UNIVERZA NA PRIMORSKEM
FAKULTETA ZA MATEMATIKO, NARAVOSLOVJE IN INFORMACIJSKE TEHNOLOGIJE

ZAKLJUČNA NALOGA
(FINAL PROJECT PAPER)

UPORABA INTERAKCIJE S SESTAVLJANKO PRI PODPORI POMNJENJA INFORMACIJ IZ DIGITALNIH ZEMLJEVIDOV

(**USING PUZZLE-LIKE INTERACTION IN SUPPORTING INFORMATION RETENTION IN DIGITAL MAPS**)

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Zaključna naloga
(Final project paper)

Uporaba interakcije s sestavljanko pri podpori pomnjenja informacij iz digitalnih zemljevidov

(Using Puzzle-Like Interaction in Supporting Information Retention in Digital Maps)

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Izvleček: Zemljevidi zagotavljajo uporabne informacije za turiste in poudarjajo razpoložljive interesne točke (POI). Vendar so zemljevidi danes pogosto na voljo na digitalnih javnih prikazovalnikih, kjer jih je mogoče narediti interaktivne. Da bi raziskali, ali lahko interaktivni elementi, podobni igri, pomagajo pri ohranjanju informacij, ki so na voljo na takšnih zemljevidih, smo razvili "*Retzzles*", interaktivni sistem na zaslonu na dotik, ki dopolnjuje tradicionalno obliko zemljevida tako, da uporabnikom omogoča reševanje ugank in interakcijo s POI, ki prikazujejo ključne informacije. V ta namen smo primerjali dva pogoja: enega z vmesnikom samo z zemljevidom, kjer so uporabniki lahko sodelovali s točkami interesnih točk, in drugega z vmesnikom s sestavljanko, kjer so morali udeleženci rešiti sestavljanko, preden so lahko sodelovali s točkami interesnih točk. Medpredmetna študija z 28 udeleženci je pokazala boljši besedilni (informacije o točkah POI) in prostorski spomin (lokacija točk POI na zemljevidu), ne pa tudi vizualni spomin (katere točke POI so bile prikazane in katere ne) za stanje s sestavljanko. Vendar statistična pomembnost ni bila ugotovljena. Navajamo tudi podrobno analizo podatkov o interakciji s sestavljanko. Naše ugotovitve prispevajo k oblikovanju in vrednotenju interaktivnih zaslonov na dotik za učne scenarije, ki vključujejo ohranjanje informacij.

Key words documentation

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Abstract: Maps provide useful information for tourists emphasising the available points of interest (POIs). However, maps are nowadays often available on digital public displays where there is a possibility to make them interactive. To investigate whether interactive game like elements could help memory retention of information available on such maps, we developed "*Retzzles*", an interactive touchscreen system that augments the traditional map format by allowing users to solve puzzles and interact with POIs displaying key information. To this aim, we compared two conditions: one with map-only interface where users could interact with POIs, and one with a jigsaw puzzle interface where participants had to solve the puzzle before being able to interact with POIs. A between-subject study with 28 participants showed improved textual (information about POIs) and spatial recall (location of POIs on the map) but not visual recall (which POIs were shown and which not) for puzzle condition. However, no statistical significance was found. We also provide a detailed analysis of puzzle interaction data. Our findings contribute to the design and evaluation of interactive touchscreens for learning scenarios involving information retention.

Acknowledgement

I would like to express my gratitude to the HICUP Lab for their invaluable supervision and support throughout the development of this research, as well as the equipment they provided when needed. Their guidance and encouragement have played a significant role in bringing this idea to reality. I am immensely grateful to my mentors for their dedication and expertise. Their insights and guidance have been instrumental in my growth as a researcher. The meetings and discussions were always thought provoking. Their problem-solving approaches and ideas greatly aided me throughout the research process for this thesis.

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List of Abbreviations

i.e.	that is
e.g.	for example
et al.	and others
VR	Visual Recall
NS-VR	Negative Symbol Recall
SR	Spatial Recall
TR	Textual Recall
N-TR	Name Textual Recall
C-TR	Category Textual Recall
AR	Augmented Reality
ARLE	Augmented Reality Learning Experiences
POI	Point of Interest
NASA-TLX	NASA Task Load Index
ICF	Informed Consent Form

Because You Are Afraid Of It.

Kratos,
God Of War, 2018

1 OVERVIEW

With the increasing prevalence of digital maps, retaining information from them can be enhanced with interactive and gamified techniques. For example, simple jigsaw puzzles can be used as a tool for users to engage with the map while combining its pieces together, to achieve better understanding and memorise the information on the map [21, 36]. To fully understand the concept of engagement, it is crucial to recognize the significance of the relationship between people and their surroundings, including the materials and objects they interact with. This requires careful examination of the various ways in which individuals engage with and navigate through their physical environment. Furthermore, it is important to note that engagement is not simply a matter of an individual's cognitive processes, but rather a complex interplay between the user, the task at hand, and the environment in which they are situated [11]. Research has shown that learning engagement through technology helps learners in the learning process [20, 37], little is known on how casual engagement with map puzzles help with memorising from the map.

Engaging in puzzles has always been a popular pastime for people of all ages. Not only do puzzles provide entertainment and fun, but research has also suggested that they have benefits in cognitive development and brain health [10,17,30,43]. By exploring the potential benefits of puzzles into creating and interacting with digital maps, we aim to contribute to the development of innovative and effective methods of augmentation strategies that aid information retention. This thesis investigates using puzzles as an casual engagement tool in digital map interfaces, with the goal of enhancing the understanding of the map and memorising information on it.

Retaining information, whether for a short-term or long-term duration, is crucial for various reasons. First and foremost, it enables us to remember crucial details, such as a formulas for an exam or a key piece of information for a project.

Additionally, accessible information serves as a foundation for several cognitive processes, including comprehension, the application of intellectual skills, creative thinking, and attitude change. In essence, information retention is a fundamental aspect of our ability to learn, grow, and thrive as human beings [29].

1.1 TARGET HYPOTHESIS AND CONTRIBUTION

As part of this thesis, we wish to inquire on the following hypothesis:

- H0: Jigsaw puzzle-like interaction will lead to better engagement, and better information recall on map-related tasks.

In order to answer this hypothesis we plan, to develop two maps for users to interact with. Such maps can be used on interactive public displays to attract tourists and increase engagement with information presented. One map is a regular map with information presented on it, while the other map is first presented as a puzzle with large puzzle pieces. Both maps show the same information and on both maps users can touch various points of interest (POI) to interact with. Also, both maps were presented on a large touchscreen display. The only difference between them is that the puzzle-like map requires users to arrange pieces of information in order to view a complete map. We will investigate primarily the effectiveness of jigsaw puzzle-like interaction with the map for information retention.

The main contributions of this work are:

- **Artifact**: We present the prototype named *Retzzles*, an interactive touch-screen interface for engaging with maps.
- **Empirical**: We present findings of a user study between two conditions (map vs puzzle) on evaluating visual, spatial and textual recall.
- **Design Guidelines**: A set of recommendations learned from our user studies in helping interaction designers in the development of surfaces and screens that help in a specific learning scenario.

1.2 STRUCTURE OF THE THESIS

This thesis is organized as such: (i) the following chapter 2 presents the existing literature and related work in the field of interactive tables and surfaces in the context of maps, augmented reality learning, research on icons, symbols and label, and most importantly puzzles, (ii) Chapter 3 focuses on the system design, architecture, and implementation of the prototype called *Retzzles*, (iii) in Chapter 4, the method and procedures used to conduct the user study are described, (iv) Chapter 5 presents the findings and results obtained from the user study, analyses and interpretation of the collected data, and key observations, (v) Chapter 6 offers a discussion of the research questions and in the light of the results presented before, and discusses possible further exploration in the field, (vi) the thesis ends with the conclusion.

2 RELATED WORK

Several studies have explored information retention, engagement and digital maps. The most relevant research areas to this work highlight applications utilising interactive tables and surfaces as maps and augmented reality learning. Additionally we will mention research that utilised puzzles.

2.1 INTERACTIVE TABLES AND SURFACES AS MAPS

Compared to traditional interaction methods involving a mouse to control a cursor, direct input minimises the cognitive distance between intention and execution [2]. That is, the user's physical input action on the display aligns directly with their intended action. This aspect of direct input can enhance the usability and user experience of interactive maps [13]. It not not surprising that a lot of research has been done on large public touch-based displays.

