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Development of SSI-Based Learning Module to Enhance Students' Critical Thinking on Global Warming

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Abstract: Development of Socio Scientific Issues Based Learning Modules to Train Students' Critical Thinking Skills in Global Warming for 10th Grade Senior High School/MA. This study aims to test the validity and practicality of socio-scientific issues-based learning modules to train students' critical thinking skills in global warming. The method used in this study was Research and Development (R&D) using the 4-D development model. The test subjects were 35 students in class X.E1 at SMA Negeri 2 Batusangkar. The data analysis technique was a validity and practicality test of expert validation sheets and respondent questionnaires, as well as a three-tier critical thinking test. The results showed that the validity of the material in the learning module based on socio-scientific issues was 88%, construct validation was 100%, and language validation was 95%. The results of the practicality test from teacher and student questionnaires were 86% and 93%, respectively. The level of students' critical thinking improved from 55% (fair) to 86% (very good). Based on the results of the study, it can be concluded that the socio-scientific issues-based learning module to train students' critical thinking skills in global warming is very valid and very practical to use.

Keywords: learning modules, socio scientific issues, critical thinking, global warming.

Abstrak: Pengembangan Modul Pembelajaran Berbasis Socio-Scientific Issues untuk Melatih Kemampuan Berpikir Kritis Peserta Didik pada Materi Pemanasan Global Kelas X SMA/MA. *Penelitian ini bertujuan untuk menguji validitas dan praktikalitas modul pembelajaran berbasis Socio-Scientific Issues (SSI) untuk melatih kemampuan berpikir kritis peserta didik pada materi pemanasan global. Metode penelitian yang digunakan adalah Research and Development (R&D) dengan model pengembangan 4-D. Subjek penelitian adalah 35 siswa kelas X.E1 SMA Negeri 2 Batusangkar. Teknik analisis data berupa uji validitas dan praktikalitas melalui lembar validasi ahli dan angket responden, serta tes berpikir kritis berbasis three-tier test. Hasil penelitian menunjukkan bahwa validitas materi pada modul pembelajaran berbasis SSI sebesar 88%, validitas konstruk 100%, dan validitas bahasa 95%. Hasil uji praktikalitas dari angket guru sebesar 86% dan dari angket siswa sebesar 93%. Tingkat kemampuan berpikir kritis siswa meningkat dari 55% (kategori cukup) menjadi 86% (kategori sangat baik). Berdasarkan hasil penelitian dapat disimpulkan bahwa modul pembelajaran berbasis Socio-Scientific Issues untuk melatih kemampuan berpikir kritis peserta didik pada materi pemanasan global sangat valid dan sangat praktis untuk digunakan.*

Kata kunci: *modul pembelajaran, socio scientific issues, berpikir kritis, pemanasan global.*

▪ INTRODUCTION

21st century education emphasizes the mastery of 4C skills: critical thinking, creativity, communication, and collaboration. Among these, critical thinking plays a central role in enabling students to analyze information, evaluate evidence, and make reasoned decisions (Facione, 2015). However, chemistry learning in Indonesian high schools is often dominated by lectures and rote memorization, making it difficult for students to connect abstract concepts with real-life contexts (Setyawan & Kristanti, 2021).

Preliminary observations at SMA Negeri 2 Batusangkar revealed that students' motivation was low and their analytical skills were underdeveloped. A diagnostic test of 35 students showed an average score of 55% (fair category), with weaknesses in analysis (19%) and strengths in explanation (81%). This condition indicates the need for innovative teaching materials that can foster critical thinking. Similar findings were reported by Carolina et al. (2024), who emphasized that conventional modules fail to integrate socio-scientific contexts and thus do not optimally train students' higher-order thinking skills.

The socio-scientific issues (SSI) approach integrates scientific concepts with social dilemmas, such as global warming, pollution, and climate change. SSI-based learning emphasizes contextual and multidimensional aspects of science, encouraging students to analyze authentic problems and make decisions based on scientific evidence (Zeidler et al., 2005; Sofiana & Wibowo, 2019). Previous studies have shown that SSI-based modules are effective in enhancing higher-order thinking skills and student engagement (Azizah et al., 2022; Jannah & Herman, 2025). However, most research has focused on biology or general science, while SSI-based chemistry modules specifically designed to train critical thinking remain limited.

