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Can augmented reality boost students' cognitive levels in geography?

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Abstract: Understanding spatial relationships and human-environment interactions is an important aspect of geography, but many students still struggle to develop the cognitive skills to understand the concept. Augmented Reality (AR) provides an interactive learning experience for students, but previous studies generally have focused on lower-order cognitive skills. This study aims to examine the effect of AR on students' ability to understand (C2), apply (C3), and analyze (C4). This study used quasi-experimental with a posttest-only control group design. 71 tenth-grade students were selected as samples through purposive sampling. The test instrument comprised multiple-choice and essay-type questions across three cognitive levels. Data were analyzed using a non-parametric method, namely the Mann-Whitney U test. The analysis showed no significant difference between the experimental and control classes in the understanding (C2) and applying (C3) domains. However, there are variations in results on several indicators in these two domains, so AR shows the potential to improve students' understanding and application in certain aspects. In contrast, there was a significant difference in the analyzing domain (C4), with all indicators showing significant differences. Thus, AR can effectively support students' analytical skills, while its role in improving understanding and application needs further study.

Keywords: Augmented reality, cognitive skills, geography learning

Abstrak: Memahami hubungan spasial dan interaksi manusia-lingkungan merupakan aspek penting geografi, tetapi banyak siswa masih kesulitan mengembangkan keterampilan kognitif untuk memahami konsep tersebut. *Augmented Reality* (AR) memberikan pengalaman belajar interaktif bagi siswa, tetapi penelitian sebelumnya umumnya berfokus pada keterampilan kognitif tingkat rendah. Penelitian ini bertujuan untuk menguji pengaruh AR terhadap kemampuan siswa untuk memahami (C2), menerapkan (C3), dan menganalisis (C4). Penelitian ini menggunakan *quasi-experimental* dengan desain *posttest-only control group design*. Sebanyak 71 siswa kelas sepuluh dipilih sebagai sampel melalui purposive sampling. Instrumen tes terdiri dari pertanyaan pilihan ganda dan esai pada tiga level kognitif. Data dianalisis menggunakan metode non-parametrik, yaitu uji Mann-Whitney U. Analisis menunjukkan tidak ada perbedaan yang signifikan antara kelas eksperimen dan kontrol dalam domain pemahaman (C2) dan penerapan (C3). Namun, ada variasi hasil pada beberapa indikator dalam dua domain ini, sehingga AR menunjukkan potensi untuk meningkatkan pemahaman dan penerapan siswa dalam aspek tertentu. Sebaliknya, terdapat perbedaan yang signifikan pada ranah analisis (C4), dengan semua indikator menunjukkan perbedaan yang signifikan. Dengan demikian, AR dapat secara efektif mendukung keterampilan analisis siswa, sementara perannya dalam meningkatkan pemahaman dan penerapan perlu dipelajari lebih lanjut.

Kata kunci: Augmented reality, keterampilan kognitif, pembelajaran geografi

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INTRODUCTION

Geography learning is essential in education because it helps students understand space, place, and the relationship between humans and their environment. However, many students still have difficulty developing the cognitive skills needed to understand these concepts (Jo & Hong-Dwyer, 2023). Things like plate tectonic movement, climate change, or demographics can often be challenging to understand if relying solely on reading books or viewing static maps. This is where technology begins to play a significant role in education. Technological advances help students explore spatial relationships and geographical processes more engagingly (Bolkas et al., 2024). Various digital tools present dynamic simulations and visualizations to improve students' understanding and analytical skills (Sinton, 2023). This research is important because it offers a new technology-based learning approach and encourages innovation in geography teaching methods.

Among the various advanced technologies that are developing, Augmented Reality (AR) is one of the promising technologies that is changing the world of education. AR is a system that superimposes virtual content on the real one, enabling a person to see the real world augmented with even more digital explanation (Damopolii et al., 2022; Nahri et al., 2024; Susanto et al., 2024). AR opens new educational horizons to present learning materials more interactively and effectively than conventional learning (Familoni & Onyebuchi, 2024). Characteristics of AR enable 3D visualization to support exploration activities in learning (Adedokun-Shittu et al., 2020). Several studies in various subjects, such as science, mathematics, history, and language, show that AR can improve conceptual understanding, student engagement, and material retention (Volioti et al., 2022). Therefore, AR is increasingly considered a tool with great potential to revolutionize learning in the digital era.