Large public displays have become increasingly popular as a means of facilitating community and social activities [2, 8, 40], as well as promoting tourism [32]. It has been shown that just adding interactivity to traditional non-interactive content has a cognitive effect on users and therefore increases the ability to remember what they have seen on the screen [2]. However, the question of how to encourage users to engage with these displays remains a question; designing an interactive situated or public displays requires careful consideration of how the display will invite interaction, as this is a crucial factor in determining whether or not users will approach it [1]. In line with this observation, Brignull and Rogers suggest that introducing novelty and ambiguity can be an effective means of drawing users in and promoting engagement with the display [7].

Interactive tables and surfaces have become increasingly popular tools for visualising and presenting various types of information, including maps. Interactive tables and surfaces provide a more engaging and interactive experience compared to traditional methods of displaying maps, such as paper maps or digital displays [27]. For example, interactive tables and surfaces have been used in urban planning projects to facilitate collaborative decision-making among users. These tools allow users to visualise and manipulate information together, which can lead to more effective decision-making [6].

Various input methods explored in public displays include (i) gesture-based direct manipulation through the use of controllers [4] or (ii) sensors [44]; (iii) vision-based immersive effects expanding screens to 3d viewing experiences [35]; or (iv) touch-enabled interactions with visual elements projected in a screen [19]. In the latter, playful interactions have been inspired such as tangible interactive parts [38], draggable puzzle pieces and codeblocks [18, 31] among others. While This thesis builds upon these prototypes by exploring interaction with maps by engaging users in a playful experience to investigate , by developing a touchscreen prototype that promotes interaction and, notably, encourages exploration of visual elements such as puzzle pieces and abstract symbols.

2.2 ICONS, SYMBOLS AND LABELS AND LEARNING

The research conducted by Wiedenbeck [42] comparing the efficacy of different interface designs for an application program merits particular attention. The study evaluated the learning outcomes of participants using interfaces that utilised buttons with text labels, icons, or a combination of icons and text labels. The results indicate that learners of the application program are better aided in initial learning when using interfaces that incorporate icons with text labels or text labels alone, as opposed to icons lacking labels. Specifically, learners utilising the icon-only interface exhibited poor performance in the early stages of learning, although they eventually caught up to the performance of the other two groups by the end of the first session. We will expand further on the importance of this paper when we talk about the design of our prototype (see **chapter 3**).

Fujimoto et al. [14], proposed that displaying AR annotations associated with a target object's real-world location (i.e. directly on the map where they are located) would enhance users' memory skills better than annotations connected to an unrelated location (i.e. off the map and linking them to their location by other means). They indeed showed that the retention depends on the location of the icons being remembered. Other research also indicates that linking information to specific locations in the real world can improve human memory retention and recall [12]. Both studies highlight that the location of items to be memorised in relation to the map presented has a significant importance, which needs to be taken into consideration when presenting users with maps.

According to Perkins [34], a crucial aspect of educational environments is the provision of tools and resources that facilitate the construction and manipulation of symbols. Such resources, ranging from hand-held slates to laptops, enable learners to record and organize their ideas, develop outlines, and formulate and manipulate equations, thereby supporting their short-term memory processes. On the other hand, abstract symbols serve us as Points of Interest (POI), which reflect a constant location and information (e.g., a name and address) [39].

Finally, Forrest and Castner [26] conducted research on the cognitive processing of symbolic representations, revealing that iconic symbols required more time to locate than abstract symbols, but yielded fewer identification errors. They also discovered that the benefits of iconicity for identification, and of simple abstract shapes for visual search, could be combined through the use of geometric frames (e.g., triangles, circles, and squares) to enclose iconic symbols. In this thesis, we will be using abstract symbols as a way to implement an unknown interact-able component where the users will be assessed on later in the testing phase of user studies.

2.3 PUZZLES

Puzzles have been observed to help make learning enjoyable for students [22, 24]. They provide an engaging and challenging visual experience that requires individuals to engage in focused attention, problem-solving, and spatial reasoning. Existing frameworks and research support that activities where people "learn by doing" along with social interaction supports cognitive development which then helps users learn in general [28]. Specifically, the use of jigsaw elements, which is one of the most common puzzle games has been observed to help students acquire a deeper understanding of certain concepts and terminologies [23] in the broader context of learning. Moreover, research has explored various aspects of puzzle solving, including the cognitive and perceptual processes involved [9], as well as, the benefits for brain development and cognitive function [5].

Other factors that can influence puzzle-solving performance are the level of complexity, the size and shape of puzzle pieces, and the level of expertise or experience of the individual solver. Overall, the study of jigsaw puzzles provides valuable insights into the nature of visual perception, cognitive processing, and the benefits of engaging in mentally stimulating activities. As such, there is opportunity to work on the unexplored benefits of puzzle and puzzle-like interactions. In this thesis, we exploit this opportunity in the context of interactive touchscreen maps and abstract symbols in understanding information retention.

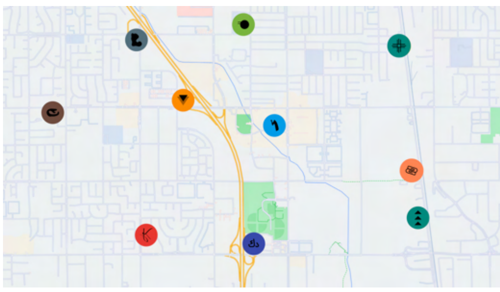
3 RETZZLES

In this section, we will provide a detailed overview of the *Retzzles* prototype. Our investigation focuses on participant interactions with an augmented map and their ability to retain information. The name *Retzzles* reflects this focus, combining retention and puzzles. We will first discuss the features offered by the system before delving into the implementation of the scenes and overall storyboard.

3.1 SYSTEM FEATURES

The prototype was developed in Unity and it features two modes: Map-only mode and Puzzle mode. Both present the same information but the latter shows it first as a jigsaw puzzle. Both modes first show the Training followed by the Main scene. The Training scene represents the main square of Ljubljana, the Prešeren Square. We wanted to give users a familiar scene, where they would explore the features of the prototype. We augmented the map by adding buttons representing Points of Interest (POI): Prešeren Square, Franciscan Church and Triple Bridge, as seen in Figure 1a.

(a) Tutorial Scene.



(b) Main Scene.

Figure 1: Scenes of prototype *Retzzles*.

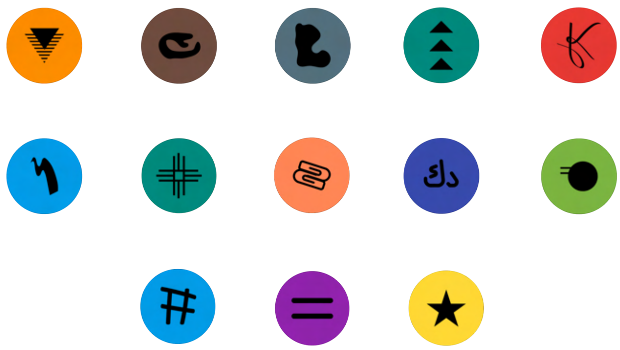


Figure 2: Interact-able Points of Interest (POI) of the *Retzzles*.

The study scene or the Main scene featured a map created using Snazzy Maps, representing Lancaster, CA. After users familiarised with the features we wanted to present them a map they have not seen before. This map was augmented with 10 POI: Alderbrook Nursing Facility, Bowlero, Costco Grocery Store, Oxford Suites Hotel, Red Salmon Restaurant, Sun Flower Caffe, Sunnydale School, Target Grocery Store, The Tire Store and U-Haul Moving Supplies. You can see the final version here in Figure 1b).

POIs are represented by abstract symbols in forms of interact-able buttons designed based on the related work presented in previous chapter (see Figure 2). When tapping on a POI information card associated with it pops up (see Figure 3). The information provided on the cards includes: a photo of a POI, its name, the abstract symbol associated with a POI, and the address of the location. POI and information cards used on both scenes were designed and created in Canva. In total we identified thirteen abstract symbols (as shown in Figure 2) to use as buttons that were randomly assigned to the POIs and interaction cards users were able to open. This design of information cards was based on Wiedenbeck's work [42].

3.1.1 Puzzle Mode

As already mentioned, the Puzzle mode shows the same information but first shown as a jigsaw puzzle users had to solve both for Training and Main scenes. We used GIMP (graphics editor used for image manipulation) and its jigsaw pattern feature

Figure 3: Example of clicking on the POI and opening the information card.

to create a puzzle out of an asset (see Figure 4).

