Enhancing Military Planning Through Virtual Reality: A Study on Spatial Skills and Map Interpretation

Jerson Geraldo Neto
Brazilian Army (ESAO), Federal University of Rio Grande do Sul
Rio de Janeiro, Brazil
jerson.neto@inf.ufrgs.br

Anderson Maciel
Instituto Superior Tecnico, U Lisboa, Federal University of Rio Grande do Sul
Lisboa, Portugal
anderson.maciel@tecnico.ulisboa.pt

Luciana P. Nedel
Federal University of Rio Grande do Sul
Porto Alegre, Brazil
nedel@inf.ufrgs.br

ABSTRACT

The use of maps for navigation dates to ancient times, remaining the most utilized means for military operation planning. Topographic maps, represented by contour lines, are employed for this purpose. However, interpreting contour lines or 2D information might pose challenges, relying heavily on individuals' spatial abilities to mentally visualize and facilitate interpretation. Thus, traditional methods like sandboxes are often employed, albeit subject to the modeler's precision.

To address these issues, technology, such as virtual reality (VR), has been widely adopted, offering immersive applications for enhanced data visualization and interpretation, yielding novel outcomes. Accordingly, a VR application was developed leveraging real data, providing a seamless transition from conventional methods. The aim is to demonstrate how VR can enhance individuals' map reading and interpretation skills, particularly in military planning for position selection. Hypotheses suggest that VR can develop spatial skills, consequently improving map interpretation and planning performance.

The study evaluates VR's efficacy compared to conventional methods for individuals with limited spatial perception. Thirty-six participants were divided into groups based on spatial skills, employing within-subjects technique, alternating between conventional and VR applications. Variables included position choices and plan evaluations quantified on a scale of 0 to 10.

Results show VR influences position choices, improves grades, and reduces disparities, notably for users with lower spatial skills. VR offers better planning conditions, yielding higher grades and closer positions. Experiment order also impacts outcomes, with individuals performing better in conventional planning after VR use.

In conclusion, VR enhances decision consistency, reducing data variation compared to conventional methods. Spatial skills significantly affect planning outcomes, emphasizing technology's potential as a teaching tool to mitigate individual characteristic-related issues.

ABOUT THE AUTHORS

Jerson Geraldo Neto holds a bachelor’s degree in military sciences, Cavalry Course, from the renowned Agulhas Negras Military Academy - AMAN (2015), an institution recognized for its excellence in military education. During his training, he acquired a solid theoretical and practical foundation in combat strategies, leadership, and military resource management. Additionally, he sought to enhance his knowledge through specializations at the Armored Instruction Center, where he deepened his understanding of the operation of the Armored Personnel Carrier M113 BR (2019), and at the School of Specialized Instruction, where he trained in Material Management (2021). Also noteworthy is his contribution as an instructor in the Battle Simulator (SIMBAT) at the Military Academy of Agulhas Negras during the biennium of 2022/2023, where he was responsible for conducting military training and education through virtual simulation, employing software such as VBS 3, Steel Beasts, and Combat Mission. This experience provided a broad understanding of simulation technologies and their practical application in military training. In pursuit of academic improvement and broadening horizons, he holds a master's degree in computer science in the Human-Computer Interaction, Virtual Reality, and Augmented Reality research line at the respected Federal University of Rio Grande do Sul. As a researcher, he has been dedicated to studying the use of virtual simulators in the teaching and learning process, as well as applications of virtual and augmented reality.

Anderson Maciel is currently a visiting associate professor at the Instituto Superior Tecnico of the University of Lisbon. He is on leave as an associate professor at the Institute of Informatics of the Federal University of Rio Grande do Sul (UFRGS), where he teaches classes in Human-Computer Interaction, Interactive Animation and Computer Graphic Simulation. He holds a master's degree in computer science from UFRGS and a PhD in Computer Graphics from the Swiss Federal Polytechnic Institute of Lausanne (EPFL). He held a postdoctoral degree at Rensselaer Polytechnic Institute in the United States, and is an associate member of INESC-ID. He coordinates scientific research and innovation projects in visual computing linked to the Graduate Program in Computing at UFRGS, where he advises master's and doctoral students on the following topics: computer graphics, virtual reality, surgical simulation by computer, interactive simulation based on physics, human-computer interaction, and immersive visualization. He is the author of more than a hundred articles in indexed journals and peer-reviewed conferences. He is a member of the Association for Computing Machinery (ACM), the Institute of Electrical and Electronics Engineers (IEEE), the IEEE Computer Society Technical Committee on Visualization and Graphics, the IEEE Haptics Technical Committee and the Sociedade Brasileira de Computação (SBC). Prof. Anderson Maciel is a CNPq Research Productivity Scholar.

Luciana P. Nedel works at Federal University of Rio Grande do Sul (UFRGS), where she has an assistant professor position since 2002. She is involved on education at Under graduation and Graduation Courses on Computer Science and Computer Engineering. She is also supervising Undergraduate, Master and PhD students and making research in the Computer Graphics Group, at Informatics Institute, UFRGS. Luciana received a Ph. D in Computer Science from Swiss Federal Institute of Technology (EPFL), Lausanne, Switzerland under the supervision of Prof. Daniel Thalmann. Since 1991 she participates in computer animation and virtual humans' simulation research and since 1996 also with virtual reality, non-conventional interaction and more recently visualization. In these fields, she published more than sixty scientific articles in journals, conference Proceedings and edited books. Nowadays her main interests include interactive visualization, virtual humans, computer animation, path-planning, and non-conventional interaction techniques and devices.

