Towards Understanding Group Collaboration Patterns Around Mobile Augmented-Reality Interfaces for Geospatial Science Data Visualizations

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ABSTRACT

Research has shown benefits of providing collaborative learning opportunities in undergraduate Earth Science classrooms as it enables student groups to visualize, discuss, and make meaning of the complex Earth System Science. Augmented Reality (AR) applications have been increasingly used to present geodata visualizations in their innate three-dimensional format to support Earth Science learning. However, little is known about how student groups naturally collaborate around AR applications to interpret and make sense of geodata visualizations. To bridge this gap, we studied how groups of pre-service Earth Science teachers collaboratively explored a mobile AR application showcasing Earth's ocean system. In our findings of groups' natural collaboration behaviors, we found that most groups tended to work closely where both group members talked about content and interacted with the AR app together. Our findings will inform the design of future mobile-AR geospatial data visualization interfaces to effectively support collaborative learning in classrooms.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); Empirical studies in HCI.

KEYWORDS

Augmented reality, Collaboration behaviors, Collaborative learning, Geo-Science data visualization, Pre-service teachers, Touchscreen gestures, Education technology

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1 INTRODUCTION

Research has shown the benefits of providing collaborative learning opportunities in undergraduate Earth Science classrooms as it enables student groups to visualize, discuss, and develop a shared understanding of the complex Earth System Science Concepts [5]. More specifically for pre-service teachers, the Next Generation Science Standards (NGSS) emphasize the importance of data visualizations, especially 3D geospatial data visualizations, for students in K-12 classrooms [2], which provide students a way to collaboratively visually inspect, discuss, and understand complex spatial relationships in global data [1]. Augmented Reality (AR) applications have been increasingly used to present global geodata visualizations in their innate three-dimensional form (e.g., as virtual globes versus flat maps) to support Earth Science learning, as they enable learners to see invisible, interrelated, and spatially complex processes [7, 8]. Despite the importance of collaborative learning for global data analysis and the increasing use of AR-based geodata visualization applications [6, 8, 14], we know little about how students collaboratively learn around mobile-based AR applications

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in a formal classroom setting. Our study takes a step towards addressing this gap. We conducted a lab-based design probe study where 14 pre-service teachers (in groups of 2) collaborated with our custom-built AR application about the Earth's ocean temperature system. Our research goal was to deeply investigate student groups' natural collaboration behaviors [11] (e.g., collaboration mechanics, gestures, or talk patterns) when collaboratively exploring geo-spatial data visualization around a mobile-AR application. The findings of this study could help us pinpoint critical collaboration behaviors within future AR applications designed to support collaboration and learning that lets groups focus on exploring the educational content at hand rather than focusing on how to operate the interface collaboratively.

