Effectiveness of a handheld AR cube for examining 3D spatial structures

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In this work-in-progress study, we examine the use of a handheld augmented reality (AR) cube solution that we developed for the scientific exploration of astronomy data. Our primary purpose in this study is to examine if the AR solution might be a competitive alternative to a desktop 3D visualization with more familiar mouse-keyboard interactions. In relation to a known tension between objective performance and subjective opinion, we purposefully designed traditional information visualization tasks for which we expected that AR solution might fail whereas participants might still like the solution. An additional key consideration in the study is examining participants' ability to use the handheld cube in relation to their mental rotation abilities, as the handheld cube literally requires rotating the AR visualization to solve the tasks we designed. As expected, our results based on a preliminary user experiment (n=16) show that participants on average do better with the desktop 3D by objective measures, yet nevertheless, strikingly all participants believe that the AR solution has potential for scientific exploration. We argue that the discrepancy between performance metrics and intuition of our participants is explained by task type, possibly by lack of familiarity with the interaction type to a degree, rather than visualization type, which we plan to test in the next steps. Furthermore, participants with higher mental rotation abilities commit fewer errors with the AR solution, suggesting that individual differences might be important to consider in future work.

CCS Concepts: • **Computing methodologies → Mixed / augmented reality**; • **Human-centered computing → Information visualization**; *Scientific visualization*; **User studies**.

Additional Key Words and Phrases: AR, data visualization, immersive analytics

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1 INTRODUCTION

In information visualization, the unnecessary use of 3D graphics has been long discouraged for good reasons [4][8]. However, previous studies show that there is merit in using 3D in scientific visualization contexts that require spatial sense-making, especially stereo 3D [7]. Dust, gas or similar matter often found in space observations cannot be easily represented by monoscopic depth cues such as perspective, occlusion, shading, color, or familiar size. Given the unknown nature of the phenomena and the lack of monoscopic depth cues, stereopsis offers important information binocular

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displays or utilization of motion parallax (i.e., wiggle stereoscopy). In general, viewing the phenomenon from multiple perspective is a good principle, and 3D viewing for exploration can lead to important discoveries, e.g., in mapping gas waves or detecting the conditions in which stars are formed [1][11].

2 IMPLEMENTATION OF THE GLUE AR CUBE

Motivated by the previous work summarized above, in this pilot study, we prototype and user-test a 3D visualization solution in the form of an augmented reality (AR) Python plugin for the open-source software Glue[1]. Glue has been originally developed for astronomy research and was later extended for broader use in any scientific visualization context [3] (Figure 1).

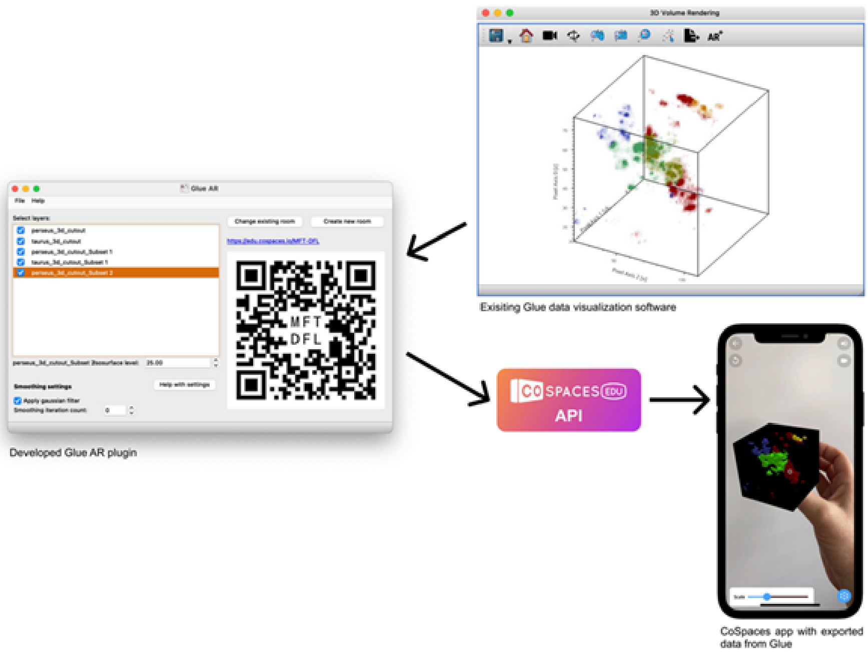

Fig. 1. Plugin interface (left), glue desktop version (top right) and the MergeCube AR display (bottom right).