Enhancing Military Planning Through Virtual Reality: A Study on Spatial Skills and Map Interpretation

Jerson Geraldo Neto
Brazilian Army (ESAO), Federal University of Rio Grande do Sul
Rio de Janeiro, Brazil
jerson.neto@inf.ufrgs.br

Anderson Maciel
Instituto Superior Tecnico, Federal University of Rio Grande do Sul
Lisboa, Portugal
a.maciel@inf.ufrgs.br

Luciana Porcher Nedel
Federal University of Rio Grande do Sul
Porto Alegre, Brazil
nedel@inf.ufrgs.br

INTRODUCTION

To achieve success in military operations, there are crucial steps considered predominant factors for success. The main one is planning, which represents the art and science of understanding the situation, envisioning the desired future, and developing pathways to achieve the desired conditions, being essential to communicate to subordinates the commander's understanding of the situation and their visualization of the operation to be executed (Brasil, 2019). This is accomplished through the study of decision factors, which describe the characteristics of an operational area and are concentrated on analyzing how they can affect mission accomplishment, namely: Mission, Enemy, Terrain, and Weather Conditions, Means and available support, Time, and Civil considerations (Brasil, 2020).

For the correct assessment of these factors, the commander conducts reconnaissance, which can be defined as the study of available information about the Operational Environment and the mission context. It can be conducted in two ways, either through on-site verification or through the study of the topographic map, see Figure 1. According to the Command Work Manual (Brasil, 2019), this work consists of surveying movement restrictions, observing access routes and mobility corridors of use, and evaluating each of them regarding the terrain's military aspects. Additionally, locations where their own weapons can be deployed to support platoon movements are verified, as well as the initial position of neighboring elements relative to their unit.

Due to the characteristics of the operation, whether time constraints or resource limitations, reconnaissance work is generally carried out by checking available data about the environment based on maps or aerial/satellite images, and about the enemy, omitting on-site reconnaissance, which can make planning imprecise, impairing its execution (Brasil, 2019). This is because interpreting maps or topographic charts is not an easy task, requiring an association between graphic representation and the real world (Newcombe; Huttenlocher, 2000). Therefore, the usual solution to assist in this process is the comparison between 2D (topographic map) and 3D (terrain representation) due to their similarity to reality (Liben; Kastens; Stevenson, 2002).

Figure 1. The military planning activity, using maps in the decision-making process (ARMY LEADER, 2024)

In the military context, the sandbox, Figure 2, was the solution found to enable correspondence between both. It consists of a scaled-down representation of the operational area through manual elevation modeling, associated with vegetation, hydrography, constructions, roads, as well as miniatures to symbolize the positioning of weapons and vehicles on the battlefield (Brasil, 2021).

However, this auxiliary representation is subject to errors, as its preparation is done manually and directly depends on the individual's ability to interpret 2D contour lines and represent them in 3D. In other words, the ability to read and interpret maps is still directly associated with their creation. Moreover, Ishikawa's study, "Why students have trouble with maps" (Ishikawa; Kastens, 2005), showed an association between the ability to read and interpret maps and individuals' spatial ability. It observed that students with lower spatial ability had greater difficulties in performing tasks with maps and their relation to the real world.

Figure 2. A Cadet of Brazilian Military Academy using the sandbox to represent contour levels.

Within this context, virtual reality (VR) has proven to be a valid and effective tool for performing tasks, providing a better understanding of navigation mechanisms (Cogné et al., 2017; Atit et al., 2016), allowing data visualization from new perspectives, generating new interpretations (Munzner, 2014; Kraus et al., 2022). It enables data and object manipulation, as well as interactions in an immersive environment that offers new perspectives to the user, as observed by Domingo et al. in "Education Student Perceptions of Virtual Reality as a Learning Tool" (Domingo; Bradley, 2018). Furthermore, analyzing the topology of geographic data in VR can lead to a broader and more intuitive understanding of the terrain, providing valuable information for the success of military operations (Medeiros et al., 2022).

Thus, seeking to provide a new perspective for topographic data analysis as an accessory to the planning process, aiming to mitigate deficiencies arising from individual spatial abilities, it was decided to develop an implementation in VR capable of reproducing reconnaissance elements (topography, aerial images, topographic map) associated with main weapons and vehicles used, in 3D models, associated with their range. For development purposes, it was deemed appropriate to replicate aspects like those used in the sandbox, to seek naturalness.

Therefore, the purpose of this study was to investigate how virtual reality can enhance the reconnaissance and planning process in military operations, comparing it with conventional methods. Additionally, it sought to explore how such a mechanism can impact the performance of individuals with diverse levels of spatial abilities, aiming to offer a solution that aids in terrain interpretation and data visualization during the decision-making process.

EXPLORING THE CORRELATION BETWEEN SPATIAL ABILITIES AND MAPS READING SKILLS

The ability to mentally manipulate and interpret spatial information appears to be a common thread that enhances individuals' proficiency in tasks requiring the translation of two-dimensional representations into three-dimensional conceptualizations (Cohen; Hegarty, 2012), as observed in contexts ranging from engineering to geology. Thus, map interpretation is directly associated with how individuals mentally represent terrain, which is depicted in 2D through contour lines, in a 3D structure, as highlighted by Newcombe in several studies conducted in this context (Newcombe et al., 2015; Atit et al., 2016).