Users are provided with a background photo that serves as a visual guide for assembling the jigsaw puzzle (see Figure 5). The opacity of this background image is slightly reduced to denote that the image is not complete. The puzzle pieces are located around the photo and need to be dragged on the respective position. As users bring the puzzle pieces closer to their respective positions on the background image, the pieces automatically snap into place when they let off the piece. Once the final piece is correctly positioned, the complete image of the scene is fully displayed, and the POIs associated with the assembled pieces become clickable. While in the Map mode the scene is fully displayed and interactive from the start.

The inclusion of a background image indicating the correct placement of puzzle pieces simplifies the puzzle-solving process to some extent, but as the pieces are scattered around the scene, the task still remains engaging. By incorporating POIs within the jigsaw puzzle pieces, we not only enhance the puzzle itself, but also augment the map experience as a whole.

The scenes provide a clear plot for the task, guiding users throughout the

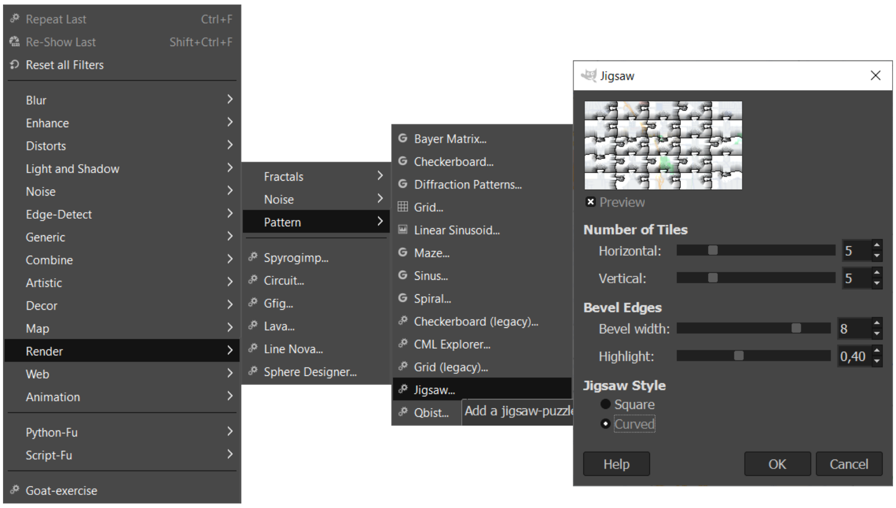


Figure 4: Example of settings to create a jigsaw puzzle out of a picture.

experience. Right from the beginning, users are introduced to the objective of what the prototype is used for and its task. This is accomplished through tutorial scenes, where both written instructions and a moderator's guidance (if needed) orienting users towards their tasks.

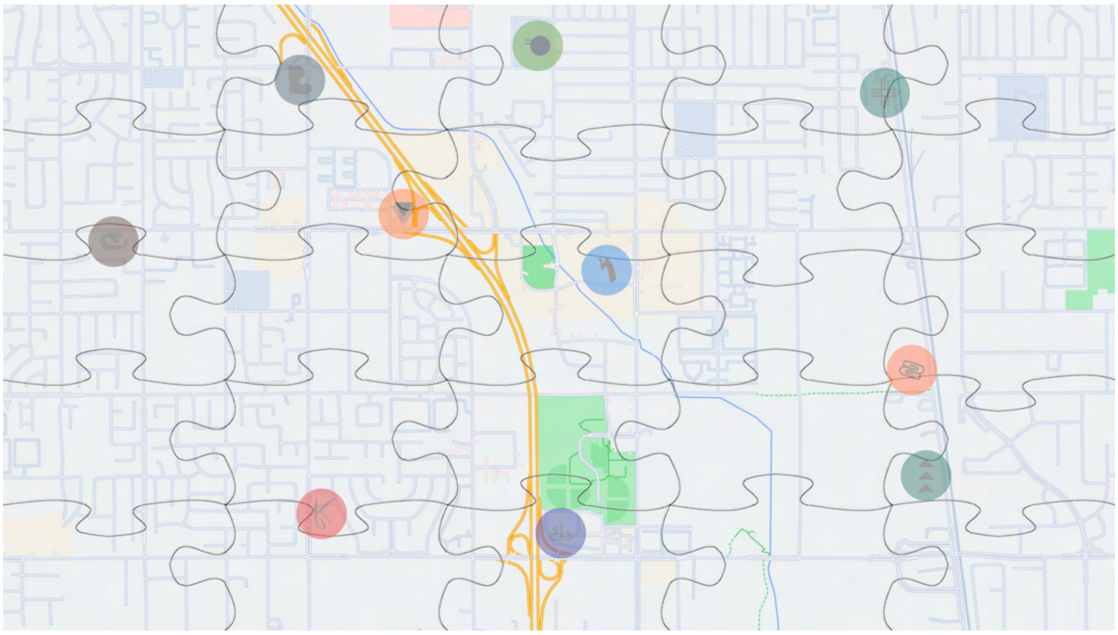


Figure 5: Puzzle version of the Main Scene.

4 USER STUDY

The objective of the study is to check our hypothesis as outlined in chapter 1: can jigsaw puzzle-like interaction lead to better engagement, and information recall on map-related tasks. To accomplish this, we have employed a between-subject study design participant study, where we compare the Map-only and Puzzle conditions. Each of the conditions was supported by one of the modes described in the previous section.

The dependent variables include cognitive load and information recall. For information recall we measured visual, spatial, and textual [3, 25, 33] recall by custom questionnaires. The cognitive load was assessed using the NASA-TLX that measures the participants' perceived workload and engagement levels. The independent variables in this study are the presence or absence of puzzle-like interactions.

4.1 PARTICIPANTS

The study was done with 28 participants (15 M, 13 F). The number of participants between the conditions was balanced, 14 per condition. The study took place in Koper, Slovenia (from the 29th of March to the 4th of April), at the University of Primorska, Faculty of Mathematics, Natural Sciences and Information Technologies. The participants were students aged between 18 and 33 years, with the mean of $M = 21.9$ and $SD = 2.64$ (with an approximately 0.8667 female to male ratio).

4.2 APPARATUS/EQUIPMENT

In the designated study room, we arranged two tables to accommodate the moderator's equipment and all the required paperwork for conducting the study. The participant's table was positioned across the touchscreen display. Additionally, we set up our recording equipment on the right side to capture the participants' interactions (see Figure 6).

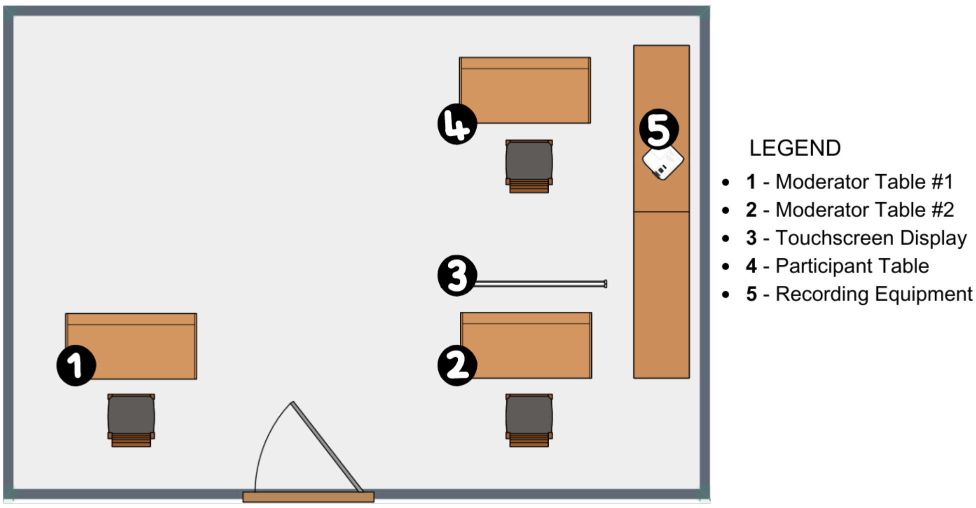


Figure 6: Schematic of the floor plan of the study room.

The prototype was displayed on a 55 inch, 3840 x 2160 Samsung display, 50 cm away from the participant (see Figure 7 for the setup). We used a Dell XPS 15 9570 with 8th Generation Intel Core i7-8750H processor, equipped with 16GB DDR4 2666MHz RAM, 512GB SSD and NVIDIA GeForce GTX 1050Ti, and the connection to the Samsung display was establish via HDMI connection. Prototype was running at an average of 60 frames per second with no trials dropping below 50. Participants interacted with the prototype using touch based interactions. All the experiments/interactions were recorded using Google Pixel 3a.

