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Culturally Responsive Teaching (CRT) on Thermochemistry with AR: Action Research

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ABSTRACT: Mastering thermochemistry can be challenging for students. This study tackles teaching thermochemistry, a challenging subject with complex concepts, calculations, and lab work that students often struggle with. A structured learning approach integrating Culturally Responsive Teaching (CRT) with Augmented Reality (AR) was implemented. Conducted through action research over two cycles, the study involved 35 high school students during the 2023/2024 academic year. The study found significant improvements, with average scores rising from 76.74 in Cycle I to 83.94 in Cycle II, and the percentage of students achieving classical completion increasing from 65% to 77%.

Keywords: Action Research, Augmented Reality Media, Culturally Responsive Teaching, Discovery Learning, Thermochemistry

INTRODUCTION

Thermochemistry is a fundamental topic in high school chemistry that explores the complex relationship between chemical reactions and energy changes. This subject is a branch of chemistry that studies temperature changes during chemical reactions [1]. The curriculum on thermochemistry includes energy and heat, calorimetry and enthalpy changes, thermochemical equations, standard enthalpy changes (ΔH^o), average bond energy, and enthalpy changes of reactions [2]. This topic is closely related to natural phenomena that can be observed, measured, analyzed, concluded, and explained. In thermochemistry, understanding how energy is transferred and transformed during chemical reactions is crucial for designing efficient chemical processes, both in industry and research. Measuring and analyzing these energy changes allow scientists to optimize reaction conditions, develop new processes, and understand the molecular interactions underlying various chemical phenomena.

In fact, the teaching of thermochemistry in schools continues to face significant challenges [3]. Research indicates that interviews with high school chemistry teachers revealed that the academic performance of the majority of students in three schools in the area is below satisfactory levels [4]. This assessment of student learning outcomes is conducted to evaluate the depth of students' understanding of thermochemical principles. Most students still struggle to build concepts, resulting in scores below the set standards. Another study also revealed that 78% of students still have difficulty understanding thermochemistry material [5]. The purpose of this assessment is not only to measure students' factual knowledge but also to gauge how well they can apply various thermochemistry concepts more broadly and relevantly. Specifically, Aprialisa's [6] research mentioned that most students find it difficult to understand how to calculate reaction enthalpy, making the subject less appealing. This is partly because thermochemistry encompasses factual, conceptual, and procedural dimensions in its learning process [7]. Therefore, students are required to apply mathematical equations and concepts in understanding the material, which often leads to difficulties. One of these difficulties is caused by incomplete concepts built by students during the learning process. Random and conventional teaching methods are a contributing factor to this issue [8]. Hence, it is necessary to identify more effective teaching models to improve students' understanding of this subject, enabling them to achieve higher and more satisfactory academic performance.

Discovery learning is a teaching model that encourages students to be more active and think critically in developing concepts during classroom learning. This model can be adapted to the diverse needs, abilities, and interests of students. In this teaching approach, students focus on building their knowledge through exploration and independent discovery, guided by instructions provided by the teacher [9]. Essentially, discovery learning guides students through a problem that will eventually be solved through a series of systematic steps [10]. Through the process of stimulus, problem identification, data collection, data processing, verification, and drawing conclusions, students are encouraged to think systematically and critically [11]. This process enhances students' critical and systematic thinking, improving their analytical skills. In a classroom action research study conducted by Suyati and Sutiani [12], the discovery learning model successfully increased students' learning outcomes in thermochemistry by 56.7%. However, the study also found that many students remained passive in the initial stages, hindering the effectiveness of the learning process and leading to a slower learning pace. To address this, integrating the discovery learning approach with Culturally Responsive Teaching (CRT) could be an effective solution. CRT uses students' cultural references as part of the learning process, creating a more relevant and engaging context for students. This approach not only makes thermochemistry topics easier to understand but also enhances student engagement by connecting the subject matter with real-life applications. Therefore, combining discovery learning and CRT can improve students' understanding and make learning more effective and meaningful.

