Web module on nuclear disaster mitigation using ENACT Model: An effort to enhance student social responsibility

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Abstract
Past failures in nuclear technology have highlighted the essential role of society in mitigating radiation impacts and ensuring proper oversight. To enhance awareness and understanding, especially among students, about the effects of technological failures and the necessary mitigation measures, more effective and efficient education is needed. This study aims to develop a web module based on the ENACT (Engage, Navigate, Anticipate, Conduct, and Take Action) model designed to enhance students' social responsibility. Social responsibility is a critical aspect that every individual in society should possess, particularly in addressing and mitigating nuclear disasters that require deep knowledge and high social awareness. Through the Socio Scientific Issues (SSI) approach, this web module integrates theoretical and practical aspects of learning, enabling students not only to comprehend the concepts of radiation physics but also to develop a responsible attitude towards society and the environment. This research employs a research and development (R&D) method encompassing analysis, design, development, implementation, and evaluation phases. The results indicate that the use of the ENACT model in this web module is effective in fostering students' social responsibility, as evidenced by their improved understanding of radiation physics and active engagement in discussions and simulations of nuclear disaster mitigation. The implications of this study highlight the importance of integrating educational technology with character development to produce a generation that is competent and socially responsible in facing global challenges.

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1. Introduction

The numerous nuclear technology failures that have occurred in the past (Meiliasari et al., 2022). Have underscored the crucial role of society in radiation impact mitigation and oversight (IAEA, 2014). To foster awareness and understanding, especially among students, about the impacts of technological failures and the measures for mitigation, more effective and efficient education is required(Erna et al., 2023; Syarif et al., 2023). The importance of social responsibility education for educators, students, and the broader community is well-documented (Ko, Y., Shim, S. S., & Lee, 2021). Although there is no specific definition of social responsibility, it generally emphasizes social activism to enhance the welfare and common good of society and the environment (Bielefeldt, 2018; Godhade, 2018; Ko, Y., Shim, S.S. & Lee, n.d.; Pimple, 2002; Wyndham et al., 2015).

In this context, fostering student responsibility in understanding the concepts of physics related to nuclear disaster mitigation becomes essential for raising awareness and capability within society to face nuclear disaster threats. It is essential to emphasize social responsibility in education given the growing complexity of nuclear technology and the possible hazards connected with technological failures. The environment, public health, and safety are all seriously threatened by nuclear disasters (Faishal, 2024), it is essential to inform and equip people with the knowledge and skills necessary to respond appropriately. Students can acquire the knowledge and perspective required to manage such situations appropriately by incorporating social responsibility into their curriculum.

Based on the identification of research trends in the field of socioscientific issues (SSI) using relevant articles and journals from 2019–2023 processed by VOSviewer. The keyword "Social Responsibility" showed up in small clusters and was not directly connected to socio-scientific issues, which means that there are few keywords applied to SSI or engagement during this period of time. The observation of this provides an area for future research (Allman et al., 2024), with the authors

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noting that there has been limited work in this space, and thus it serves as a clear direction to advance models from SSI exploration, namely through the ENACT model approach (Ko, Y., Choi, Y., 2022).

The research trends on social responsibility with the ENACT model have provided many study fields. One study examines the effect of education on social responsibility among science and engineering students in Korea by having adults at home create online courses (Erna et al., 2023; Gahyoung Kim, Hyunju Lee, Yeonjoo Ko, 2021). Research has also been done on simulation technologies in science and engineering as part of STEM education research at Korean campuses. The existence of educational programs that deal with social responsibility among university students in Indonesia will still be limited. This points to a very important aspect to be improved (Erna et al., 2023). In order to narrow this gap, the research reported in this paper aims at contributing to the evolution of studies dealing with physics teaching. This research combines a thorough literature review with state-of-the-art design methodologies to build an educational product that includes fundamental physics concepts in disaster-aversion learning oriented towards the problems of nuclear technology failures.

The ENACT (Engage, Navigation, Anticipate, Counduct and Take action) encompasses two cycles. The first cycle aims to help students understand the basics of science and technology knowledge through three steps: engage, navigate, and anticipate. These steps guide students to comprehend four key elements: the social implications of science and technology, the perspectives of various stakeholders, the moral and ethical aspects of science and technology, and the complexity and uncertainty (Ko, Y., Choi, Y., 2022). In the second cycle, through the conduct and take action steps, students are encouraged to practice responsive, inclusive, reflective, and sustainable learning activities (Erna et al., 2023; Serena Shim, Sungok, 2020).

