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Development of Augmented Reality (AR) Physics Learning Media Based on STEM-R for Students' Concept Understanding

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Abstrak. Learning media that can overcome students' difficulties in understanding abstract concepts through the integration of modern technology with character values is challenging. This study aims to develop, determine the feasibility, student response, and effectiveness of STEM-R-based AR media on concept understanding in heat temperature material. This research uses Research and Development (R&D) with the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). Data collection was conducted through interviews, expert validation, and pretest-posttest. The validation results showed that the media was feasible for use based on the assessments of media experts, subject matter experts, and religious experts in the feasible category. The average concept comprehension scores of students in both schools showed an increase. Small-scale tests and field tests of student responses in both schools showed a very good category. The validity level of STEM-R-based AR media on students' concept comprehension is interpreted as feasible for use, and student responses to this learning media are also very good, reflecting an increase in motivation and involvement in the teaching and learning process. This research is expected to strengthen the integration of religious values in modern science learning and serve as a reference for the development of AR media based on Islamic values.

Keywords: augmented reality, STEM-R, conceptual understanding

1. Introduction

The development of digital technology in education has changed the direction and patterns of learning. If the teaching and learning process was previously instructor-oriented, it is now student-centered. This demonstrates that technology supporting contextual and interactive learning is crucial [1]. Physics learning is a vital branch of knowledge for technological advancement in daily life. This subject is considered difficult because many concepts are abstract and require a high level of representational ability. For example, the topic of heat and temperature requires a profound understanding of the phenomena due to the difficulty in grasping and misinterpreting the concepts. Conventional learning, which relies on lectures and static media, is be less effective in conveying abstract concepts [2]. Understanding the concepts of temperature and heat can become difficult due to the lack of learning materials that can realistically and interactively illustrate the phenomenon of thermal energy transfer.

Research conducted at SMAN 5 and SMAN 7 Bandar Lampung reveals that students have a low interest in physics (58%), are passively engaged in class, and do not fully understand the concepts well. Interviews with educators reveal a deficiency in incorporating interactive learning media into the learning process. Therefore, we need to introduce more interactive and engaging learning media innovations. Augmented Reality (AR) represents a significant innovation with considerable promise for science education. This technology enables individuals to observe three-dimensional virtual items within their actual surroundings, facilitating direct engagement with educational subjects for students

[3]. Studies indicate that AR adoption enhances student involvement and clarifies abstract ideas by providing opportunities for direct interaction with virtual models, thereby offering an advantage over traditional educational methods [4]. In the context of physics learning, AR technology can help students understand the relationship between theory and real-world phenomena through visualization-based simulations [5]. Additionally, AR can be utilized on smartphones, facilitating self-directed learning and enhancing student engagement [6]. Thus, AR becomes a medium that can increase student engagement and facilitate understanding of physics concepts [7].

However, the use of AR in learning can be effective when integrated with the appropriate approach. The educational methodology known as STEM, which encompasses Science, Technology, Engineering, and Mathematics, advocates for the cohesive integration of various academic fields to address practical, real-world challenges [8]. This kind of instruction can enhance students' ability to think critically, collaboratively, and creatively. Research conducted by Pei et al. changes in STEM education themes over two-decade period and found an increased integration between science, technology, engineering, mathematics, and the humanities and social sciences, indicating a shift toward a more holistic approach [9]. According to Wang et al., they emphasize the importance of integrated STEM education (iSTEM), which addresses and develops more effective practical applications. However, the conventional STEM approach often overlooks the moral, ethical, and spiritual aspects of learning [10].

Moral and ethical principles are typically not emphasized in STEM approaches that focus solely on mastering science skills [11]. Science education not only teaches cognitive skills but also fosters character development [12]. One effort to build students' character is by integrating religious values into the learning process [13]. Therefore, developing STEM into STEM-R (Science, Technology, Engineering, Mathematics, Religion) becomes a solution by integrating religious values to increase spiritual awareness, responsibility, morality, and understanding [14].

