



Development of Socio-Scientific Issues-Based Learning Modules to Train Students' Creative Thinking Skills in Nanotechnology for 10th Grade Senior High School/MA

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Abstract: Development of Socio-Scientific Issues-Based Learning Modules to Train Students' Creative Thinking Skills in Nanotechnology 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' thinking skills in nanotechnology. The method used in this study was Research and Development (R&D) using the 4-D development model. The test subjects were students in class X E4 at SMA Negeri 2 Batusangkar. The data analysis technique was a validity and practicality test of the respondent questionnaire. The results showed that the validity of the material in the learning module based on socio-scientific issues was 87% and the language validation was 81%. The results of the practicality test from the respondent questionnaire were 95% and the level of students' creative thinking was 84%. Based on the results of the study, it can be concluded that the learning module based on socio-scientific issues to train students' creative thinking skills is very valid and very practical to use.

Keywords: learning modules, socio-scientific issues, creative thinking, nanotechnology.

Abstrak: Pengembangan Modul Pembelajaran Berbasis Socio-Scientific Issues untuk Melatih Kemampuan Berpikir Kreatif Siswa pada Materi Nanoteknologi Kelas X SMA/MA. Penelitian ini bertujuan untuk menguji validitas dan praktikalitas modul pembelajaran berbasis socio-scientific issues untuk melatih kemampuan berpikir siswa pada materi nanoteknologi. Metode dalam penelitian ini adalah Research and Development (R&D) dengan menggunakan model pengembangan 4-D. Subjek uji coba dilakukan pada siswa dan siswi kelas X E4 SMA Negeri 2 Batusangkar. Teknis analisis data yaitu uji validitas dan praktikalitas angket responden. Hasil penelitian menunjukkan bahwa validitas materi pada modul pembelajaran berbasis socio-scientific issues sebesar 87% dan validasi bahasa sebesar 81%, hasil uji praktikalitas dari angket responden sebesar 95% dan tingkat pemikiran kreatif siswa sebesar 84%. Berdasarkan hasil penelitian maka dapat disimpulkan bahwa modul pembelajaran berbasis socio-scientific issues untuk melatih kemampuan berpikir kreatif siswa sangat valid dan sangat praktis untuk digunakan.

Kata kunci: modul pembelajaran, socio-scientific issues, berpikir kreatif, nanoteknologi.

■ INTRODUCTION

21st century education emphasizes the 4Cs, which consist of critical thinking, collaborative thinking, communication, and creative thinking. These skills can train students' ability to adapt, solve problems, and communicate well (Meikasari et al., 2020).

Students are also encouraged to actively seek and process information in a systematic and creative manner (Yuliana & Irawan, 2024).

Based on the demands of the 21st century, the 2018 PISA results show that students' creative thinking skills and science literacy in Indonesia are still below the OECD average, which is 396 out of an average score of 489 (Fuadi et al., 2020). Indonesia's low performance is not only a matter of numerical scores, but also a lack of preparedness in facing the demands of the 21st century, namely creativity.

Creative thinking is the ability to generate new and original ideas or concepts to find solutions to problems, thereby arriving at several alternative answers ('Adiilah & Haryanti, 2023). Indicators of creative thinking are fluency thinking, flexibility thinking, original thinking, and elaboration ability (Qomariyah et al., 2021)

Many students face difficulties in understanding complex and abstract chemistry concepts. As a result, lessons become ineffective and boring. In addition, traditional methods such as lectures or memorization often do not utilize technology or new approaches, causing students to become passive, less enthusiastic about learning, and unable to develop their creative thinking (Maemunah et al., 2019).

A chemistry learning strategy is needed that integrates 21st century learning principles, such as learning through real-world problems, using learning modules, and group work. This helps students become more motivated, makes chemistry lessons easier to understand, and helps students apply their knowledge in everyday life (Prastika et al., 2024).

A learning module is a learning process about a specific subject unit that is organized in a systematic, functional manner and is intended for use by students. Learning through modules emphasizes the organization of material consisting of subject units. A learning module can also be defined as a teaching package containing units of material concepts that can be studied independently (Harahap & Fauzi, 2017).