Integrating teaching with Culturally Responsive Teaching (CRT) within the framework of discovery learning is defined as the use of the diverse cultural characteristics, experiences, and perspectives of students as a means to teach more effectively [13]. CRT utilizes cultural references as part of the knowledge, abilities, and attitudes. This aspect creates opportunities to reflect local knowledge and traditions back to students [14, 15]. Through this approach, students can participate more actively because the context built from culture is closer to their daily lives or based on their own experiences. This allows students to better "relate" to their knowledge, enabling them to understand the material more effectively [3]. The cultural aspect helps students grasp the lessons while also preserving culture within classroom learning [16]. With CRT, students' cultural awareness increases, making them more attentive to their environment and the culture within it. Therefore, CRT is highly suitable for pairing with discovery learning to enhance student understanding of thermochemistry, providing a rich and relevant context that facilitates a more effective and meaningful learning process.

Integrating augmented reality (AR) technology into educational media can significantly enhance the understanding of abstract subjects, making them more tangible and engaging, particularly in thermochemistry [17]. AR technology can overcome the challenges of visualizing chemical reactions and the energy changes occurring during thermochemical processes, thereby simplifying the comprehension of these concepts. The development of AR in chemistry education has been extensively explored, incorporating various features that have positively impacted learning [18]. By integrating AR, educators can provide more concrete and dynamic visual representations, which not only facilitate understanding but also improve students' knowledge retention. This technology allows students to observe and interact with chemical reaction simulations directly, enriching their learning experience and fostering a greater interest in studying chemistry.

Based on this background, the researchers purpose the study entitled “Discovery Learning Model on Thermochemistry: Integrating Culturally Responsive Teaching (CRT) with Augmented Reality in an Action Research”. The objectives of this research are:

1. To analyze students’ learning needs regarding thermochemistry.
2. To determine the effects of discovery learning integrated with CRT and augmented reality media on thermochemistry.

The research is expected to enhance the quality of student learning, positively impacting learning outcomes. It is hoped that students' mastery of thermochemistry will improve with the implemented learning approach.

RESEARCH METHODS

Research Design

This study is a type of classroom action research conducted in two cycles. The primary goal of the research is to understand and enhance the quality of classroom learning [19]. Through this study, practitioners systematically identify the issues they face by collecting various data and then implement changes as needed [20]. Due to its specificity and need for practical solutions, this type of research is frequently conducted by practitioners, such as teachers [21]. Therefore, classroom action research is often used as a reflective process that helps teachers explore and examine aspects of teaching and take actions to improve them. This study involves Practitioner Action Research, which focuses on solving student group issues by the teacher. Unlike Participatory Action Research, which involves the group being studied in finding solutions, Practitioner Action Research centres on problem-solving by the teacher based on the group's needs [22].

The learning sessions were conducted over four meetings during the 2023/2024 academic year. The study followed a two-cycle pattern, beginning with "Cycle 0" or known as Pre-Cycle that conducting a non-cognitive diagnostic test to identify each student's learning style using Google Forms as a basis for needs analysis and conducting observations to assess student needs or student issues and the learning process.

The first cycle involved teaching the concepts of thermodynamics and concluded with a summative cognitive test to measure students' understanding. The second cycle focused on teaching thermodynamics calculations. An overview of the two-cycle classroom action research can be seen in Figure 1.