Several previous studies have discussed the importance of integrating information technology with educational approaches to foster social responsibility among students. For instance.(Lawhon, 1976; Liu, L., & Johnson, n.d.; Sheard & Markham, 2005; Woo et al., 2008) that combine online and face-to-face learning for increased student engagement. However, these previous studies have not fully integrated disaster mitigation into the learning process. In addition, none of the other studies have focused on implementing an enrichment module through a web-based learning unit about physics for mitigation and then integrating it with the ENACT model (Engage, Navigate, Anticipate, Conduct, Take Action) to prevent disaster as well. As such, this study aims to address this gap by producing a web module based on the ENACT model to increase awareness of student accountability in science.

Prior research has shown that the ENACT model, or scaffolding instruction to foster student responsibility, with (Serena Shim, Sungok, 2020) provides templates for instructors on how they can use a number of learning tools. The effects of the ENACT model can vary across different fields of science and engineering. STEM professionals may be more sensitive to environmental consequences or human safety and welfare, depending on their specific field. Some fields are accustomed to communicating with the general public, while others primarily interact within their own communities (Erna et al., 2023). The ENACT model can be applied across all fields of science and engineering, as each field has its own societal issues to address, and SSIs naturally create an environment where STEM professionals and other stakeholders collaborate to resolve these issues. In this study, the ENACT model will be integrated with nuclear disaster mitigation steps and core physics concepts, providing a comprehensive and engaging learning experience. Students will not only gain a robust understanding of core physics theory and radioactivity but will also be encouraged to take concrete actions and make responsible decisions, as supported by (Ko, Y., Shim, S. S., & Lee, 2021; Payne & Jesiek, 2018)

The aim of this research is to identify the steps in the web module development process using Canva media design, collaborating with WordPress, and integrating SSI elements within the ENACT model to foster student social responsibility. This approach reflects the complex interrelationships between science, technology, and society, as discussed by (Subiantoro, 2017., Eastwood et al., 2012; Subiantoro, 2017a; Zandvoort et al., 2013; Zeidler, D L, T D Sadler, M L Simmons, 2005). Additionally, this study incorporates elements of social responsibility such as considering the social impact of science and technology, efforts to protect human welfare and safety, environmental sustainability, and effective communication with the community to reduce risks, as highlighted by (Ko, Y., Shim, S. S., & Lee, 2021).

2. Method

This research utilizes a research and development (R&D) approach, combining both qualitative and quantitative methodologies. The aim of this R&D approach is to produce a product through systematic processes including analysis, design, development, and evaluation (J. Michael Spector et al., 2014). The R&D method is adapted from the Borg & Gall development research model. Researchers can use these ten steps as needed, but they are not required to follow all development steps. Therefore, the researchers limited their study to the fifth step, the design revision. This decision was made because the research problem is focused on determining the product's usability. Additionally, the design revision stage is crucial in the development of a product or program, as it involves validating the product design by experts to correct deficiencies and maximize benefits. (Borg Walter R and Meredith D Gall 1983,). See Figure 1.

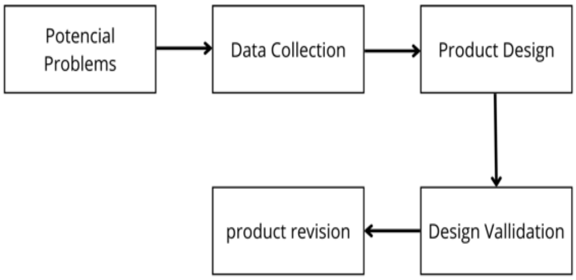


Figure 1. Research Method

In the design validation stage, data is collected through validation processes involving material and media experts. This step ensures that the design of web-modules using the ENACT model meets the required standards and is accepted by validators who are experts in the relevant fields. Although this validation is rational and has not been directly tested in the field, the evaluation results provide valuable insights for product improvement. The validation process is conducted in two stages. First, material experts test the validity of various types of materials, including nuclear energy content. They assess material elements, systematic presentation, and organizational structure to ensure the content meets college-level learning requirements. Recommendations for improvement are also provided. These experts ensure the presented information is relevant, accurate, and complies with applicable standards, offering a comprehensive perspective on potential issues in the material. Second, media experts evaluate the overall web-module design, offering input and criticism to ensure the product is user-ready. They focus on design aspects of the ENACT model to guarantee the product is engaging, informative, and user-friendly. See Table 1.