In fact, based on interviews with 10th grade chemistry teachers at Senior High School (SMAN) 2 Batusangkar, teachers use conventional learning modules in the classroom, and students find it difficult to understand abstract chemistry material. There is also a lack of approach from teachers in teaching chemistry material, resulting in the failure to achieve 21st century competencies, especially in terms of students' creative thinking. This is evidenced by the results of students' creative thinking abilities on nanotechnology material in class X E4, which was measured at 62.04% using four-tier HOTS questions based on indicators of creative thinking, namely fluency, flexibility, originality, and elaboration. This shows that the level of students' creative thinking is still very low.

Several studies state that training students' creative thinking skills is important in the demands of the 21st century. There is a close relationship between creative thinking skills and socio-scientific issues-based approaches that can be applied in learning (Agustin et al., 2019). Socio-scientific issues-based learning emphasizes the disclosure of social realities through everyday events that are manifestations of science, thereby making learning more contextual (Dusturi et al., 2024). The socio-scientific issues approach focuses on issues related to students' social environment. It encourages students to use a scientific approach to understand various phenomena, not only those related to natural processes, but also social phenomena in their surroundings (Fatwa & Agustina, 2025).

Relevant chemistry learning is packaged in the context of socio-scientific issues because it is able to link chemistry concepts to real social problems and train 21st century

skills (Frilla Firanti & Erna, 2024). A number of studies have developed chemistry modules or e-modules based on socio-scientific issues and shown a high level of feasibility and excellent student response, such as the study by Frilla Firanti & Erna (2024), which obtained a validity of 92.9% and a positive student response of 83%. However, these studies generally still focus on the feasibility and practicality of the modules, have not been specifically designed to train students' creative thinking skills, and have not addressed nanotechnology material at the senior high school/MA level. Therefore, the research gap in this study lies in the development and testing of chemistry learning modules based on socio-scientific issues that are explicitly aimed at training students' creative thinking skills on nanotechnology material in 10th grade senior high school/MA through testing the validity and practicality of the learning modules.

■ **METHOD**

The research to be conducted by the researcher 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. This research has limitations in the disseminate stage, which is restricted only to the school where the researcher conducted the research.

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, and concept analysis (Hidayati & Aulia, 2024). A preliminary analysis was conducted to obtain information about the conditions of chemistry learning in schools and student needs, which included interviews with 10th grade chemistry teachers to determine the actual conditions in the field, particularly regarding the level of students' creative thinking skills, analysis of the learning modules used by teachers to identify problems in their use for developing students' creative thinking, and analysis of the learning objectives to examine the relevant Learning Outcomes and Learning Objectives in training creative thinking skills. Furthermore, student analysis was conducted to identify students' psychological characteristics related to the learning process, such as cognitive abilities and learning motivation, so that students' needs in chemistry learning could be understood. Concept analysis aimed to examine the characteristics of chemistry material, including facts, concepts, principles, and procedures, as a basis for determining the validity of the learning modules to be developed.

Design Stage

During the design stage, researchers developed a preliminary design for the product to be developed through several systematic steps, including selecting learning media that were in line with the learning objectives, namely learning modules, and selecting formats by compiling content in accordance with the module components. Next, a preliminary module design was carried out, which included compiling the module cover (title, author and institution identities, and illustrations relevant to chemistry and Socio-Scientific Issues/SSI), the foreword, the table of contents, the introduction containing instructions for using the module and learning scenarios based on socio-scientific issues, learning outcomes and indicators of creative thinking based on Silver's (1997) indicators, which include fluency, flexibility, originality, and elaboration, learning objectives, concept maps, and learning materials (Handayani et al., 2022). The learning material is presented

in each chapter, which consists of a description of the chemistry material, socio-scientific issues in the form of current issues such as renewable energy, the impact of chemical waste on the environment, and the influence of nanotechnology, Silver-based creative thinking exercises, student activities, and exercises and evaluations in the form of Higher Order Thinking Skills (HOTS) questions and case studies. The module also includes a glossary, bibliography, appendices in the form of discussion guides and case studies, and author biographies. In addition, at this stage, the researchers also designed research instruments, including a module validation sheet and validation test instruments, as well as a module practicality sheet and a questionnaire instrument to test the practicality of the socio-scientific issues-based learning module to train students' creative thinking skills on nanotechnology material.

