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Development of an SSI-Based Chemistry E-Module Integrating Islamic Values to Support Critical Thinking in Chemistry Learning

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Abstract

Critical thinking skills are essential competencies in 21st-century education; however, preliminary observations indicate that first-semester Chemistry Education students at UIN Mahmud Yunus Batusangkar tend to have limited critical thinking abilities and focus mainly on theoretical understanding. This study aimed to develop a socio-scientific issues (SSI)–based chemistry e-module integrated with Islamic values and to evaluate its feasibility in terms of validity and practicality. A research and development (R&D) approach using the 4D model (Define, Design, Develop, and Disseminate) was employed, with data collected through expert validation instruments and student response questionnaires involving 12 first-semester students. The results showed that the developed e-module achieved a very high level of validity, with an overall mean score of 3.76. In addition, the practicality assessment yielded an average score of 3.39 on a four-point scale, categorized as practical. These findings indicate that the e-module is feasible for use in chemistry learning. The extent to which this e-module supports students' critical thinking skills has not yet been measured and remains a direction for future research, particularly through effectiveness testing in broader instructional settings.

Keywords: chemistry e-module, critical thinking, islamic values integration, socio-scientific issues, validation study

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1. Introduction

The complexities of 21st-century life demand that education systems equip learners with the capacity to navigate present and future challenges that are increasingly multifaceted and interconnected (Battelle, 2019). Students are therefore expected to cultivate a range of essential competencies, including critical and creative thinking, collaboration, communication, adaptability, and digital literacy (Trilling & Fadel, 2009; Voogt & Natalie Pareja, 2012). Within this educational paradigm, the development of higher-order thinking skills (HOTS) has emerged as a central learning objective across all levels of instruction (Agustina, 2021).

Critical thinking has been recognized as a fundamental dimension of higher-order thinking in contemporary education (Facione, 2015; Paul & Elder, 2019) and represents a competency that must be deliberately cultivated across all educational levels (Ennis, 2011). At its core, critical thinking involves the capacity to analyze, evaluate, and interrogate information within varied contexts, enabling learners to move beyond surface-level comprehension toward deeper understanding (Bailin et al., 1999). Students who develop strong critical thinking abilities consistently demonstrate enhanced conceptual mastery, more sophisticated problem-solving strategies, and a greater capacity to transfer knowledge to authentic situations (Halpern, 2014). In chemistry education specifically, instructional approaches that foreground critical thinking have been shown to increase student engagement and deepen conceptual understanding (Zoller & Pushkin, 2007; Overton & Randles, 2015).

Despite its recognized importance, empirical evidence reveals that students' critical thinking skills in introductory chemistry courses frequently remain underdeveloped. Studies conducted across multiple Indonesian universities indicate that many chemistry students struggle to apply critical thinking when confronting contextual chemical problems, with performance levels ranging from low to moderate (Lusi et al., 2023; Restutiningsih et al., 2023). For instance, preliminary assessment conducted among first-semester students in the Tadris Chemistry Program at UIN Mahmud Yunus Batusangkar using a four-tier HOTS-based diagnostic instrument yielded an average score of 38.48 on reaction rate topics. A result indicating that students tend to rely predominantly on memorization rather than engaging in the analytical reasoning required to connect facts, concepts, principles, and procedures.

This persistent gap suggests that students' limited critical thinking capacity cannot be attributed solely to individual cognitive constraints but is substantially shaped by the nature of learning materials and instructional methods employed in chemistry classrooms (Cooper, 2015; Towns, M. H., & Kraft, 2012). Learning materials serve not merely as repositories of information but as scaffolds that structure students' cognitive engagement and guide the development of disciplinary thinking (Taber, 2013). However, chemistry learning materials in many higher education contexts continue to privilege expository text and algorithmic problem sets, offering limited opportunities for students to grapple with authentic contexts or engage in higher-order reasoning (Chittleborough & Treagust, 2008; Holme et al., 2010). Consequently, there is an urgent need for innovative instructional materials designed to promote active, contextually grounded, and analytically rigorous learning experiences in chemistry education.

One form of innovative instructional material that addresses these limitations is the chemistry e-module. An e-module is a systematically designed digital learning material that supports independent learning through the integration of instructional content, learning activities, and assessment components in an electronic format (Fitri & Ardhana, 2023). Compared to conventional printed modules, e-modules offer clear advantages in terms of accessibility, flexibility, and their capacity to support deeper conceptual understanding through interactive and self-paced learning experiences (Arifin et al., 2024). Chemistry education research further confirms that e-modules effectively facilitate higher-order thinking skills particularly critical thinking through activities that engage students in analysis, evaluation, and reflection (Sandi et al., 2025; Yanti & Iriani, 2024).

However, such ideal conditions have not yet been fully realized in the Chemistry Education (Tadris Kimia) Program at UIN Mahmud Yunus Batusangkar. Interactive e-modules that explicitly support critical thinking and contextual learning remain scarce. Most existing learning materials are conventional in character - built around textual explanations, worked examples, and routine exercises - with little in the way of interactive or cognitively challenging features. As a result, these materials have not been optimally designed to develop higher-order thinking or encourage students to critically engage with chemistry concepts. The absence of meaningful contextual integration further limits students' opportunities to connect chemical ideas with real-world phenomena, pointing to an urgent need for a contextual learning approach that can be embedded systematically within instructional materials.