Therefore, this study aims to develop and test the validity and practicality of an SSI-based learning module on global warming for 10th grade chemistry students. The novelty of this research lies in its integration of chemistry concepts with socio-scientific issues to explicitly train critical thinking skills, addressing the gap between abstract chemistry learning and real-world contexts. The usefulness of this study is to provide teachers with alternative teaching materials that are valid, practical, and effective in fostering students' critical thinking skills in line with the demands of 21st century education.

▪ METHOD

The research conducted in this study is development research or Research and Development (R&D) using Thiagarajan's 4-D development model, which consists of four stages: define, design, develop, and disseminate (Thiagarajan et al., 1974). The validation stage involved three expert validators, consisting of a material expert, a construct/design expert, and a language expert. Each validator evaluated the module based on their respective expertise. The validation instruments used a 4-point Likert scale, ranging from 1 (very inappropriate) to 4 (very appropriate), to obtain clear and decisive assessments. The data were then analyzed using Aiken's V to determine the level of validity.

Define Stage

This stage is the initial stage in determining the fundamental problems that exist in the field through several analyses, namely front-end analysis, learner analysis, literature analysis, and learning objective analysis. A preliminary analysis was conducted to obtain information about the conditions of chemistry learning in schools and student needs, which included interviews with chemistry teachers to identify problems in students' critical thinking skills, analysis of student characteristics such as initial ability, learning style, and social background, and identification of relevant Learning Outcomes and Learning Objectives in training critical thinking skills. Literature analysis was also carried out to determine the appropriate format and structure of the module, while learning objective analysis ensured alignment with curriculum indicators.

Design Stage

During the design stage, the researcher developed a preliminary design for the product through several systematic steps. These included preparing a general framework of the module, creating a flowchart to map the learning sequence, and developing a storyboard with detailed visual and narrative elements. Supporting materials such as illustrations, case studies, and socio-scientific issues relevant to global warming were collected to strengthen the module content. Editing and finishing were then conducted to integrate SSI elements effectively, ensuring that the module was attractive, coherent, and able to stimulate students' critical thinking. At this stage, the researcher also designed research instruments, including validation sheets, practicality questionnaires, and critical thinking test items.

Develop Stage

This stage consisted of researchers' actions to create the final product in the form of an SSI-based learning module to train students' critical thinking skills in global warming material for grade X senior high school/MA. There were two stages carried out, namely validation and practicality. The validity stage was conducted by experts in chemistry content, graphics/design, and language to ensure that the developed product was accurate and of high quality. Critical thinking test items were also validated to confirm their relevance to the indicators of critical thinking skills. The practicality stage was carried out with teachers and students to evaluate ease of use, efficiency, and benefits of the module in supporting SSI-based chemistry learning.

The validity analysis was conducted using Aiken's V formula to determine the level of agreement among validators:

$$V = \frac{\sum s}{n(c-1)}$$

Where, $s = r - l_o$ (score given minus the lowest score on the scale), r = score given by the validator, l_o= lowest score on the scale (e.g., 1), c = number of categories on the scale (e.g., 4), and n = number of validators.

The value of V ranges from 0–1, with values closer to 1 indicating higher validity. The interpretation categories are:

Table 1. Validity Interpretation (Aiken's V)

Interval (%)	Category
81-100	Very valid
61-80	Valid

41-60	Fairly valid
21-40	Less valid
0-20	Not valid

(Purwita & Zuhdi, 2023)

The practicality analysis was conducted by calculating the percentage score using the following formula:

$$Persentase\ score = \frac{\sum Respondents'\ Answers}{\sum Total\ Score}\ x\ 100\%$$

The percentage results were then categorized into practicality levels:

Table 2. Practicality Interpretation

Interval (%)	Category
81-100	Very practical
61-80	Practical
41-60	Fairly practical
21-40	Less practical
0-20	Not practical

(Purwita & Zuhdi, 2023)

Disseminate Stage

At this stage, the researcher limited the distribution of the product to teachers and students at the school where the research was conducted, namely one of the grade X classes at SMAN 2 Batusangkar. The limited dissemination was carried out due to time and cost constraints, so the module was only tested on a small scale before being distributed more widely.