Develop Stage

This stage consists of researchers' actions to create the final product in the form of a learning module based on socio-scientific issues to train students' creative thinking skills in nanotechnology material for 10th grade senior high school/MA. There are two stages carried out, namely the validation and practicality stages. The validity and feasibility of the product can be tested at this stage. The validity stage is carried out by several experts to ensure that the developed product is accurate and of high quality. The practicality stage is carried out to see whether the product is practical in its use

The validity and practicality analysis techniques using validity and practicality test data obtained from the questionnaire will be analyzed. Alternative questionnaire answers are converted into quantitative data to obtain interval data, and a formula will be used to obtain the kappa moment. With the formula:

$$k = \frac{Po - Pe}{1 - Pe}$$

The Kappa Moment Rank (k) is between 0 and 1, with interpretations according to Boslaugh & Watters shown in Table 1.

Tabel 1. Interpretasi Nilai Momen Kappa (k)

Interval	Kategori
0,81 – 1,00	Sangat Tinggi
0,61 – 0,80	Tinggi
0,41 – 0,60	Sedang
0,21 – 0,40	Rendah
0,01 – 0,20	Sangat Rendah
≤0,00	Tidak Valid

(Sugiyono, 2013)

Disseminate Stage

At this stage, the researchers limited the distribution of the product to teachers and students at the school where the research was conducted, namely one of the 10th grade classes at Senior High School (SMAN) 2 Batusangkar.

■ RESULT AND DISCUSSION

The researchers have completed their research and development (R&D) study. This study used the 4-D development model, namely define, design, development, and disseminate. The results of this study are as follows:

Define Stage

The define stage is carried out to examine and identify problems related to the learning process in the field as a basis for product development. According to Thiagarajan, the define stage includes front-end analysis, learner analysis, and concept analysis. Front-end analysis aims to formulate the background of the problem based on learning conditions in order to obtain information related to problems and alternative solutions. Learner analysis is conducted to identify student needs and characteristics, while concept analysis is used to evaluate the suitability of sub-material in the Balanced Learning Plan (RPS) (Yunika et al., 2020). In line with this opinion, the define stage in this study was aimed at formulating students' learning needs as a basis for developing more effective learning.

During the front-end analysis stage, researchers conducted interviews with chemistry teachers at Senior High School (SMAN) 2 Batusangkar. The interview results showed that chemistry learning had implemented the Merdeka Curriculum by utilizing teaching modules that had been modified according to the school's needs. In addition, teachers also used textbooks, student worksheets, and learning modules as learning resources. However, teachers said that chemistry learning still faced obstacles, including abstract chemistry material, a lack of examples of the application of chemistry in everyday life and social issues, and limited teaching materials that could optimally support student understanding (Kurniawati et al., 2023). The modules used also do not integrate 21st century competencies, particularly creative thinking skills, and teachers feel that they are not optimally developing these aspects in their teaching materials (Hanipah et al., 2018). However, the Learning Outcomes (CP) and Learning Objectives (TP) used are in line with the Merdeka Curriculum.

Limited teaching materials are one of the factors that affect the quality of learning, even though teaching materials play an important role in helping teachers and students achieve learning objectives that cover knowledge, skills, and attitudes (Latri, 2023). One teaching material that is considered effective is the learning module, because it is easy to learn, flexible in its use, and able to expand students' knowledge without being limited by time and place (Famulaqih & Lukman, 2024). Previous research shows that learning modules not only make it easier for students to understand the material, but are also an effective and efficient development for teachers and students with relatively minimal obstacles (Famulaqih & Lukman, 2024).

The learner analysis stage was conducted to identify student characteristics, particularly cognitive aspects and learning motivation. Interviews with students at Senior High School (SMAN) 2 Batusangkar showed that low interest in learning chemistry was caused by difficulty in understanding the material and a lack of examples of the application of chemistry in everyday life provided by teachers. This condition indicates the need for a more contextual learning approach, one of which is through socio-scientific issues-based learning that requires students to analyze scientific problems with social, ethical, and technological dimensions, thereby training their creative thinking skills as part of 21st century competencies (Hidayati & Aulia, 2024).