Socio-Scientific Issues (SSI) represent one such approach. SSI refer to complex, socially relevant problems that are closely tied to scientific concepts while simultaneously carrying ethical, environmental, or societal dimensions (Viehmann et al., 2024). Because SSI are inherently controversial and resist simple resolution, they naturally require students to critically examine scientific evidence and weigh competing perspectives. In this way, SSI provide an authentic learning context that bridges abstract scientific content and real-world challenges (Sadler et al., 2016; Zeidler, 2016). Within chemistry education specifically, SSI integration has been shown to meaningfully develop students' critical thinking particularly in analysis, evaluation, and reflective judgment. While also helping students recognize chemistry not merely as abstract knowledge, but as a discipline with tangible social, environmental, and ethical consequences (Mutmainah & Cornelia, 2025; Utami & Budimarwanti, 2025).

Beyond these cognitive and contextual dimensions, chemistry education in Islamic higher education carries an additional and equally important responsibility: the cultivation of students' moral, spiritual, and character development (Chanifah et al., 2021). In this context, chemistry holds genuine potential as a vehicle for nurturing Islamic values inviting students to reflect on natural phenomena as expressions of Allah's creation, a practice known as *tadabbur* of the *kauniyah* verses (Hosaini & Akhyak, 2024). Realizing this potential, however, requires that Islamic values be intentionally and systematically woven into the fabric of instructional design, rather than treated as peripheral additions (Qomar et al., 2024).

A systematic review of literature published between 2020 and 2025 reveals a persistent gap in the field: no existing study has simultaneously integrated SSI-based contextual learning, Islamic values, and an e-module format within a single, validated instructional product. A search across Google Scholar, ERIC, and SINTA-indexed Indonesian journals using combined keywords "SSI chemistry e-module," "Islamic values chemistry learning," and "HOTS e-module higher education" returned 47 potentially relevant studies, none of which, upon full-text screening, addressed all three dimensions at once. While Arifin et al. (2024) and Yanti & Iriani (2024) developed SSI-based or problem-based chemistry e-modules, Islamic values integration was absent from both. Studies focused on Islamic values in chemistry such as Hosaini & Akhyak (2024) and Qomar et al. (2024) operated at conceptual or curricular levels without producing validated, student-ready materials. Chanifah et al. (2021) addressed Islamic values in science education but without SSI as the contextual driver for critical thinking. Meanwhile, Mutmainah & Cornelia (2025) and Utami & Budimarwanti (2025) affirmed SSI's effectiveness for critical thinking development, yet neither incorporated Islamic values nor adopted an e-module format. The triple integration of SSI-based contextual learning, systematic Islamic values, and an e-module designed for higher-order thinking at C4–C6 levels remains unexplored and this constitutes the distinctive contribution of the present study.

The triple integration of SSI-based contextual learning, systematic *ayat kauniyah* integration, and a higher-order thinking e-module designed at the C4–C6 levels of Bloom's Taxonomy remains unexplored in the existing literature. It is this gap that the present study attempts to fill not through theoretical or methodological novelty, but through the development and feasibility validation of a structured instructional product. The contribution of this study, therefore, lies in operationalizing what the authors term the *Three-Phase SSI–Ayat Kauniyah Integration Framework*: a deliberate and progressive design model in which chemistry content, SSI contextual cases, and Islamic values are sequenced across three phases within an e-module built around FRISCO-based critical thinking tasks. It must be honestly acknowledged that this study focuses on product development and validation, and that effectiveness data particularly regarding the e-module's actual impact on students' critical thinking remain to be addressed in future research.

2. Research Method

This study adopted a research and development (R&D) approach, guided by the 4-D development model introduced by Thiagarajan. The model consists of four sequential stages: *define*, *design*, *develop*, and *disseminate*. Before describing each stage in detail, it is important to be transparent about the scope of this study: the research was deliberately bounded to the first three stages define, design, and develop with the disseminate stage conducted only in a limited form as part of the practicality assessment. No effectiveness testing was carried out, and the impact of the e-module on students' critical thinking skills has not been empirically measured. This limitation is acknowledged openly and is identified as the primary direction for future research.

2.1. Define

The define stage was aimed at identifying fundamental problems and learning needs that would inform the development of the instructional product. This involved a front-end analysis covering five areas: needs analysis, student characteristics analysis, curriculum analysis, content analysis, and task analysis (Putri et al., 2023). The needs analysis explored students' requirements for instructional materials, their familiarity with Socio-Scientific Issues (SSI), and their awareness of Islamic values as a meaningful dimension of chemistry learning. Data gathered through a structured questionnaire. Student characteristics analysis examined learning profiles and students' baseline conditions with respect to critical thinking, drawing on preliminary observations and existing learning documentation. Curriculum analysis reviewed the Program Learning Outcomes (CPL), Course Learning Outcomes (CPMK), and Sub-CPMK of the Basic Chemistry course to ensure the e-module aligned with the Outcome-Based Education (OBE) framework. Finally, content and task analyses were conducted to map the essential chemistry topics, select contextually relevant SSI cases, identify the most appropriate *ayat kauniyah* for integration, and design learning activities that reflect critical thinking indicators at the C4–C6 levels.