Multiple prior works have explored mobile-AR application design to support collaborative learning in the context of geodata [6, 13]. For example, Morrison et al. [6] developed an interactive mobile-AR map that enhances traditional paper maps by dynamically overlapping real-time information and media icons through the camera. In their between-subjects evaluations, the authors compare interaction experiences with the mobile-AR map versus a standard 2D map with 37 subjects (ages 7-50). Based on the analysis of users' behaviors in different interaction scenarios (e.g., collaborative usage and walk while using), the paper found that even slight differences in embodied interaction enabled by AR features in the map could influence the way an individual user orients to their surroundings and the way the groups collaborated. For example, the mobile-AR map requires users to hold the map as a background surface for the AR overlay to function effectively. This necessity for stability of the AR feature prompts users to gather closely around the map, fostering collaborative interaction and joint decision-making within the group. In another study, Zimmerman et al. [14] investigated the immersion experience of 17 family groups as they collaboratively made sense of geological periods and phenomena using a mobile-AR app in a learning-on-the-move study conducted in an informal learning setting. In their analysis the authors found that the mobile-AR application supported sensory and social immersion, while facilitating observational inquiries and meaningful discussions during collaborative learning. Although not in the context of student groups and AR interfaces, Soni et al. [11] explored family groups' natural collaboration behaviors in the context of geodata visualization exploration around multi-touch spherical displays. The authors analyzed groups' collaboration behaviors (e.g., collaboration profiles and physical arrangements), and contributed design guidelines for designing more effective group learning applications for spherical displays. This study illustrated the importance of understanding groups' natural collaborative behaviors to help us design effective collaborative learning applications. In another study, Satriadi et al. [8] explored the interaction design space of head-mounted AR and tangible globes for geospatial data visualization exploration. Using a prototype tangible globe device, the authors further prototyped nine use cases. For example, the authors created a tangible globe interface that displayed augmented lines above the globe surface, with their height mapped to the distance between origin and destination, employing color coding and animation to indicate direction. Based on an interview study with experts from cartography and immersive analytics the findings of this work showed that as compared to tangible globes with integrated electronic displays, AR globe promises comparable display and interaction capabilities without requiring specialized hardware. Overall, the above-mentioned prior work provides insights into designing more effective AR-based interfaces and noting the importance of understanding groups' natural collaboration behaviors for non-AR 3D spherical display learning applications. Our work builds and extends this prior work by studying the nature of groups' collaboration behaviors with mobile-AR geospatial data visualization applications. Overall, our findings underscore the potential of mobile-AR applications in fostering collaborative learning through active engagement with geodata visualizations and point to the need to incorporate multi-user gestures into future mobile-AR applications to support group learning. Our findings could inform the design of future geospatial data visualization mobile-AR interfaces, especially in terms of what type of collaboration behaviors to support.

2 DESIGN PROBE STUDY METHODOLOGY

Participants: To understand how student groups naturally collaborate when learning from a geospatial data visualization mobile-AR application, we conducted an exploratory design probe study [16]. We recruited our study participants through in-class announcements at a US university. All participants were pre-service teachers who had completed an introductory Earth Science class. A total number of 14 students, in 7 pairs, participated in our study (6 female, 1 woman, 1 woman/non-binary, 4 male, 1 gender-fluid, and 1 genderqueer[1]). The participants ranged from freshmen to seniors, and had experience working with touchscreen technologies including smartphones. All participants (N=14[2]) reported interacting with Google Earth, 7 with Geographic Information Systems (GIS), 4 had used NASA World Wind.

Procedure: The design probe study was conducted as a part of a larger focus group study to understand how pre-service teachers might interact in a lab setting. The goal of the focus group was to understand students' collaborative geodata analysis practices in classrooms. The design probe study where students in groups of 2 interacted with our AR application (described later) happened at the end of the focus group. Each design probe study lasted 7-11 minutes during which participants were asked to complete three tasks collaboratively using our AR application (Figure 1). The AR application was running on a Google Pixel 5a (6.34 inches). Broadly speaking, the three tasks included the following: 1) Explore the application with your group collaboratively; 2) Take a look at the sea surface temperature near the Gulf of Mexico. How did this temperature change over time for the year 2021? What type of patterns did you notice for the sea surface temperature near the Gulf of Mexico?; and 3) Look at both sea surface temperature and coral reefs near Florida. What patterns do you see during early 2022. What type of patterns and relationships did you notice between coral reef bleaching and temperature near Florida? After completing each task, participants were asked to share their answers and what they learned. At the end, they were asked to fill out a brief demographic questionnaire. All study sessions were audio

[1] Participants self-identified gender.
[2] "N" represents the total number of subjects or observations in a population or sample.

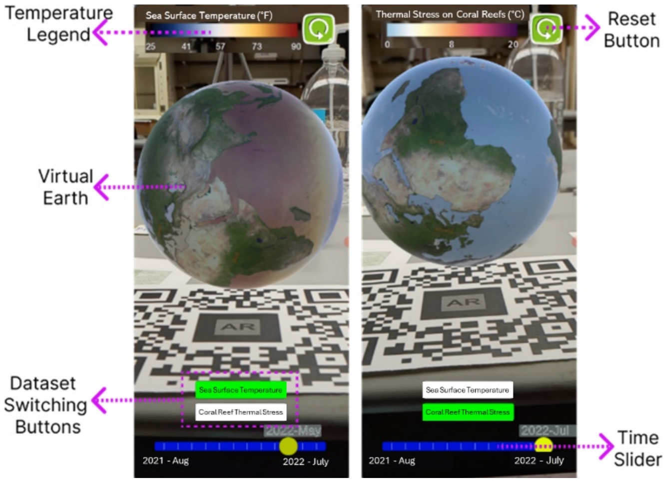

Figure 1: Our Mobile-AR Prototype Application for Geospatial Data Visualization of Earth's Ocean System.