Based on previous research, it has been demonstrated that AR can enhance academic performance and motivation to learn; however, most studies have only used AR as a visualization tool, without integrating it into a comprehensive pedagogical framework. Research on *Augmented Reality* (AR) in physics education primarily emphasizes cognitive dimensions, including problem-solving abilities and conceptual comprehension. However, the affective aspect, which is also important in character formation for students, has not received adequate attention. On the other hand, regarding the application of religious values in STEM education, some studies indicate that it can increase student engagement [15], motivation, and learning outcomes [16], as well as enhance students' problem-solving abilities an and make learning more meaningful. Additionally, STEM-R can also enhance students' understanding of heat transfer material [17]. However, integrating religious values into STEM learning, especially with technologies like AR, is still limited. Additionally, there has been limited research specifically integrating AR and STEM-R into physics learning.

In this study, it is used the STEM-R approach servers as the basis for developing learning media that combine AR technology. This research integrates both components into a cohesive learning platform. The current approach diverges from prior investigations, which typically distinguished between the evolution of educational technology and the implementation of religious principles. The integration not only focuses on mastering the material but also on character development and spiritual awareness by utilizing AR to create interactive learning experiences and leveraging the ability to visualize abstract concepts [18]. Additionally, it adopts the STEM-R framework, which has been proven effective in enhancing critical and reflective thinking [19].

This study is urgently needed because low conceptual understanding in physics education remains significant problem, particularly with abstract concepts such as heat and temperature. The lack of proper visualization and interactive experiences in today's traditional teaching methods leads to low student engagement and misconceptions. Additionally, although STEM education has become increasingly popular worldwide, its application often overlooks the moral, ethical, and spiritual aspects that are crucial for students' overall development, particularly in Islamic educational settings. This disparity generates a pressing need for cutting-edge educational materials that can enhance both character

development and cognitive comprehension simultaneously. A relevant response to these pedagogical issues is the combination of AR technology and the STEM-R method, which provides a solution that is consistent with both contemporary technical advancements and Islamic educational principles.

This research develops learning media that can enhance students' understanding of physics concepts while fostering their religious identity. The study aims to determine the STEM-R-based AR physics learning media's heat and temperature, assess the feasibility of the learning media from the perspective of media, material, and religious experts, and analyze students' responses to the developed learning media. However, this research has several limitations: it focuses on 11th-grade students from two high schools in Bandar Lampung; requires stable internet access and adequate smartphone devices; examines only heat and temperature material; does not measure long-term retention or affective aspects such as religious attitudes; and was conducted within a limited timeframe, August-September 2025.

Nevertheless, this research offers a theoretical enhancement by expanding the existing body of knowledge concerning the integration of Augmented Reality (AR) technology and the STEM-R approach in physics learning and responding to the demand for broader STEM-R approaches. Practically speaking, the developed media offers a creative solution for educators to overcome the problem of visualizing abstract concepts in physics learning while building students' religious character. This medium also helps educators meet educational needs in Indonesia and other Muslim countries. The findings of this research can serve as a reference for curriculum developers and education policymakers to integrate modern learning technologies with local and religious values. These results will support an educational vision that produces learners who are not only cognitively capable but also moral and strong.

2. Method

The research utilizes the Research and Development (R&D) method. This is a method of research used to develop new products and conduct feasibility testing [20]. The product is a media for learning physics through Augmented Reality (AR), consisting of materials in the form of a canvas and the AR-assisted application Assembler Edu. This method was chosen because it is suitable for obtaining a feasible and effective product. The research model employed is the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). This model is utilized because it has systematic and structured stages, starting from the analysis of needs to the evaluation of the product, to produce relevant and effective learning media for the learning process. Figure 1 illustrates the steps involved in developing the ADDIE model.