The association between spatial ability and the inherent individual capacities in map reading and interpretation has been the subject of observations since 1978, when Potash (Potash; Farrell; Jeffrey, 1978) conducted a study on the topic at the United States Military Academy, as well as Pick (2012), demonstrating the relevance of the topic in the military context. Therefore, given its importance, various tests have been developed over the years with the aim of measuring spatial ability, such as the Perspective Taking Spatial Orientation Test (PTSOT) (Friedman et al., 2020), the Santa Barbara Sense-of-Direction Scale (SBSOD) (Hegarty et al., 2002), and more recently, the Cross-Section Test (Cohen; Hegarty, 2012).

Seeking solutions to this problem, aiming to mitigate the interference of individual characteristics in map interpretation, associated with spatial abilities, various solutions have been proposed. Halik, for example, compared the use of 2D and 3D representations of urban topographies in an immersive environment (Halik; Kent, 2021). Baumann, in 2023, used augmented reality to teach the distinct characteristics of terrain (Baumann; Arthurs, 2023).

In addition to these, the use of virtual reality applications to assist users in the process of interpreting terrain and conducting geographical studies has also been explored in "Virtual reality geographical interactive scene semantics research for immersive geography learning" (Lv; Li; Li, 2017). In this application, with a head-mounted display (HMD), the user can visualize geographical data in an immersive manner, such as topology, which has shown to be quite promising. However, among the deficiencies presented, the most relevant is the quality of the devices used in the study, which, at the time, had extremely inferior quality and functionalities compared to current ones, which may have hindered the proper use of the tool.

VIRTUAL REALITY AND ITS POTENTIAL IN THE DECISION-MAKING PROCESS

Data visualization represents a simplified and abstract view of the real world, in a reduced portion, providing better understanding (Yau, 2013). Thus, it can offer both analyses from a specific point of view and explorations from different angles of the same information, generating new interpretations through new perspectives. Consequently, decision-making processes, such as those occurring in military planning, can be enhanced by technologies such as virtual and augmented reality.

Obviously, to make interpretations, the data in question must be understandable to the individual intending to manipulate them, as they need to know what they wish to obtain or search for. Therefore, the connection between data and how to visualize it is crucial for optimal utilization in this activity. To provide new forms of data representation, various mechanisms are currently being introduced in this context, such as computer-based visualization. These mechanisms can assist people in visualizing data more effectively (Munzner, 2014).

The integration of modern technologies applied to information analysis goes hand in hand with the constant need to improve human capabilities through immersive data visualization and interaction (KRAUS et al., 2022). Consequently, the use of virtual and augmented reality devices has been incorporated into this context, providing a new perspective for data analysis and visualization, thus generating new results and understandings. Examples of how the employed technology can be used in this context can be found in different areas, such as the construction industry (Albahbah; Kivrak; Arslan, 2021; Alizadehsalehi; Hadavi; Huang, 2019; Chou; Hsu; Yao, 1997), healthcare (Yiannakopoulou et al., 2015; Pelargos et al., 2017; Venson et al., 2018), topography (Ruzickova; Ruzicka; Bitta, 2021), and military (Medeiros et al., 2022; Gonçalves; Raposo, 2022).

However, concerning the analysis of information and data related to the military decision-making process, with a focus on planning, few solutions are found. In this context, the work entitled "The Potential of VR-based Tactical Resource Planning on Spatial Data," by Medeiros (2022), sought to evaluate the usability of virtual reality as an accessory during crisis periods, offering an implementation that allowed the visualization of fields of view and the 3D representation of terrain elements, buildings, and vegetation in specific areas. However, there was no testing with the target audience, which hampers the evaluation of such a mechanism.

It is worth noting that there are other solutions aimed at assisting in the development of cognitive skills in military activities. The application presented by Laviola (2015), for example, uses augmented reality. Additionally, Mao's study (2017) experimentally analyzed the learning effect in Military Decision-Making Process training exercises in an augmented reality (AR) system. It was observed that due to the usability and ease of AR, there was a relevant impact on the users' training execution compared to the traditional method.

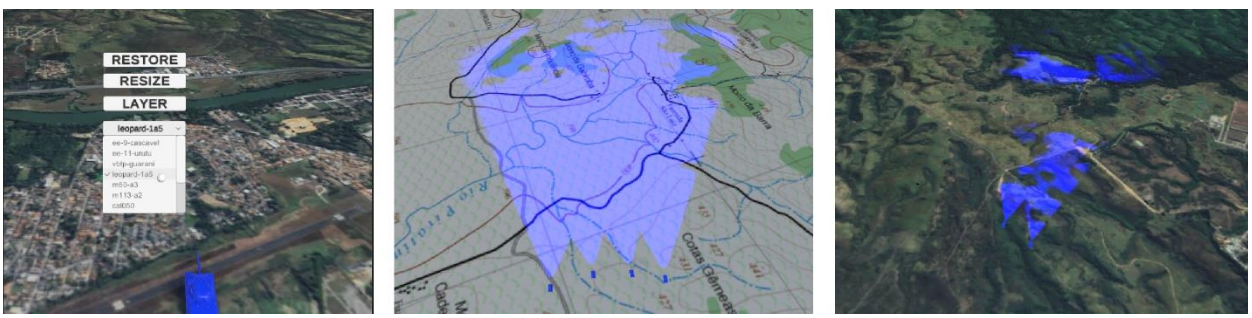
In this same context, Korkiakoski and Chakal (2023) developed the Augmented Reality Tactical Sandbox (ARTS), an immersive analytics tool for the unified battlefield in a cooperative environment. It provides real-time immersive visualizations and analytics of mission-critical information from heterogeneous data sources projected on a map using an AR head-mounted display (HMD). The application provides the operator with a three-dimensional (3D) AR map for better Situational Awareness (SA) and understanding in the command-and-control center and/or in the field, displaying the 3D map, real-world assets, and various other information as part of the user's real-world view through the see-through lenses of the HoloLens 2 HMD. The positions and information about friendly assets and hostile actors as well as points of interest are updated in real time. However, the study highlights that the use of 3D maps in an AR environment to perform map reading tasks has not been sufficiently explored yet.