Currently, there have been many studies that highlight the contribution of AR in improving students' understanding of geography. Research by Mondro et al. (2024) reveals that AR improves spatial reasoning and long-term retention of topographic features. Similarly, a study by Rellia (2022) found that AR significantly improves students' learning experience, so they gain a deep understanding of geography phenomena. Furthermore, a systematic literature review of 59 studies by Heydemans and Elmunsyah (2024) concludes that AR has the potential to enhance students' cognitive skills and conceptual understanding in various educational contexts. However, these studies still focus on the general impact of AR on cognitive development without examining how it contributes to different cognitive levels. Existing studies have emphasized conceptual understanding more, so there is less exploration of how AR enhances students' application and analysis skills. Therefore, this study seeks to fill in the gap by exploring how AR not only helps students understand (C2) the concept of geography but also how students can apply (C3) and analyze (C4) information in more depth.

Although many studies have shown the advantages of AR in improving students' conceptual understanding, there is still debate regarding how much it affects students' cognitive improvement. Several studies have shown that AR effectively makes it easier for students to learn complex concepts (Bothra, 2022; Prananta et al., 2024). However, in other studies, AR causes excessive cognitive burden if not appropriately designed (Hönemann et al., 2023). In addition, some studies highlight that AR has a more significant impact on the affective domain, such as increased student engagement and learning motivation, than increased cognitive abilities (Erbas & Demirer, 2019; Shen & Tsai, 2022). This raises the debate about whether AR is effective for high-level cognitive development or is limited to other aspects. With this in mind, this study aims to provide an in-depth understanding of how AR supports students' application (C3) and analysis (C4) skills instead of only focusing on the level of understanding (C2).

Cognitive ability plays a crucial role in education. This ability encourages the improvement of the student learning process and improves problem-solving skills, critical thinking, and understanding of concepts in depth, which is helpful for academic success. In geography, cognitive skills are essential for understanding spatial information and the dynamics of natural and social phenomena (Galvani et al., 2021). Students can process, analyze, and apply spatial information effectively with these skills. However, many students struggle to connect theory with real situations and solve complex problems (Tan et al., 2023). This is due to the dominance of conventional learning that relies on textbooks and static maps (Tenberga, 2024). This method often lacks interactive experiences to help students visualize geographical phenomena like plate movement or atmospheric dynamics (Tenberga, 2024). As a result, students' understanding is still limited to memorization due to a lack of ability to apply and analyze concepts further (Zou et al., 2024). This is where a more innovative approach, such as AR, is needed.

In geography, AR provides convenience in improving various aspects of students' cognition. This technology can make hard-to-observe phenomena such as plate shifts or water cycles more concrete through interactive 3D visualization (Ustun et al., 2022). Furthermore, AR can also be used for virtual field trips so students can explore the field without leaving the classroom (Alalwan et al., 2020). This technology helps students understand the concept of geography (C2) more deeply through interactive experiences, such as climate change visualization or observation of natural phenomena (Matkovič, 2024). Students can not only understand concepts, but they can also apply them (C3) to spatial-based tasks, such as mapping, remote sensing, and GIS (Wijayanto et al., 2023). Students also have the opportunity to analyze (C4) causal relationships of various phenomena and solve complex spatial reasoning problems through interactive manipulation and interpretation of geographic data (Chu & Sung, 2016). Thus, AR not only makes learning more interesting but also assists students in improving their problem-solving and analytical skills in geography.

Considering the quickly changing educational technology field, adopting AR in geography education can create new opportunities to transform cognitive understanding for students outside of rote learning. AR by enabling immersive, interactive, and spatially dynamic learning experiences, has the possibility of providing solutions to difficulties in grasping complex geographical phenomena (Volioti et al., 2022). However, it is important to look at not only how AR helps with conceptual understanding but also how this technology supports the high-level skills associated with comprehension. As such, the study examines the integration of AR in geography education by highlighting its potential to support comprehension, application, and analytical skills, which are essential in facilitating students' higher order thinking.

METHOD

The study included a quasi-experimental study with a post-test-only control group design. This study uses the topic of the water cycle, which is part of the hydrosphere dynamics material. Two classes were selected through purposive sampling. Random assignment was used to determine which class was the experimental class and which was the control class. The experimental and control classes will learn about the water cycle, but the treatment will differ. Table 1 shows the design of this study.