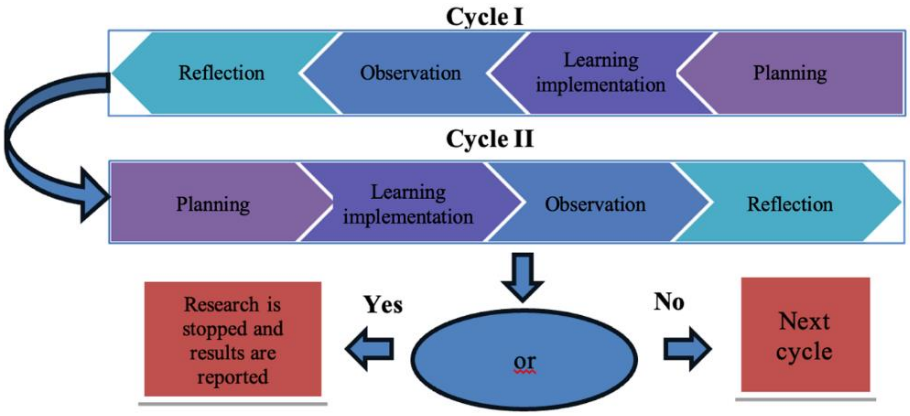

FIGURE 1. Learning Cycle on Action Research

Participant and Settings

In this study, sampling was conducted using convenience sampling based on the availability and willingness of participants [20]. The research was carried out at a high school in Indonesia with a sample of 35 second-year high school students, consisting of 15 boys and 20 girls, who will be studying thermochemistry. The details of the lesson plan can be seen in Table 1.

TABLE 1. Details of the Designed Learning

Cycle	Meeting	Materials	Culture	Technology	Learning Activities
I	1	Principle of Energy Conservation; Systems and Their Surroundings; Exothermic-Endothermic Reactions; and Standard Enthalpy Changes	Traditional Culinary Culture, specifically "satay" and the fermentation process of "tempeh"	PhET: Interactive Simulation Web	Students ask questions related to the process of making satay, which involves combustion, and the fermentation process of tempeh
	2	Calorimeter	-	Virtual Lab by Pearson Education Lab	Laboratory practical
II	3	Hess' laws	Traditional Jember culinary specialy; prol tape	-	Students are asked to study the fermentation process of cassava into tape, which undergoes an exothermic reaction by releasing heat.

Cycle	Meeting	Materials	Culture	Technology	Learning Activities
	4	Bond Energy	Unique Syawal celebration culture with hot air balloons in the Ponorogo and Wonosobo areas	**Augmented Reality** integrated with media; comic, board card, and video animation	Conventional hot air balloon flights still use hydrogen, which, when undergoing combustion with oxygen, experiences bond breaking and bond formation. Students are asked to develop their questions as hypotheses in learning about bond energy

In the first meeting of Cycle I, the lesson began with planning according to the syntax of the discovery learning model. Students were asked to create a summary of the material that addresses problem identification. The core activity started with providing a stimulus through the Culturally Responsive Teaching (CRT) approach, linking thermochemistry concepts to traditional culinary culture, such as "sate" and "tempeh" fermentation. Students were given worksheets on energy and its changes and were directed to group according to their learning styles. They collected and processed data using virtual laboratory simulation web media, then analyzed it in an open class forum.

In the second meeting, the lesson focused on the subtopic of calorimeter experiment that held in laboratory. Students independently identified problems, collected, and processed data through practical activities. The verification phase involved presenting their work digitally using virtual lab by Pearson Education Lab according to their learning styles, ending with assignments tailored to students' interests and skills. At this meeting, students were not given CRT particularly calorimeters' context. However, starting with providing a stimulus through the CRT approach and reviewing previous concepts about enthalpy on satay combustion and tempeh fermentation.