THE PROPOSED SOLUTION: VIRTUAL REALITY SANDBOX

As we know, map reading and interpretation are directly associated with spatial ability (Potash, 1978), which can influence decision-making processes, such as choosing the positions of elements on the battlefield. Thus, the use of technology, such as virtual or augmented reality, due to its potential to enhance individual capabilities, has been a sought-after alternative to address this deficiency.

However, there is still a lack of studies regarding the analysis of how such mechanisms can improve the ability to read maps during their use (Korkiakoski; Chakal, 2023). In this way, a solution was developed that integrates a 3D virtual terrain model based on real topographic data and virtual assets within the same context. This involved the construction of a database for information visualization and the creation of a platform capable of simulating the same interactions present in the physical sandbox within the virtual world, see Figure 3.

Among other possibilities, VR allows for the manipulation of data and objects through interactions in an immersive environment, offering new perspectives to the user, as observed in "Education Student Perceptions of Virtual Reality as a Learning Tool" (Domingo; Bradley, 2018). Consequently, data can be visualized in an immersive environment, where users can interact with the application, exploring various combinations, thus aiding in military operations planning and decision-making processes.



(a) **(b)** **(c)**

Figure 3. The VR Sandbox application (a), designed with elements like a conventional sandbox, comprising a terrain constructed from real satellite data, 3D models at true scale (including weapons and armored vehicles), and the ability to visualize the range of fire as light, allowing for real-time interaction with the terrain. Users have the option to select between a high-resolution satellite image (c) or a topographic map (b) to aid in their decision-making process.

To develop it, the Unity platform was used, which offers various plugins and accessories for the development of virtual reality software. The chosen HMD (Head Mounted Display) was the Quest 2, produced by Meta, which combines several capabilities, such as hand tracking, inside-out head and hand tracking, with a high-quality screen, storage capacity of up to 256 GB, and longer battery life without the need to be connected to an external computer for graphic processing, while still rendering high-quality interactive graphics. The application was thus based on three main principles:

Terrain

The digital terrain was built using the Terrain Tool application available in Unity, the engine used in the application's development. For terrain generation, it requires a file related to the digital elevation model of the area of interest, obtained from the Earth Explorer website. Due to its large dimensions (around 100 km²), it was necessary to perform a clipping to reduce it only to the area to be used. For this purpose, QGIS (Quantum Geographic Information System) was used, capable of maintaining the accuracy and georeferencing of the data during manipulation.

To facilitate navigation, the corresponding texture was used as both the satellite image, obtained through Google Earth, and the topographic map, available in the Geographic Database of the Brazilian Army (BDGEx). This way, the user can interact with the 3D digital terrain, modeled from real data, and navigate using both the aerial image and the corresponding topography of the region of interest, as seen in Figure 4.

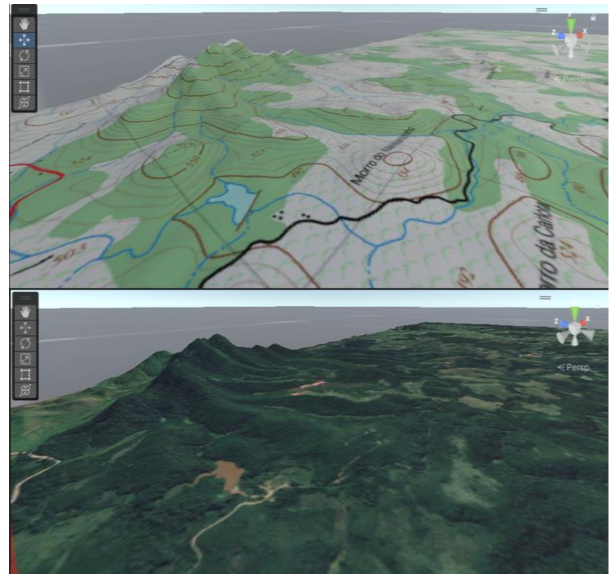


Figure 4. The digital terrain made in Unity Terrain Tool with satellite and topographic maps as a texture.

Models and Dataset

Like what is employed in the conventional sandbox to enable the visualization of chosen positions on the battlefield, 3D miniatures of the main vehicles and weapons used in Brazilian Army operations were inserted, as seen in Figure 5. These models were crafted at full scale with an elevated level of detail for use in virtual simulators, such as the Virtual Battlespace Simulator 3 and Steel Beasts Professional.

To facilitate their manipulation, their sizes were reduced to a 1/250 scale in relation to their true size. To provide the capability to visualize the models' field of view, it was necessary to develop a database containing information such as firing range, maximum range, and minimum/maximum elevation of the weapon. These were compiled into a CSV file and subsequently transformed into a spotlight associated with its respective model, as seen in Figure 5.

Thus, when positioned over the digital terrain, the model with its respective spotlight provides the user with the ability to check the interaction between the range and the 3D terrain. Consequently, it is possible to distinguish, according to the chosen position, the locations where it will be possible or not to act.