2.2. Design

The design stage translated the findings from the define stage into a concrete instructional prototype. Drawing on established principles of e-module design (Wijaya et, al., 2022), the team selected the e-module format as the primary instructional medium, given its capacity for interactive and self-directed learning. The prototype structure included learning outcomes, SSI-based chemistry content integrated with *ayat kauniyah*, FRISCO-based critical thinking tasks, evaluation instruments, chapter summaries, a glossary, references, and appendices. It is worth noting that the design decisions including the sequencing of SSI cases, the placement of Qur'anic verses as conceptual anchors rather than decorative elements, and the formulation of guided reflection questions were grounded in the *Three-Phase SSI–Ayat Kauniyah Integration Framework* described in the introduction, rather than applied generically.

2.3. Develop

The develop stage consisted of two phases: expert appraisal and developmental testing (Marinu, 2024). Expert appraisal involved the structured validation of the e-module by three domain-specific validators: a chemistry content expert, an instructional design expert, and an Islamic integration expert. Each validator used a purpose-built rubric with 1–4 Likert-scale items accompanied by a qualitative comment field, allowing for both quantitative scoring and substantive written feedback. Developmental testing was subsequently conducted with 12 first-semester students using a practicality questionnaire covering ease of access and navigation, interface clarity, time efficiency, and suitability for self-directed learning.

2.3.1. Validator Role and Validation Procedure

To establish the credibility and face validity of the expert appraisal process, validators were selected according to specific academic qualifications and domain expertise relevant to the e-module's content and design. Table 1 summarizes the validator roles, domains assessed, and instruments used.

Table 1. Validator Roles, Domains Assessed, and Instruments Used

Validator Role	Domain Assessed	Instrument Used
Chemistry Content Validator	Scientific accuracy; SSI relevance; HOTS task quality (C4–C6); language appropriateness for first-semester students	Content Validity Rubric (20 items, 1–4 Likert + qualitative comment field)
Instructional Design (Construct) Validator	Instructional flow coherence; learning objective clarity; structural component adequacy; format suitability for independent learning	Construct Validity Rubric (16 items, 1–4 Likert + qualitative comment field)
Islamic Integration Validator	Contextual relevance of Qur'anic verses; conceptual depth of integration; theological accuracy; consistency across all five topics	Islamic Integration Validity Rubric (12 items, 1–4 Likert + qualitative comment field)
Practicality Respondents (Student Panel)	Ease of access, use, and navigation; time efficiency; interface attractiveness; ease of SSI and Islamic values implementation; content suitability	Student Response Questionnaire (9 items, 1–4 Likert + open-ended comment field)

The validation procedure followed a structured, sequential protocol designed to ensure methodological transparency and replicability. First, the complete e-module draft was compiled in PDF format and distributed to each validator along with their respective domain-specific rubric and a scoring guide explaining the 1–4 Likert descriptors. Each validator then assessed the e-module independently, without consultation with other validators or the research team, before submitting their completed rubric and written qualitative feedback. The research team reviewed all feedback and categorized it into three revision types: (a) content accuracy revisions, (b) content sequencing revisions, and (c) Islamic values integration revisions. Every recommended revision was recorded in a structured revision log documenting the original validator comment, the revision category, and the specific action taken and the revised e-module was returned to each validator for confirmation before final validity scores were calculated.

Following expert validation, the practicality assessment was conducted in a single structured session. Twelve first-semester students independently navigated and used the e-module, then completed the practicality questionnaire individually without guidance from the research team. This step-by-step procedure is documented in full here to support replicability, enabling other researchers to reproduce the appraisal process in comparable development contexts.

To further clarify the most novel and potentially ambiguous component of the validation process the assessment of Islamic values integration. Table 2 presents the complete Likert-scale descriptors for the Islamic Integration Validity Rubric. These descriptors operationalize the distinction between *conceptual* and *symbolic* integration, making the standard verifiable and reproducible across different contexts.

Table 2. Likert-Scale Descriptors for the Islamic Integration Validity Rubric

Score	Category	Descriptor: Conceptual Depth of Islamic Values Integration	Descriptor: Guided Reflection Question Quality
4	Very Valid	Islamic values are organically embedded as conceptual frameworks that directly shape how students analyze, evaluate, or solve the SSI problem; the verse/value is indispensable to the learning task, not decorative	Open-ended question requires students to explicitly connect the verse's meaning with a specific scientific or social dimension of the SSI case; answer cannot be resolved by quoting the verse alone
3	Valid	Islamic values are contextually relevant and meaningfully connected to the topic, but integration is primarily through text presentation rather than as an active learning framework in student tasks	Question prompts students to reflect on the verse in relation to the topic, but the connection to the SSI analysis is general rather than specific; a surface-level response is possible
2	Quite Valid	Qur'anic verse is present but its relationship to the chemistry content or SSI case is implicit; the integration reads as supplementary or decorative rather than conceptually necessary	Question asks students to state the meaning of the verse without requiring connection to the scientific topic; reflection is devotional rather than analytical
1	Not Valid	No Qur'anic verses or Islamic values are present, or those included are theologically inaccurate or contextually unrelated to the chemistry topic	No guided reflection question is provided, or the question can be answered without reading the verse or engaging with the chemistry content

2.4. Disseminate

The disseminate stage in this study was carried out in a limited scope, focusing on the distribution of the finalized e-module to students of the Chemistry Education (Tadris Kimia) Program, Faculty of Tarbiyah and Teacher Training, UIN Mahmud Yunus Batusangkar, as part of the practicality assessment. To reiterate what was stated at the outset: this study does not include effectiveness testing. Any reference to the e-module's potential to support critical thinking should be understood as a theoretically and design-grounded claim-derived from the framework's alignment with FRISCO indicators and C4–C6 cognitive levels-rather than an empirically demonstrated outcome. Whether the e-module actually improves students' critical thinking skills remains an open question and constitutes the most important direction for future research.