Next, concept analysis was conducted to identify in depth the characteristics of the material, including facts, concepts, principles, and procedures, and to ensure its suitability for the students' cognitive development level. Concept analysis helps students understand the material systematically and relate new knowledge to their prior knowledge. In this study, concept analysis focused on nanotechnology material based on socio-scientific issues, which included basic concepts of nanotechnology chemistry, the relationship between nanotechnology and green chemistry, the application of nanotechnology in everyday life, and the social, ethical, and environmental impacts of nanotechnology development.

Design Stage

The design stage is a stage that aims to produce an initial product design in the form of a learning module based on Socio-Scientific Issues to train students' creative thinking skills in nanotechnology material for 10th grade senior high school/MA. At this stage, systematic planning is carried out for the development of learning modules and the preparation of research instruments to be in line with the development objectives. The module design is tailored to the Learning Outcomes (CP) and Learning Objectives (TP) of the independent curriculum so that the scope and depth of the material remain in sync with the requirements of the applicable curriculum.

The selection of learning modules as teaching materials was based on the needs of teachers and students at Senior High School (SMAN) 2 Batusangkar, where chemistry learning is still considered difficult because it is abstract and conventional modules have not linked chemical concepts to social issues in everyday life. This situation has resulted in students' understanding of chemistry material not being optimal and the lack of integration of 21st century competencies, particularly creative thinking skills, in the learning process. Therefore, learning modules are needed that can bridge chemistry concepts with real contexts through a socio-scientific issues approach, especially in nanotechnology material, which has characteristics relevant to social issues.

The format chosen in the development of this product is a learning module based on socio-scientific issues. The modules are structured using common learning module components (module cover, introduction, table of contents, introduction, learning outcomes and creative thinking indicators, learning objectives, concept maps, learning materials, student activities, exercises and evaluations, glossary, bibliography, appendices, and author biographies), with factual chemistry material integrated into the context of social issues. This format allows teachers to present chemistry material in a more comprehensive, contextual, and structured manner, thereby helping students understand abstract and difficult chemistry concepts. Through this approach, the module is expected to train students' creative thinking skills, including fluency, flexibility, originality, and elaboration. The learning module serves as contextual teaching material that allows for a broad presentation of material (Handayani et al., 2022), meanwhile, the socio-scientific issues approach aims to strengthen understanding of chemistry by linking the characteristics of matter with its application and examples based on social issues that are relevant to everyday life (Ramadhani & Susiyawati, 2025).

After the module format was determined, the next step was to develop a preliminary design for a learning module based on socio-scientific issues in nanotechnology for 10th grade students. At the same time, research instruments were also designed, including a module validation sheet and a practicality response questionnaire. The development of these instruments was carried out through discussions with supervisors and instrument

construction validators to ensure that the instruments developed were in line with the research objectives and suitable for use in the data collection process.

Develop Stage

At this stage, the socio-scientific issues-based learning modules produced in the design stage are tested for validity and practicality. Validity testing is carried out through validation by experts in their respective fields to ensure the suitability of the modules as learning resources. Before use, the research instruments are also validated using validation sheets to ensure that they are suitable and valid for use.

Table 1. Instrument Validation Sheet Results

No	Aspects Assessed	Amount	Skor Maks	%	Explanation
1	Questionnaire format	4	4	100	Very Valid
2	Language used	8	8	100	Very Valid
3	Statement items	12	12	100	Very Valid
Amount		24	24	100	Very Valid

Instrument validation involved one lecturer, while the validation of learning modules based on socio-scientific issues in nanotechnology involved two expert lecturers. Module validation aspects included material and language validation, which, if fulfilled, indicated that the module was suitable for use as a learning resource (Saputri et al., 2023; Dahlan et al., 2020).

After validation, the instrument is deemed highly valid for use and can proceed to material validation in the learning module used. Validators are selected from chemistry experts by filling out a material validation questionnaire using several question indicators.