4.3 STUDY PROTOCOL

Participants were briefly oriented about the study by the moderator. They were provided with the Informed Consent Form (ICF), which they had to sign and

Figure 7: Participant studies.

consent to if they wished to proceed with this study. They were given the chance to ask questions and seek clarifications on specific matters that were not clear to them.

Before the actual study started, the participants were presented with the Training scene to familiarise themselves with interaction. When they clicked on the finish button the prototype proceeded to the Main scene with which they could interact for up to 6 minutes. For both conditions, the task was to memorise as much information about POIs and corresponding information cards as possible. Conditions were assigned randomly to participants. In the puzzle condition, participants had to solve a jigsaw puzzle of a map (see Figure 8 top right) while in the map-only condition the mas was visible from the start (see Figure 8 top left). POIs became available to interact with when a particular jigsaw puzzle pieces that contained parts of POI on them were placed and connected to each other on the map (see Figure 8 bottom right).

4.3.1 Cognitive Assessment

Before interacting with POIs, participants were asked to complete the simplified NASA Task Load Index (NASA-TLX) questionnaire (see Figure A) [15, 16].

4.3.2 Visual Assessment

After completing the NASA-TLX participants answered the questionnaire that tested their visual recall. This questionnaire contained 20 abstract symbols of which 10 that were not in the Main scene and 10 were. The task was to cross the symbols that were on the Main Scene (see Figure B).

4.3.3 Spatial Assessment

Next, they received a questionnaire that tested their spatial recall. This questionnaire consisted of a map of the Main Scene with blank spots in POIs place and participants had to connect the 10 available POIs with blank spots on the map. After completing this task, participants were asked to go back in front of

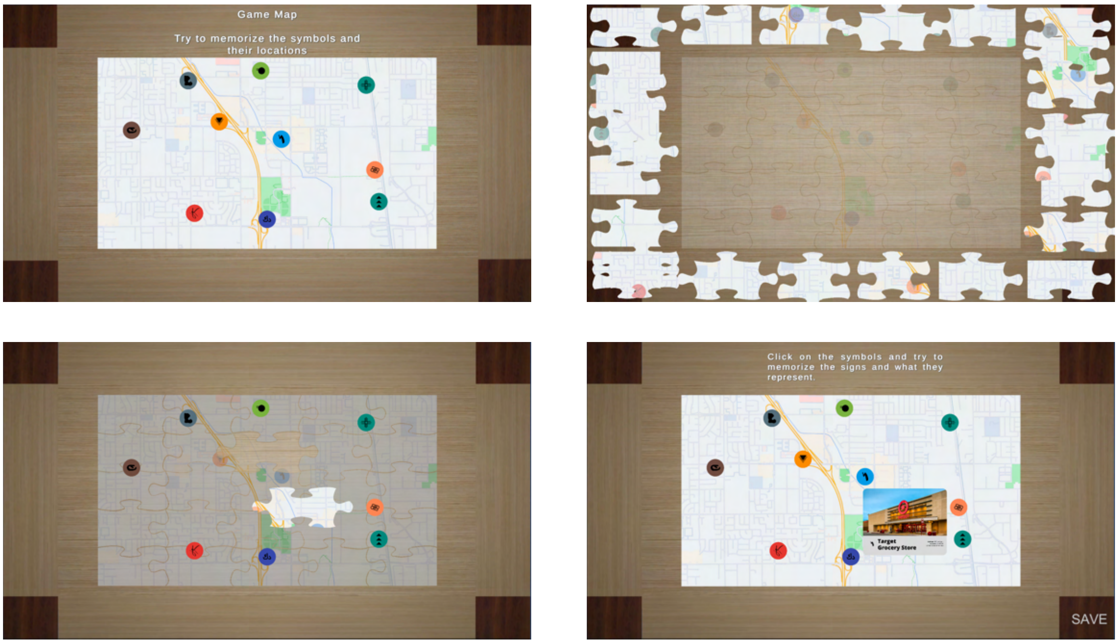


Figure 8: Different conditions and stages of Retzzles. Top Left: the initial stage of the map-only condition. Top right: the initial stage of the puzzle condition. Bottom Left: One piece left; when it will be placed in, the map will be displayed as in top left. Bottom Right: The information card opened when tapped on the corresponding POI.

the touchscreen display and they were now allowed to interact with POIs (see Figure C).

4.3.4 Textual Assessment

At the end, participants answered the last questionnaire that tested their textual recall. They had to write the information that they remembered about each of the 10 POIs symbols (see Figure D).

5 RESULTS

We analysed several variables, including visual recall (VR), spatial recall (SR), and textual recall (TR), and cognitive load using the NASA-TLX scale. To test visual recall, participants were presented with a map containing 20 abstract symbols (10 were present on the map and 10 were not) and asked to identify the symbols they have seen on the map. Spatial recall was assessed by asking participants to remember the position of the 10 symbols on the map and to place them in their correct locations. For textual recall, participants were shown ten symbols on the map and asked to provide information from the card for each symbol, including its name and category. For example, they had to provide the name "Costco" and the category "Grocery Store".

Descriptive statistics of the data were analysed using Jamovi [41]. To test for normal distribution, we used Shapiro-Wilk test since we did a between-subject study design. We found that the variables are normally distributed ($p \geq 0.05$ see Figure 9 and Figure 10) except for the visual recall of symbols. Based on the participants' mean scores alone, the puzzle condition performed better except for the visual recall ($SR : 68.6, N - TR : 50.7, C - TR : 68.6$, see Table 1). Likewise, for the cognitive load, we can see that the puzzle condition was less mentally demanded in comparison to the map-only condition ($MD : 36.1$, see Table 2). We conducted the Mann-Whitney U test, a form of independent samples t-test, to further test the significance of the different metrics. Based on our sample size of 28 participants, we found no significant difference ($p \geq 0.05$) across all variables. Thus, we reject the hypothesis.

Based on the participants' mean scores in the puzzle condition that were generally higher than the map-only condition, our sample size may not be big enough to arrive at a more concrete conclusion. Several factors contributed to the effects on visual recall, such as the colours used in the POIs. Several participants shared