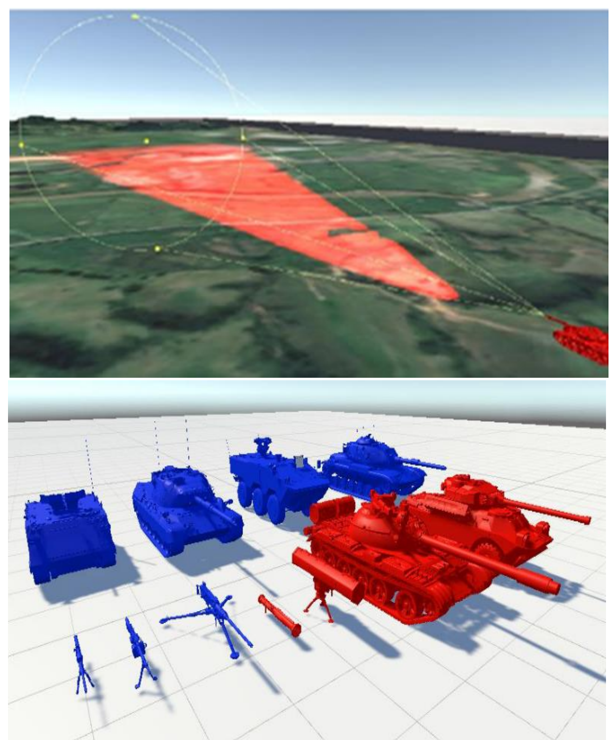


Figure 5. The 3D Models used in the VR implementation and the spotlight component made with the range elements.

Interaction

The sandbox is conventionally positioned underground, associated with miniatures representing the elements to be used to fulfill the planned task to assist in choosing positions for mission fulfillment. Therefore, the implementation in virtual reality sought to follow the same principles, aiming to bring naturalness and ease of adaptation to potential users.

Thus, the digital terrain was dimensioned to allow the user to walk on it and visualize a representation equivalent to 1 km in one meter. Due to the capabilities of the chosen VR device, the user could walk through the VR space just as in the real world, without the need to use the controller for such actions, as well as squat and move their head naturally.

Figure 6. A Participant of the experiment using our VR application.

Additionally, vehicles and weapons, represented through 3D models, were amplified in relation to their true size compared to the terrain to facilitate their manipulation, like what happens in the sandbox. However, aiming to bring realism and precision to the position choosing process, a resizing method was implemented. Thus, the user could, by pressing a button in the menu or using a shortcut on the VR device controller, reduce the size of the models to the same scale as the terrain. To maintain the possibility of manipulating the objects when reduced, a sphere associated with the models through a line allowed their identification and assisted manipulation.

Taking advantage of the possibilities that immersive technology offers and seeking to combine new capabilities that facilitate the interpretation and analysis of data during the application's use, new visualization methods were inserted. Inspired by the work developed by Wagner (Wagner; Stuerzlinger; Nedel, 2021), three main viewpoints were defined: egocentric, which refers to the natural mode of visualization, with objects and terrain in reduced dimensions and the user in real scale; Huge, with the user reduced to the same dimension as the terrain and object; and exocentric, with the user's scale enlarged. In addition to these visualization methods, an alternative method, allowing the user to resize themselves in the scene, was developed. Thus, they have the autonomy to choose which viewpoint is most pleasant and beneficial during the decision-making process.

THE EVALUATION OF APPLICATION CAPABILITIES: USER STUDY

After completing the application design, we formulated a user experiment to gauge its impact on the planning process and its potential to enhance spatial and map-reading abilities during task execution. Our aim was to mitigate any negative effects on individuals with lower skill levels. Our primary hypothesis posits that virtual reality (VR) could address this issue by swiftly removing barriers between users. Initially, we needed to identify our target audience based on their spatial and map-reading skills. To accomplish this, we administered two tests to a sizable group primarily comprising cadets and instructors from the Agulhas Negras Military Academy (AMAN). These tests were:

- Topographic Mapping Assessment (Baumann & Arthurs, 2023): This test consists of sixteen questions designed to evaluate map interpretation abilities across various tasks. Examples include selecting the correct correlation between a point of view depicted on a map and a 3D representation of the terrain, as well as determining the flow of water between two points by analyzing contour lines.
- Santa Barbara Solids Test (Cohen & Hegarty, 2012): This multiple-choice test, comprising thirty items, assesses individual differences in the ability to identify the two-dimensional cross-section of a three-dimensional geometric solid.

A total of 106 military personnel took these tests, enabling us to identify skill levels to target for improvement. The tests yielded a total of 51 scores, ranging from 9 to 42, with a median score close to twenty-nine. From this range of scores, we selected potential participants based on three median quartiles, grouped as follows: higher levels (scores between 34 and 42, Group A), medium levels (scores between 25 and 33, Group B), and lower levels (scores between 9 and 24, Group C).

The experiment entails executing a task in which users must select two positions to establish an observation post in a specified area on the map, as illustrated in Figure 7, consistent with prior work (Neto et al., 2024). Participants are directed to choose their desired direction of movement to occupy the post, along with the primary weapons they intend to use for the mission. They must then analyze the terrain, utilizing either the topographic map or a satellite image, to determine which position would be optimal based on military considerations such as weapon range and line of sight, addressing the question: Can they engage a target within the monitoring area without any obstructions?