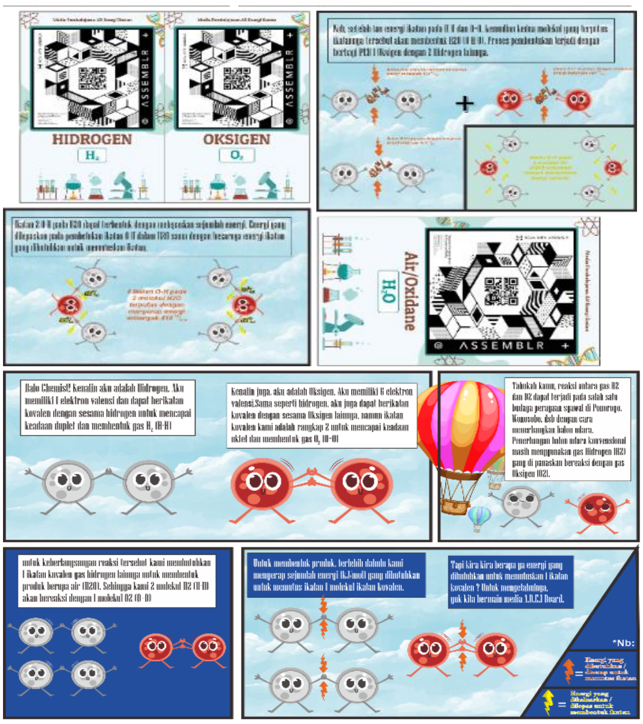

FIGURE 2. Thermochemistry Comic

In Cycle II, the first meeting focused on Hess's Law with a learning approach connecting traditional Jember culinary culture, such as prol tape, with enthalpy change material. The learning process began with providing a stimulus through the Culturally Responsive Teaching (CRT) approach, where students developed hypothesis questions regarding Hess's Law. Data on enthalpy changes were collected through various methods, including the use of media such as animated videos. The lesson concluded with group presentations and conclusions from the educator. At this meeting, there was no technology that given to students.

In the second meeting of Cycle II, the lesson focused on the subtopic of Bond Energy. The CRT approach was used to connect the material with the Syawal celebration culture through hot air balloon flights in various regions particular on enthalpy of hydrogen combustion. Students were encouraged to develop hypothesis questions regarding bond energy of combustion hydrogen in their learning. Data collection was facilitated using Augmented Reality (AR) technology, which integrated understanding through various media such as board card, comic, and animated video. In this lesson, students were assisted with AR-based learning media. The AR media included comics, a board card, cards, and an AR scanner application. All these media were developed and originally made by the researcher. The comics and cards used as media are shown in Figure 2.

Comic used as a medium to explain thermochemistry material, particularly on the concept of bond energy. To reinforce their understanding, students are asked to match cards to the appropriate places on the board. Through the provided AR, students can obtain bond energy data and then calculate it, allowing them to place the cards according to the results shown on the board. The design of the board used is presented in Figure 3.

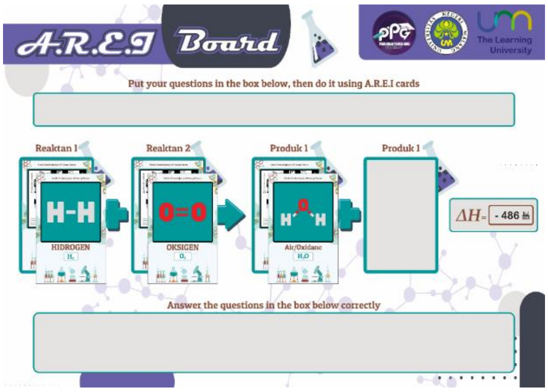

FIGURE 3. Learning Media Board

The provided AR not only serves to offer a visual representation of molecules but also acts as a source of bond energy data. AR displays simple animations showing the state of the molecule before and after bond dissociation. Before the bond is broken, students can view explanations related to the molecule, including the type of bond, the atoms involved, and the bond energy data. After clicking, the display changes to show the state after bond dissociation, including the bond energy data. Additionally, students can interact with the AR molecule by rotating or zooming in. The display of the AR utilized is presented in Figure 4.