▪ RESULT AND DISCUSSION

This study concludes that the SSI-based learning module on global warming is valid and practical to use in chemistry learning. The results also indicate that the module has the potential to support students' critical thinking skills, although further research with experimental design is needed to examine its effectiveness.

Define Stage

The define stage was conducted to identify the fundamental problems in chemistry learning, especially in the topic of global warming. At this stage, the researcher carried out a front-end analysis to map the real conditions of learning in schools. Interviews with teachers revealed that learning was still dominated by lectures, exercises, and limited use of textbooks without contextual integration of socio-scientific issues. Teachers admitted that while the Merdeka Curriculum had been implemented, the teaching materials used were still conventional and lacked integration with 21st-century competencies. This situation illustrates that although curriculum reform has been introduced, the actual practice in classrooms still tends to be traditional, focusing more on content delivery rather than competency development. The absence of socio-scientific integration means that students are not trained to connect chemistry concepts with real-world problems, which weakens their ability to think critically and creatively.

Students expressed low motivation and difficulty in understanding abstract concepts, but showed interest when chemistry was linked to real-life social issues. This finding supports Zeidler et al., (2005), who emphasized that socio-scientific dilemmas stimulate critical thinking, and is consistent with Carolina et al., (2024), who found that SSI-based modules can promote higher-order thinking. The interviews revealed that students often felt disconnected from the material because it was presented in a way that seemed irrelevant to their daily lives. However, when teachers provided examples related to climate change, pollution, or energy use, students became more engaged and curious. This shows that contextualization is a key factor in motivating learners. The implication is clear: chemistry learning must be designed not only to deliver knowledge but also to foster curiosity and engagement through real-world connections.

The analysis of teaching materials showed that the chemistry textbook used (Sudarmo, Erlangga) focused only on content delivery without integrating social contexts or critical thinking activities. This confirms Kamaruddin (2021) view that traditional learning often neglects socio-scientific dimensions. The textbook presented global warming as a scientific phenomenon, explaining causes and effects, but did not provide opportunities for students to analyze dilemmas, debate solutions, or reflect on ethical implications. As a result, students were limited to memorizing facts rather than applying knowledge to solve problems. This gap highlights the importance of developing supplementary materials such as SSI-based modules that can complement textbooks by embedding socio-scientific contexts and critical thinking activities.

Students' responses also indicated that contextual approaches would increase engagement, in line with Sofiana & Wibowo (2019), who argue that SSI-based chemistry modules provide multidimensional learning experiences. When asked about their preferences, students expressed enthusiasm for activities that involved discussion, role-play, or case studies related to environmental issues. They felt that such approaches would make chemistry more relevant and easier to understand. This aligns with the principle of multidimensional learning, which integrates cognitive, affective, and social dimensions. By engaging students in socio-scientific issues, teachers can foster not only knowledge acquisition but also values, attitudes, and skills needed to navigate complex societal challenges.

In addition, student interviews revealed that most learners considered chemistry difficult, full of formulas, and abstract. However, they expressed interest when chemistry was connected to everyday social issues, such as climate change or pollution. This supports Dewi & Rahayu (2022), who emphasized that SSI-based learning can optimize chemical literacy by linking scientific concepts with real-world contexts. For example, when students were asked to relate the concept of greenhouse gases to their daily activities, such as transportation or energy use, they began to see the relevance of chemistry in their lives. This demonstrates that SSI-based modules can serve as a bridge between abstract scientific concepts and tangible experiences, thereby reducing the perception of chemistry as a difficult subject.

Thus, the define stage confirmed the urgency of developing a module that integrates socio-scientific issues to foster student motivation and critical thinking. The identification of these problems became the foundation for designing a module that not only delivers content but also trains students to analyze, evaluate, and make decisions based on scientific and social evidence. The findings from teacher interviews, student responses, and material analysis all point to the same conclusion: current teaching practices are insufficient to develop 21st century competencies. Therefore, the development of an SSI-

based module on global warming is not just an innovation but a necessity to ensure that students are equipped with the skills to understand, evaluate, and respond to complex socio-scientific challenges in their environment.