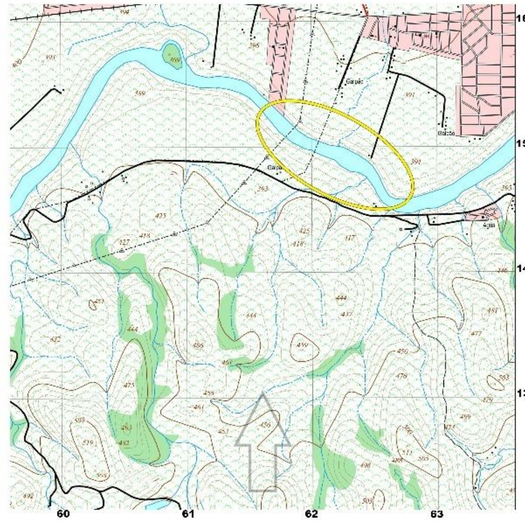


Figure 7. An example of a map used in the experiment. The yellow ellipse represents the area to observe.

To assess the application's influence on this process, we devised a protocol in which users performed tasks using two methods, with varying execution orders: the conventional approach involving topographic maps, satellite images, and a sandbox, and our virtual reality implementation. To prevent biasing decisions, we created two variations of the task, A and B, set in different areas but under identical conditions. The test protocol, outlined in Table 1, was designed to meet all conditions.

Table 1. User experiment protocol: the three firsts' lines represents the users' identifications, and the lines below shows which map (A or B) or interface (Conventional or VR) they will use during the task's execution.

A	**id1**	**id2**	**id3**	**id4**	**id5**	**id6**	**id7**	**id8**	**id9**	**id10**	**id11**	**id12**
B	**id13**	**id14**	**id15**	**id16**	**id17**	**id18**	**id19**	**id20**	**id21**	**id22**	**id23**	**id24**
C	**id25**	**id26**	**id27**	**id28**	**id29**	**id30**	**id31**	**id32**	**id33**	**id34**	**id35**	**id36**
Map 1	A	B	A	B	A	B	A	B	A	B	A	B
Map 2	B	A	B	A	B	A	B	A	B	A	B	A
Interface 1	VR		Conv		VR		Conv		VR		Conv	
Interface 2	Conv		VR		Conv		VR		Conv		VR	

To conduct the user experiment according to the conditions outlined in Table 1, we must select thirty-six volunteers based on their skill levels (A, B, and C). Therefore, prior to the test, all participants were assigned an identification number corresponding to the interface they would begin with and the task map (A or B) they would use.

To measure the influence of the different methods, we compared the positions chosen by participants in both methods after normalization and validated the results by assigning grades on a scale of 0 to 10. The evaluated factors align with field manuals used by the Brazilian Army, focusing on observation range (Brasil, 1990) and localization (Brasil, 1984). An impartial instructor was invited to conduct evaluations, with access only to the positions on the map represented by points, without knowledge of the process employed.

RESULTS AND DISCUSSIONS

The thirty-six participants of the user experiment were requested to complete a consent form agreement that provided an explanation of the procedures and stages involved in the activity, regarding the anonymity of them, together with an initial questionnaire. Our participants are all cadets of AMAN, being 55,3% first year, 23,7% second year, and 21,1% third year cadets. Most of them had not experienced the use of virtual (60.5%) or augmented reality equipment (57.9%). Furthermore, less than half used 3D games more than once a month (47.4%), and only one-third had a frequency of more than once a week (29%). Half of the individuals had some visual impairment, such as myopia

(28.9%), astigmatism (18.4%), or both (2.6%). However, it was not possible to measure any discomfort that may have arisen from these characteristics during the use of the application or any influence on the results obtained.

The results of the experiment could be divided in the grades analysis and the correlations between them and the execution order. To identify how the grades are distributed, we did a Shapiro-Wilk test, and the results shows that the VR grades did not have a normal distribution (p-value < 0,05), but the conventional had it (p-value > 0,05). For that, we choose to use the Kruskal-Walli's test when we did the comparisons rather than ANOVA test to do the statistical analysis to search for significantly differences between their results. Furthermore, we applied the Tukey Test to identify the perceptual differences between the mean grades obtained by each group in conventional and VR method, separately.

We collected all the grades attained by participants concerning their skill levels and the method employed (VR or Conventional), as depicted in Figure 8. Upon analyzing the results, we observed a direct correlation between grades and the spatial abilities of the groups. Higher grades corresponded to Group A (participants with the best initial test results), median grades to Group B (those close to the median in the initial test), and lower grades to Group C (participants with the lowest test results), irrespective of the method utilized.

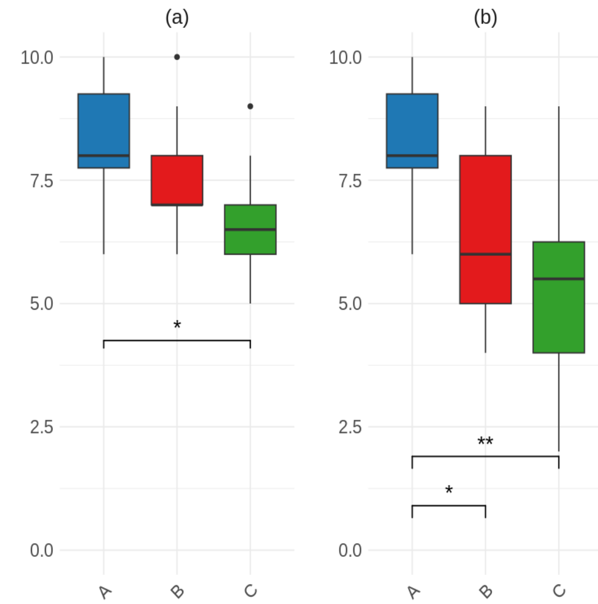


Figure 8. Grades distribution by skill groups in both methods, VR on the left (a) and conventional on the right (b). Those skill groups are represented by the following colors: A - blue, B - red, and C - green. The significance marks represent p < 0.05 (*), p < 0.01 (**), and p < 0.001 (***).