and video recorded, and touch logs were collected by our AR application. Participants received a $15 gift card for their participation. The study was approved by the university's Institutional Review Board (IRB).

Our Mobile AR Prototype Application: Informed by prior work [11, 12], our AR prototype application was developed using Unity 3D. The goal of our application was to help students collaboratively explore Earth's ocean system, especially any trends and correlations between sea surface temperature and coral reef thermal stress (Figure 1). The data visualization for sea surface temperature and coral reef thermal stress presented on a virtual globe in our AR prototype were taken from NOAA's public dataset [15], including the temperature legends which were provided in degrees Celsius and Fahrenheit, and allowed students to observe and correlate overall temperature patterns. The AR application displayed a virtual earth overlayed with sea surface and coral reef data visualizations, a button to switch between sea surface and coral reef datasets (tap gesture), a button to reset virtual earth to its default location and size (tap), a draggable time slider (drag) that let students drag over it to change months and visualize how sea temperature impacted coral reef over time of years 2021 and 2022. Participants can drag, rotate, and zoom through the virtual earth to explore the different geographical areas across space and time. Each visualization had titles and associated temperature legends.

Data Analysis: To answer our research question of investigating groups' natural collaboration behaviors with mobile-AR geodata visualization application, we created a codebook by adapting codes presented in prior work on collaborative learning technologies for geodata visualization [11]. The codebook included codes such as interface element participants were interacting with, and gestures used, number of participants talking or interacting with the application, collaboration profiles <strike/>(e.g., turn-taker and driver-as-a-guide) [9, 11] and talk categories (e.g., content talk and how-to-talk) [9, 11] (see supplementary materials for detailed codebook). Before starting the final coding, two researchers coded 28.60 % of all videos, (N =7) to develop consensus in the coding process and resolve any disagreements, including noting sample examples to develop a shared mental model of different profiles and talk categories. For final analysis, two researchers independently analyzed 71.40% of all videos (N=7) and 28.60% of all videos (N=7), respectively. One of the groups had 4 participants. For analysis, we divided this group into two sub-groups of two participants each. During analysis, all video recordings were coded in 30-second segments. Overall, our coding resulted in a total of 138 30-second segments. Out of this, 80 30-second segments were included in our analysis presented in this paper. 58 segments where participants were listening to or answering experimenters' questions and not collaborating using the AR application were not included in our analysis. After final coding, Microsoft Excel pivot tables was used to do frequency analysis and identify groups' natural collaboration behaviors based on our codebook. Next, we present our findings of groups' collaboration patterns.

3 FINDINGS

In our findings we discuss groups natural collaboration behaviors in terms of gesture patterns, collaboration profiles, group talk, while they interacted with our AR prototype application.