Design Stage

The design stage produced a module aligned with curriculum indicators and SSI syntax. At this stage, the researcher carefully mapped the chemistry curriculum, particularly the global warming topic, to ensure that the module was not only in accordance with the Merdeka Curriculum but also responsive to students' needs. The storyboard integrated contextual issues such as climate change, greenhouse effect, and mitigation efforts, along with role-play, meta-reflection, and evaluation tasks. Each of these components was deliberately chosen to provide a balance between scientific accuracy and socio-scientific relevance. For example, the greenhouse effect was not only explained in terms of molecular interactions but also linked to real world dilemmas such as rising sea levels and food security. This integration ensured that the module could serve as a bridge between abstract chemical concepts and tangible social issues, thereby making learning more meaningful and engaging.

Supporting materials were collected and integrated into the module design, ensuring alignment with learning objectives. These materials included textbooks, scientific articles, government reports on climate change, and visual aids such as diagrams and charts. The inclusion of diverse sources was intended to provide students with multiple perspectives and reliable references. This design is consistent with Dewi & Rahayu (2022), who emphasized the importance of optimizing chemical literacy through SSI-based learning. By grounding the module in credible references, students were encouraged to critically evaluate information rather than passively accept it. Moreover, the supporting materials were adapted to the students' cognitive level, ensuring that complex scientific data could be understood without oversimplification. This careful selection of materials reflects the principle that SSI-based modules must be both scientifically rigorous and pedagogically accessible.

By including role-play and meta-reflection, the module encouraged students to analyze dilemmas from multiple perspectives, which supports the constructivist approach to learning Zeidler et al., (2005). Role-play activities were designed to simulate real-world debates, where students assumed roles such as policymakers, environmental activists, or industrial entrepreneurs. Through these activities, students were challenged to defend their positions using scientific evidence while also considering ethical and social implications. Meta-reflection tasks required students to evaluate their own learning process, identify biases, and articulate how their understanding evolved during discussions. This dual approach experiential through role-play and introspective through reflection ensured that students developed not only cognitive skills but also metacognitive awareness. Such activities are crucial in SSI-based learning because they foster empathy, critical analysis, and the ability to navigate complex socio-scientific dilemmas.

The design also reflects Laksono & Wibowo (2022), who argued that SSI-based modules can train higher-order thinking skills by linking scientific concepts with social, ethical, and environmental issues. In the module, scientific explanations of global warming were consistently paired with socio-scientific dilemmas, such as the trade-off between economic growth and environmental sustainability. For instance, students were asked to analyze the impact of industrial emissions not only in terms of chemical reactions but also in relation to community health and ecological balance. This integration of

multiple dimensions encouraged students to move beyond rote memorization and engage in higher-order thinking processes such as analysis, synthesis, and evaluation. By embedding ethical and environmental considerations into the design, the module aimed to cultivate responsible citizenship alongside scientific literacy.

The module was structured into three main learning activities: (1) understanding global warming and greenhouse effect, (2) analyzing causes and impacts of global warming, and (3) exploring mitigation efforts. Each activity included contextual dilemmas, role-play exercises, and reflective tasks. In the first activity, students were introduced to the scientific basis of global warming, supported by visualizations and simple experiments. The second activity required students to analyze case studies, such as deforestation or excessive use of fossil fuels, and discuss their socio-scientific implications. The third activity focused on solutions, encouraging students to propose mitigation strategies such as renewable energy adoption or waste reduction. Each activity was carefully sequenced to build upon the previous one, ensuring a coherent progression from knowledge acquisition to critical application. This structure reflects the pedagogical principle that learning should move from concrete understanding to abstract reasoning and finally to practical problem-solving.

This structure ensured that students not only learned scientific content but also practiced decision-making and problem-solving based on socio-scientific issues. Such integration is aligned with Handayani et al., (2024), who found that SSI-based problem-based learning enhances both critical thinking and eco-literacy. By engaging with real-world dilemmas, students were trained to evaluate evidence, consider multiple perspectives, and make informed decisions. For example, when discussing mitigation efforts, students had to weigh the feasibility of renewable energy solutions against economic constraints. This process required them to apply scientific knowledge in complex, uncertain contexts an essential skill for the 21st century. Furthermore, the emphasis on eco-literacy ensured that students developed an awareness of their role in environmental stewardship. Thus, the design stage laid a strong foundation for the module's effectiveness in fostering both cognitive and affective dimensions of learning.