Table 1. Likert Scale

Percentage	Criteria	Description
75 % ≤ P ≤ 100 %	Very Good	Highly valid, can be used without revision
50 % ≤ P < 75 %	Good	Fairly valid, can be used with minor revisions
25 1% ≤ P < 50 %	Less Good	Less valid, not recommended for use due to major revisions needed
0% ≤ P < 25 %	Not Good	Not valid, cannot be used

2.1. Potencial Problems

The study conducted online interviews with students of the Physics Education program at UIN Raden Intan Lampung. The interview instruments focused on their understanding of socio-scientific (SSI) issues in physics and their perspective on social responsibility. Although students generally understand the use of technology and the internet in learning and the concept of SSI in physics education, some issues were identified, such as a lack of in-depth understanding and a lack of social responsibility awareness for the social problems around them. Furthermore, there is limited effort to integrate the concept of physical learning into the context of disaster mitigation.

The researchers considered developing modules as structured, easy-to-use, and independently accessible learning resources, which would then be integrated with a website supporting learning activities with additional discussion features and more interactive assignments. Website-based learning is classified into three types: fully online websites, courses combining online and face-to-face components, and online courses reinforced with face-to-face sessions (Asyhari & Diani, 2017; Lau et al., 2014). The type of website to be developed by researchers is a learning website that combines online and face-to-face components. The use of web modules allows students from various backgrounds and locations to take advantage of this learning material. Given the varying conditions and resources available in different educational institutions, this flexibility is crucial.

2.2. Data Collection

The data and information collection in this study includes the use of journals, previous research, books, as well as opinions from subject matter and media experts. Data and information are collected and analyzed thoroughly to obtain valid and relevant results.

2.3. Product Design

The ENACT model is used to integrate the web-module design during the design phase. Figure 2 describe the incorporates the steps from Cycle I and Cycle II as shown in Figure 2. The module is designed considering the steps in Cycle I, such as Engage, Navigate, and Anticipate, as well as the steps in Cycle II, including Responsive, Inclusive, Reflective, and Sustainable (Serena Shim, Sungok, 2020).

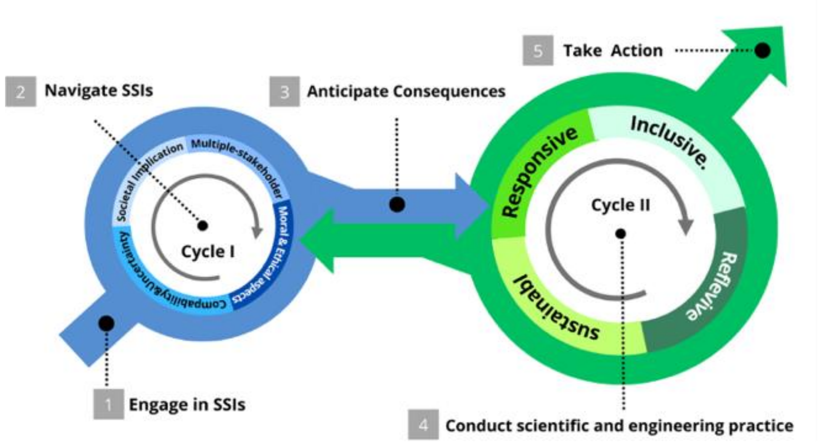


Figure 2. The ENACT Model

The module's content is compiled and pertinent topics, including nuclear energy, are properly integrated, thanks to the combination of Cycle I and II into the web-module structure, known as a flowchart, as shown in Figure 3.