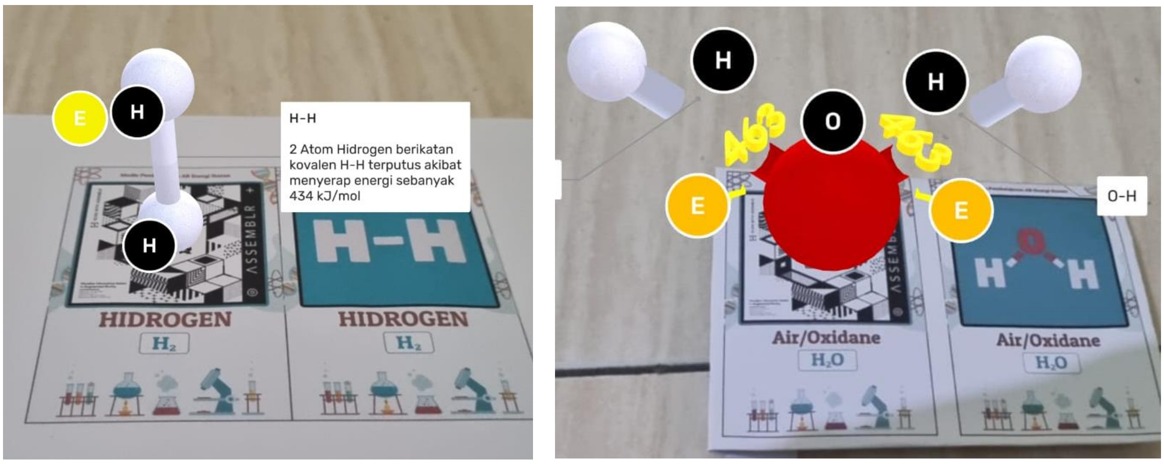

FIGURE 4. Augmented Reality displayed by the media

Data Collection and Analysis

The test data will be analyzed using descriptive quantitative analysis. Quantitative data will include cognitive learning scores of students based on post-test results from each cycle. The comparison of cognitive learning outcomes between Cycle I and Cycle II will be done using the average class scores from the post-tests and the percentage of students exceeding the Minimum Mastery Criterion (KKTP, ≥75). The cognitive learning outcomes in this study will be averaged and analyzed for classical completeness at the end of each cycle.

According to Setyawan et al. [23], classical learning completeness refers to the level of learning achievement in a class that can be integrated with technology. A class can be considered complete in terms of learning if 75% of the students exceed the KKTP in that class. The level of student learning completeness is categorized as shown in Table 1.

RESULT AND DISCUSSION

Results of Student Needs Analysis in Thermochemistry Learning

Before designing the instruction, the teacher conducted a needs analysis for the students. This analysis was carried out through observations and diagnostic tests. The results of the observations indicated that a diagnostic test on learning styles was performed to determine the compatibility of students' learning styles with the developed instructional media. This test was conducted using a Google Form link that students were required to complete. The results of the non-cognitive diagnostic test on students' learning styles are presented in Figure 5.

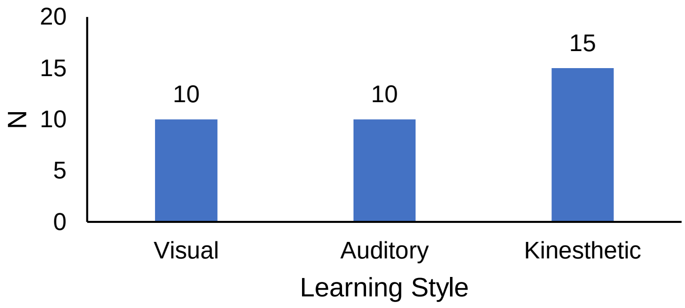

FIGURE 5. Results of the non-cognitive diagnostic test ton the learning styles of 11th-grade students

Based on the table above, the number of students according to their learning styles can be determined. The results of the learning style test reflect the most dominant learning style, which usually has the greatest impact on how a person learns. This understanding is important because the developed media is Augmented Reality (AR), which is a learning tool focusing on visualization for students [24, 25]. Thus, students with a visual learning style should benefit the most from this AR learning media. However, other research indicates that AR still has a medium effect on learning outcomes regardless of students' learning styles [26]. This may be related to the primary effect of AR, which is motivation [26]. This is also due to the nature of AR as a medium that primarily offers exploration and simulation activities [26].