Develop Stage

The development stage was carried out to validate the instruments, the module, and the test items, followed by practicality testing with teachers and students, and finally measuring students' critical thinking skills. Each validation was conducted by experts in their respective fields to ensure that the SSI-based module on global warming was valid, practical, and effective.

Table 1. Analysis of Instrument Validation Results

No.	Validation Aspect	Score	Max	%	Category
1	Questionnaire format	7	8	88	Very valid
2	Language used	14	16	88	Very valid
3	Questionnaire items	21	24	88	Very valid
Amount		**42**	**48**	**88**	**Very valid**

Based on Table 1, the validation of the research instrument obtained an overall score of 88% with the category very valid. This shows that the questionnaire format, language, and items were clear, coherent, and aligned with the objectives of the study. Valid instruments are essential to ensure that the data collected accurately reflects students' experiences and supports reliable evaluation of the module (Andromeda et al., 2018).

As the instruments were declared valid, the next step was to validate the practicality questionnaire to ensure consistency in measuring ease of use and relevance.

Table 2. Analysis of Practicality Questionnaire Validation Results

No.	Validation Aspect	Score	Max	%	Category
1	Questionnaire format	7	8	88	Very valid
2	Language used	14	16	88	Very valid
3	Questionnaire items	21	24	88	Very valid
Amount		**42**	**48**	**88**	**Very valid**

The practicality questionnaire validation also reached 88% (very valid). This indicates that the instrument used to measure practicality was appropriate and reliable. The practicality questionnaire ensures that feedback collected truly represents ease of use, efficiency, and relevance, supporting the evaluation of how the module functions in practice (Lastri, 2023).

With the instruments validated, the module itself was then assessed by subject-matter experts to ensure accuracy, depth, and contextual relevance.

Table 3. Results of Material Validation by Experts

No.	Validation Aspect	Score	Max	%	Category
1	Suitability with CP	6	8	75	Valid
2	Accuracy of material	21	24	88	Very valid
3	Up-to-date content	8	8	100	Very valid
4	Stimulation of curiosity	6	8	75	Valid
5	Depth of material	8	8	100	Very valid
Amount		**49**	**56**	**88**	**Very valid**

The material validation achieved 88% overall, categorized as *very valid*. The accuracy and depth of the material scored highly, confirming that the module provided correct and comprehensive scientific content. Up-to-date content reached 100%, ensuring that the module was relevant to current socio-scientific issues such as global warming. However, suitability with curriculum achievements (75%) and stimulation of curiosity (75%) indicated areas that required improvement.

Validators recommended adding international references and contextual examples from local issues in Sumatera Barat to make the module more relatable and engaging. They also suggested incorporating inquiry-based questions to stimulate students'

curiosity and encourage active participation. These revisions were implemented by updating the bibliography with recent international journals and embedding local case studies, which made the module more comprehensive and contextually relevant.

This finding is consistent with Azizah et al. (2022), who emphasized that teaching materials should not only be accurate and up-to-date but also contextual and inquiry-driven to foster creativity and deeper understanding. Similarly, Lastri (2023) highlighted that effective modules must integrate local relevance and global perspectives to strengthen students' engagement and comprehension.

By addressing these aspects, the SSI-based module became more robust, ensuring that it was scientifically accurate, pedagogically sound, and contextually meaningful for students.

After the material was validated, the construct or design of the module was examined to ensure that its physical and visual presentation supported learning.

Table 4. Results of Construct Validation by Experts

No.	Validation Aspect	Score	Max	%	Category
1	Module size	4	4	100	Very valid
2	Design (cover and layout)	56	56	100	Very valid
Amount		**60**	**60**	**100**	**Very valid**

Construct validation achieved 100%, categorized as very valid. This shows that the module's physical design, layout, and graphics were appropriate and attractive. The results confirm that the module has met the principles of readability, consistency of appearance, and suitability with the standards of teaching materials. The validators did not provide additional suggestions, which indicates that the module was already optimal in terms of construct. This finding is consistent with Nafi'a et al. (2022), who emphasized that instructional design must be visually appealing and systematically organized to facilitate learning. A well-designed module enhances students' motivation and interest, making it easier for them to engage with the content.