Regarding conventional grades, significant differences were evident between Groups B and A ($p < 0.05$), as well as between Groups C and A ($p < 0.01$). However, there appears to be a significant difference in VR grades only between Groups C and A ($p < 0.05$), while other comparisons did not yield statistically significant differences.

Furthermore, Groups B and C exhibited improved results when using the immersive reality application during their planning. This is evidenced by certain outliers identified in their VR grades, with scores surpassing the group median, indicating a positive influence of technology on their performance. Overall, grades showed enhancement when participants utilized the immersive application compared to the conventional process, as illustrated in Figure 8. In VR, the results were more concentrated at higher levels (between 5 and 10) compared to the conventional method (ranging from 2 to 10). However, while VR proved beneficial for those experiencing planning difficulties, it did not significantly affect the performance of individuals in Group A. The average grades obtained in both methods, represented by the blue columns, were identical for this group.

As a means to assess if there was an impact on users' performance considering the inherent peculiarities of spatial skill levels, a paired t-test (with 95% confidence interval) was conducted to verify differences between the results obtained by them within the groups based on the experiment's execution order, as seen in Table 2. It is possible to observe that the order significantly affected individuals belonging to group C ($p = 0.0014$) when they started with VR, implying an improvement in the mean obtained in conventional grades (from 4 to 7).

Other interesting aspects that can be subject to analysis in Table 2 reside in the increase in performance for all

Table 2. The paired t-test applied in the grades obtained by the participants regarding their ability's levels and the mean grades of them in both methods (Conventional and VR) in relation to the order of execution (beginning in Conventional or VR).

Grade	Group	P-value	Begin Conv	Begin VR
	A	0.437	7.83	8.50
Conv	B	0.516	6.00	6.67
	C	0.001	4.00	7.00
	A	0.239	8.67	7.67
VR	B	0.158	7.00	8.00
	C	0.232	7.00	6.17

individuals in the mean grades obtained in the conventional process compared to VR, regardless of the skill group to which they belong. Depending on the execution order of the experiment, whether starting in VR or the conventional process, a significant difference was observed in the grades obtained by participants in the conventional planning result. This indicates some form of knowledge acquisition resulting from the use of the application, reflecting improved performance when starting with VR.

CONCLUSION

In conclusion, our VR Sandbox application has demonstrated significant potential in enhancing individuals' spatial and map interpretation skills, particularly benefiting those facing challenges in such tasks. Our main hypothesis regarding the efficacy of virtual reality (VR) in mitigating these challenges has been substantiated by the outcomes of our user experiment.

While the results are promising, it is imperative to acknowledge certain limitations, notably the small sample size comprising only three participants for each map/condition pair. Consequently, caution must be exercised in generalizing the findings. To further advance this research, future investigations should focus on exploring practical implementations of VR in activity planning while considering both its advantages and limitations. Continuous monitoring and periodic evaluations of VR's efficacy as a teaching tool will be crucial in refining our understanding and uncovering new insights.

Moreover, delving into the intersection of VR technology with varying levels of spatial skills, as evident in our study results, offers valuable insights into individual preferences based on this specific characteristic. This avenue of exploration holds promise for tailoring VR applications to better suit diverse user needs and preferences.

ACKNOWLEDGEMENTS

The authors thank the study participants for their feedback and the reviewers for their insightful comments, as well as the support of the Agulhas Negras Military Academy (AMAN) and *Escola de Aperfeiçoamento de Oficiais* (ESAO) from the Brazilian Army. They acknowledge financial support from CNPq--Brazil. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001. This work is partially funded by *Fundação para a Ciência e a Tecnologia* (Portuguese Foundation for Science and Technology) through grant 2022. 09212.PTDC (XAVIER) under the auspices of the UNESCO Chair on AI\&XR.

References

Albahbah, M., Kivrak, S., & Arslan, G. (2021). Application areas of augmented reality and virtual reality in construction project management: A scoping review. J. Constr. Eng. Manag. *Innov*, 4, 151–172.

Alizadehsalehi, S., Hadavi, A., & Huang, J. C. (2019). Virtual reality for design and construction education environment. *AEI 2019: Integrated Building Solutions—The National Agenda, American Society of Civil Engineers Reston*, VA, 193–203.

Atit, K., et al. (2016). Learning to interpret topographic maps: Understanding layered spatial information. *Cognitive Research: Principles and Implications*, 1, 1–18.

Baumann, S., & Arthurs, L. A. (2023). Augmented reality technology used for developing topographic map-reading skills in an earth science course and its potential implications in broader learning venues. *Journal of Science Education and Technology*, 32(2), 284–293.

Brasil, M. (1984). CI 6-135: Manual de Campanha Ajustagem do Tiro de Artilharia pelo Combatente de Qualquer Arma (4th ed.). Brasília.

Brasil, M. (1990). C 6-130: Manual de Campanha Técnica de Observação do Tiro de Artilharia de Campanha (1st ed.). Brasília.