3.1 Gesture Interaction Patterns

In this section, we discuss the findings related to how participants interacted with the AR application during our study. During the analysis, we saw participants exploring the application using multiple supported gestures such as tapping (during 60.00% of all the 30-second segments analyzed across all groups, N=80 segments included in our analysis), dragging (76.25%) and zooming (60.00%) the virtual earth, dragging time slider to visualize how sea surface temperature and coral reef visualization change over months (67.50%). We did not see participants using the rotate gesture as frequently as other gestures (only during 15.00% of the segments). We coded a gesture to rotate when participants rotated their wrist when performing the gesture. We observed that participants preferred the drag gesture (horizontally or vertically) to explore data visualizations overlayed on the virtual earth across space, and only employed the rotate gesture when they wished to change both the orientation and size of the virtual earth, which involved a combination of dragging and zooming. An example when participants used rotate gesture was in Group G765: P1 and P2 decided to dive deeper into the Mariana Trench. P1 realized they were not located at the Mariana Trench, and said "*Ok, wait. We just weren't looking in the right place. Ok, everything is about to be set down. Hold on, let's fix this.*" P1 rotated the wrist and zoomed the two fingers at the same time to locate the Mariana Trench. As a result, the virtual earth displayed the Mariana Trench in the front. Additionally, we also observed participants performing bi-manual gestures where they manipulated different interface elements simultaneously using two hands. In G463-2, for example, when the group engaged in observing coral reef thermal stress near Florida, one participant used their right hand to hold the phone, employing one finger to slightly drag the timer slider, and two fingers on the left hand to zoom into the virtual earth simultaneously. Along the same lines, we also observed participants using multi-user gestures when the two participants interacted with the interface at the same time. As an example, for G724, we saw P1 holding the phone and dragging the time slider across to see the temporal pattern change for coral reef thermal stress, remarking "*. . . that looks pretty extreme.*" As P1 drags, P2 tries to tap the virtual earth element to pinpoint it, querying "*can we click? Can we pinpoint or something*", but the interface does not respond. **Overall, we found that participants employed diverse touchscreen gestures including both multi-touch (e.g., dragging virtual earth while dragging time slider) and multi-user gestures (e.g., participant dragging slider and the other tapping the virtual earth), when collaboratively interacting with our AR application. This highlights the importance of supporting both multi-touch and multi-user gestures when designing AR-based collaborative learning interfaces.**

3.2 Group Talk

We analyzed how and what participants were talking about when exploring our prototype. In terms of number of participants talking, our analysis showed that when collaboratively learning about Earth's Ocean temperature system using our AR application, both group members were talking for majority of the time (for 86.25% of the 30-second segments, N=80), Only 8.75% of the segments had one member talking. No group member talked for 5.00% of the segments. During our analysis, we dug into the nature of talk between group members. As listed Table 1, we analyzed 6 categories of talks. Overall, the top two most common group talk patterns coded were *content talk* (51.25%), *group process talk* (21.25%). We saw *content talk* (51.25%) as the most frequent talk pattern across all three tasks, and especially for the third task which asks participants to observe both sea surface temperature and coral reefs near Florida in early 2022. Content talk involves dialogue where participants engage in discussing the learning content (e.g., temperature patterns across continents). For example, this segment of group G463-1 was coded as *content talk* where during their exploration participants P1 and P2 were sharing their observations on the temporal patterns of sea surface temperature, as P1 says "*Ok it starts off cool, especially towards the coast. Okay, it does get warmer? It looks slightly colder in February. . .*" [dragging the time slider slowly], and when P1 hands off the mobile phone to P2, P2 affirms the corresponding coral reef thermal stress pattern change with numerical value by stating "*no thermal stress. . .then thermal stress stays blue*" [dragging time slider]. Beyond *content talk***,** *group process talk* (21.25%) was seen as the second most common talk type across three tasks. *Group process talk* involves discussion about how group members should interact with each other or with the interface. As an example, in G765, P2 takes charge of interacting with the interface, and P1 gives suggestions on what P2 should interact with. P1 asked P2, "*Do you mind using the scale to move it?*" P2 agreed and started to drag the time slider. P1 observed, "*It starts off pretty warm. . . I can't really tell what number it is, but it's probably 80.*" P2 agreed and kept dragging slightly, saying, "*Yeah, and it goes to 70 degrees, and that's for 2022.*" P1 asked, "*So it gets colder?*" P2 replied, "*Yeah.*" We also saw groups engaging in *how-to-talk* during 10.00% of the analyzed 30-second segments. *How-to-talk* occurs when participants talk about how interface elements work. As an example, we coded a segment in G724 as *how-to-talk* when P1 and P2 explored the prototype, P1 remarked