Development of Student Learning Outcomes Using AR-CRT Media

The designed learning is intended to improve student outcomes on the topic of thermochemistry. The statistical description of the two cycles of this study showed an increase in performance. In the first cycle (Cycle I), out of 35 respondents, the minimum score was 58 and the maximum score was 94, with an average score of 76.74 (SD = 9.74). In the second cycle (Cycle II), the minimum score was 51 and the maximum score was 100, with an average score of 83.94 (SD = 12.60). These data indicate an increase in the average score from the first to the second cycle, reflecting improvements in the results achieved by respondents during the study. The full student outcomes, including classical completeness and averages, are presented in Figure 6.

From the diagram above, it can be seen that in Cycle I, the average score was 77 out of 35 students. The percentage of classical completion reached 65%, with 23 students completing the material and the remaining 12 students not completing it. In Cycle II, the average student score increased to 84, with the classical completion percentage reaching 77%. When comparing the completion percentages between Cycle I and Cycle II, there was an average increase of 7%. The data were then analyzed using inferential statistics.

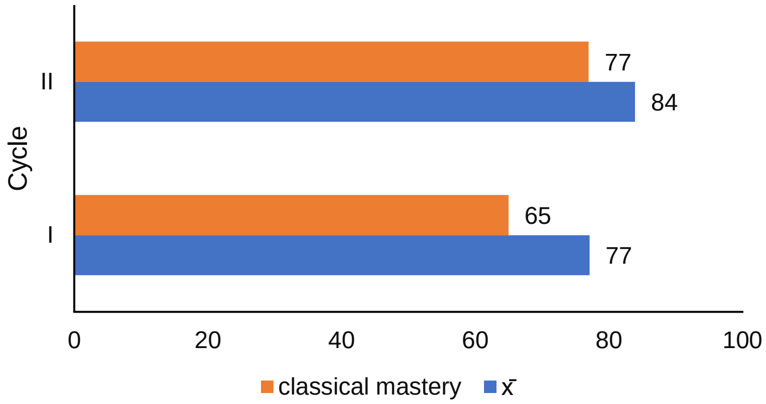

FIGURE 6. Student Learning Outcomes in Two Cycles

A Shapiro-Wilk normality test was conducted for both data cycles. The test results showed that the data in Cycle I were not normally distributed, W (35) = 0.922, p = 0.016. Similarly, the data in Cycle II were also not normally distributed, W (35) = 0.905, p = 0.005. Both tests indicate that the data in both cycles were not normally distributed. Therefore, the data were analyzed using a non-parametric difference test, specifically the Wilcoxon test. The results of the Wilcoxon signed-rank test showed that student learning outcomes in Cycle I increased significantly after the designed learning was implemented, z = -2.94, p = 0.003. These results indicate that AR learning with CRT has a significant impact on student learning outcomes in thermochemistry. Thus, the increase in learning outcomes is influenced by the presence of AR and CRT in the designed learning.

During the learning period, students exhibited a positive attitude towards the designed learning, particularly towards the AR media presented. Students displayed high enthusiasm and curiosity in exploring the media, which positively impacted their participation in learning. This engagement made them active learners, fostering a better understanding compared to reflective or passive learners [28]. AR promotes learning motivation, making students more active in their learning [29]. The increase in learning motivation corresponds with an improvement in students' academic performance [30]. In addition, the media developed includes various activities beyond AR that require students to be more active. For example, students need to place the appropriate cards on the board before using AR. In doing so, they must apply their knowledge. The AR then displays the structure of the related compound. This process accommodates the learning style needs of each student, encouraging improvement across all groups. Essentially, AR serves as a learning medium that enhances student understanding through the provided visualizations [24]. Despite being a visual medium, AR had a significant and evenly distributed impact on all student groups, even though many students have different learning styles. Furthermore, AR use in learning can improve students' conceptual understanding and academic retention [31]. Although there are not many studies that develop AR for thermochemistry material, the few that do, including this study, have shown positive results [32].