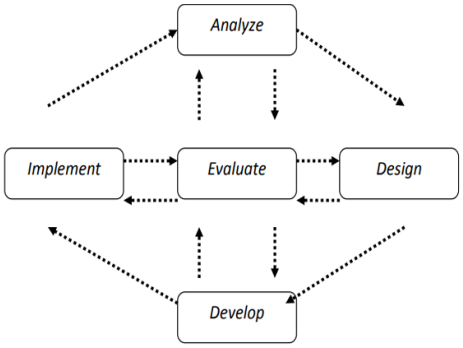

Figure 1. Stages of the ADDIE Model Research [21].

The initial step taken is to examine the problems that arise, identify the core issues, and formulate alternative solutions. The next stage is the design stage, which includes setting objectives, preparing test instruments, and designing the subsequent process. After it moves to the development stage, various teaching materials needed are prepared. Next is the implementation stage, where all the designs that have been made are adjusted to their roles so that they can be used in practice. After the product is completed, a trial is conducted to evaluate its performance. After the trial, the results are evaluated and revised to obtain a more optimal product. The final stage is the evaluation stage, which is the last step in the ADDIE model, determining whether the designed media meets expectations. This method is

written in section 2. However, if the author includes several sections after the introduction, the method can be placed in the section that follows these additional sections.

The testing design comprises a series of experimental activities conducted during the development of learning media [22]. The trial model in this research comprises several forms of product testing, including expert assessments, limited trials, and broader trials. The data collection process is applied in two schools, namely SMA Negeri 5 Bandar Lampung and SMA Negeri 7 Bandar Lampung.

In this research, the data collection instrument utilizes Google Forms to facilitate the completion of questionnaires and the collection of responses. The Google Forms link is shared through the class WhatsApp group. The use of Google Forms aims to provide convenience for respondents. The respondents were asked to complete the provided questionnaire. Data was collected sequentially, starting with observations of the research location, followed by interviews, distribution of questionnaires to students, and the provision of comprehension tests to assess changes in students' concept mastery.

Techniques related to data analysis in this research include feasibility analysis through expert validation and analysis of comprehension test results to see the levels of student mastery of the material on temperature and heat. The feasibility analysis involving experts aims to assess the extent to which the developed product meets its criteria. The assessment related to feasibility, as conducted by the experts in this research, utilizes a Likert scale with a range of 1-4. The values generated through the expert validation process are then processed using the following data processing method:

$$Interptretasi\ skor = \frac{\sum skor\ perolehan\ (n)}{\sum skor\ tertinggi\ (n)}\ x\ 100\% \quad (1)$$

By using this equation, the assessment score is obtained from the data collection in the form of expert validation questionnaires. Then the percentage results can be converted into statements. The conversion is carried out according to the feasibility interpretation, as shown in Table 1.

Table 1. Percentage feasibility categories [23].

Percentage	Category
<20%	Very Unfeasible
21% - 40%	Unfeasible
41% - 60%	Fairly Unfeasible
61% - 80%	Feasible
81% - 100%	Very Feasible

The table categorizes media feasibility into five categories. If the media receives an assessment score of 81% to 100%, it is very feasible; if the score is 61% to 80%, it is feasible. If the score obtained is 41% to 60%, then the media will be categorized as fairly feasible. With a score of 21% to 40%, the media is declared unfeasible. If the score obtained is less than 20%, the media is declared very unfeasible.

The student and educator response questionnaire is used to determine students' responses to the STEM-R-based AR learning medium based on the temperature and heat material that has been developed. The assessment score in the student response questionnaire uses a Likert scale with a score range of 1-4, with a value of 1 indicating very poor, 2 indicating poor, 3 indicating fairly satisfactory, 4 indicating satisfactory, and 5 indicating very satisfactory. The criteria for the Likert scale in the questionnaire are presented in Table 2.

Table 2. Assessment score criteria[24].

Score	Criteria
5	Very Good
4	Good
3	Fairly Good
2	Poor
1	Very Poor

We assess students' understanding of heat and temperature materials through pretests and posttests. The criteria for understanding the concept are based on the percentage of students who achieve an average score, as shown in Table 3.