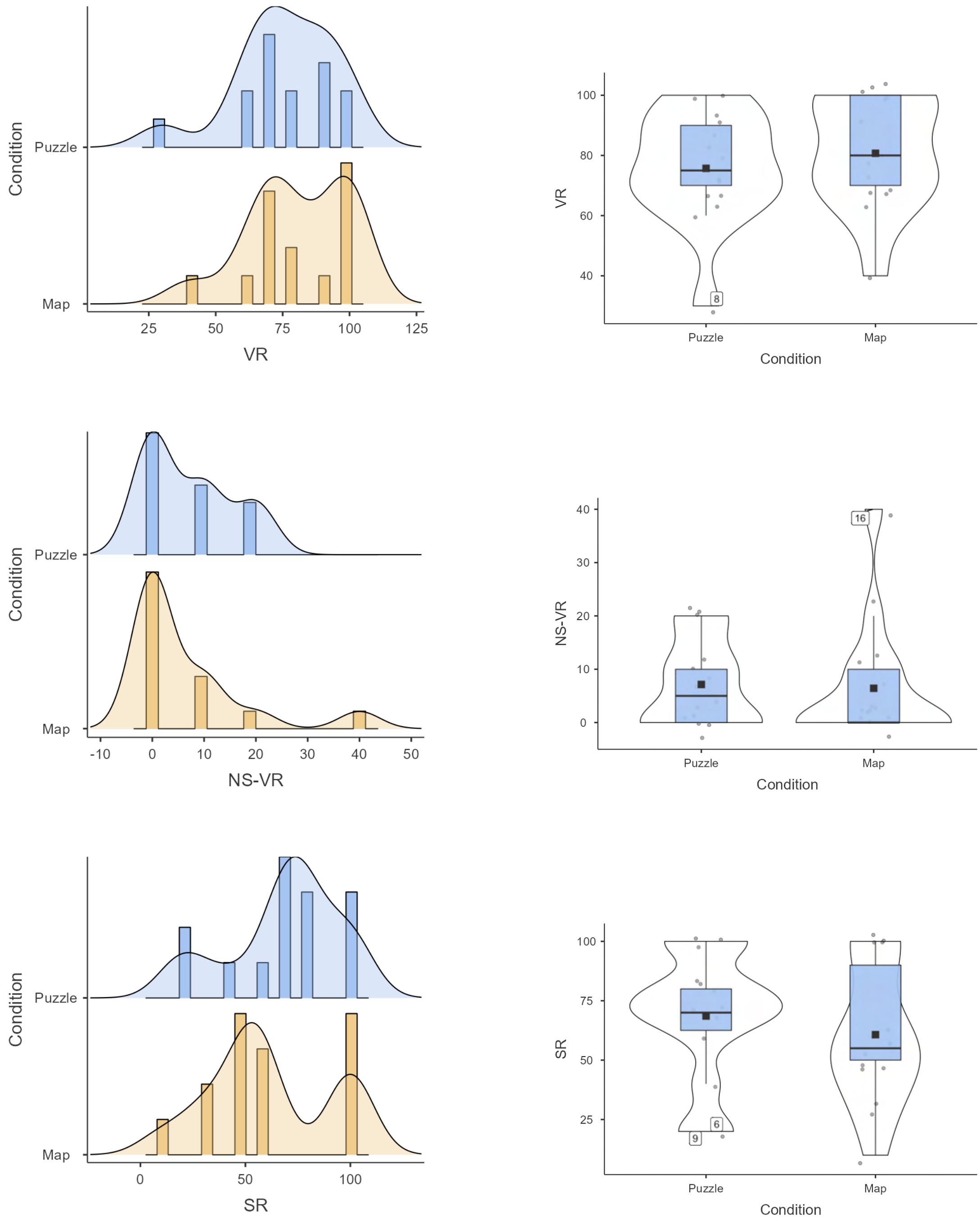


Figure 9: a) Curve and violin plots showing distribution across several variables in our study.

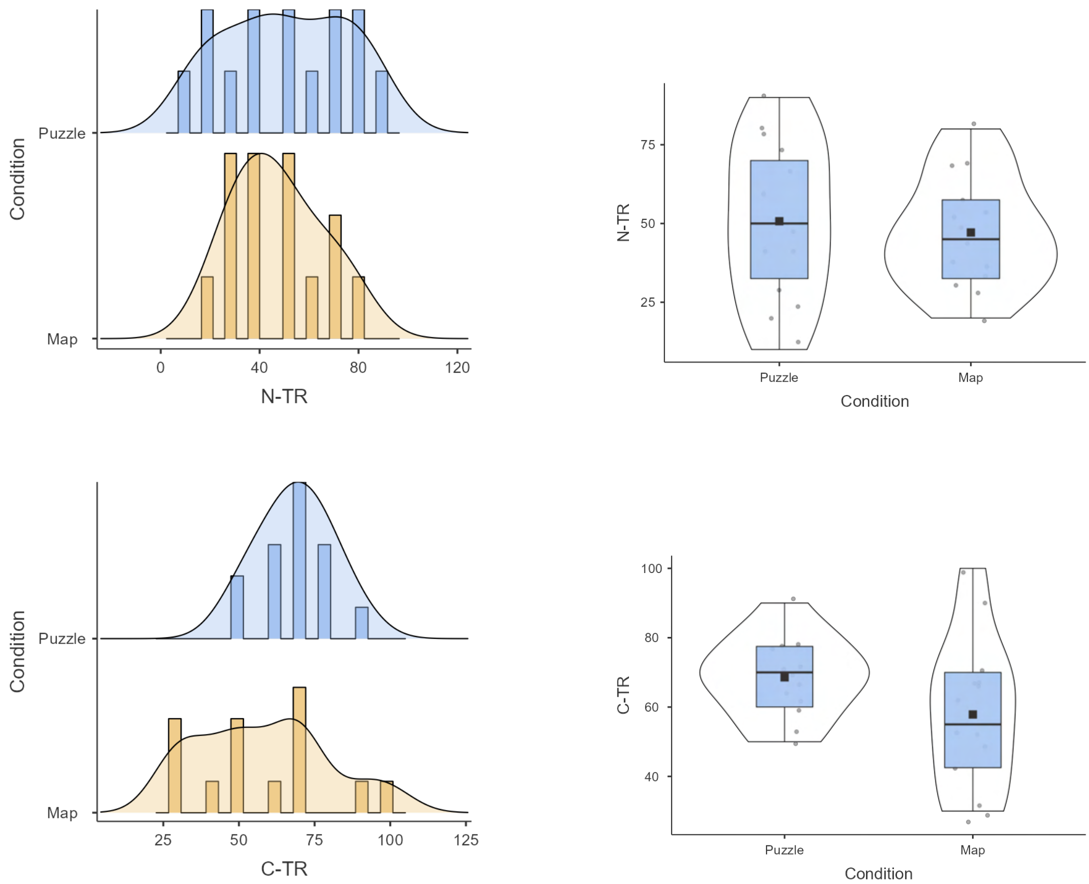


Figure 10: b) Curve and violin plots showing distribution across several variables in our study.

Table 1: Information Recall Scores Between Two Conditions

	cond	VR	NS-VR	SR	N-TR	C-TR
mean	puzzle	▼75.7	▼7.14	▲68.6	▲50.7	▲68.6
	map	80.7	6.43	60.7	47.1	57.9
std dev	puzzle	18.7	8.25	26.3	25.3	11.7
	map	18.6	11.5	29.2	17.7	21.9
Shapiro-Wilk W	puzzle	0.915	0.767	0.880	0.956	0.936
	map	0.876	0.638	0.882	0.948	0.928
Shapiro-Wilk p	puzzle	0.184	0.002	0.059	0.661	0.370
	map	0.051	$<.001$	0.062	0.525	0.289
Mann-Whitney U	p	**0.452		**0.328	**0.693	**0.116
	H_a $\mu_{puzzle} \neq \mu_{map}$,**no sign. diff.					

Legend: *Cond*: Condition, *VR*: Visual Recall, *NS-VR*: Negative Symbol Recall, *SR*: Spatial Recall, *N-TR*: Name Textual Recall, *C-TR*: Category Textual Recall

during the after-test briefing that they associated some POIs with the colours instead of the symbols on them, which were not considered a variable in our study.

5.1 TOUCHSCREEN PUZZLE INTERACTION DATA

To evaluate the interaction data collected with our prototype, we wrote Python scripts to process and interpret the data. The data were stored on Google Drive and accessed through Google Colab. This analysis focuses specifically on the puzzle condition, aiming to gain insights into participants' behavior and patterns of solving the puzzle.

Table 2: Overview of NASA-TLX Cognitive Scores

	cond	MD	PD	TD	P	E	F
mean	puzzle	▼36.1	▼8.21	▲24.6	▼28.6	▼37.5	▼12.1
	map	49.3	8.57	19.3	29.6	45.0	14.3
std dev	puzzle	26.3	05.04	22.5	16.0	25.9	6.71
	map	19.2	06.02	16.0	18.0	24.3	14.9
Shapiro-Wilk W	puzzle	0.899	0.697	0.792	0.906	0.850	0.879
	map	0.958	0.672	0.785	0.915	0.962	0.697
Shapiro-Wilk p	puzzle	0.109	<.001	0.004	0.139	0.022	0.057
	map	0.686	<.001	0.003	0.185	0.750	<.001
Mann-Whitney U	p	**0.122		**0.758	**0.871	**0.309	
	H_a $\mu_{puzzle} \neq \mu_{map}$,**no sign. diff.						

Legend: *Cond*: Condition, *MD*: Mental Demand, *PD*: Physical Demand, *D*: Temporal Demand, *P*: Performance, *E*: Effort, *F*: Frustration

5.1.1 Building the Tools

In our data analysis, we focused on tracking participants' progression from the starting positions to the ending positions of the puzzle pieces (see Figure 11). The tool provided the flexibility to explore the data from different perspectives, facilitating a comprehensive analysis of the participants' interactions and aiding in identifying patterns or trends within the puzzle-solving process. The scripts extracted the following data from the logs of the prototype:

- Total time of puzzle solving: Calculating the overall time it took for the participant to complete the puzzle.
- Analysis of Puzzle Time: By analysing the timestamps we can identify participants with fastest and slowest completion time, as well as, the average time.

- Time per Piece: This option helped us identify levels of difficulty and complexity associated with specific pieces.
- Ordered list of snapped pieces per participant: The scripts generates a list of puzzle pieces in order they were completed/snapped in their correct position. This allowed us to identify any patterns or strategies between the participants.
- Ordered movement chunk count per participant: By analysing the movement data of participants' interactions, we obtained valuable insights into the number of times each puzzle piece was picked up by individual participants.

