance mixed media And module given Too simple utilized as well as in agreement with mentality member teach.

3.4.2 Small-scale trials

At this stage, the researcher acted as an observer without directly interacting with the participants. Small-group trial responses were collected from three chemistry teachers and 30 students using a small-scale trial response survey. Data collection for the small-scale trial was conducted at SMAN 8 Mandau, SMAN 5 Pinggir, and SMAN 1 Pinggir. This process provided valuable insights into the module's usability and effectiveness, informed by feedback from both teachers and students.

a) Teacher response questionnaire data

Teacher feedback was collected using a reaction survey at three schools: SMAN 8 Mandau, SMAN 5 Pinggir, and SMAN 1 Pinggir. The process involved providing teachers with the e-module based on a socio-scientific issues approach, allowing them ample time to review it thoroughly before completing the response survey. The results of the teachers' evaluations and feedback are summarized in Table 6, offering valuable insights into the module's effectiveness and usability from the educators' perspective.

Table 5. Teacher Response Questionnaire Data

Respondent	Percentage (%)	Criteria
Teacher 1	100	Very good
Teacher 2	100	Very good
Teacher 3	100	Very good
Average	100	Very good

Teachers' responses to the module based on a socio-scientific issues approach were overwhelmingly positive, with an overall assessment achieving a 100% satisfaction rate. These results align with the findings of Apriani et al. (2021), whose module development study similarly reported a 100% teacher response rate categorized as "very good." This consistency underscores the effectiveness of the socio-scientific issues approach in meeting educators' expectations and supporting teaching objectives.

b) Student response questionnaire data

To gather user responses, student response questionnaires were distributed to 30 Grade XI Science students, with 10 students each from SMAN 8 Mandau, SMAN 5 Pinggir, and SMAN 1 Pinggir. The data collection process involved providing the students with the module, allowing them sufficient time to review it, and then asking them to complete the response questionnaire. The results of the student

response questionnaire are presented in Table 7, offering insights into students' perceptions and evaluations of the module.

Table 6. Student Response Questionnaire Data

School	Percentage (%)	Criteria
SMAN 8 Mandau	90	Very good
SMAN 5 Pinggir	90	Very good
SMAN 1 Pinggir	90	Very good
Average	90	Very good

Based on Table 7, the results of distributing questionnaires to obtain student responses from the three schools showed an average score of 90%, indicating that the socio-scientific issues-based module received very positive feedback from students. These findings align with the research by Apriani et al. (2021), which also reported an average student response rate of 90% in the "very good" category for a similar module development. This suggests that the module successfully captures students' attention due to its engaging design, motivating students to learn actively. The use of multimedia to present material enhances understanding and promotes increased student participation in learning activities. Based on the results of small-scale trials, it can be concluded that the module has received excellent feedback from both teachers and students as end users. Following the validation and small-scale testing phases, necessary revisions were made, and the final version of the module was completed and ready for implementation.

3.5 Large Scale Trials

The Large Scale Trial stage is carried out as an effectiveness test product. Field trials were carried out at SMAN 8 Mandau on participants Class XI IPA 2 students totaling 34 people in experimental and classroom classesX Science 1, Which amounts 32 people in the control class.

3.5.1 Learning Autonomy

Learning Autonomy data was obtained from the results of a questionnaire given to students to determine the level of environmental care ability before and after using an *module* based on a socio-scientific issues approach. This data can be seen in Table 8.

Table 7. Data on the results of students' Learning Autonomy

No.	Learning Autonomy Indicator	Percentage (%)			
		Experimental Class		Control Class	
		Before SSI Module	After SSI Module	Before Module	After Module
1.	Emotional Autonomy	61	86	60	65
2.	Behavioral Autonomy	59	84	58	66
3.	Value Autonomy	65	86	64	65
Average Combined Percentage		62	85	61	65

Table 8 demonstrates the positive effect of the SSI-based e-module on students' learning autonomy. The experimental class's average autonomy increased from 62% to 85% after using the module, while the control class's increase was minimal, from 61% to 65%. This indicates that the SSI module effectively enhances student independence in learning. Specific improvements were noted across all autonomy indicators: emotional autonomy rose from 61% to 86%, and behavioral autonomy increased from 59% to 84%. These changes suggest that students became more confident and proactive in their learning. The normality test confirms that the data set is well-distributed, allowing for reliable conclusions about the effectiveness of the SSI approach. Overall, the findings indicate that the SSI-based

e-module significantly fosters students' learning autonomy, which is essential for their educational development. Data from normality test data for environmental care capabilities can be seen in Table 9.