Table 3. Criteria for interpretation of concept understanding [25].

Score	Criteria
<20	Very Poor
21-40	Poor
41-60	Fairly Good
61-80	Good
81-100	Very Good

The analysis of the concept understanding test sheets is applied through the calculation of N-gain using the formula:

$$n_{gain} = \frac{Skor\ Posttest - Skor\ Pretest}{Skor\ maksimal - Skor\ Pretest} \text{ x } 100\% \quad (2)$$

Then the percentage of scores obtained through the results of pretests and posttests is converted into categories of improvement in students' conceptual understanding, as shown in Table 4.

Table 4. N-gain score categories.

N-gain	Category
N-gain ≥ 0.7	High
0,3 ≤ ngain ≤ 0.7	Medium
ngain < 0.3	Low

According to Table 4, the improvement in conceptual understanding through interactive learning media is categorized as high if the N-gain score is greater than 0.7. If the score obtained is 0.3 ≤ N gain ≤ 0.7, the improvement in conceptual understanding is said to be medium, and it will be stated as low improvement if the N gain obtained is < 0.3.

3. Results and Discussion

3.1. *Results*

This research was conducted in the odd semester of 2025/2026. This section presents the research process its results, along with discussions based on the findings. The product resulting from this research is the STEM-R-based AR physics learning media on the topic of heat temperature, which is suitable for use and has received a positive response from students. The data results are based on expert tests and educator as well as student trials and responses conducted in both schools. This media was developed following the research and development steps outlined below:

3.1.1. Analysis Stage

The initial stage of the research is the analysis phase. This stage involves collecting all relevant information and identifying learning needs in the field. The analysis is conducted through interviews, questionnaires, and documentation. Interviews were conducted in November 2024 with educators from SMA Negeri 5 Bandar Lampung and SMA Negeri 7 Bandar Lampung. The analysis reveals that students are uninterested in physics, inactive in learning, and struggle with concepts because the learning media remain conventional and uninnovative. Some educators still use textbooks and electronic media such as PowerPoint (PPT) in their teaching. This condition results in students' conceptual understanding to be low, thus requiring new learning media that are more engaging, interactive, and relevant. Therefore, we urgently need to develop AR-based STEM-R media to foster a learning environment that actively engages students in the learning process.

3.1.2. Design Stage

The next stage is the design stage, follows the identification of problems. In this stage, the design steps include formulating learning objectives, integrating STEM-R aspects into the material, creating storyboards, determining AR objects, and integrating Islamic values into the learning content. The media display is designed using Canva, while the 3D objects can tangibly visualize concepts. Table 5 displays the integration of STEM-R into the material designed for the product.

Table 5. Integration of STEM-R in Material Development.

Aspect	Description
Science	The science section explains the fundamental concepts of temperature, including kinetic energy, average particle motion, and heat as from of transferable energy, the law of conservation of energy, and the phenomenon of phase change.
Technology	Demonstrating the application of technology to measure temperature, control heat, and visualize abstract concepts using digital media or Augmented Reality (AR).
Engineering	Designing and creating experiments to prove heat transfer
Mathematics	Mathematical calculations are utilized to determine changes in heat, temperature, and phase.
Religion	This process connects science learning with Islamic values.

3.1.3. Development Stage

In this stage, the media is developed according to the initial concept and then validated by experts. Two lecturers serve as media experts, 2 lecturers who specialize in material expertise, and 2 lecturers who act as religious experts. The average validation assessment results from these experts are as follows:

Table 6. Results of Media Expert Validation.