Table 1. The design of study

Class	Treatment	Post-test
Experimental Class	X	O
Control Class	-	O

Note :
X = Learning with AR
O = Post-test experimental and control classes

The subjects studied are grade X students of SMAN 1 Boyolangu, Tulungagung, for the even school year 2023/2024. Class X-11, with 38 students, was selected as an experimental class that applied AR. Class X-9, with 33 students, was selected as a control class that applied conventional learning. The two classes were chosen because they have almost the same learning achievement characteristics as the previous material chapters, 88.84 and 87.02.

Data collection was carried out through a post-test concerning three Bloom's cognitive levels, namely C2 (Understanding), C3 (Applying), and C4 (Analyzing), with predetermined indicators. The indicators were adapted from Eggen & Kauchak (2012) for Understanding and from Anderson & Krathwohl (2001) for Applying and Analyzing. These indicators were also cited in previous studies (Yasmansyah & Sesmiarni, 2022; Mulatsih, 2021; Wagola & Mataheru, 2023). See Table 2 for details.

Table 2. Indicators of the understanding, applying, and analyzing levels

Cognitive Domain	Indicators	Reference
C2 (Understanding)	Defining, connecting, identifying, giving examples	Eggen & Kauchak (2012)
C3 (Applying)	Executing, implementing	Anderson & Krathwohl (2001)
C4 (Analyzing)	Differentiating, organizing, attributing	Anderson & Krathwohl (2001)

The test instrument used consisted of ten multiple-choice questions and five description questions. Multiple-choice questions were chosen because they were efficient in measuring students' initial understanding and ability to apply simple concepts, so they were effective in measuring the dimensions of C2 (understanding) and C3 (applying). However, because multiple-choice questions are very susceptible to guessing and are not able to measure students' thinking processes, essay-type questions are also used to be able to measure students' analytical skills in the C4 (analyzing) dimension.

The test instrument was validated through construct validation by ensuring that the questions follow *Capaian Pembelajaran (CP), Tujuan Pembelajaran (TP)*, and three cognitive levels to be achieved. An expert lecturer also reviewed the test instrument to ensure that the questions aligned with the concepts being measured and that the results accurately reflected the students' abilities.

Furthermore, the collected data will be processed using the IBM SPSS Statistic 23 application for prerequisite and hypothesis testing. The prerequisite tests include normality testing through Kolmogorov-Smirnov and homogeneity testing using Levene's Test to determine whether the data met parametric assumptions. See Table 3 for results.

Table 3. Normality test results

Cognitive Level	Kolmogorov-Smirnov (Sig.)	Normality
C2 (Understanding)	Experimental = 0.000, Control = 0.000	Not normal (both)
C3 (Applying)	Experimental = 0.002, Control = 0.089	Experimental: Not Normal, Control: Normal
C4 (Analyzing)	Experimental = 0.002, Control = 0.200	Experimental: Not Normal, Control: Normal

The normality test results in Table 3 show that not all data meet parametric assumptions. Since some cognitive levels were not normally distributed, hypothesis testing was conducted using the Mann-Whitney U Test. The first stage involved testing the three cognitive levels to identify whether there were significant difference between the experimental and control classes. Subsequently, further tests were conducted on each indicator to determine which indicators showed significant differences.

RESULTS AND DISCUSSION

Overall differences across the three cognitive domains (understanding, applying, and analyzing)

The Mann-Whitney U test was conducted to see if there was a significant difference between the experimental class and the control class in each cognitive domain. The test results are presented in Table 4.

Table 4. Mann-Whitney U test results for each cognitive domain

Cognitive Domain	Mean Rank Experimental	Mean Rank Control	p-value (Sig.)	Conclusion
C2 (Understanding)	39.09	32.44	0.095	Not significant
C3 (Applying)	39.54	31.92	0.117	Not significant
C4 (Analyzing)	42.04	29.05	0.008	Significant

The results of data analysis showed that at the level of understanding ($p = 0.095$) and applying ($p = 0.117$), there was no significant difference between the experimental and control classes because the p-value was greater than 0.05. This shows that AR does not significantly impact these two domains. However, there was a significant difference at the analyzing level with a p-value of 0.008 ($p < 0.05$). In addition, the mean rank in the experimental class (42.04) was also higher than that of the control class (29.05), thus showing that AR positively improved students' analytical skills. Therefore, AR improves students' analytical skills more effectively than understanding and applying. This finding aligns with the research results by Weng et al. (2020), which revealed that AR positively impacted students' analytical skills compared to the level of understanding and remembering. This result is also supported by Shen and Tsai (2023), who found that AR has more impact on the level of memory and application than the level of comprehension.