Furthermore, a strong construct aspect ensures that the module is user-friendly, supporting independent learning and reducing cognitive load during study. According to Gunawan (2022), teaching materials with good construct design help students focus on the content rather than struggling with presentation issues. This means that the SSI-based module not only delivers accurate material but also provides a visually supportive environment that encourages effective learning.

Following construct validation, the language used in the module was assessed to ensure clarity and suitability for students.

Table 5. Results of Language Validation by Experts

No.	Validation Aspect	Score	Max	%	Category
1	Clarity	12	12	100	Very valid
2	Communicativeness	11	12	92	Very valid
3	Suitability for students	8	8	100	Very valid

4	Language design/layout	7	8	88	Very valid
Amount		**38**	**40**	**95**	**Very valid**

The language validation achieved 95% with the category very valid. This indicates that the module used clear and communicative language, adapted to the level of students, and followed the rules of Indonesian grammar (PUEBI). Validators emphasized that the language should be simple, precise, and free from unnecessary jargon, so that students can easily understand the material.

The results confirm that the module has met the criteria of readability and clarity. The use of communicative language ensures that students can engage with the content without linguistic barriers, while suitability for students guarantees that the module is aligned with their developmental stage. This finding is consistent with Ewina (2015), who highlighted that language clarity supports comprehension, and with Elsyavalia et al. (2023), who stated that language adapted to students' level optimizes understanding of learning materials. Furthermore, Ananda (2019) emphasized that simple and communicative language is essential for teaching materials to be easily understood by learners.

No additional suggestions were provided by validators in this aspect, which means the language component of the module was already optimal. Thus, the module can be directly used without further revision in terms of language. This strengthens the conclusion that the SSI-based module is not only scientifically accurate but also linguistically accessible, ensuring effective communication of concepts to students.

Following the language validation, the next stage was the practicality test, which involved one chemistry teacher and 35 students from class X.E1. This stage was designed to evaluate how easily the SSI based module on global warming could be implemented in real classroom settings.

Table 6. Results of Practicality Test by Teacher

No.	Validation Aspect	Score	Max	%	Category
1	Ease of use	13	16	81	Very practical
2	Language	8	8	100	Very practical
3	Time efficiency	14	16	88	Very practical
4	Construct/graphics	6	8	75	Practical
5	Usefulness	14	16	88	Very practical
Amount		**55**	**64**	**86**	**Very practical**

The teacher's responses indicated that the module achieved **86%**, categorized as *very practical*. The teacher emphasized that the module simplified the teaching process, used clear and accessible language, and presented content in an attractive format aligned with students' characteristics. Moreover, the chemistry teacher expressed interest in using the SSI-based module because it effectively trained students' critical thinking skills in addressing global warming issues. This finding is consistent with Siska et al. (2020), who argued that a practical module is one that is easy to use in classroom learning. It also

aligns with Gunawan (2022), who highlighted that user-friendly teaching materials support independent learning.

Table 7. Results of Practicality Test by Students (Class X.E1)

No.	Validation Aspect	Score	Max	%	Category
1	Ease of use	526	560	94	Very practical
3	Time efficiency	255	280	91	Very practical
5	Usefulness	531	560	95	Very practical
Amount		**1312**	**1400**	**93**	**Very practical**

The responses of 35 students showed a 93% score, categorized as *very practical*. Students reported that the module was easy to use, efficient, beneficial, and engaging due to its illustrations, colors, and contextual activities. They also felt that the module helped them understand the concept of global warming more quickly and trained their critical thinking in connecting environmental issues with everyday life. These findings are in line with Yanto (2019), who noted that modules integrated with technology can enhance the effectiveness and efficiency of learning time. Furthermore, students' responses support the SSI theory (Zeidler et al., 2005; Sofiana & Wibowo, 2019), which emphasizes that SSI-based learning is contextual and multidimensional, thereby fostering critical thinking and motivation.

After the practicality test involving the chemistry teacher and students of class X.E1, the critical thinking test items were examined to ensure they measured the intended skills effectively.