3. Result and Discussion

3.1. Define

Result and discussion contain the results of the analysis of phenomena in the research area that are relevant to topic of the study. Research results should be compared with relevant theories and research findings.

3.1.1. Needs Analysis

The needs analysis revealed that Basic Chemistry learning at the Tadris Kimia program had not been implemented in a contextual manner. Instructional materials in use still emphasized theoretical concepts without connecting them to real-world socio-scientific issues such as environmental problems, food safety, public health, or emerging technologies, leaving students with limited opportunities to engage in meaningful chemical reasoning. No SSI-based instructional materials had been systematically developed for this course, and Islamic values were introduced only incidentally, without a structured and conceptually grounded framework. To quantify this gap, a diagnostic assessment was administered to 32 first-semester students at the beginning of the academic year. The results were telling: 87.5% of students (28 out of 32) scored below the minimum competency threshold of 60 on HOTS-based tasks, with a class mean of 38.49. Furthermore, 91% of students (29 out of 32) had never encountered an SSI-based learning context in their prior chemistry education, and 78% (25 out of 32) were unable to identify any connection between Qur'anic verses and chemical phenomena when prompted. These figures confirm that the need for contextual, value-integrated learning materials is not merely theoretical. It has concrete, measurable consequences for students' readiness for higher-order thinking. Additionally, more than 70% of students (23 out of 32) expressed a preference for digital learning materials in the form of e-modules, citing their flexibility, accessibility, and capacity to support independent learning as key advantages.

3.1.2. Student Characteristics Analysis

Student characteristics analysis confirmed the picture painted by the diagnostic data. Based on a four-tier HOTS-based multiple-choice assessment on the topics of the greenhouse effect and global warming, first-semester students demonstrated a low average critical thinking score of 38.49. This result indicates that students' thinking at this stage tends to be dominated by memorization and surface-level recall, rather than analytical or evaluative reasoning a profile that the designed e-module directly seeks to address.

3.1.3. Curriculum Analysis

Curriculum analysis showed that the Program Learning Outcomes (CPL), Course Learning Outcomes (CPMK), and Sub-CPMK of the Basic Chemistry course place explicit emphasis on the development of higher-order thinking skills, including critical thinking, within an Outcome-Based Education (OBE) framework. These curricular mandates provided clear guidance for determining content scope, selecting relevant SSI contexts, and identifying appropriate points for Islamic values integration. The developed e-module was therefore structured to align directly with these stated learning outcomes.

3.1.4. Content Analysis

Content analysis identified five core Basic Chemistry topics as the basis for the e-module: atomic structure and the periodic system, chemical bonding, stoichiometry, acid–base concepts, and thermochemistry. Each topic was examined for its relevance to contemporary socio-scientific issues, including the greenhouse effect, global warming, nanoparticles and food safety, water pollution, industrial waste, and environmentally friendly energy technologies. At the same time, each topic was systematically mapped to relevant Qur'anic principles, including the halal–haram framework, the prohibition of wastefulness (*israf*), environmental stewardship (*khalifah fil ardh*), and the principle of balance (*mizan*). The analysis confirmed that all five selected topics have strong conceptual potential for SSI contextualization and Islamic values integration, providing a solid foundation for the e-module design.

3.1.5. Task Analysis

Task analysis identified the specific learning tasks embedded in the e-module, all of which are organized around the FRISCO critical thinking framework. These tasks include: (1) Focus: problem identification activities requiring students to analyze SSI cases and identify core issues; (2) Reason: argumentation tasks requiring justification using scientific concepts, empirical data, and Qur'anic principles; (3) Inference: conclusion-drawing exercises guiding students to formulate evidence-based solutions; (4) Situation: contextual problem-solving tasks applying chemical concepts to real-world issues; (5) Clarity: explanation tasks requiring students to clarify scientific terms, chemical processes, and ethical reasoning; and (6) Overview: reflective activities in which students evaluate their own reasoning and ethical decisions comprehensively.

3.2. Design

3.2.1. Media Selection

Based on the findings from the define phase, an e-module was selected as the instructional medium. This decision was informed by the e-module's capacity to present content in a flexible digital format, support self-directed learning, and accommodate the integration of SSI-based contextual cases and Islamic values within a coherent learning system.

3.2.2. Format Selection

The e-module was designed using a structured, eight-component format: (1) Introduction/Learning Motivation, (2) Learning Objectives, (3) Chemistry Content, (4) SSI Contextual Cases, (5) Qur'anic Verses/Islamic Values, (6) Learning Activities, (7) Summary, and (8) Evaluation or Final Assessment. This format was selected to support systematic progression from conceptual understanding to contextual application and ethical reflection.

3.2.3. Initial Product Design and E-Module Structure

The initial product design translated the define-phase findings into a concrete instructional prototype. The figures below (Figures 1–5) present selected visual samples of the e-module's interface and content structure.