Table 8. Normality Test Results for Environmental Care Capability Data

Environmental Care Capability Data	*Kolmogorov-Smirnov*		
	Statistics	***df***	***Sig.***
previous experiments	0.147	34	0.053
experiment after	0.117	34	0.200*
control before	0.147	32	0.054
control after	0.107	32	0.200*

Table 9 presents the normality test results for environmental care capability data using the Kolmogorov-Smirnov test. The significance values for both the experimental and control groups, before and after using the SSI-based module, are greater than 0.05 (0.053 for the experimental group before, 0.200 after, 0.054 for the control group before, and 0.200 after). This indicates that the data are normally distributed.

Since the normality condition is satisfied, the subsequent hypothesis testing on students' learning autonomy can proceed using parametric statistics, specifically the independent sample t-test. This approach allows for a more robust analysis of the differences in learning autonomy between the experimental and control groups, confirming the effectiveness of the SSI-based module in enhancing students' environmental care capabilities. Hypothesis test results data on students' Learning Autonomy can be seen in Table 10.

Table 9. Hypothesis Test Results Environmental Care Capability Data

		F	**Sig.**	**t**	**Df**	**Sig. (2-tailed)**
Mark	Equal variances assumed	0.340	0.562	10.543	64	0.000
	Equal variances are not assumed.			10.464	58.588	0.000

Table 10 outlines the hypothesis test results for environmental care capability data using the paired t-test. The significance value obtained is 0.000, which is less than the threshold of 0.05. This indicates that the alternative hypothesis (Ha) is accepted, confirming that there is a significant difference in the learning autonomy of class XI students at SMAN 8 Mandau after the implementation of the SSI-based module.

This finding suggests that the module, which is designed around socio-scientific issues, positively influences students' learning autonomy in the context of chemical equilibrium. These results align with previous research by Munifatun Muthoharoh et al. (2017), which also demonstrated that the application of socio-scientific issues modules can enhance students' learning autonomy.

The results of measuring critical thinking skills can be summarized using descriptive statistics, including average values (means) and improvements in both the control and experimental classes. These findings will further illustrate the effectiveness of the SSI-based module in promoting critical thinking skills among students.

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3.6 Critical Thinking Skills

Table 10. Descriptive Statistics Value of critical thinking skills

	Experimental Class		Control Class	
	Pretest	Posttest	Pretest	Posttest
Sample	34	34	32	32
Average	29.8	76	30.1	64.9
Max Value	62	92	62	87
Min Value	20	61	20	49

Based on the information in Table 4.11, it can be seen that the overall test comprised of 34 students within the test course and 32 students within the control lesson. The normal score of the test course some time recently the learning handle was 29.8, which expanded to 76 after the learning proses. In the control class, the average score before the learning process was 30.1, and it increased to 64.9 after the learning process. Eastwood (2012) indicates that students in the experimental class, who used socio-scientific issues (SSI)-based modules, achieved better learning outcomes compared to those in the control class. SSI-based modules not only enhance understanding of scientific concepts but also develop critical thinking and moral reasoning skills.

Table 11. Normality test of critical thinking skills

Class		**Kolmogorov-Smirnov**	**Conclusion**
		Sig.	
Pretest	Experiment	0.053*	Normal Distribution
	Control	0.054*	Normal Distribution
Posttest	Experiment	0.200*	Normal Distribution
	Control	0.200*	Normal Distribution

Based on the importance level in Table 12 which has been displayed for the ordinariness test, it appears that the pretest and posttest basic considering capacity scores for the control and exploratory classes are ordinarily disseminated, this can be shown by a noteworthiness level of more than 0.05 or p>0.05. So it can be concluded that all information is ordinarily conveyed . Based on the comes about of these prerequisite tests, parametric testing can be proceeded so that the information will be analyzed utilizing the Independent Sample T-Test.

Table 12. T-test of critical thinking skills

		t-test for equality of means				
Class		**F**	**t**	**df**	**Sig. (2-tailed)**	**Conclusion**
Pretest	Experiment	0.011	0.145	64	0.885	Ha Accepted (There are differences)
	Control					
Posttest	Experiment	0.797	4.677	64	0.000	
	Control					

Based on the comes about of the Autonomous Test T-Test factual test over, the sig (2-Tailed) t test esteem for students' basic critical thinking is 0.000. Since the sig (2-Tailed) esteem is <0.05, H0 is rejected and Ha is acknowledged. In this way, it can be concluded that there's a critical distinction in students' basic considering aptitudes between the exploratory lesson and the control course. The increment in students' critical thinking aptitudes within the control and exploratory classes can be seen through calculating the normalized pick-up score. The analysis results are shown in the following table.