Because there are significant differences in the analyzing domain (C4), further tests are carried out using the Mann-Whitney U test to see the differences in each domain indicator. A more detailed discussion of each domain and its indicators, including the C4 domain, will be presented in the following sections.

Differences in the understanding domain (C2)

Table 5 compares the results between the experimental and control classes in the understanding domain (C2) based on four indicators.

Table 5. Descriptive statistics and Mann-Whitney U test for understanding domain indicators

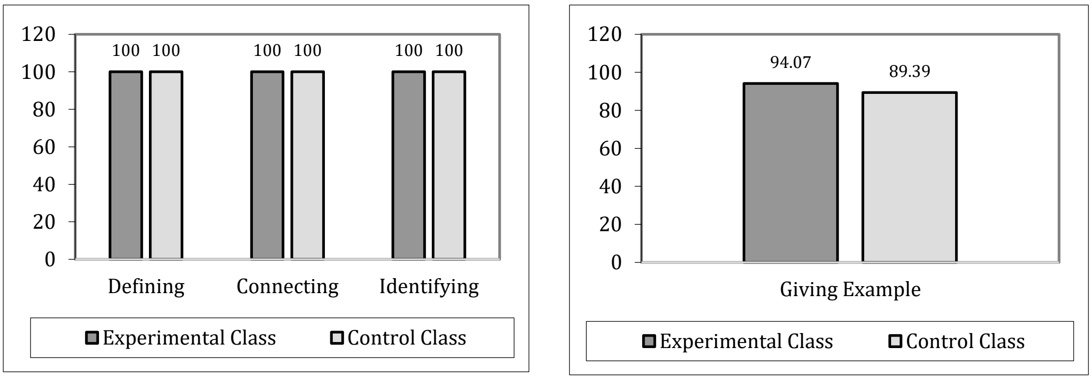
Indicator	Experimental (Mean Score/Rank)	Control (Mean Score/Rank)	p-value (Sig.)	Conclusion
Defining	100/36.00	100/36.00	1.000	Not significant
Connecting	100/36.00	100/36.00	1.000	Not significant
Identifying	100/36.00	100/36.00	1.000	Not significant
Giving Example	94.07/39.09	89.39/32.44	0.095	Not significant (descriptive tendency)

According to Table 5, students' learning outcomes for the understanding level, specifically defining, connecting, and identifying concepts, did not show significant differences between the experimental and control classes. Both classes obtained perfect scores (100) on all three indicators, with identical mean ranks (36.00) and a p-value (Sig.) of 1.000. These results suggest that AR does not necessarily have a significant impact on indicators that emphasize low-level understanding, such as recognizing definitions and identifying simple characteristics. This finding aligns with Shen and Tsai (2023), who stated that AR is more effective for high-cognitive domains, such as application, rather than basic comprehension. The visualization of the three indicators can be seen in Figure 1(a).

Indicators of defining, identifying, and connecting concepts rely on theory-based understanding that can be achieved effectively through verbal explanations. This explains why the experimental and control classes achieved the same results (100). Manjula and Kanakadurga (2017) emphasized that well-structured verbal explanations can improve the clarity of the material. This is in line with Titsworth et al. (2015), who stated that verbal instruction that is easy to understand can significantly improve students' conceptual understanding.

Furthermore, the similarity of results in these three indicators can be related to students' prior knowledge, especially in the experimental class, which was already sufficient even before AR was given. For example, on the topic of the water cycle, some students already have a basic knowledge of the water cycle, so they can define the stages and identify their characteristics without the need for the help of AR. A study by Hunaepi et al. (2023) revealed that the effectiveness of AR depends on the novelty of the content presented. Dhaas (2024) also states that when AR content does not offer new information, its impact on cognitive engagement becomes limited. This is reinforced by the opinion of Chen and Abidin

(2023), who emphasize the importance of engaging content that can stimulate students' initial knowledge.



(a) (b)

Fig. 1. (a) Diagram of defining, connecting, and identifying indicators; (b) Diagram of the giving example indicator.