Table 1: Talk categories and descriptions (N= 80)

Talk Category	Descriptions	% of segments
Content talk	Users ask questions/make statements about the learning content such as visualization, timeline, or continents (e.g., "let's see Antarctica," what's the template in Florida")	51.25%
Group-process talk	Users discuss how group members should interact. (e.g., saying "do not touch," "why don't; you change the year" etc.).	21.25%
Combination	Users discuss two different types of talks during a 30-second interaction segment	12.50%
How-to-talk	Users discuss how to operate the interface (e.g., "how to interact with the time slider," "what happened just now?" or "how to reset the earth.")	10.00%
No Talk	No user is talking	5.00%
Off-topic	Talk not related to content or operation of the interface.	0.00%

"*I don't know what to do, what is this?*" P2 replied, "*I don't know.*" P1 dragged the slider around and found, "*Oh, you can change the date. Oh, cool. That's cool.*" Then P1 tapped the dataset switch button and said, "*So, this is sea surface temperature.*" **Overall, we observed our AR application facilitated group members to actively talk about the geodata patterns. These findings demonstrate the potential of mobile-AR applications to support effective group discussion and facilitate collaborative learning about geospatial data visualization.**

3.3 Collaboration Profile

To understand different roles group members played during collaboratively learning with our AR application, we qualitatively coded different collaboration profiles. Collaboration profiles (Table 2) help us pinpoint different verbal and physical indicators linked to effective collaborative learning [9, 10]. Among the 5 collaboration profiles, *driver-as-a-guide*, *turn-taker*, and *driver-navigator* are the top three most common collaboration profiles we saw in our analysis, accounting for 45.00% (N=80), 31.25%, and 17.50% segments, respectively. The least common collaboration profiles included *independent* (6.25%) and *driver-passenger* (0.00%). *Driver-passenger* was defined and coded but not identified in any group. In our analysis, 45.00% of the segments were coded as *driver-as-a-guide*, where one participant (acting as both driver and guide) actively interacts with the interface, describing their observations and interpretations of the AR content, while the other participant observing, listening, and briefly responding to the driver's questions. For example, a segment from G247 was coded as *drive-as-a-guide*, where P1 guided the collaboration by both expressing the temperature observations

Table 2: Collaboration profiles and descriptions (N = 80)

Collaboration Profile	Descriptions	% of segments
Driver-as-a-Guide	The driver interacts while simultaneously explaining the content displayed to other group members, who listen passively but in an engaged manner.	45.00%
Turn-Taker	Both users make and accept suggestions and observations; they coordinate multi-touch gestures.	31.25%
Driver Navigator	Both users are engaged. The navigator contributes with suggestions; the driver listens and performs most actions	17.50%
Independent	Users are absorbed in their own activity with minimal communication.	6.25%
Driver-Passenger	The driver is engaged, and the passenger is not focused on the task. The driver performs most actions.	0.00%

as well as manipulating the interface [zoom virtual earth], while P2 engaging listened to P1, offering no significant contributions or suggestions: P1 is zooming in and out of the Gulf of Mexico and dragging the time slider to observe coral reef stress and states "*it's closer to zero no, maybe ten, no, zero for sure.*" P1 taps the dataset button for sea surface temperature and determines "*sea surface temperature... I noticed in January it started off really warm but February and March it tends to get cooler*", and P2 was engaged and briefly acknowledged what P1 was talking about with "*yeah*" while focusing on observing the interface. The second most common collaboration profile seen in our analysis was *turn- taker* (31.25%). A segment was coded as *turn-taker* when both participants contributed comparably to the collaboration by actively communicating and interacting with the interface. For example, a segment for G463-1 was coded as a *turn-taker* in which P2 dragged the time slider while verbalizing the coral reef thermal stress: "*Kinda blue.*" P1 agreed, saying, "*Yes, not too much change.*" Then, P1 zoomed out and dragged on the virtual earth, while stating, "*I was just looking at this a little, but yes, there isn't so much change in the thermal stress.*" P2 added, "*Not in 2022.*" This segment shows both group members closely collaborating to make sense of how coral reef thermal stress was changing over time. **Overall, our findings showed how groups used multiple collaboration patterns in which both group members made different levels of contribution. The most common patterns seen had one group member taking lead on the interacting with the AR application and talking aloud their interpretations while the other group member listened carefully (*driver-as-a-guide*) or contributed equally to the discussion (*turn-taker*).**