5.1.2 Investigating Key Questions

With the data extracted we focused on answering the following questions:

- **What strategies participants employed in solving the puzzle?** By examining the interaction data, we aimed to uncover the strategies and decision-making processes employed by participants during the puzzle-solving task. We analysed the order in which pieces were selected, the time taken to complete each piece, and the overall completion time for each participant.
- **Can we compare/categorise strategies participants employ to solve the puzzle?** Through comparative analysis, we explored variations in participants' approaches to the puzzle. We examined differences in completion times, paths taken, and the sequence of piece selections across different participants. This allowed us to identify unique strategies and common patterns in puzzle solving.
- **What conclusions can we draw from the comparisons between participants?** By comparing the puzzle-solving approaches of different participants, we were able to draw conclusions about the effectiveness of certain strategies or identify challenges faced by participants during the task. These findings shed light on the puzzle's difficulty level, the impact of different piece configurations, and potential design improvements.

5.1.3 Findings and Key Insights

Through our analysis of the interaction data, we uncovered several important findings and gained valuable insights into participants' puzzle-solving behavior. Some of the key findings include:

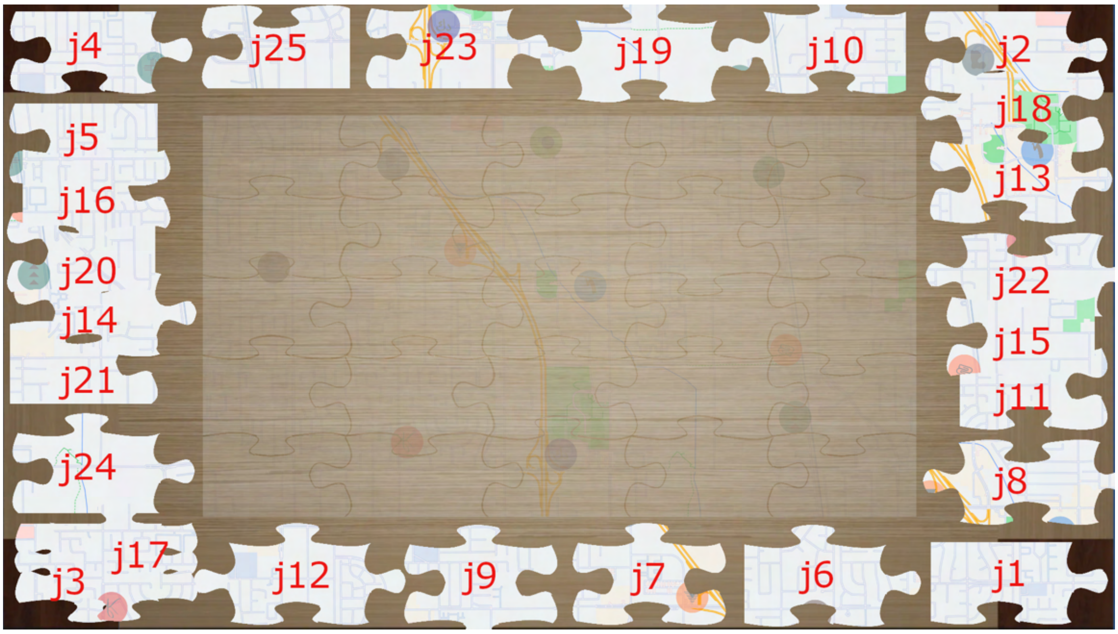
- Patterns in piece completion: We observed that certain pieces were consistently completed early on by most participants, suggesting their attractiveness or perceived importance in the puzzle-solving process. These pieces are: **j23** (4 out of 14 participants), **j25** (4 out of 14 participants) and **j1** (3 out of 14 participants). The pieces that took the least amount of time to be completed are: **j21** - 24 seconds, **j25** - 24 seconds, **j10** - 26 seconds and **j1** - 30 seconds. The pieces with least amount of pickups are: **j1**, **j2**, **j5**, **j10**, **j15**, **j23** and **j25**, all with 14 pickups. This means that they were picked once by all participants while solving the puzzle.

- Varied completion times: The fastest completion time was **1 minutes and 38 seconds**. The slowest completion time was **4 minutes and 15 seconds**. This tells us that participants exhibited different levels of efficiency when solving puzzles. On the other hand, the average completion time was: **2 minutes and 13 seconds**.

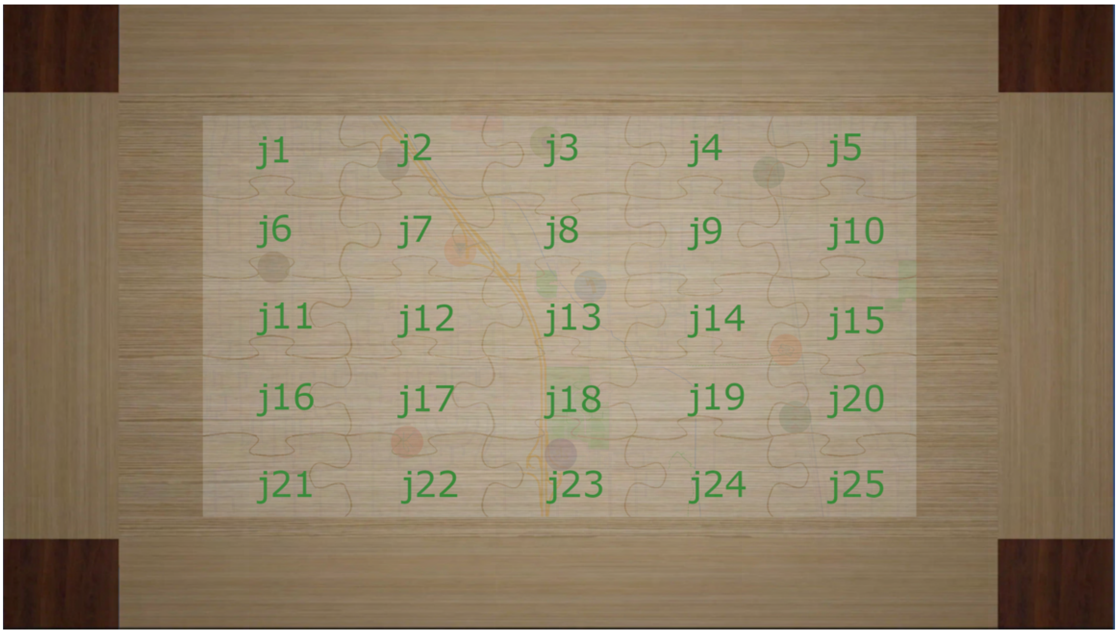
- Troublesome pieces: Certain pieces appeared to cause difficulty for multiple participants, as evidenced by longer completion times or frequent backtracking. These pieces may warrant further investigation for potential design improvements. The most frequently pieces that were completed last are: **j12** (4 out of 14 participants) and **j9** (3 out of 14 participants). These pieces are the middle pieces and they contain no POI elements on them. The pieces that took the longest time to be completed are: **j14** - 99 seconds, **j4** - 81 seconds, **j19** - 77 seconds, **j20** - 74 seconds. Here we have border pieces j4 and j20 and middle pieces j14 and j19. All containing some POI elements on them. We can provide more insight into this by looking at how many chunk instances of pieces across all participants are there. The top three pieces by most amount of pickups are: **j14** - 24 chunks, **j17** - 23 pickups and **j18** - 22 pickups.

- Participant-specific strategies: Each participant showcased unique puzzle-solving approaches, highlighting the individuality and creativity in problem-solving behaviors. Each participant had a unique path of solving the puzzle.

These findings not only provide insights into the puzzle-solving process but also inform potential improvements for future iterations of the touchscreen puzzle. We will provide more feedback in the following chapter (see chapter 6)



(a) The starting positions of the puzzle pieces.



(b) The ending positions of the puzzle pieces.

Figure 11: Look at puzzle positions in the prototype *Retzzles*.

6 DISCUSSION

In this chapter, we delve into the limitations of our prototype, participant feedback and suggestions, and design recommendations for future improvements. Furthermore, we aim to provide an analysis of the data, discussing the significance of our findings and exploring possible reasons behind the observed patterns.