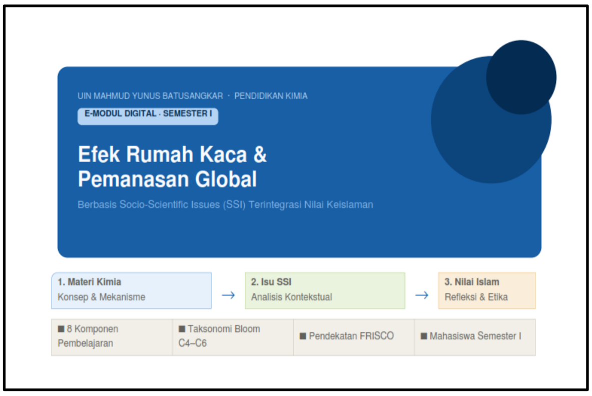

Figure 1. Cover of E-Module

Figure 1 shows the cover of the module, which presents the title "Efek Rumah Kaca & Pemanasan Global" with a Socio-Scientific Issues (SSI) and Islamic integration approach. This section is designed to build foundational understanding of environmental chemistry phenomena.

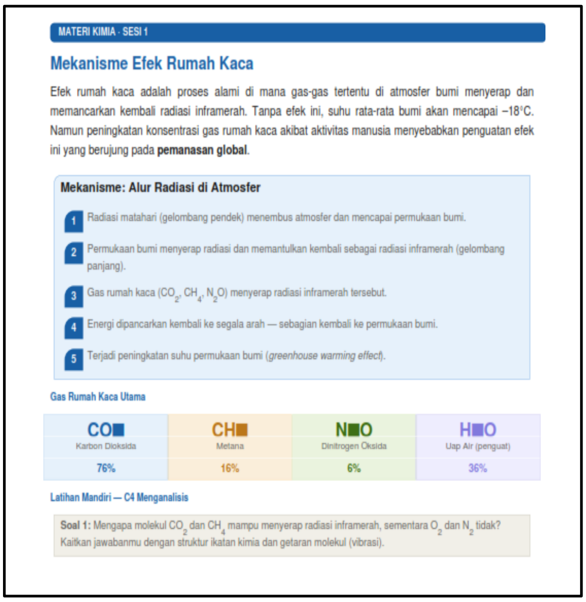

Figure 2. Chemistry Content Page

Figure 2 continues with the main conceptual explanation of the greenhouse effect, describing radiation mechanisms and atmospheric processes. This section builds foundational understanding of environmental chemistry concepts.

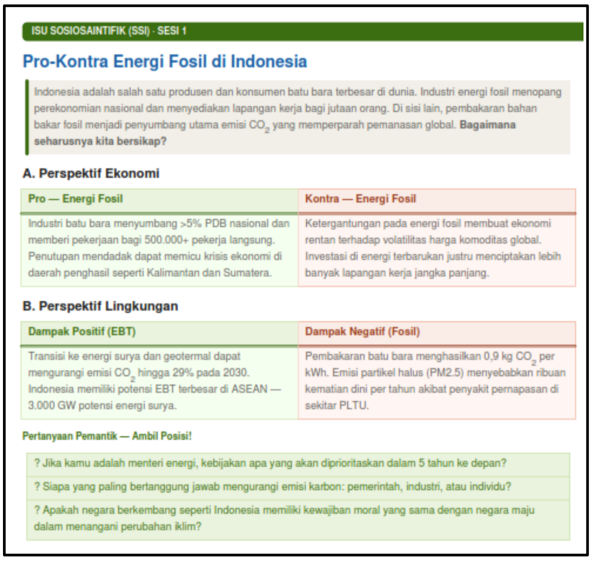

Figure 3. Sample SSI Content Page

Figure 3 presents the Socio-Scientific Issues (SSI) activity on pro–contra fossil energy use in Indonesia. It encourages students to analyze real-world issues from economic and environmental perspectives while developing critical thinking skills.

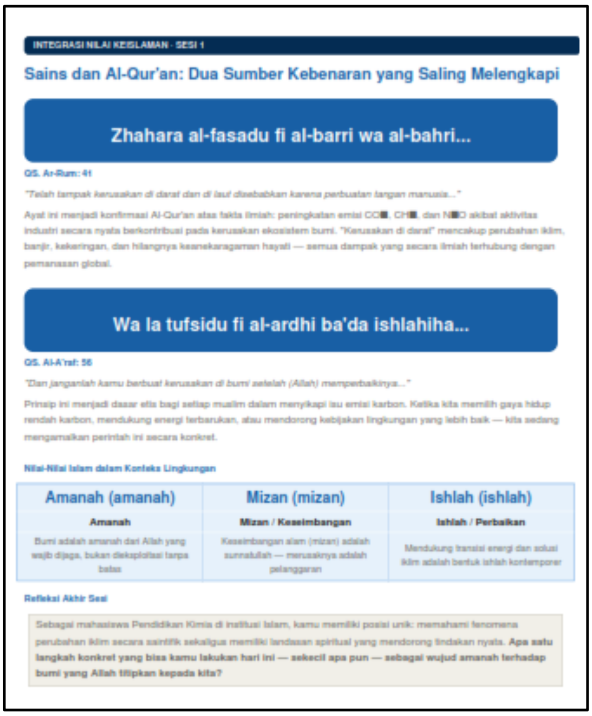

Figure 4. Sample Islamic Values Integration Page

Figure 4 shows the Islamic value integration page, linking environmental issues with ethical and religious responsibility.