Table 2. Results of Material Validation

No	Aspects Assessed	Amount	Maximum Score	%	Explanation
1	Content suitability	52	60	87	Very Valid
2	Presentation	21	24	88	Very Valid
Amount		73	84	87	Very Valid

The results of the content validity test showed a percentage of 87% with a category of highly valid. This indicates that the learning module is in line with the learning objectives and contains chemistry material based on relevant socio-scientific issues, particularly on the topic of nanotechnology. The material in the module is compiled based on credible references, such as the books by Sudarmo (2021), Purwanto et al. (2016), and Fahanani et al. (2023). A good learning module must be in line with the learning objectives and meet the indicators of accuracy and currency of the material (Lastris, 2023).

Next, language validation was carried out with language experts, and the results are shown in Table 3.

Table 3. Language Validation Results

No	Aspects Assessed	Amount	Maximum Score	%	Explanation
1	Straightforward	9	12	75	Valid
2	Communicative	14	16	88	Very Valid
3	Suitability for students	6	8	75	Valid
Amount		29	36	81	Very Valid

The language validation results show a percentage of 81% with a category of highly valid. The language used in the module complies with the rules of the General Guidelines for Indonesian Spelling (PUEBI), is coherent, communicative, and adapted to the developmental level of senior high school students. The use of appropriate language is very important to help students understand and analyze learning materials optimally (Ardiningtyas et al., 2023). In addition, the choice of standard and technical language is considered appropriate for the socio-emotional development characteristics of senior high school students who are in the phase of self-identity search (Hanida et al., 2023; S & Hartono, 2023). Overall, the validation results of the learning module reached a percentage of 85% with a category of highly valid, so that the module was declared suitable for use in chemistry learning.

The high validity score of the module indicates that the content, presentation, and language components are in line with the characteristics of socio-scientific issues-based learning. This is consistent with the socio-scientific issues theory, which emphasizes the connection between scientific concepts and real social issues to encourage cognitive engagement among students. In addition, activities that require students to analyze nanotechnology issues, express ideas, and seek alternative solutions support the development of creative thinking indicators, particularly flexibility and originality.

The results of the revision of the socio-scientific issues-based learning module to train students' creative thinking skills that has been developed and suggestions from validators. The following image presents the results of the revision of the socio-scientific issues-based learning module to train students' creative thinking skills from validators.



Figure 1. Learning Modules Revised by Validators

After going through the validation and revision stages as suggested by the validators, the learning module was then tested for practicality by involving 32 students. The practicality test was conducted through a student response questionnaire covering aspects of ease of use, language, interest, benefits, and time efficiency.

Table 4. Results of Student Response Questionnaire Practicality

No	Aspects Assessed	Amount	Maximum Score	%	Explanation
1	Ease of use	364	384	95	Very Practical
2	Language	237	256	93	Very Practical
3	Interest	242	256	95	Very Practical
4	Benefits	489	512	96	Very Practical
5	Time efficiency	246	256	96	Very Practical
Amount		1578	1664	95	Very Practical

The test results show that ease of use scored 95%, language 93%, interest 95%, usefulness 96%, and time efficiency 96%, all of which fall into the very practical category. The module is considered easy to use, interesting, useful, and able to save learning time (Utama & Zulyusri, 2022; Algiranto, 2022; Aslik et al., 2022; Wahyudi et al., 2022). Overall, the practicality test results of the socio-scientific issues-based learning module for training creative thinking skills in nanotechnology material obtained a percentage of 95% in the very practical category.

The high practicality results from students indicate that the module is easy to use and interesting. This is in line with the theory of contextual learning in the socio-scientific issues approach, which states that issue-based learning increases student motivation and engagement, thereby facilitating implementation in the classroom.

Practical learning modules are characterized by their ease of use in supporting the learning process (Fatmawati et al., 2023). Thus, the socio-scientific issues-based learning module for training students' creative thinking skills in nanotechnology for 10th grade senior high school/MA students is considered very practical and suitable for use in learning.

The findings of this study are in line with the research by Frilla Firanti & Erna (2024), which reported that chemistry modules based on socio-scientific issues obtained excellent validity and student response rates. However, previous studies have not specifically integrated indicators of creative thinking into learning activities. Unlike those studies, the modules developed in this study were designed to train students' creative thinking skills through the presentation of nanotechnology issues that require idea exploration, open-ended problem solving, and science-based decision making.