6.1 INTERPRETING THE DATA

Describing the data, mean values and significance: Participants in the puzzle condition exhibited higher mean scores in both the spatial and textual assignments, indicating a potential advantage in retaining and recalling information compared to the map-only condition. However, in the visual assignment, participants in the puzzle condition had lower mean scores compared to the map-only condition. One possible interpretation of this finding is that the puzzle condition may have provided additional engagement and cognitive stimulation for participants, leading to improved retention and recall of spatial and textual information. Solving puzzles and interacting with abstract symbols may have encouraged active engagement and deeper processing of the information, resulting in better performance. However, it is worth noting that the puzzle condition may have also introduced additional cognitive load or distractions, which could have contributed to the lower mean scores in the visual assignment.

Furthermore, upon reviewing the video data of the participants, we observed that participants assigned to the map-only condition appeared visibly nervous. We attribute this observation to the nature of the task, which required them to solely “look and memorise” the information, in contrast to the puzzle condition where participants were engaged in solving the puzzle before proceeding to the next step of memorising information. We believe this distinction likely contributed to the variance in perceived cognitive effort between the two conditions.

Although the observed differences in mean scores between the conditions may seem noteworthy, it is important to note that these differences were not statistically significant. Consequently, we must interpret these findings with caution and refrain from making definitive conclusions based solely on the mean values.

The lack of statistical significance suggests that the observed differences could be due to random chance or variability within our sample. It is possible that the puzzle condition's slight advantage in spatial and textual assignments and disadvantage in the visual assignment could be attributed to individual differences, learning styles, or other factors that were not captured in our study.

We discovered that each participant produced a unique path when solving the puzzle. Given the limited size of our data sample, we anticipate that with a larger data set, we would be able to identify more comprehensive puzzle-solving patterns and gain a deeper understanding of the strategies employed by users. Similarly, the lack of statistical significance between the conditions could also suggest that the sample size of our study was insufficient to detect smaller, yet meaningful, differences between the conditions. A larger sample size might be necessary to reveal the true effects of the puzzle condition on information retention across different assignment types.

6.2 PARTICIPANT FEEDBACK

During the study, 20 out of 28 of the participants expressed a tendency to focus on the colour rather than the abstract symbol presented in the button or point of interest (POI). Although this behavior did not appear to significantly impact overall participant performance in completing the assigned tasks, it is a noteworthy variable that should be considered in future investigations. By acknowledging and addressing participants' inclination towards colour, we can refine the design and consider colour theory principles to optimize participant engagement and information retention.

6.3 DESIGN RECOMMENDATION

Part of the contribution of this thesis is to shed light on the design of future interfaces that support information retention and recall. We provide design recommendations based on what we have learned from our findings, which can contribute to a more effective interface design.

- Incorporate additional modalities: Introducing audio options to read text aloud or guide users through different scenes could enhance accessibility and cater to a wider range of learning preferences. The inclusion of an assistant, perhaps in the form of a visually appealing character, could also increase participant engagement and motivation.

- As mentioned earlier, exploring colour as a variable might be another option: Given participants' tendency to focus on colour, future tests should consider incorporating colour theory principles into the design. By systematically varying colours and evaluating their impact on participant performance and engagement, we can gain valuable insights into the role of colour in information retention and retrieval.

- Provide diverse options: In addition to abstract symbols, offering users familiar alternatives could cater to individual preferences and learning styles. By allowing users to choose between abstract symbols and more recognisable representations, we can accommodate a broader range of participant preferences and potentially enhance information retention.

6.4 LIMITATIONS

One significant limitation of our prototype was the absence of multi-touch support, restricting users to interacting with the screen using only one finger. While the majority of participants adapted to this constraint without major issues or found it natural from the outset, a minority of users encountered glitches, particularly when moving puzzle pieces. The lack of multi-touch functionality hindered the full potential of the prototype, and future iterations should prioritise incorporating this feature to enhance participant experience and mitigate any unintended difficulties.

Our prototype study has shed light on the limitations of the current design and provided valuable participant feedback and suggestions. The data analysis, while preliminary, offers promising insights into the potential benefits of our approach in improving textual and spatial recall. Further investigation is required to understand the lack of significant improvement in visual recall. Our findings contribute to the ongoing discourse on employing interactive touchscreens in casual learning scenarios aimed at enhancing memory retention. By addressing the identified limitations and incorporating design recommendations, future iterations of the system can strive for greater effectiveness and participant satisfaction.

7 CONCLUSION AND FUTURE WORK

In this thesis, we explored whether touchscreen visual elements, such as puzzle pieces and abstract symbols, can help users become more engaged towards better retention. We presented our prototype, *Retzzles*, where users solved puzzles and interacted with abstract symbols displaying key information as an alternative to the map format. Results of our between-subject study, involving $n = 28$ participants, showed better mean scores; however, no significant difference between these conditions. We believe we can arrive at better results with a larger sample size and if we consider other variables such as colour.

We also analysed some of our puzzle interaction data. This gave us exciting insights into how users build customised paths when solving puzzles. This examination allowed us to gain an understanding of how the arrangement of puzzle pieces influenced the ease or difficulty of solving particular segments. This valuable information sheds light on user behavior and preferences. We posit the results presented in this study are a step in understanding how touchscreen puzzles and augmented maps with abstract symbols can affect users' retention skills. We also plan to integrate a mixed reality approach to explore interaction and direct manipulation differences with the puzzle pieces, focusing on engagement and retention. Our goal is to guide designers in creating engaging interactions in practical fields such as tourism, civics, and digital humanities.

8 POVZETEK NALOGE V SLOVENSKEM JEZIKU

Zaradi vse večje razširjenosti digitalnih zemljevidov in potrebe po njihovi uporabi na poti bi bilo ohranjanje informacij precejšen izziv. Trdimo, da bi lahko uganke uporabili kot orodje, ki bi pomagalo pri tej težavi in informiralo pri ustvarjanju digitalnih zemljevidov [21,36]. Ukvarjanje z ugankami je že od nekdaj priljubljena zabava za ljudi vseh starosti. Uganke ne zagotavljajo le zabave in razvedrila, temveč raziskave kažejo tudi na njihove koristi pri kognitivnem razvoju in zdravju možganov [10, 17, 30, 43]. Z raziskovanjem potencialnih koristi ugank pri ustvarjanju in interakciji z digitalnimi zemljevidi želimo prispevati k razvoju inovativnih in učinkovitih metod strategij razširitve, ki pomagajo pri ohranjanju informacij. V tem diplomskem delu raziskujemo uporabo ugank kot orodja za vključevanje v vmesnike digitalnih zemljevidov s ciljem povečati, koliko informacij uporabniki obdržijo.

Shranjevanje informacij, bodisi kratkoročno ali dolgoročno, je ključnega pomena iz različnih razlogov. Predvsem nam omogoča, da si zapomnimo ključne podrobnosti, kot so formule za izpit ali ključne informacije za projekt. Poleg tega dostopne informacije služijo kot osnova za več kognitivnih procesov, vključno z razumevanjem, uporabo intelektualnih spretnosti, ustvarjalnim razmišljanjem in spreminjanjem stališč. Brez trdnega razumevanja tega, kako se informacije ohranjajo, je te kognitivne procese težko izčrpno razložiti. V bistvu je ohranjanje informacij temeljni vidik naše sposobnosti učenja, rasti in uspeha kot človeških bitij [29].

Za popolno razumevanje koncepta vpletenosti je ključnega pomena, da se zavedamo pomena odnosa med ljudmi in njihovim okoljem, vključno z materiali in predmeti, s katerimi so v interakciji. Za to je treba skrbno preučiti različne načine, na katere posamezniki sodelujejo s svojim fizičnim okoljem in se po njem gibljejo. Poleg tega je pomembno opozoriti, da zavzetost ni zgolj stvar posameznikovih kognitivnih procesov, temveč je zapleteno medsebojno delovanje med uporabnikom, opravljeno nalogo in okoljem, v katerem se nahaja [11].

8.1 HIPOTEZE

V okviru te diplomske naloge želimo preveriti naslednje hipoteze:

- H0: Interakcija, podobna sestavljanki, bo pripomogla k večji zavzetosti in boljšemu priklicu informacij pri nalogah, povezanih z zemljevidi.

8.2 PRISPEVEK DIPLOMSKEGA DELA

V tej diplomski nalogi raziskujemo interakcije uporabnikov na razširjenem zemljevidu, predvsem učinkovitost interakcij razširjenega zemljevidnega vmesnika na zaslonu na dotik, ki so podobne sestavljanki, v upanju, da bodo spodbujale ohranjanje informacij. Uganki podobne interakcije se nanašajo na interaktivne izzive, ki od uporabnikov zahtevajo, da uredijo dele informacij, v našem primeru informacije na zemljevidu, in tako oblikujejo celoten zemljevid.