No	Assessment Aspect	Score	
		Expert 1	Expert 2
1.	Visual appeal	4	4
2.	Clarity of illustrations and images	4	4
3.	Color harmony	4	4
4.	Accuracy in font selection	4	4
5.	Font limitation level	4	4
6.	Layout harmony	4	4
7.	Consistency of layout	4	4
8.	Suitability of AR objects with materials	4	4
9.	Accuracy of AR representation	4	4
10.	Responsiveness of AR interaction	4	4
11.	Ease of interaction with AR objects	4	4
12.	Stability of AR display	4	4
13.	Visual quality in AR	4	4
14.	Integration of STEM-R components	4	4
15.	Ease of navigation	4	4
16.	Availability of usage instructions	4	4
17.	Smooth performance of the application	4	4
18.	Compatibility with various devices	4	4
	Total	72	72
	NP	80%	80%
	Description	Feasible	Feasible

Table 7. Results of expert validation of material.

No	Assessment Aspect	Score	
		Expert 1	Expert 2
1.	Suitability of material	12	13
2.	Integration of material with STEM-R	4	5
3.	Concept understanding	28	28
4.	Accuracy of material	23	21
5.	Currency of material	9	8
6.	Encouraging curiosity	7	9
7.	Clarity	13	12
8.	Communicative	5	4
9.	Dialogic and interactive	4	4
10.	Suitability with student development	8	8
11.	Suitability with rules	10	8
12.	Presentation technique	8	9
13.	Support for presentation	13	15
14.	Learning presentation	4	5
15.	Contextual nature	8	10
16.	Contextual components	10	12
	Total	166	171
	NP	83%	83,5%
	Description	Very Feasible	Very Feasible

Table 8. Results of Religious Expert Validation.

No	Assessment Aspect	Score	
		Expert 1	Expert 2
1.	Quality of content	18	20
2.	Language	15	16
3.	Emphasis on material	14	16
	Total	47	52
	NP	72.3%	80%
	Description	Feasible	Feasible

The results of the validation by the three experts, namely material, media, and religion, indicate that STEM-R-based AR physics learning media regarding heat and temperature are to develop. Figure 2 presents the assessment results.

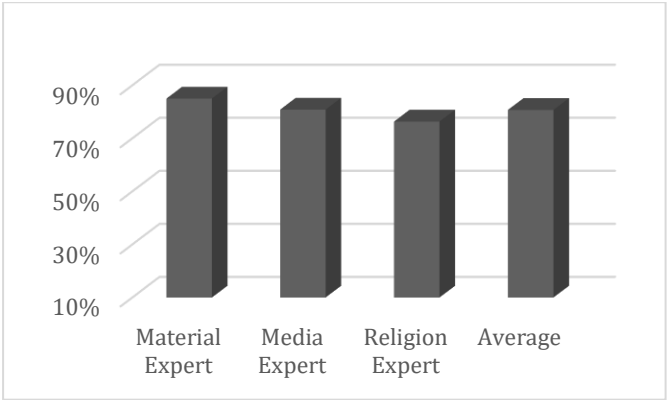

Figure 2. Diagram of Media Product Validation Percentage

3.1.4. Implementation Stage

This stage involves media that have been validated and then tested on students in class XI at SMA Negeri 5 Bandar Lampung and SMA Negeri 7 Bandar Lampung. The testing was applied in two stages: small-scale testing (20 students) and large-scale testing with 72

students/respondents from each school. The student response test results included criteria that were particularly interesting criteria, as shown in Table 9 and the comparison graph below in Figure 3.

Table 9. Recapitulation of Students' Responses Results.

School	Small-Scale Test	Field Test	Category
SMA Negeri 5 Bandar Lampung	88.75	86.35	Very Interesting
SMA Negeri 7 Bandar Lampung	86.75	85.55	Very Interesting