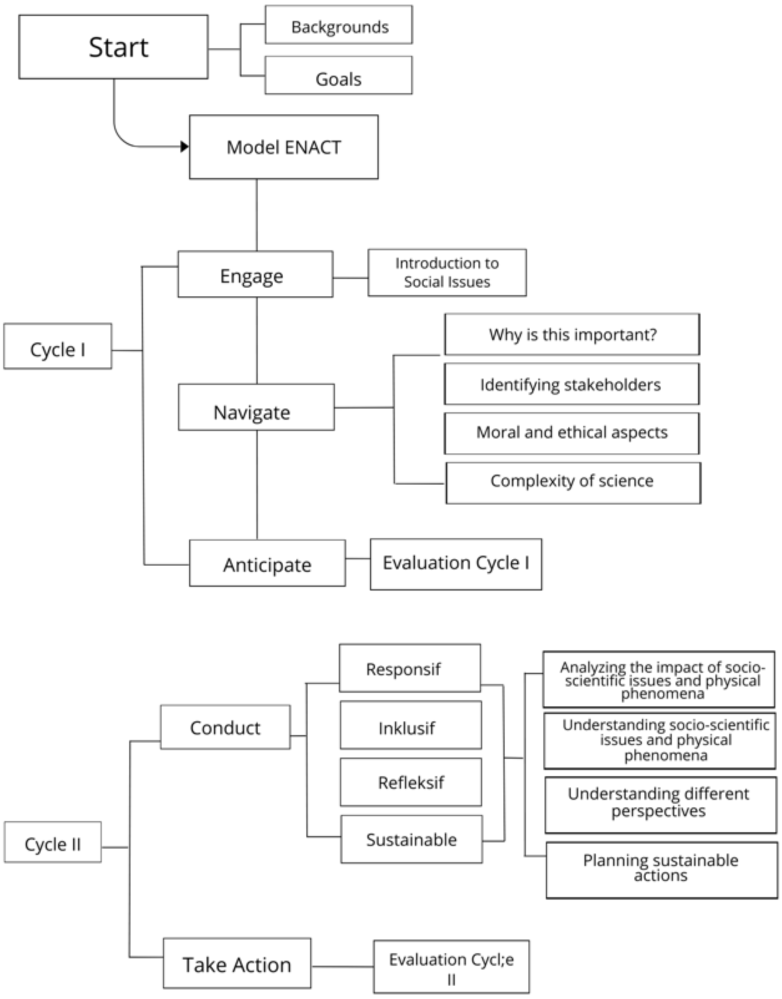


Figure 3. Flowchart Content

Furthermore, content design and activity tasks that support learning activities are created. Combining the Cycle I and II steps of the ENACT model helps to compile the content of the module and ensure that relevant materials, such as nuclear energy, are well integrated. Activity tasks are made to accelerate learning. Table 2 shows the content development matrix.

Table 2. Content Development Matrix

ENACT Component	Components within the module	Learning Activities in Modules	Social Responsibility Indicators loaded
Engage	Identification of nuclear disaster issues	explore the socioscientific issues that arise in the Web-modules of the selected issues is Nuclear Energy	Concern for human welfare and safety. (HUMAN)
Navigate	Understanding the Social Implications of Science and Technology,	Presentation of the theory of atomic core structure and nuclear reactions, radioactivity, and nuclear power plants	Risk considerations and social consequences (CONSEQ).
	Knowing multiple stakeholder	Identify the various parties involved.	Engagement and Community Service (CIVIC). The needs and demands of society (NEEDS).
	Moral and Ethical Aspects	Involve pupils in efforts to raise education and awareness about the risks and impacts of nuclear disaster.	Engagement and Community Service (CIVIC). Considerations of risk

ENACT Component	Components within the module	Learning Activities in Modules	Social Responsibility Indicators loaded
			and social consequences (CONSEQ).
	Understanding the Uncertainty of Science and Technology	Understand scientific uncertainty, including the provision of accurate and transparent information to the public about nuclear technology, potential accident risks, and existing mitigation measures.	Considerations of risk and social consequences (CONSEQ).
Anticipate	Writing and discussing ethical aspects and social responsibility	Writing and discussing what will happen in the future, students will discuss the ethical aspects and social responsibility in the context of nuclear hatred.	Considerations of risk and social consequences (CONSEQ).
Conduct	Responsive	Understanding social issues Analyze the impact of social issues, identify how nuclear waste management.	The needs and demands of society (NEEDS). Concern for environmental sustainability (ENVIR)
	Inclusive	Identify and understand different perspectives related to nuclear hatred, whether from the perspective of the agency or the government, the public perspective and the scientific/research perspective	Participation in policy decision-making (POLICY). The pursuit of goodness together (COMGOOD)
	Reflection and Sustainability	Understanding Mitigation and Action Planning	Participation in policy decision-making (POLICY).
Take Action	Sharing solutions, advanced research, awareness campaigns	They can investigate topics in depth, analyze data, and formulate recommendations based on their findings. Awareness campaigns by creating media posters, brochures or other media and through this platform to disseminate information, facts, and solutions to a wider audience.	Engagement and Community Service (CIVIC). Communication with the community (COMMU)

The integration of the ENACT model into the study of nuclear disaster mitigation in understanding physics concepts aims to align the stages of ENACT with the stages in mitigation learning. This approach intends to create a more structured and innovative learning experience in physics focused on disaster mitigation. The use of a module website as a learning medium provides flexible and interactive learning facilities. Therefore, integrating the ENACT model into the learning of nuclear mitigation in physics is an innovative contribution to education.