3.4 Collaboration Patterns and Group Talk

We also analyzed which type of group talk was more common among different collaboration profiles. *Driver as a guide* and *content talk*, the most common collaboration pattern and talk category, frequently occurred simultaneously. For all the segments coded as *driver as a guide*, 58.33% (N=36) were coded as *content talk.* As an example of *content talk* and *driver-as-a-guide*, in G463-1, the two participants talked about the sea surface temperature change near the Gulf of Mexico. P1 took on the role of the driver, interacting with the time slider and leading the discussion by verbalizing temperature patterns. Meanwhile, though not interacting with the interface, P2 stay engaged and added lightly to P1's interpretations: P1 observed the virtual Earth while dragging the time slider, saying, "*So if you look more closely, it already started out pretty warm. Look, it's actually getting cooler.*" P2 pointed at the screen and said, "*Hotter than here.*" P1 dragged the time slider back a little bit and replied, "*Yes, that was 2022. Okay, right here it's December. It looks like the coldest, I guess, around 59 degrees.*" We also saw content talk to be most frequently occurring with the second most common collaboration profile, *turn-taker.* For all the segments coded as *turn-taker*, 56.00% (N=25) were coded as *content talk.* For example, in G463-1, P1 and P2 took turns interacting with the interface, discussing changes in both two datasets. P1 held the phone and dragged the time slider, stating, "*Okay, does it get warmer? It looks like it's slightly colder in February and gets warmer again towards March and April. That's for the sea surface temperature. Do you want to look at that?*" P2 nodded, took the phone, and tapped the dataset switch button, saying, "*Thermal stress, I was looking at this...*" **Overall, we saw participants actively discussing learning content (e.g., temperature changes and coral reef thermal stress changes across time) when collaborating as *driver as a guide* and *turn-taker*, underscoring the need of supporting these collaboration profiles through design to facilitate collaborative data exploration.**

4 DISCUSSION

The goal of our work was to investigate the nature of group collaboration behaviors students exhibited when collaboratively learning with a mobile-AR application. Overall, we highlighted how groups used diverse range of gestures, group talk patterns, and collaboration profiles when exploring geodata visualizations using a mobile-AR application. Our findings are in line with Zimmerman et al.'s [14] study on geo-information collaborative learning facilitated by mobile-AR in outdoor informal learning settings. While the context differs (theirs was family groups and ours is pre-service teachers who have taken an Earth science class), similar to Zimmerman et al. [14] our findings highlight the potential of mobile-AR application for collaborative learning in formal educational settings. Our findings demonstrated how AR application facilitated content talk and provided space for group members to discuss and learn together (*driver-as-a-guide* and *turn-taker*). This underscores the potential of AR application for pre-service teachers in Earth science classrooms for geodata exploration. Although not in the AR space, prior work by Soni et al. [10, 11] found that participants naturally coordinate multi-touch gestures on the spherical display to collaboratively interact with geospatial datasets. Our work adds to this prior work in the context of mobile-AR applications. Our findings illustrated how despite the limited screen real-estate, participants in our study tended to use multi-user gestures both contributing to interacting with the interface at the same time (e.g., one user dragging virtual earth and the other changing time). **Thus, we suggest designers of future mobile-AR applications for collaborative learning to consider supporting multi-user gestures that allow multiple users to interact with different aspects of visualization interface concurrently.**

4.1 Qualitative Feedback and Design Implications

At the end of each study, participants were verbally asked for their feedback about their interaction experience with the mobile-AR application. We analyzed their feedback to identify what our participants liked and disliked. We present design implications based on our frequency analysis and qualitative feedback.