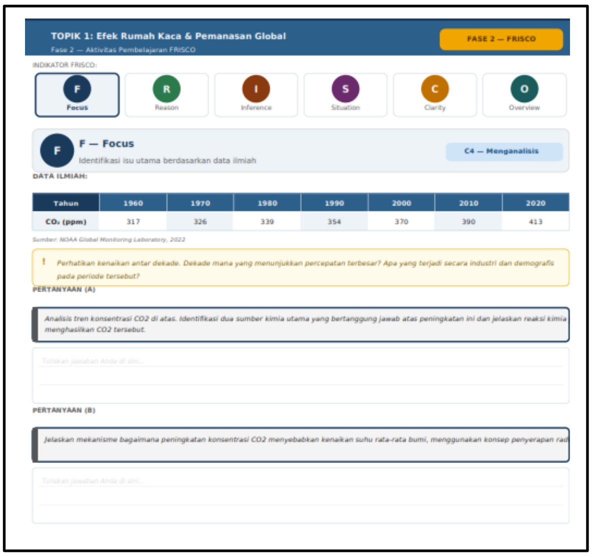

Figure 5. Sample FRISCO Learning Activity Page

Figure 5 presents the FRISCO-based learning activity page, which guides students in structured critical thinking. The eight components of the e-module are not presented as isolated elements but are organized as an interconnected learning system governed by the Three-Phase SSI–Ayat Kauniyah Integration Framework, which sequences learning across three progressive phases in each session:

Phase 1 - Chemistry Content Presentation. Each session opens by introducing foundational chemistry concepts progressively, from simpler to more complex ideas, calibrated to the level of first-semester students. This phase equips students with the scientific knowledge they need before engaging with more complex and contested issues. For example, in the Greenhouse Effect and Global Warming topic, students are first introduced to the chemical basis of the greenhouse effect: the role of CO_2, CH_4, N_2O, and H_2O in absorbing and re-emitting infrared radiation. A common student misconception - that the greenhouse effect is inherently harmful - is directly addressed at this stage: the e-module explicitly distinguishes between the natural greenhouse effect (essential for life) and the enhanced greenhouse effect (driven by anthropogenic emissions).

Phase 2 - SSI Contextual Case Presentation. Once conceptual understanding is established, students are guided to analyze real-world socio-scientific cases from multiple perspectives: scientific, social, economic, and environmental. SSI cases are presented with factual data, triggering questions, and contextual scenarios relevant to students' lives. In the Greenhouse Effect topic, for instance, students are presented with data from the Ministry of Energy and Mineral Resources (2022) indicating that coal combustion accounts for approximately 40% of Indonesia's national electricity generation, releasing an estimated 220 million tons of CO_2 annually. Against Indonesia's Paris Agreement commitment to a 29% emissions reduction by 2030, students are asked: *"Given Indonesia's energy needs and its climate commitments, should the country accelerate the phase-out of coal power plants? Construct your argument using chemical data, economic considerations, and ethical reasoning."* This type of triggering question requires students to synthesize chemical concepts with socioeconomic and policy dimensions, exemplifying authentic SSI-based learning.

Phase 3 - Integration of Islamic Values. Islamic values are not confined to a single section of the e-module but are distributed strategically across three integration points within each session. *First*, at the opening of each session, Qur'anic verses related to human responsibility toward nature (e.g., QS. Al-Baqarah: 30; QS. Al-A'raf: 56) are presented as spiritual motivation. *Second*, after the chemistry content, *ayat kauniyah* are integrated as theological confirmation that science and revelation are complementary. For example, QS. Ar-Rum: 41 is introduced following the explanation of greenhouse gas emissions, with a guided reflection question requiring students to explicitly connect the verse's message with the scientific data they have analyzed - not simply to quote it. *Third*, at the close of each session, Islamic ethical values - including *amanah* (stewardship), *mizan* (balance), and *ishlah* (reform) - are presented as ethical lenses through which students evaluate their proposed solutions to the SSI case. This distributed integration demonstrates that Islamic values function as active analytical frameworks, not decorative additions.

The e-module's instructional design adheres to the principles of coherence and learning sequence proposed by Branch (2009). Coherence is operationalized through the logical interconnection among the eight components: each element is designed to reinforce the others, so that students experience the content as a unified learning journey rather than a collection of isolated parts. The learning sequence principle is operationalized through the three-phase flow, where each phase builds progressively upon the previous one. It must be honestly acknowledged that the current version of the e-module is presented in text and image format and does not yet include interactive features such as embedded videos, simulations, or automated feedback systems. This is recognized as a limitation, and the addition of interactive elements is planned as part of future development to more fully distinguish the e-module from a static document and to enhance student engagement.

3.3. Develop

3.3.1. Expert Validation (Validity Results)

The expert appraisal phase aimed to determine the validity of the developed e-module across three domains: chemistry content, instructional design (construct), and Islamic values integration. Validation results show that the e-module achieved an overall mean validity score of 3.76, placing it in the Very Valid category. The full validation results are presented in Table 3.