Meanwhile, CRT is an approach that connects students' prior knowledge with chemistry learning, making it easier for them to absorb new information and deepen their understanding of chemistry. Culturally Responsive Teaching (CRT) essentially accommodates the diverse prior knowledge of students, incorporating it into the learning process and enabling them to learn more effectively [33]. This approach promotes knowledge construction and designs instruction that builds on students' experiences (prior knowledge) while further developing it [34]. Like AR, the CRT approach enhances student motivation and engagement [35]. CRT significantly benefits students from various ethnic backgrounds by increasing engagement, improving achievement, and creating an inclusive learning environment. Effective CRT requires well-prepared teachers who possess socio-cultural awareness and can integrate students' cultural backgrounds into their teaching [36]. When combined with the discovery learning model, CRT is well-suited for fostering student knowledge and encouraging active participation.

In this study, the first learning session began with culinary culture, specifically satay, which is made through a grilling process, and tempeh, which is produced through fermentation. The grilling process involved in making satay serves as an example of an exothermic reaction. In this process, charcoal burning generates heat that cooks the satay meat. This is an example of an exothermic reaction resulting from the combustion of charcoal [37]. During this process, charcoal, primarily composed of carbon, hydrogen, and oxygen, produces carbon dioxide (CO_2) and water (H_2O) as the main byproducts [38]. Similar to satay, in tempeh fermentation, an exothermic reaction also occurs which causes tempeh to feel warm during the fermentation process. Satay is a well-known dish in Indonesia, making it easy for students to observe and helps enhance contextual understanding. The heat generated during the grilling process helps students grasp thermochemical phenomena.

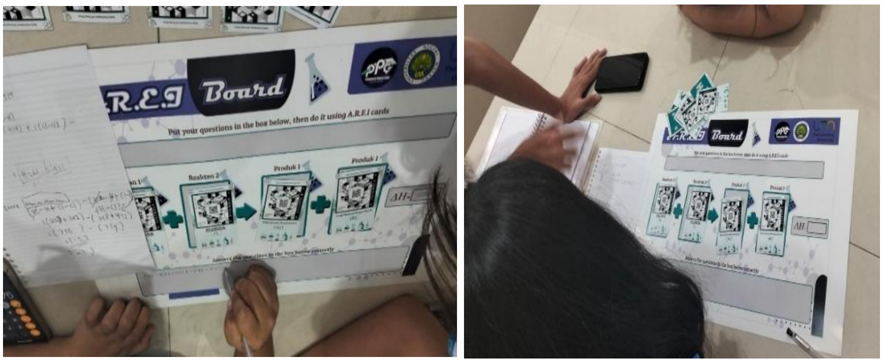

FIGURE 7. Image of the Process of Media Use by Students

To support microscopic and macroscopic conceptual understanding, educators provide virtual lab simulation media by PhET regarding energy changes and exotherm-endotherm reactions. reflection results at the first meeting showed student progress in understanding both contextual components on CRT and conceptual on virtual lab but students could not find a correlation between the context in CRT into virtual lab media. The second meeting implemented the calorimeter virtual lab media by Pearson Education without providing the CRT context. Utilization of virtual laboratories can improve readiness for learning activities in the laboratory and strengthen conceptual knowledge [39]. Educators find that students have been able to understand conceptual knowledge on calorimeters but not with a cultural context because there is no culture that can be very relevant to learning calorimeters.

In the third meeting, students learned through prol tape culinary which is a typical culinary from one of the regions in Indonesia, Jember. In this meeting, students learned about fermentation which is one example of an exothermic reaction. Fermentation was chosen as the learning context in the second and third meetings. In the fermentation process, changes occur that release a lot of energy. Tempe and tape are fermented foods that have been attached to the Indonesian people [40]. The fermentation process is exothermic which can be characterized by an increase in temperature during the fermentation process. This increase in temperature can be found in tempe and tape. These two foods that are close to students make it easier for them to observe the thermochemical phenomena around them.