2.4. Design Validation

After the initial design validation by material and media experts, product revisions are made based on validator responses to enhance the quality and effectiveness of the nuclear disaster mitigation web module. Revisions include content modification, appearance adjustments, and interactive feature enhancements to ensure the modules are informative, engaging, and easy to use. Improvements involve strengthening teaching materials relevant to learning objectives and disaster mitigation, as well as adjustments to visual elements and navigation. The data obtained from validator evaluations are analyzed using the following formula:

$$P = \frac{S}{N} x\ 100\ \% \quad (1)$$

Where P represents the percentage of validator approval, S is the total score for each selected criterion, and N is the sum of the ideal score. The scores obtained are then used to determine the validity of the developed product with the corresponding interpretation provided in Table 2, which utilizes a Likert scale.

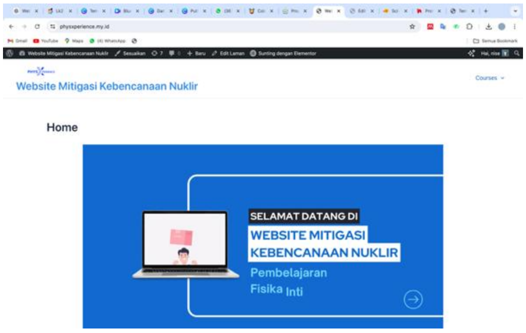
3. Results and Discussion

This section presents the findings from the study on developing a website module using the ENACT model for mitigating nuclear disasters within the framework of physics concepts. The results are divided into two subsections aimed at addressing specific research questions. The first subsection discusses the developmental phases of the website module based on the ENACT model framework, while the second focuses on the feasibility analysis of the module.

3.1. Development

This section displays the results of a case study displaying how to build website module for mitigrating nuclear disasters within in the scope of physics concepts using an ACT model. The results are split in two subsections to Address different research questions. The first sub-section describes the developmental phases of the website module using ENACT model framework, and second focuses on feasibility analysis of the module.

The development of the website module began with the setup of physxperience.. After the website was created, Elementor and Astra themes were installed on site. Built-in were all the necessary plugins and modifications to make it more usable, including a user interface optimized for both computer and smartphone viewing. There was a clear home/front view that had menus and some tips for the user.



a)

b)

Figure 4. a). Computer view, b). Smartphone view

The home view of the website presents a user guide to the feature, and users can directly access the available features by clicking on the section. See Figure 5.

Figure 5. Website Module Features

3.2. Learning Content Development

The ENACT components were integrated by collecting accurate and relevant learning materials aligned with the RPS physics core. In an effort to cultivate social responsibility, this section has been designed with several learning activity features that require students to meet specific social responsibility assessment indicators (VSRoSE). This part has been built with learning activity components that require students to fulfill specified social responsibility assessment indicators (VSRoSE) in an attempt to foster social responsibility. The learning module was structured according to the stages of the ENACT model, incorporating the following steps:

3.2.1. Engage

Students were engaged through case studies of nuclear disasters such as Chernobyl and Fukushima, highlighting their relevance to the Indonesian context and the importance of mitigating nuclear disasters.

3.2.2. Navigate

This phase guided students through fundamental physics concepts including atomic nucleus structure, nuclear reactions, radioactivity, and nuclear power plants. It encompassed: (1) Social implications of science and technology: Introducing students to the societal and technological impacts of nuclear energy. (2) Understanding stakeholders: Exploring the roles of scientists, researchers, and other stakeholders in nuclear mitigation. (3) Moral and ethical considerations: Discussing ethical responsibilities and the moral implications of nuclear technology. (4) Scientific uncertainty: Educating students about the complexities and uncertainties inherent in nuclear physics and technology.