Table 7. Results of Critical Thinking Test Validation

No.	Validation Aspect	Score	Max	%	Category
1	Didactic	12	16	75	Valid
2	Construct	15	20	75	Valid
3	Language	9	12	75	Valid
4	Technical requirements	3	4	75	Valid
Amount		**39**	**52**	**75**	**Valid**

As shown in Table 6, the validation of critical thinking test items reached 75%, categorized as valid. This indicates that the test could be used, but several aspects required improvement, particularly in didactic clarity, construct design, language, and technical requirements. Validators suggested simplifying the format of the questions from four-tier to three-tier, making them easier to understand and more suitable for the research context. This adjustment was important because overly complex test structures may distract students from the actual critical thinking skills being assessed.

The revisions ensured that the test items were better aligned with the six indicators of critical thinking skills proposed by Facione (2015): interpretation, analysis, evaluation, inference, explanation, and self-regulation. By refining the answer options and

simplifying instructions, students were more likely to demonstrate these skills effectively. This finding is consistent with Zahra et al. (2021), who emphasized that SSI-based modules must integrate assessment items carefully to measure higher-order thinking skills. Furthermore, Farida & Musyarofah (2021) highlighted the importance of aligning test formats with research objectives to ensure accurate measurement.

Overall, the validation process confirmed that the critical thinking test items were valid but required revisions to maximize clarity and effectiveness. After these adjustments, the test became more practical and reliable for evaluating students' critical thinking skills in the context of socio-scientific issues such as global warming.

With the module and instruments validated, the next stage was the practicality test, conducted with teachers and students to evaluate ease of use, efficiency, and relevance in classroom learning.

Disseminate Stage

The dissemination stage was conducted in a limited scope, focusing only on one class at SMAN 2 Batusangkar due to constraints of time, cost, and resources. Even though dissemination was not carried out broadly, the limited trial provided valuable insights into the feasibility of the module in real classroom settings. Teachers and students were able to interact directly with the module, giving feedback on its clarity, relevance, and usability. This limited dissemination aligns with the principle of gradual implementation in educational research, where products are first tested in small groups before being scaled up to wider audiences.

The limited dissemination also allowed the researcher to identify practical challenges in classroom application. For example, some students initially struggled with role-play activities because they were not accustomed to taking on different perspectives such as government officials, activists, or entrepreneurs. However, with guidance, students began to appreciate the importance of analyzing socio-scientific dilemmas from multiple viewpoints. Teachers also noted that the module encouraged more active participation compared to traditional lecture-based methods. This finding is consistent with Carolina et al. (2024), who emphasized that limited dissemination is an effective strategy to refine educational products before mass adoption.

Although dissemination was restricted, the results demonstrated that the SSI-based module was valid, practical, and effective in improving students' critical thinking skills. The improvement from 55% to 86% in critical thinking indicators illustrates the transformative potential of SSI based learning. This supports Sofiana & Wibowo (2019), who argued that SSI-based chemistry modules contextualize science learning and promote multidimensional engagement. The high validity scores obtained in this study indicate that the developed module meets the criteria of good instructional materials in terms of content, construct, and language. This finding is consistent with the theory of instructional material development, which emphasizes that valid learning resources must be aligned with curriculum objectives, scientifically accurate, and systematically organized (Gunawan, 2022).

The material validation result (88%) reflects that the module content is accurate and relevant to current scientific developments, particularly in the context of global warming. This supports the view of Azizah et al. (2022), who stated that teaching materials integrating socio-scientific issues must present up-to-date and contextual information to enhance meaningful learning.

Furthermore, the construct validation result (100%) indicates that the module design is visually appropriate and systematically structured. This aligns with Nafi'a et al. (2022), who argued that well-designed instructional materials improve readability and facilitate students' engagement with learning content.

The language validation result (95%) also demonstrates that the module uses clear and communicative language, which is essential for supporting students' comprehension. According to Ananda (2019), the use of simple and effective language in teaching materials helps reduce cognitive load and enables students to focus on conceptual understanding.

The limited dissemination thus served as a crucial step in validating the module's effectiveness, providing a strong foundation for future expansion to other classes, schools, and potentially integration into broader curriculum frameworks.

▪ CONCLUSION

This study concludes that the Socio Scientific Issues (SSI) based learning module on global warming is a valid and practical innovation that effectively fosters students' critical thinking skills. By bridging abstract chemistry concepts with real world contexts, the module provides meaningful learning experiences aligned with 21st century competencies. Although dissemination was limited to one class, future research is recommended to expand its application to other topics and schools to strengthen its generalizability.

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