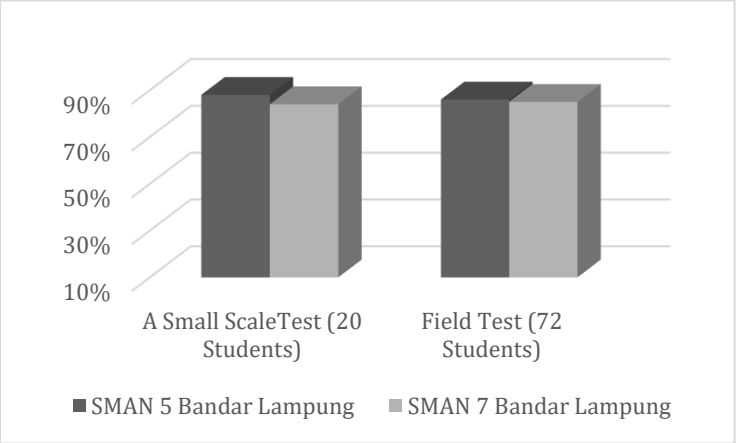

Figure 3. Diagram of Students' Responses to Media.

In addition to the response questionnaire, a pretest-to-posttest design was also conducted to measure understanding of the concepts. The results are presented in Table 10 and the graph in Figure 4.

Table 10. Data Processing Results of Pretest-Posttest

School	*Pretest*	*Posttest*	N-gain	Category
SMAN 5 Bandar Lampung	54.81	77.71	0.49	Medium
SMAN 7 Bandar Lampung	52.69	86.48	0.70	High

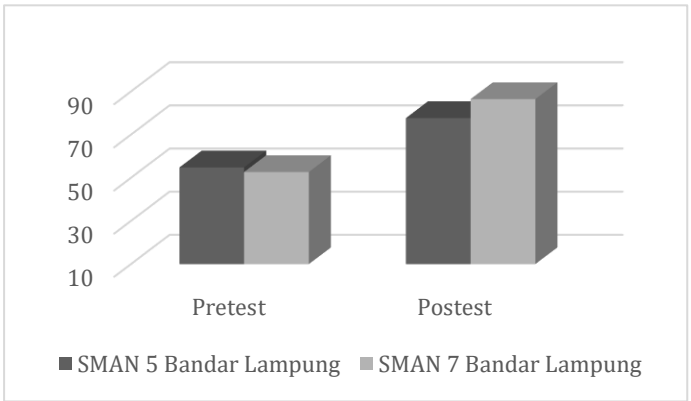

Figure 4. Diagram of Students' Responses to Media.

From the data obtained as written in Table 10, it can be seen that the calculation of (N-gain) obtained falls into the category of improvement in the understanding of concepts for students at SMA Negeri 5 Bandar Lampung, with a medium category with an (N-gain) of 0.49, and the category obtained for students at SMA Negeri 7 Bandar Lampung is 0.70. This is in accordance with the category of (N-gain) for students' understanding of concepts. An

improvement in the understanding of concepts is said to be "high" if it obtains a score of 0.7 < (N-gain) [26]. This data shows that this media is capable of significantly determining how far students' understanding has progressed, especially at SMA Negeri 7 Bandar Lampung, which has reached a high category. This study demonstrates that learning with AR media based on STEM-R can help students develop a deep understanding of abstract concepts.

3.1.5. Evaluation Stage

The final stage is evaluation. At this stage, a review and reassessment were conducted to identify any remaining weaknesses in the media. The results of the evaluation showed that the media already met the feasibility criteria, both in terms of visual design, content, and the integration of Islamic values, and were proven effective in measuring students' level of understanding.

3.2. *Discussion*

This research develops AR-based physics learning media integrated with the STEM-R approach using the ADDIE model. At the analysis stage, several problems were identified, including low student interest in physics lessons and a lack of variety in learning materials, which resulted in poor conceptual understanding and limited active engagement during learning activities. Consequently, the need arose for a teaching tool that could assist both students and educators. So, STEM-R-based physics learning media with AR technology ware developed. This align with Dian, to who states that the use of technology-based interactive learning media is an effective strategy for improving understanding [27].