In contrast to the previous three indicators, the indicator of giving examples shows the difference in results between the experimental and control classes. According to Table 5, the experimental class that applied AR obtained a higher result, namely 94.07, than the control class, with a score of 89.39. In addition, the mean rank of the experimental class was 39.09, higher than the control class of 32.44 with a p-value (Sig.) of 0.095. This result suggests that AR may play a role in helping students to relate theories to real-world examples, although statistically, with the Mann-Whitney U Test, the understanding domain (C2) did not show a significant impact. The visualization of the giving example indicator can be seen in Figure 1(b).

One possible explanation for this result is that interactive visualization of AR may help reduce students' cognitive load, making it easier for students to relate abstract concepts of geography to real-world examples (Turan et al., 2018). AR also allows students to observe and interact with concepts that are challenging to observe directly, such as the water cycle (Ustun et al., 2022).This immersive experience may help students improve their understanding and assist in providing examples of abstract concepts of geography (Sathyapriya et al., 2024).

Both classes were able to provide examples, but the experimental class showed slightly higher results than the control class. This may be due to the additional visual support provided by AR. In contrast, conventional learning generally relies on lectures and minimally uses interactive media. Verbal explanations tend to provide fewer visual descriptions to students, so students must rely on their imagination to visualize a concept (Luft, 2022). In addition, traditional textbooks often present information in 2D format, which limits students' ability to visualize concepts effectively (Nigam and C, 2022).

The difference in results on the indicator of giving examples shows that although AR does not significantly improve the overall understanding domain, AR may still offer some support for tasks that require the relationship of abstract concepts to real examples. However, given that the results of the Mann-Whitney U test did not show significant differences in the understanding domain, further studies are needed for this indicator.

Differences in the applying domain (C3)

Table 6 compares the results between the experimental and control classes in the applying domain (C3) based on two indicators.

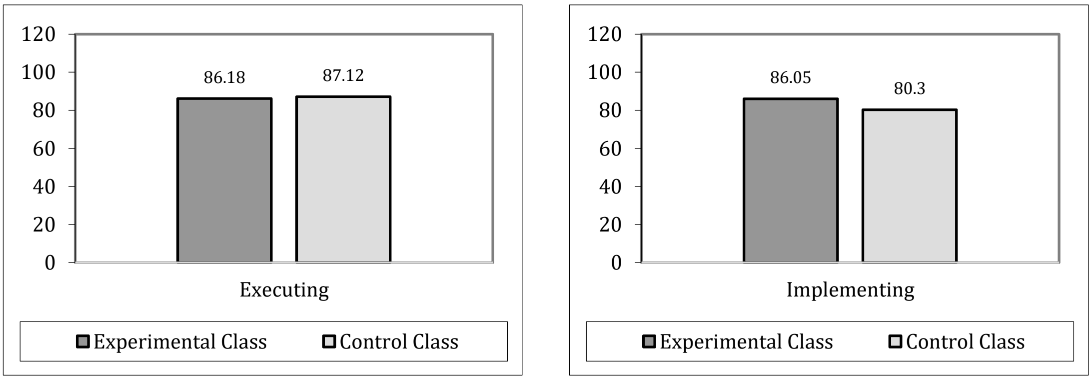
Table 6. Descriptive statistics and Mann-Whitney U Test for applying domain indicators

Indicator	**Experimental (Mean Score/Rank)**	**Control (Mean Score/Rank)**	**p-value (Sig.)**	**Conclusion**
Executing	86.18/35.38	87.12/36.71	0.754	Not significant (control class had a slight desciptive edge)
Implementing	86.05/40.04	80.30/31.35	0.071	Not significant (experimental class had a desciptive edge)

The results of the data analysis in Table 6 show an interesting finding on the executing indicator. Descriptive analysis showed that on this indicator, the control class that applied conventional learning recorded slightly higher results (87.12) than the experimental class that applied AR (86.18). In addition, the mean rank of the control class was 36.71, slightly higher than the experimental class which had a mean rank of 35.38 with a p-value (Sig.) of 0.754. However, this difference was not statistically significant in the overall C3 domain. One factor that may support this result is the characteristics of conventional learning that emphasize verbal instruction in detail and systematically. Detailed verbal instruction allows students to understand the material in depth and apply their knowledge in a structured manner to familiar situations (Kasim & Joseph, 2022). Esparrago-Kalidas et al. (2023) emphasized that repetitive verbal instruction positively strengthens students' concepts and skills. The visualization of the results in the executing indicator can be seen in Figure 2(a).