3.2.3. Anticipate

This phase concluded Cycle I with activities preparing students to comprehend the long-term risks and impacts of nuclear disasters through scenarios and simulations. The activities are designed to cultivate and meet the indicators of social responsibility. Students will engage in discussions about ethical considerations and social responsibility in the context of nuclear disasters. See Figure 6.

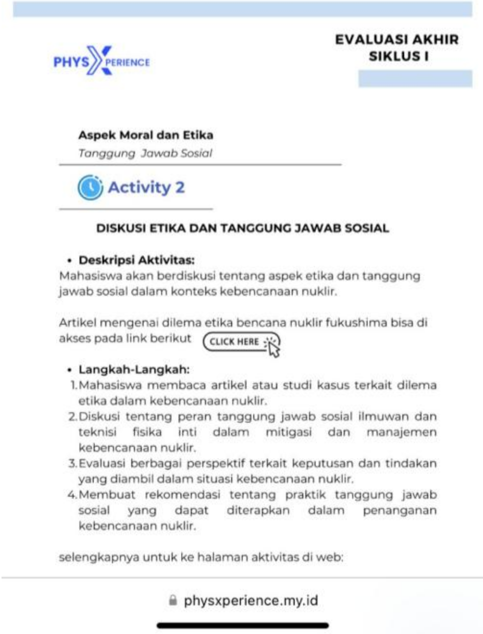


Figure 6. Learning Activity Cycle I on the Website Module

3.2.4. Conduct

Cycle II of the ENACT model began with: (1) Responsive: Addressing social issues related to nuclear technology and analyzing their impacts. (2) Inclusive: Understanding diverse perspectives on nuclear issues from stakeholders. (3) Reflective and Sustainable: Planning sustainable actions to mitigate nuclear disasters, analyzing risks, and educating communities.

In the reflective and sustainable phase, students are taught how to implement mitigation actions according to accessible guidelines from the Nuclear Energy Regulatory Agency (BAPETEN). This stage is very important, as it requires following the starting guidelines for such types and making sure about safety standards. Examples of material mitigation measures that can be widely deployed are shown in Figure 7.

Figure 7. Mitigation Steps on Website Module

3.2.5. Take Action

This phase concludes Cycle II with student activities that will combine two important components: the development of a sustainable action plan to raise awareness and public preparedness for nuclear hatred; the assignment of personal reflections on their learning in these modules and their social responsibilities as future scientists or professionals; and the involvement of students in educational campaign activities through the design and duplication of posters that reflect social responsibility in nuclear diseaster mitigation as the final evaluation of the module. See Figure 8.

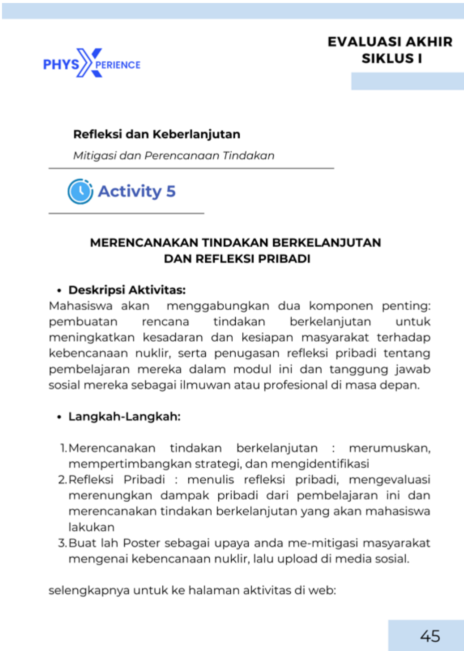


Figure 8. Learning Activity Cycle II on the Website Module

3.2.6. Module Website Feasibility

The nuclear disaster mitigation module website underwent a comprehensive design phase followed by product validation by both material experts and media experts.

Table 3. Validation Result

Validation	Aspect	Percentage	Average	Category
Material Expert	Content Feasibility	93%	89%	High Feasible
	Presentation Feasibility	87%		
	Language Assessment	87%		
Media Expert	Graphic Feasibility	85%	81%	High Feasible
	Software	81%		
	User Interface	80%		
	User Experience	80%		

Each assessment aspect received positive feedback from the validators. Although there were no significant changes or overhauls, some materials and components were added. The researchers made revisions to address the product's shortcomings based on the validators' suggestions. These additions stemmed from the material expert's recommendations on integrating the ENACT model components into the module website's structure.