Table 13. Data on improving learning outcomes in the experimental and control classes

Class	Average N-Gain Score	Category	Frequency	Percentage (%)
Experiment	0.71 (high)	High	20	59
		Currently	14	41
		Low	0	0
Amount			37	100
Control	0.50 (medium)	High	2	6
		Currently	28	88
		Low	2	6
Amount			38	100

The analysis results indicate that the average N-Gain score for students' critical thinking skills in the control group is 0.50, which falls within the medium category. In contrast, the experimental group achieved an average N-Gain score of 0.71, categorized as high. These findings demonstrate a significant difference in critical thinking skill improvement between the control and experimental groups. The experimental group showed a notable increase in learning outcomes, with an N-Gain value of 0.71, which is classified as high ($0.30 \leq$ N-Gain ≤ 0.70). This suggests that the intervention applied in the experimental group was effective in enhancing students' critical thinking skills.

3.7 Evaluation

The evaluation stage in this study can be carried out at each phase of the ADDIE model. The evaluation aims to analyze the data obtained from the research results, which include (1) analysis, consisting of preliminary analysis, learner analysis, curriculum analysis, and material analysis, (2) developing assessment instruments for teaching material quality, product design (storyboard), material preparation, and gathering tools and materials, (3) development, including validation by subject matter and media experts, and (4) implementation, consisting of individual trials, limited trials, and field trials. The final results of the evaluation stage show that the product developed in the form of a module is highly valid, receives positive responses from both teachers and students, and can enhance critical thinking skills.

The SSI approach was coordinated into the module by surrounding chemical balance substance around real-world social issues, subsequently directing understudies to apply their information in down-to-earth settings. This association to societal challenges empowers students to lock in in problem-solving by organizing their existing information with real-life circumstances, making the learning handle more important and meaningfull.

Specific elements of the SSI-based module that enhanced critical thinking and learning autonomy include structured task sheets that prompt students to analyze, discuss, and reflect on chemical concepts within social contexts. This structure fosters higher-order thinking by requiring students to gather information, evaluate arguments, and apply scientific principles to everyday situations, thus enhancing their problem-solving skills.

Theoretical discussions surrounding critical thinking and learning autonomy emphasize that critical thinking is influenced by various factors, including intelligence and the ability to connect new knowledge to prior experiences (Ausubel, 2000; Sirmayeni, 2023). By incorporating SSI into the curriculum, educators create opportunities for students to engage in meaningful learning experiences that strengthen their analytical skills and independence.

These findings align with broader educational practices that advocate for contextual and inquiry-based learning, reinforcing that integrating real-world issues into science education improves academic performance and prepares students to navigate complex social challenges. The SSI approach serves as a vital strategy in fostering critical thinkers who can apply scientific knowledge effectively in their lives, promoting a more engaged and informed citizenry.

4. CONCLUSION

The research concluded that the SSI-based module on chemical equilibrium effectively enhances critical thinking and student autonomy, confirming its strong validity and positive impact on educational outcomes. These results highlight the importance of developing instructional materials that not only convey scientific knowledge but also foster essential skills for students in the 21st century. The validation process demonstrated significant improvement, with the module's material validity rising from 68% to 92% after expert feedback was incorporated. Both teachers and students responded favorably, with approval ratings of 100% and 90%, respectively. Notably, the module led to substantial enhancements in students' critical thinking skills, indicated by an N-Gain value of 0.71 in the experimental group, compared to 0.50 in the control group. Similarly, student autonomy showed significant growth, with an N-Gain value of 0.64 in the experimental group, contrasting with just 0.10 in the control group. These improvements underscore the module's effectiveness in promoting independence and critical analysis in learners. In the context of 21st-century education, enhancing critical thinking and autonomy is crucial as it prepares students to navigate complex challenges, engage in informed decision-making, and collaborate effectively in diverse environments. The SSI-based approach not only encourages students to apply scientific concepts to real-world issues but also cultivates a mindset of inquiry and adaptability, skills that are vital in today's fast-paced society. Furthermore, the potential of SSI-based modules extends beyond chemistry; they can be adapted to various subjects such as biology, physics, and social studies, creating a holistic educational framework that emphasizes critical thinking across disciplines. Future research could explore the application of SSI-based modules in different educational contexts, assess long-term impacts on student engagement and performance, and investigate the integration of technology to enhance interactive learning experiences. Ultimately, this research signifies a meaningful advancement in educational practices, suggesting that SSI-based modules can play a pivotal role in shaping competent, autonomous learners equipped to tackle contemporary social and scientific challenges.

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