Another possible explanation for why the experiment class is slightly lower than the control class in the executing indicator is the complexity of AR. Higashiguchi (2019) noted that technical understanding using AR could distract students from focusing on procedural tasks. Herbert et al. (2022) mentioned that AR visualizations that are too complex can hinder students' performance on simple tasks. Research by Dharmawan and Setyaningsih (2022) suggests that in some cases, students may be more interested in visuals from AR than focusing on task procedures. These findings indicate that while AR can pose additional complexity, it also offers unique benefits for students. This suggests that conventional and AR-based learning have their advantages in supporting students' cognitive abilities.

In contrast to the result of the executing indicator, the experimental class obtained a higher result (86.05) than the control class (80.30) in the implementing indicator. The mean rank of the experimental class was recorded at 40.04, while the control class was 31.35, with a p-value of 0.071. Although these results did not show a statistically significant difference, descriptive analysis indicates that AR may offer certain advantages in this aspect. Rakshit et al. (2023) explained that AR allows students to explore objects from various perspectives that can support deep understanding. This in-depth understanding can help students to build relationships between theory and real context (Kozov & Ivanova, 2023). As a result, students can develop better problem-solving skills and integrate them in different situations (Lee et al., 2017). These findings show that although AR does not result in a statistically significant increase, AR still has the potential for conceptual application. The visualization of the implementing indicator can be seen in Figure 2(b).



(a) (b)

Fig. 2. (a) Diagram of the executing indicator; (b) Diagram of the implementing indicator

Differences in the analyzing domain (C4)

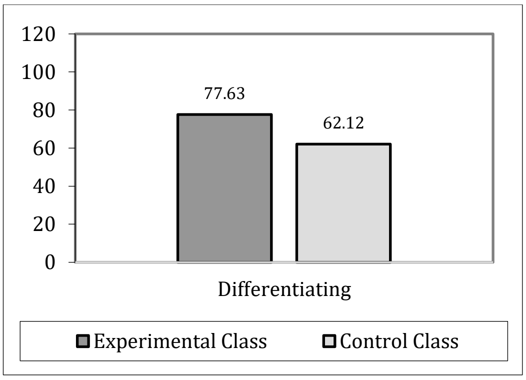
Table 7 compares the results between the experimental and control classes in the analyzing domain (C4) based on three indicators.

Table 7**.** Descriptive statistics and Mann-Whitney U test for analyzing domain indicators

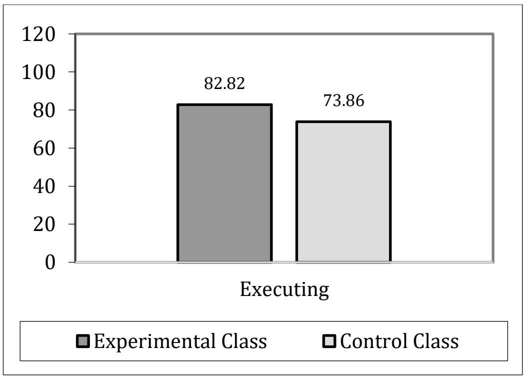
Indicator	Experimental (Mean Score/Rank)	Control (Mean Score/Rank)	p-value (Sig.)	Conclusion
Differentiating	77.63 / 40.67	62.12 / 30.62	0.020	Significant
Organizing	82.82 / 40.41	73.86 / 30.92	0.047	Significant
Attributing	80.98 / 41.07	71.59 / 30.17	0.022	Significant

Table 7 shows that students' learning outcomes in the experimental class are superior in three indicators in the analyzing dimension compared to the control class. These differences have been statistically proven through the results of the Mann-Whitney U test. This reinforces the positive impact of AR on students' analytical skills. This aligns with the research of Weng et al. (2020), whose results reveal that AR positively enhances students' ability to analyze complex information. Similarly, Chien et al. (2019) state that AR enhances high-level cognitive abilities through its ability to visualize abstract phenomena. AR visualization makes it easier for students to determine concepts well, organize information systematically, and attribute relationships to various elements of geography concepts. This ability will help students bridge theoretical concepts with real-world applications more effectively.