4.1.1 Support interactive features that let students color legends to data visualization patterns. Multiple participants in our study (p = 12/14 participants) provided input on how the implementation and alignment of the color scale bars to virtual Earth data visualizations could be further improved in the context of mobile-AR applications. In our application we had two datasets, see image in Methods section: sea surface temperature and coral reef thermal stress. Our participants expressed the desire to precisely **link color data visualizations with their respective numerical estimates** of sea surface temperature and coral reef stress, in order to effectively explore and discuss the visualizations across space and time: "*scale of the colors...it's difficult to get an exact temperature*" [G463-2]. Participants also expressed concerns about **the numerical distribution on the color bar scales of temperature and stress**, as it made it difficult for the participants to understand the gradation of colors: "*I would say [is difficult to analyze] is the color of the sea surface temperature. . .but I was kind of able to guess that this purply color was closer to red than to blue*" [G313] and "*the numbers were still a little difficult for me especially on the sea surface temperature...because it went from 25 to 41 to 57, so it's not exactly even numbers of distribution*" [G463-1]. Kelly et al. [3] suggests designers of 2-dimensional representations of scientific data consider the conventions and expectations influencing student interactive choices with proportionate scaling of axis and recommends having particular values for reference such as zero. Based on user feedback, for **even distribution scales**, rather than random number scales (e.g., 25-41-57), presenting students with evenly and clearly labeled scales that are multiples of a common number (e.g., 20-30-40 or 15-30-45) might be more effective for students to perceive the data. To directly link a color from the data to the legend, one participant in our study recommended getting access to numerical data by tapping the color: "*if you could somehow click on a specific location and it could just tell you the exact temperature of the location*" [G463-2]. This approach could allow student groups to focus more on learning from data patterns and spend less time deciphering colors and their relative value estimates. Hence, **we suggest designers of future mobile-AR applications for geodata visualization exploration consider including a scale that is labeled with more easily recognizable multiples of 5, 10, or 15 and interactive features (e.g., tapping) to link data points to colors on the map legend.**

4.1.2 Support interface features that stabilize orientation for students. Although our AR application included an interface element of resetting the orientation of the virtual earth, in our observations we did not see many participants using the reset button (was only used for 5.00% of all segments, N = 80). We speculate the reason for disengagement could because our application did a "complete" reset of the virtual earth, which included changing both size and orientation of the virtual earth by zooming out, changing to a North-South view, and changing the location away to a pre-defined location. An example of disengagement was seen in G313, where participants initially had difficulty in rotating the virtual Earth during the first task where they attempted to use rotate gesture but were not able to get their desired location, then they attempted to use the reset button, and commented: "*oh, that just rotates it.*" The Group did not interact with the reset button again for any task, but we observed multiple instances of the group refining their location manually if they zoomed in too close or rotated the Earth too far. It could be that groups did not wish to lose certain dimensions of their current orientation. Based on this, we call for **future research to systematically explore variable reset settings students prefer within gesture-based AR geodata visualization applications**. One potential design to explore is adjustment of the interface to accommodate a single orientation rearrangement. For example, a reset button that only zooms out when participants are too close to navigate to where they want to observe, or a reset button that orients to the North-South equatorial view.

5 CONCLUSION

Our on-going research lays groundwork to explore the potential of AR interfaces for collaborative learning in classrooms, in the context of geodata visualizations and pre-service teachers. We will conduct future work to empirically compare how learning supported by AR-based interfaces compared to existing 3D geodata visualization interfaces such as desktop-based Google Earth and 3D multi-touch spherical displays, in a classroom setting. More specifically, we want to delve into how gesture interaction enabled by different interfaces is linked to students' collaborative behaviors. Moving forward, we also plan to update our prototype through a longitudinal user-centered design process in undergrad classrooms, for geoscience data visualization context. Our work has explored the visualization of Earth's ocean system with mobile-AR. Future work could delve into the visualization of other meaningful Earth phenomena as well as go beyond to explore other 3D visualization concepts such as spherical geometry [4] or biology of human eye [13].

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