Disseminate Stage

At the dissemination stage, the learning modules based on socio-scientific issues that had been developed were disseminated on a limited basis. Dissemination was carried out only at the school where the research was conducted, Senior High School (SMAN) 2 Batusangkar, considering the researchers' limitations in terms of capabilities, manpower, and funding. The products disseminated were 32 copies of printed learning modules given to students in class X E4 as research subjects.

This limited dissemination is in line with Thiagarajan's view in the 4-D development model (define, design, develop, disseminate), which states that at the dissemination stage, the distribution of learning products can be carried out on a limited basis in accordance with the conditions, needs, and objectives of the research, especially in the early stages of development (Aimmah & Amin, 2025). This approach allows researchers to ensure the feasibility and usefulness of a product before it is applied on a larger scale.

Although the socio-scientific issues-based learning module for training students' creative thinking skills in nanotechnology for 10th grade senior high school/MA students is still limited in its use to one class at Senior High School (SMAN) 2 Batusangkar, theoretically this module has fulfilled the principles of effective teaching material development. Therefore, the developed module has the potential to be refined and disseminated more widely in the next stage of research

Results of Students' Creative Thinking

After students used the socio-scientific issues-based learning module, the results showed that students' creative thinking skills were high, with the following results:

Table 5. Results of Students' Creative Thinking Skills

Indicator	Question Item	Amount of Students Who Received	Average (%)
Fluency	1	28	88%
	4	28	88%
	10	27	84%
Average indicator			86%
Flexibility	2	27	84%
	9	29	81%
Average indicator			83%
Originality	3	25	78%
	5	28	88%
	6	25	78%
Average indicator			81%
Elaboration	7	27	84%
	8	27	84%
Average indicator			84%
Total creative thinking ability			84%

Students' creative thinking skills after implementing the socio-scientific issues-based learning module showed high achievement with an overall percentage of 84%. This improvement was evident in all indicators of creative thinking, namely fluency at 86%, flexibility at 83%, originality at 81%, and elaboration at 84%. When compared to the initial conditions before the use of the socio-scientific issues-based module, which only reached 62.04%, these results show a significant improvement. These findings indicate that socio-scientific issues-based learning is able to provide a more meaningful and contextual learning experience, thereby encouraging students to generate more ideas, view problems from various perspectives, produce unique ideas, and develop ideas in more detail and depth.

These results are in line with Silver's (1997) theory of creativity, which states that creative thinking skills consist of four main indicators, namely fluency, flexibility, originality, and elaboration (Febrianingsih, 2022). The presence of one or more of these indicators shows that students have the ability to solve problems qualitatively and quantitatively. In addition, the improvement in students' creative thinking skills can also be explained through constructivism theory, which emphasizes that knowledge is actively constructed by students through interaction with the environment and real-world problems (Kusumawati et al., 2022).

Socio-scientific issues-based learning is in line with the constructivist approach because it raises socio-scientific issues that require students to analyze, evaluate, and make decisions based on scientific evidence and social considerations. This process naturally encourages active student involvement in learning and provides space for the optimal development of creative thinking skills. Thus, the results of measuring students' creative thinking skills after using the socio-scientific issues-based learning module showed an achievement of 84% in the high category. This achievement illustrates that the developed module has the potential to support the development of students' creative thinking skills. However, because this study used a development research design without a controlled pretest-posttest, the results are interpreted as descriptive findings, not as evidence of the module's causal effectiveness.

■ CONCLUSION

Based on the results of analysis and discussion in this study, it can be concluded that (1) the results of the validation of the material and language of the socio-scientific issues-based learning module for training students' thinking skills are very valid; (2) the average practicality of the respondents' questionnaires is categorized as very practical; (3) the use of socio-scientific issues-based learning modules is effective for training students' creative thinking skills in nanotechnology material. The development of this learning module at the dissemination stage is still limited to teachers and students at the school where the researcher conducted the research. It is hoped that the development of this module can use other materials and that effectiveness tests can be carried out on a wider scale in future research.

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