The success of this media was reflected in the results of validation tests conducted by media experts, material experts, and religious experts, as well as in the increase in student understanding that resulted from utilizing the learning media. Two media expert validators assessed the media with a score of 80.83 and deeming it feasible for practical use. However, several suggestions for improvement were made, including incorporating STEM-R content to the material, updating AR objects to be more realistic, providing audio that matches the material, and ensuring ease of access, especially when used online. This suggestion is supported by Sukardjo & Situmorang, who stated that visualization, audio clarity, and ease of access are important indicators of the effectiveness of AR media[28]. Validation by two content experts received a score of 85% in the very feasible category. Nevertheless, the experts suggested complementing each material with relevant examples from everyday life. Validation tests conducted by religious experts yielded in a score of 76.33% in the feasible category, accompanied by suggestions to incorporate verses from the Qur'an and translations to each material, as well as to enhance the clarity of the verse writing. The integration of Islamic values supports the STEM-R concept in balancing knowledge and spirituality [29].

Overall, based on the average scores from media experts, content experts, and religious experts, this product obtained a percentage of 80.72% with a feasible category. In terms of concept understanding, students from SMA Negeri 5 Bandar Lampung achieved an average score of 77.71, whereas students from SMA Negeri 7 Bandar Lampung obtained a higher average score of 86.48. These results indicate that the level of understanding among students from both schools falls into the very good category.

The student understanding test includes pretest and posttest data as well as the gain. The average score of the pretest for SMA Negeri 5 Bandar Lampung is 54.81, and the average posttest score is 77.71, indicating an average score increase of 22.19 and a gain assessment of 0.49, which represents a moderate level of conceptual understanding. Meanwhile, for SMA Negeri 7 Bandar Lampung, the average pretest score is 52.69, and the average posttest score is 86.48, indicating an average score increase of 33.79 and a gain assessment of 0.70, which represents a high level of conceptual understanding. These findings align with WEY Fajrin (2025), which shows that AR media can significantly improve cognitive learning outcomes by making abstract visualizations more concrete [30]. However, this media still has limitations. Optimal access requires a stable internet connection, while offline use is less effective because AR features cannot be displayed comprehensively. This finding aligns with the research of Annail, B., et al., which suggests that internet infrastructure limitations are a primary challenge in implementing AR media in schools [31].

Theoretically, this research demonstrates how AR visualization, combined with the STEM-R approach, can simultaneously enhance the affective, cognitive, and spiritual aspects. This finding extends constructivist learning theory by showing that technology-mediated learning can bridge abstract concepts with concrete experiences while fostering spiritual awareness. Comprehensive studies have shown medium to large impact sizes (d=0.58-0.72) in scientific education[32], and recent meta-analyses of AR in higher education (2000-2023) show considerable beneficial effects on learning outcomes across multiple educational contexts [33]. Previous research has emphasized the importance of holistic science education that integrates technology and value-based learning. In practical terms, the developed AR-STEM-R media provides educators with an innovative tool to address challenges in teaching abstract physics concepts, such as heat and temperature. This media enhances student engagement, motivation, and character development. This aligns with recent frameworks for integrated STEM education that emphasize sustainability, equity, and societal relevance, demonstrating how emerging technologies can support pedagogical innovations rooted in local values and global educational standards [34]. This media enhances student engagement, motivation, and character development **by providing multimodal learning experiences that leverage AR's pedagogical affordances—such as visualization of abstract concepts, interactive manipulation of virtual objects, and contextualized learning-while reinforcing Islamic values through culturally responsive design [35]. The positive outcomes observed in this study-with N-gain scores of 0.49 (medium) and 0.70 (high)—are consistent with international research which shows that technology-enhanced instruction, particularly when designed with cultural responsiveness, produces superior learning outcomes compared to traditional methods [36].

4. Conclusion

Based on the findings of the research conducted, it can be concluded that the application of the STEM-R-based AR physics learning media on the temperature and heat material developed in this study is deemed suitable for use as a learning medium based on the assessment of experts, educators' responses, and students' responses. This media has also proven effective in improving students' understanding of concepts while simultaneously integrating Islamic values into modern science learning. Thus, this media can serve as an alternative and innovative teaching material to overcome the problem of abstract concepts visualization in physics learning and shape students' religious character.

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