Table 3. Expert Validation Results of the Developed E-Module

Content Validator	Construct Validator	Islamic Values Validator	Average (Category)
3.83	3.78	3.66	3.76 (Very Valid)

The high content validity score (3.83) reflects that the chemistry explanations are scientifically accurate, appropriately sequenced for first-semester students, and contextually anchored in relevant SSI cases. The construct validity score (3.78) indicates that the e-module was designed with a systematic and coherent instructional flow consistent with established instructional design principles (Branch, 2009). The Islamic values integration score (3.66) confirms that Qur'anic verses and Islamic ethical values were embedded in a conceptually meaningful way. Not as symbolic additions, but as active components of the learning process aligned with the standards operationalized in the Islamic Integration Validity Rubric. Together, these scores confirm that the developed e-module meets high validity standards and is feasible for use in Basic Chemistry learning. Importantly, these validity scores were not the only output of the expert appraisal process. Each validator also provided substantive written feedback that informed iterative revisions to the e-module. The following section presents the key qualitative findings from the validation process to provide the transparent account of the development process that is essential for a high-quality development study.

3.3.2. Qualitative Findings from Content Validation

Beyond the quantitative scores, content validators provided specific observations across three revision categories.

Content Accuracy. The chemistry content validator confirmed that chemical facts, equations, and explanations were scientifically accurate and appropriately referenced. However, the validator recommended incorporating more recent emission data (post-2020) to strengthen the SSI contextual cases. This revision was implemented by updating greenhouse gas emission figures to reflect data from the Ministry of Environment and Forestry (2022).

Content Sequencing. The validator affirmed that the three-phase progression from chemistry content to SSI to Islamic values was logical and appropriate for the target learner group. A recommendation was made to add a brief review of prerequisite concepts (e.g., molecular polarity and intermolecular forces) at the beginning of the greenhouse gas section to better bridge students' prior knowledge. This bridging section was incorporated accordingly.

Islamic Values Integration. The Islamic integration validator confirmed that the selected Qur'anic verses were contextually and theologically appropriate. The validator recommended adding explicit guided reflection questions to ensure that students actively engage with the verses rather than passively reading them. This recommendation was implemented by adding open-ended reflection prompts after each Qur'anic reference throughout the e-module, fulfilling the conceptual-rather-than-symbolic integration standard.

These revisions demonstrate that the validation process was substantive rather than perfunctory, and that the e-module presented here reflects iterative, expert-informed improvement rather than a first draft.

Sample C4–C6 Exercises: Evidence of Higher-Order Thinking Tasks

To substantiate the claim that the e-module incorporates genuine higher-order thinking exercises, the following sample questions are drawn from the evaluation section of the Greenhouse Effect and Global Warming topic. Each question is mapped to a specific FRISCO indicator and Bloom's Taxonomy cognitive level. The complete HOTS task blueprint across all six topics is provided in Table 6.

Question 1 [C4 Analyze | FRISCO: Focus & Reason]

The table below presents CO_2 concentration data (ppm) in the atmosphere from 1960 to 2020 at 10-year intervals: 317 ppm (1960), 326 ppm (1970), 339 ppm (1980), 354 ppm (1990), 370 ppm (2000), 390 ppm (2010), 413 ppm (2020). Based on this data: (a) Analyze the trend in CO_2 concentration and identify the two main chemical sources responsible for this increase. (b) Explain the mechanism by which increased CO_2 concentration causes global temperature rise, using the concept of infrared radiation absorption. (c) Identify which decade showed the greatest rate of increase and propose a scientifically grounded explanation for this acceleration.

Question 2 [C5 Evaluate | FRISCO: Inference & Situation]

Two policy proposals are being debated to address global warming in Indonesia: (Policy A) imposing a carbon tax of IDR 75.000 per ton of CO_2 on all industrial emitters; (Policy B) subsidizing a large-scale transition to renewable energy sources (solar and geothermal). Evaluate the scientific effectiveness, socioeconomic feasibility, and alignment with Islamic environmental ethics (mizan and ishlah) of both policies. Which policy would you recommend, and why? Support your judgment with chemical, economic, and ethical arguments.

Question 3 [C6 Create | FRISCO: Clarity & Overview]

Design a campus-level carbon footprint reduction program for UIN Mahmud Yunus Batusangkar. Your program must: (a) identify the three largest sources of campus CO_2

emissions and explain their chemical basis; (b) propose specific, measurable reduction strategies for each source grounded in chemical principles; (c) integrate at least two Islamic values (e.g., amanah, ishlah) as guiding principles for the program; and (d) present your plan in the form of a one-page policy brief addressed to the university rector, including projected emission reductions and an implementation timeline.

These exercises demonstrate that the e-module's evaluation tasks genuinely operate at the C4–C6 levels of Bloom's Taxonomy. Students are required to move well beyond recall and comprehension toward analysis of real data, evaluation of competing policy options, and creation of an integrated, evidence-based plan that incorporates scientific, socioeconomic, and Islamic ethical dimensions. The complete task blueprint for all six topics is provided in Table 4.

Table 4. HOTS Task Blueprint (Kisi-Kisi Soal HOTS) of the SSI-Based Chemistry E-Module

Topic	Task Description	Bloom's Level	FRISCO Indicator	Islamic Value Integrated
Greenhouse Effect & Global Warming	Analyze CO_2 trend data; argue coal phase-out policy using chemical, economic, and ethical evidence	C4–C6	Focus, Reason, Inference, Situation, Clarity, Overview	Amanah, Mizan, Ishlah (QS. Ar-Rum: 41)

Theoretical and Preliminary Empirical Basis for Expected Impact on Critical Thinking

It must be explicitly stated that this study does not include an effectiveness evaluation. The actual impact of this e-module on students' critical thinking skills has not been empirically measured, and all references to the e-module's potential to foster critical thinking should be understood as theoretically and design-grounded claims rather than empirically validated outcomes. This constitutes the primary limitation of the current study.