Brasil, M. (2019). EB60-ME-13.301: Manual de Ensino Trabalho de Comando (2nd ed.). Brasília: EGGCF.

Brasil, M. (2021). EB70-CI-11.450: Caderno de Instrução Patrulhas (1st ed.). Brasília: EGGCF.

Chou, C., Hsu, H.-L., & Yao, Y.-S. (1997). Construction of a virtual reality learning environment for teaching structural analysis. *Computer Applications in Engineering Education*, 5(4), 223–230.

Cogné, M., et al. (2017). The contribution of virtual reality to the diagnosis of spatial navigation disorders and to the study of the role of navigational aids: A systematic literature review. *Annals of physical and rehabilitation* *medicine*, 60(3), 164–176.

Cohen, C. A., & Hegarty, M. (2012). Inferring cross sections of 3d objects: A new spatial thinking test. *Learning and Individual Differences*, 22(6), 868–874.

Domingo, J. R., & Bradley, E. G. (2018). Education student perceptions of virtual reality as a learning tool. *Journal of Educational Technology Systems*, 46(3), 329–342.

Friedman, A., et al. (2020). A computerized spatial orientation test. Behavior research methods, 52, 799–812.

Gonçalves, T. Da S., & Raposo, A. B. (2022). Realidade virtual como ferramenta de apoio na tomada de decisão no combate em ambientes confinados. In: SBC. *Anais Estendidos do XXIV Simpósio de Realidade Virtual e Aumentada*, 11–15.

Halik, Ł., & Kent, A. J. (2021). Measuring user preferences and behaviour in a topographic immersive virtual environment (topoive) of 2d and 3d urban topographic data. *International Journal of Digital Earth*, 14(12), 1835–1867.

Hegarty, M., et al. (2002). Development of a self-report measure of environmental spatial ability. *Intelligence*, 30(5), 425–447.

Ishikawa, T., & Kastens, K. A. (2005). Why some students have trouble with maps and other spatial representations. *Journal of Geoscience Education*, 53(2), 184–197.

Korkiakoski, M., Chakal, K., Fernando, R., & Kostakos, P. (2023). ARTS: Augmented Reality Tactical Sandbox for improved situational awareness in a multi-user scenario.

Laviola, J., et al. (2015). Using augmented reality to tutor military tasks in the wild. In: *Proceedings of the Interservice/Industry Training Simulation & Education Conference*, Orlando, Florida.

Liben, L. S., Kastens, K. A., & Stevenson, L. M. (2002). Real-world knowledge through real-world maps: A developmental guide for navigating the educational terrain. *Developmental Review*, 22(2), 267–322.

Lv, Z., Li, X., & Li, W. (2017). *Virtual reality geographical interactive scene semantics research for immersive geography learning. Neurocomputing*, 254, 71–78.

Mao, C.-C., Sun, C.-C., & Chen, C.-H. (2017). Evaluate learner's acceptance of augmented reality based military decision-making process training system. In: *Proceedings of the 5th International Conference on Information and Education Technology*, 73–77.

Medeiros, M. L., et al. (2022). The potential of vr-based tactical resource planning on spatial data. In: IEEE. 2022 *IEEE Conference on Virtual Reality and 3D User Interfaces* (VR), 176–185.

Munzner, T. (2014). Visualization analysis and design. *CRC press*.

Neto, J., et al. (2024). Immersive data analysis for planning military operations: Design and think-aloud study. In: *Proceedings of the 25th Symposium on Virtual and Augmented Reality*. New York, NY, USA: Association for Computing Machinery, 66–76. Available from Internet: https://doi.org/10.1145/3625008.3625019.

Newcombe, N., & Huttenlocher, J. (2000). Making space: The development of spatial representation and reasoning. *MIT Press*.

Newcombe, N. S., et al. (2015). The lay of the land: Sensing and representing topography. *Baltic International Yearbook of Cognition, Logic, and Communication*, 10(1), 6.

Pick, H. (2012). Spatial orientation: Theory, research, and application. *Springer Science & Business Media*.

Potash, L., Farrell, J., & Jeffrey, T. (1978). A technique for assessing map relief legibility. *The Cartographic Journal*, 15(1), 28–35.

Ruzickova, K., Ruzicka, J., & Bitta, J. (2021). A new gis-compatible methodology for visibility analysis in digital surface models of earth sites. *Geoscience Frontiers*, 12(4), 101109.

Pelargos, P. E., et al. (2017). Utilizing virtual and augmented reality for educational and clinical enhancements in neurosurgery. *Journal of clinical neuroscience*, 35, 1–4.

The Army Leader. (n.d.). Rethinking Planning, Improving Survivability. Retrieved from https://thearmyleader.co.uk/rethinking-planning-improving-survivability/ (accessed April 2024).

Venson, J., et al. (2018). A case-based study with radiologists performing diagnosis tasks in virtual reality. In: IOS PRESS. InMEDINFO 2017: Precision Healthcare through Informatics: *Proceedings of the 16th World Congress on Medical and Health Informatics*, 245, 244.

WAGNER, J., STUERZLINGER, W., & Nedel, L. (2021). The effect of exploration mode and frame of reference in immersive analytics. *IEEE Transactions on Visualization and Computer Graphics*, 28(9), 3252–3264.

Yiannakopoulou, E., et al. (2015). Virtual reality simulators and training in laparoscopic surgery. *International Journal of Surgery*, 13, 60–64.

Yau, N. (2013). Data points: Visualization that means something. *John Wiley & Sons*.