This study presents a developmental design that integrates the ENACT model into nuclear disaster mitigation education, incorporating physics theories. The primary goal of the ENACT model is to enhance students' social responsibility (Serena Shim, Sungok, 2020) and to measure this using the VSRoSE instrument (Ko, Y., Shim, S. S., & Lee, 2021).Through SSI instruction, (Lee et al., 2012; Zeidler, D L, T D Sadler, M L Simmons, 2005) integrated character, morals, and ethics as a dimension of science literacy education. Numerous science educators and researchers emphasize the importance of SSI instruction in schools, as students live in a risky and uncertain environment (Zeidler, D L, T D Sadler, M L Simmons, 2005). Furthermore, strategies to improve students' abilities to deal with SSI and achieve satisfactory outcomes include teaching SSI to help students understand the nature of science and technology (Bencze, L., & Krstovic, 2017).

Unlike previous studies that investigated the impact of the ENACT model in promoting Indonesian students' views on the social responsibility of scientists and engineers (Erna et al., 2023), which were integrated into online courses focusing on STEM education, this research integrates the ENACT model into a learning medium in the form of a website module, with a focus on nuclear disaster mitigation using physics concepts. The goal and focus of this research are to enhance understanding and application of the ENACT model in a more specific context, namely nuclear disasters, which remain a controversial and crucial subject globally.

By integrating the ENACT learning model and aligning it with the education sector, particularly in understanding and mitigating nuclear disaster risks, the findings of this study contribute to the literature on the ENACT learning model. Through a developmental design approach, this research not only teaches students theoretical understanding of core physics and radioactivity but also equips them to think critically and responsibly when dealing with issues related to nuclear disasters.

Nuclear disasters continue to be a topic of significant global discussion due to their controversial social implications. According to analysis based on the International Nuclear Event Scale (Statista, 2011), nuclear disasters have a substantial impact on the environment and public welfare. Therefore, it is crucial for education to provide students with the knowledge and skills needed to manage and mitigate the risks associated with nuclear disasters. This research focuses not only on increasing academic knowledge but also on the practical application of measures that can help reduce nuclear disaster risks. It is expected that students will understand the social, moral, and scientific impacts of nuclear disasters and actively participate in mitigation and preparedness efforts.

Revisions to the design focused on addressing deficiencies in integrating the ENACT model stages into the learning product, resulting in a more streamlined and structured flowchart. These improvements enhanced the clarity between chapters and sub-chapters in the module, clarifying the integration flow of the first and second cycles of the ENACT model in the learning stages.

However, like all studies has limitations that should be disclosed. This means that the research has only made it to product development, not full implementation or direct evaluation framework. Consequently, the website module has yet to show its true colors during students' social responsibility and disaster mitigation in a nuclear disaster. Full implementation and evaluation will provide more information regarding the efficacy of this educational tool, which should be considered in future research.

Nevertheless, the study is very essential to contribute to the field of education through the application of the ENACT model for practical use, as it will become one example of solution mitigation for nuclear disasters. The study provides a new way for physics theories to be integrated with mitigation strategies, which ultimately can deepen the understanding and sense of social responsibility among students. Results from this study contribute to the literature on the ENACT learning model while providing educators with insights through which they may consider implementing responsive engagement strategies. In the end, this research supports the readiness of students to engage as stewards in efforts associated with the mitigation of risk, establishing a more socially responsible and knowledgeable citizen populace.

4. Conclusion

This research integrates the ENACT model into a web-based learning module focused on nuclear disaster mitigation, enhancing students' social responsibility through physics education. Unlike previous studies that applied the ENACT model to STEM courses, this study uniquely addresses nuclear disaster issues. Validation by material and media experts confirmed the module's high feasibility and effectiveness, with content feasibility rated at 93%, presentation feasibility at 87%, language assessment at 87%, graphic feasibility at 85%, software at 81%, user interface at 80%, and user experience at 80%. The module not only imparts theoretical knowledge but also trains students to critically and responsibly tackle nuclear disaster challenges. However, this study is not without limitations, including no real-world implementation and an evaluation of the module's long-term effects on students. Future research should focus on implementing the module in diverse educational settings and conducting longitudinal studies to assess its effectiveness and impact on students' social responsibility and preparedness for nuclear disasters. This research makes a substantial contribution to pedagogical practice by illustrating how the ENACT model is utilized in teaching social responsibility and readiness to students.

Author Contributions

All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

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