In the last meeting, the hot air balloons in the Syawal commemoration were used as a cultural context. Hot air balloons use hydrogen gas fuel which in the combustion reaction forms water molecules from its reaction with oxygen. This reaction releases a certain amount of heat that makes the hot air balloon fly. This example is used to study exothermic reactions and students are given data on the bond energy of each molecule involved, so they can calculate it and study it chemically. In addition to having a cultural connection with students, hydrogen balloons also have a close history with chemistry in their development. Such as the tragedy of the hydrogen balloon accident which made people aware of the importance of safety in its use [41]. The use of hydrogen gas balloons as a learning context can also be used in practicums, such as the research of Caruso et al. [42]. Thus, incorporating the hot air balloon tradition from the Syawal commemoration into chemistry lessons is highly appropriate.

These three cultural products serve as a bridge for introducing thermochemical concepts to students. Throughout the learning process, students are encouraged to think critically and observe, making it easier for them to grasp the phenomena being discussed. The teacher then explains the relevant chemical aspects and ties them to thermochemical material, facilitating student comprehension. During the lessons, students actively listen and engage with the teacher's instructions. CRT, which emphasizes the integration of prior knowledge, culture, and curriculum content, makes chemistry more accessible and easier to understand [43]. CRT unites students with diverse prior knowledge by building on shared cultural references, which helps develop a collective understanding within the class [44]. This approach is particularly well-suited for action research, as CRT can enhance student retention and inclusivity, contributing positively to a quality classroom environment [45]. Additionally, CRT reinforces students' connections to their own cultures, fostering a sense of cultural ownership [16], indirectly positioning students as cultural preservers [46].

Based on all the results of collaborative learning reflection by educators, it is found that students need learning that can encourage contextual knowledge through CRT and conceptual knowledge at macroscopic and microscopic levels through integrated technology media. The existence of media must be accompanied by a close correlation with the context in the CRT. At this meeting, the AR was made in accordance with the CRT context regarding the enthalpy of hydrogen gas combustion reaction in a hot air balloon. AR is integrated with other media such as comics and animations which are also in accordance with the context of CRT, which can help students to understand the correlation between each other. AR technology has shown positive effects on students' learning outcomes across multiple studies. For instance, AR-assisted education led to significantly higher learning achievements compared to non-AR-assisted models [47]. In language learning, AR tools enhanced learning by presenting an immersive learning context, increasing motivation, providing interaction, and reducing anxiety [48]. These benefits could potentially align with CRT principles by creating more engaging and inclusive learning environments.

Interestingly, while AR technology generally improved learning outcomes, its impact on motivation was not always consistent. One study found no significant difference in motivation levels between AR-assisted and non-AR-assisted educational models [47]. However, other studies reported increased motivation and positive attitudes towards AR-assisted learning [49, 50]. This discrepancy suggests that the effectiveness of AR in enhancing motivation may depend on various factors, including the specific implementation and context of use.

However, this study faced limitations, particularly in the need for extra support during data collection. Students, previously accustomed to conventional learning methods, initially struggled with the shift to student-centered learning. Furthermore, the limited time for action research required teachers to provide additional reinforcement, potentially causing delays in the implementation of the teaching module. The AR technology also required smart devices with specific software, and some devices with low-specification cameras were incompatible. This challenge is common in the use of AR, as noted in previous studies [51, 52]. Researchers overcome this by encouraging the use of gadgets collaboratively with classmates.

CONCLUSION

The thermochemistry material is often challenging for students due to its complexity in concepts, calculations, and laboratory work, necessitating a structured and accessible learning approach. Culturally Responsive Teaching (CRT), which incorporates students' prior knowledge and cultural backgrounds, is an effective strategy to enhance chemistry learning by unifying diverse perspectives and building shared understanding. When integrated with augmented reality (AR), CRT creates a visually engaging and interactive environment that improves student involvement and comprehension. Action research in this study showed significant improvement in student performance, with average scores rising from 76.74 (Cycle I) to 83.94 (Cycle II), alongside increased completion rates from 65% to 77%. The Wilcoxon signed-rank test confirmed a significant impact of AR-enhanced CRT on learning outcomes ($z = -2.94$, $p = 0.003$). This synergy between CRT and AR highlights the potential of immersive, culturally relevant teaching practices in fostering inclusivity and improving student engagement and outcomes, although further research is needed to fully explore their combined effects.

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