That said, there is a robust theoretical and empirical basis from prior research that supports the expectation of a positive impact. From a theoretical standpoint, Zeidler (2016) and Sadler et al. (2016) established that SSI contexts inherently facilitate the development of critical thinking because they require students to engage in evidence-based argumentation, perspective-taking, and reflective judgment - precisely the processes targeted by FRISCO-based tasks. The Three-Phase SSI–Ayat Kauniyah Integration Framework directly operationalizes this theoretical mechanism: Phase 1 builds the conceptual tools, Phase 2 applies them to contested real-world problems, and Phase 3 adds an ethical evaluative dimension through Islamic values. Empirically, SSI-integrated chemistry learning has consistently been associated with gains in critical thinking. Mutmainah & Cornelia (2025) and Utami & Budimarwanti (2025) documented improvements in students' analytical and evaluative reasoning following SSI-embedded instruction, while Yanti & Iriani (2024) and Sandi et al. (2025) found that HOTS-oriented e-modules with problem-based learning resulted in measurable critical thinking score improvements. The present e-module aligns with the instructional design principles of these studies by embedding FRISCO-based tasks and C4–C6 exercises throughout all five topics. Preliminary qualitative signals from the practicality assessment offer tentative supporting evidence. During developmental testing, students' open-ended responses indicated that they found the SSI cases "challenging but meaningful," and that the Qur'anic reflection questions prompted them to think beyond the scientific data toward ethical and social dimensions - behaviors consistent with analytical and evaluative thinking. The high practicality scores for SSI implementation (Indicator 7: P = 3.72) also suggest that the instructional conditions necessary for critical thinking development were present during the testing phase. These observations are not presented as evidence of effectiveness; they are preliminary qualitative signals that provide a principled foundation for the hypothesis - to be formally tested in a future quasi-experimental study - that this e-module has genuine potential to foster critical thinking skills in first-semester chemistry education students.

3.3.3. Practicality Assessment Results

Following expert validation, the e-module was evaluated for practicality by 12 first-semester Tadris Kimia students in a single structured session. The overall practicality score of 3.39 places the e-module in the Practical category. The results for each indicator are presented in Table 5.

Table 5. Practicality Assessment Results of the Developed E-Module

No	Practicality Indicator	Score (P)	Category
1	Ease of access to the e-module	3.72	Very Practical
2	Ease of use of the e-module	3.24	Practical
3	Ease of navigation of the e-module	3.28	Practical
4	Time efficiency for accessing the e-module	3.48	Practical
5	Time efficiency for using the e-module navigation	3.36	Practical
6	Attractiveness of the e-module interface	3.68	Very Practical
7	Ease of implementing SSI activities using the e-module	3.72	Very Practical
8	Ease of implementing Islamic values integration using the e-module	2.68	Practical
9	Suitability of e-module content for differentiated chemistry instruction	3.36	Practical
	Overall Average	3.39	Practical

The practicality scores indicate that students found the e-module easy to access (3.72, Very Practical), visually attractive (3.68, Very Practical), and well-suited to implementing SSI-based activities (3.72, Very Practical). The slightly lower score for Islamic values integration (Indicator 8: 2.68, Practical) reflects the relative novelty of this dimension for students - most had limited prior experience connecting Qur'anic content with scientific reasoning. This finding underscores the importance of the guided reflection questions introduced following validator feedback, and points to Islamic values integration as a dimension requiring continued attention in future iterations of the e-module.

The high practicality scores for SSI implementation and interface attractiveness suggest that the e-module successfully creates the instructional conditions engagement, accessibility, and navigability that are prerequisites for meaningful learning. These findings are consistent with studies on SSI-based digital learning materials that link ease of use with deeper student engagement in issue analysis and decision-making tasks (Zeidler, 2016; Mutmainah & Cornelia, 2025).

4. Conclusion

This study resulted in the development of an SSI-based basic chemistry e-module integrated with Islamic values that meets high standards of quality in terms of validity and practicality. The expert validation results indicate that the e-module is very valid, reflecting appropriate content accuracy, instructional design, and contextual integration of Islamic values. Furthermore, the practicality assessment shows that the e-module is practical to very practical, indicating that it is easy to access, easy to use, and feasible for implementation in chemistry lectures.

However, it must be transparently acknowledged that this study is limited to the validation and feasibility testing stages of the 4D development model. Several limitations of this studywarrant explicit acknowledgment. First and most critically, this study does not include an effectiveness evaluation. The claim that this e-module supports the development of critical thinking skills is a design intention grounded in established instructional theory and SSI-based learning principles, not an empirically demonstrated outcome. This distinction is fundamental. Second, the practicality assessment involved only 12 students from a single study program, which limits the generalizability of the findings.

Third, in its current form the e-module does not yet incorporate interactive digital features such as embedded videos, simulations, or automated feedback, which may affect student engagement in broader implementation settings. These limitations collectively underscore the necessity of a follow-up study employing an experimental or quasi-experimental design to empirically examine the actual impact of this e-module on students' critical thinking skills across diverse contexts.

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