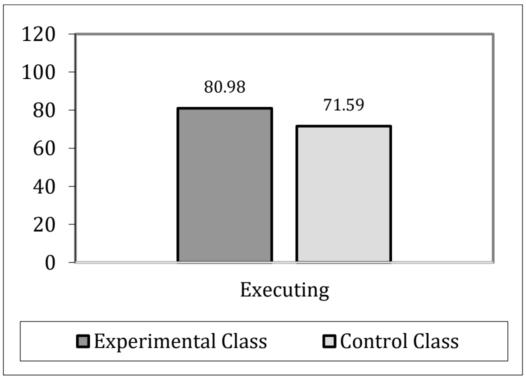
One of the key indicators in the analyzing dimension (C4) that shows significant differences is differentiating. As shown in Table 7, the differentiating indicator of the experimental class obtained a higher score (77.63) than the control class (62.12). This advantage was strengthened by the Mann-Whitney U test, which showed that the mean rank of the experimental class was higher (40.67) compared to the control class (30.62), with a statistically significant difference (p = 0.020). These results indicate that AR encourages the improvement of students' ability to differentiate information more effectively. AR allows students to compare visual objects directly to identify the distinction more clearly (Volioti et al., 2022). For example, in learning the water cycle, students can differentiate the characteristics of precipitation and evaporation through 3D visualization. Savitri et al. (2019) also found that visual exploration through AR enhances learner's comprehension of the unique characteristics of each geographical object. Thus, it further strengthens the effectiveness of AR in enhancing students' analytical skills in geography. The visualization of the differentiating indicator can be seen in Figure 3(a).



(a)



(b)



(c)

Fig. 3. (a) Diagram of the differentiating indicator; (b) Diagram of the organizing indicator; (c) Diagram of the attributing indicator

The organizing indicator in the analyzing dimension (C4) also shows significant differences between the experimental and control classes. Table 7 shows that the experimental class achieved a higher score (82.82) than the control class (73.86). The results of the Mann-Whitney U test indicated a significant difference between the two groups ($p = 0.047$), with a higher mean rank in the experimental class (40.41) compared to the control class (30.92). These indicate that AR improves students' ability to construct concepts more logically. This aligns with Turkan et al. (2017), who found that students better understand the interaction between conceptual elements using AR. With AR visualization, students can compose concepts in a more structured manner (Ustun et al., 2022). Chen et al. (2016) also emphasized that AR provides an advantage over conventional classrooms for learning that requires complex information organization. The visualization of the organizing indicator can be seen in Figure 3(b).

Like the previous two indicators, the attributing indicator shows significant differences, with a statistically significant difference ($p = 0.022$). As presented in Table 7, the experimental class obtained a score of 80.98, higher than the control class (71.59). Based on the Mann-Whitney U test results, the experimental class also had a higher mean rank (41.07) than the control class (30.17). These findings indicate that AR enhances learners' proficiency in identifying and formulating causal relationships more effectively. This can be attributed to AR's ability to present virtual exploration activities of geographical phenomena that allow students to see causal relationships (Alamäki and Dirin, 2021). For example, AR visualization allows students to understand how water cycle elements affect each other, such as the evaporation process that causes cloud formation. Sathyapriya et al. (2024) stated that exploration directly improves students' understanding of the cause-and-effect relationship. This aligns with the finding of Olim and Nisi (2020), who show that visualizing the relationship between elements helps students understand the cause-and-effect relationship well because they can see how one element affects the other. The visualization of the attributing indicator can be seen in Figure 3(c).

CONCLUSION

The analysis showed no significant difference between the experimental and control classes in the understanding (C2) and applying (C3) domains. In contrast, the analyzing domain (C4) showed significant differences. However, descriptively, there are variations in results in several indicators. In the C2 domain, the defining, connecting, and identifying indicators had the same score (100) in both classes, while the giving example, experimental class indicators showed superiority. In the C3 domain, the control class is slightly higher in the executing indicator, while the experimental class is higher in the implementing indicator. In the C4 domain, all indicators (differentiating, organizing, and attributing) showed higher results in the experimental class. Overall, AR has the potential to support students' analytical skills, but its impact on understanding (C2) and application (C3) still needs further study. Nonetheless, the use of AR shows the potential to improve the understanding and application of concepts to certain aspects.

The results of this study support previous studies on the effectiveness of AR in improving analytical thinking skills (C4). However, because the results of the C2 and C3 domains are not yet entirely significant, these findings provide a perspective that the impact of innovative technologies may vary depending on the cognitive domain developed. Therefore, further studies are needed on the effectiveness of AR in the C2 and C3 domains. The use of AR can be an effective strategy to improve students' analytical skills, so it is recommended to integrate this technology into geography learning.

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