Our implementation enables viewing 3D data from Glue in AR utilizing a third-party service called CoSpaces[2] and associated API for uploading 3D models and creating AR rooms that can be opened on the CoSpaces mobile app. The end result is displayed using a handheld cube called MergeCube[3], which can be purchased, or self-made using paper. A handheld cube enables smaller or larger rotations of the viewed scene, facilitating a novel form of a 3D experience including a tangible/tactile sensation. Figure 1 (left and top right) illustrate the Glue extension interface and the desktop version of the application, whereas Figure 1 (bottom right) illustrates the smartphone-based handheld MergeCube display as the user would experience it.

[1] https://glueviz.org
[2] https://edu.cospaces.io
[3] https://mergeedu.com/cube

3 EXPERIMENT

In a pilot experiment with 16 participants (age range 20-49, 10 men) who were students or researchers in computer science or astronomy domains but had little or no expertise in AR, we compared the baseline desktop solution and our AR cube solution. At this stage of the study, we examined the AR vs. desktop 3D solution for ten tasks that were designed for information extraction following standard task taxonomies found in information visualization such as to identify, compare, associate, locate and categorize the displayed elements (e.g., [5]). For example, participants were asked to identify the color of the largest object, the number of clusters, how many objects differed in their orientation compared to the majority of objects. We expected that participants would do worse with the AR solution because of the lack of familiarity with the type of interaction, as well as the previous studies demonstrating that 3D can be harder to work with due to issues such as occlusion, i.e., 'hidden information', forcing viewers to make inferences based on what they remember [4][2]. However, we also expected that participants would have a positive opinion on the AR solution's use and/or usefulness, because it has been previously demonstrated that people may exhibit a strong preference for 3D and realism [9][6].

4 RESULTS AND DISCUSSION

As expected, participants performed considerably better with the desktop version in terms of response speed and response accuracy: Specifically, they committed more than twice as many errors with the AR solution and were nearly twice as slow as the desktop solution (Table 1).

Table 1. Participants' efficiency (response time) and effectiveness (response accuracy) with the AR solution vs. Desktop alternative over all tasks. We only provide summary statistics here as, at this point, the statistical power is not high enough for inferential statistics.

Response time (seconds)	AR	Desktop
Maximum	106	112
Minimum	4	3
Median	24	16
Average	30	21
Response accuracy (count)	**AR**	**Desktop**
Errors	31	13
Correct Answers	129	147
Total	160	160

Additionally, we measured our participants' mental rotation abilities due to the literal rotational movements required with the handheld AR cube, using the standardized mental rotation test MRT [10]. We then examined if there was a correlation between mental rotation abilities and error rates and observed that the AR version was especially difficult for low-MRT participants (Figure 2). Also as expected, despite the clear performance measures indicating otherwise, and irrespective of their expertise or mental rotation abilities, our participants unanimously stated that the AR solution would be useful for scientific exploration. While we have a small participants pool, and thus our results are preliminary (and analysis only descriptive), this mismatch between intuition and performance has been previously documented [9], and here the same effect is replicated under different conditions. However, based on our initial observations and previous work, we believe participants' abilities and task types are critically important for these outcomes, and we hypothesize that the potential of AR is more on experience-based insights and memorability than reading specific details, which may be better represented in a plot.

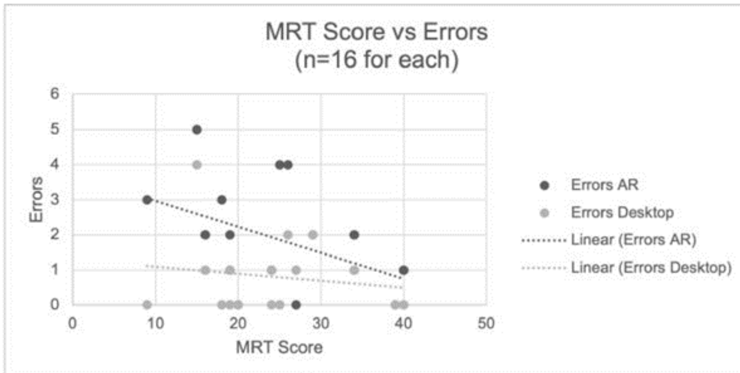

Fig. 2. Participants with higher MRT scores appear to perform considerably better with the handheld AR cube whereas the differences for the desktop version are not as pronounced. Linear regression line AR: Slope: -0.074, Pearson R: -0.415, Linear regression line desktop: Slope: -0.020, Pearson R: -0.155.

Given that first-person experiences are difficult or impossible to obtain astronomy, and insights and memorability are critical in scientific discovery and education; in the next phase, we will extend the prototype to hands-free versions of AR and extend the user experiment with a larger variety of tasks and with a larger sample of participants.

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