Predstavljamo ugotovitve in spodbujamo poglobljeno razpravo o naslednjih ciljnih prispevkih:

- **Artifact**: Predstavljamo prototip Retzzles, interaktivni vmesnik z zaslonom na dotik. ki uporabnikom omogoča reševanje ugank, s čimer podpira ohranjanje informacij.

- **Empirični**: Predstavljamo ugotovitve uporabniške študije med dvema pogojema (zemljevid proti uganka) pri ocenjevanju vizualnega, prostorskega in besedilnega priklica.

- **Smernice za oblikovanje**: Priporočila, ki smo jih pridobili iz naših uporabniških študij za pomoč oblikovalcem interakcij pri razvoju površin in zaslonov, ki pomagajo pri določenem učnem scenariju.

8.3 STRUKTURA DIPLOMSKEGA DELA

To diplomsko delo je razdeljeno na več sestavnih delov in elementov, kot je opisano v nadaljevanju:

Poglavje 1: Uvod. V tem poglavju je predstavljena raziskovalna tema, vključno z njenim opisom in motivacijo. Predstavlja tudi pregled obravnavanih raziskovalnih vprašanj in opisuje strukturo diplomskega dela.

Poglavje 2: Sorodno delo. To poglavje obravnava obstoječo literaturo in sorodno delo na tem področju. Obravnava, kako avtor postavlja svoje diplomsko delo glede na obstoječe prispevke. Natančneje, obravnava predhodno delo o interaktivnih tablah in površinah v kontekstu zemljevidov, učenje z razširjeno resničnostjo, raziskave ikon, simbolov in oznak ter, kar je najpomembnejše, uganke.

Poglavje 3: Retzule. Poglavje 3 se osredotoča na zasnovo sistema prototipa, imenovanega *Retzzles*. V njem so podrobno pojasnjeni vidiki zasnove, arhitektura in izvajanje sistema *Retzzles*.

Poglavje 4: Študija uporabnikov. V tem poglavju diplomsko delo opisuje metodologijo in postopke, ki so bili uporabljeni za izvedbo študije uporabnikov. Pojasnjuje načrt raziskave, izbor udeležencev, tehnike zbiranja podatkov in vse pomembne etične vidike.

Poglavje 5: Rezultati. V poglavju 5 so predstavljene ugotovitve in rezultati, pridobljeni s študijo uporabnikov. V njem so analizirani in interpretirani zbrani podatki ter poudarjena ključna opažanja in rezultati.

Poglavje 6: Razprava. To poglavje ponuja celovito razpravo o raziskovalnih vprašanjih in njihovih ustreznih rezultatih. Poleg tega lahko ponudi praktična priporočila in predloge za nadaljnje raziskovanje na tem področju.

Poglavje 7: Zaključek. V zadnjem poglavju so zbrane vse ključne točke, obravnavane v celotnem diplomskem delu. Povzema glavne ugotovitve, razpravlja o njihovem pomenu, predstavi zaključne pripombe in poda vpogled v morebitna področja prihodnjih raziskav.

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Appendices

A Cognitive Assessment

Participant ID

Task Questionnaire

Mark on each scale at the point that best indicates your experience of the task

Mental Demand

Low — High

How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Physical Demand

Low — High

How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Temporal Demand

Low — High

How much time pressure did you feel due to the rate of pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Performance

Good — Poor

How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Effort

Low — High

How hard did you have to work (mentally and physically) to accomplish your level of performance?

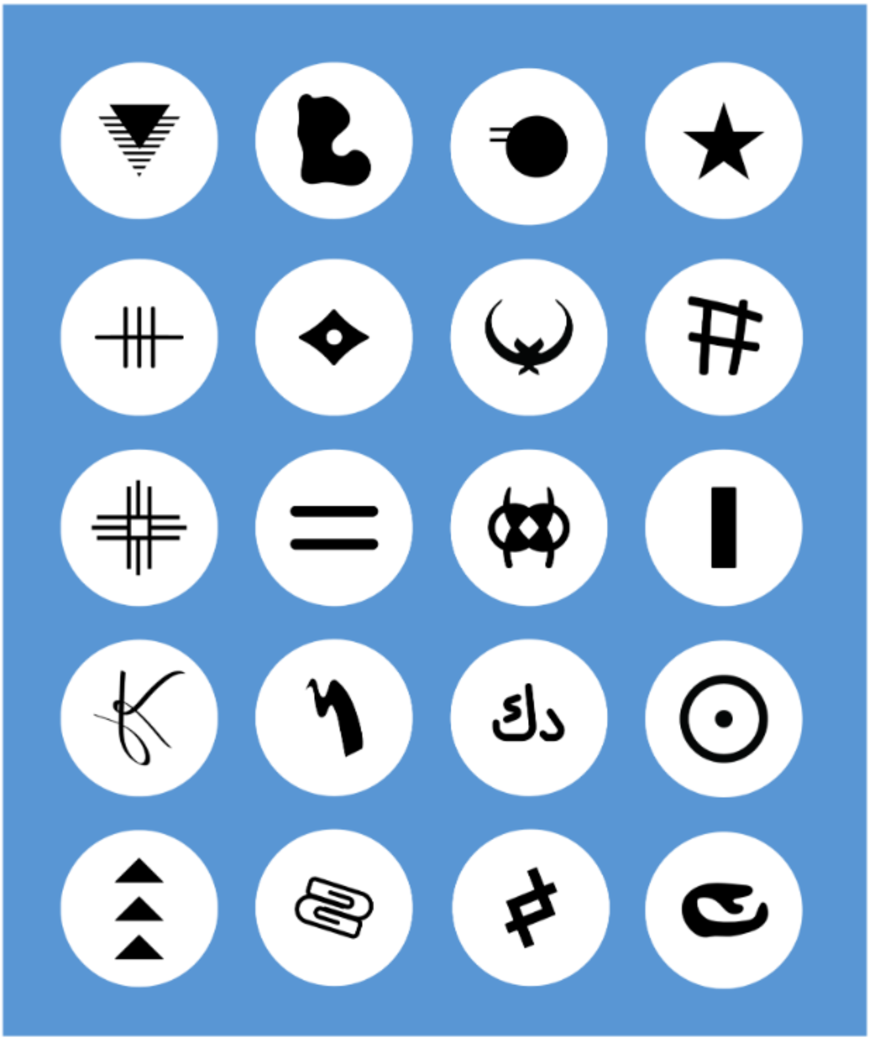
Frustration

Low — High

How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

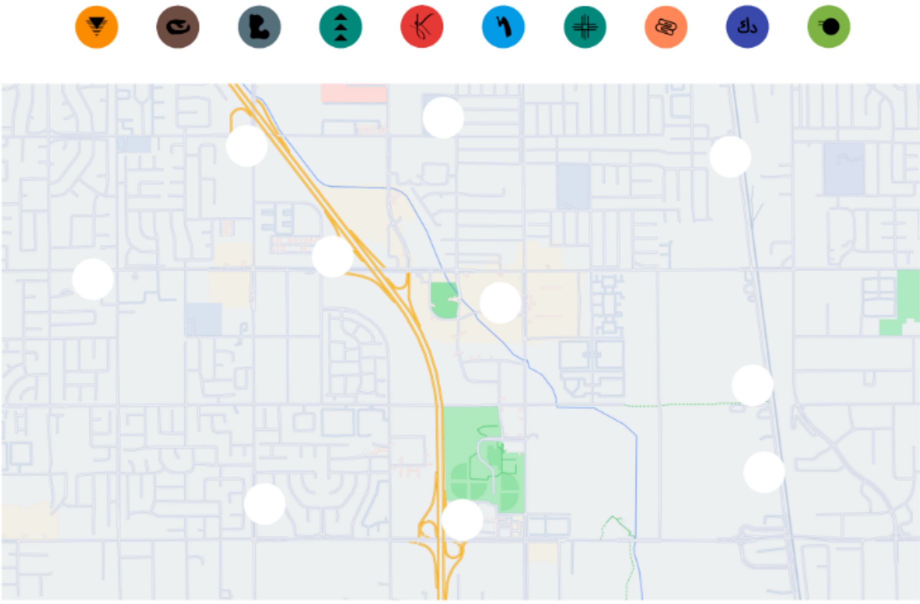
B Visual Assessment

Please cross the symbols that you think were on the last map.

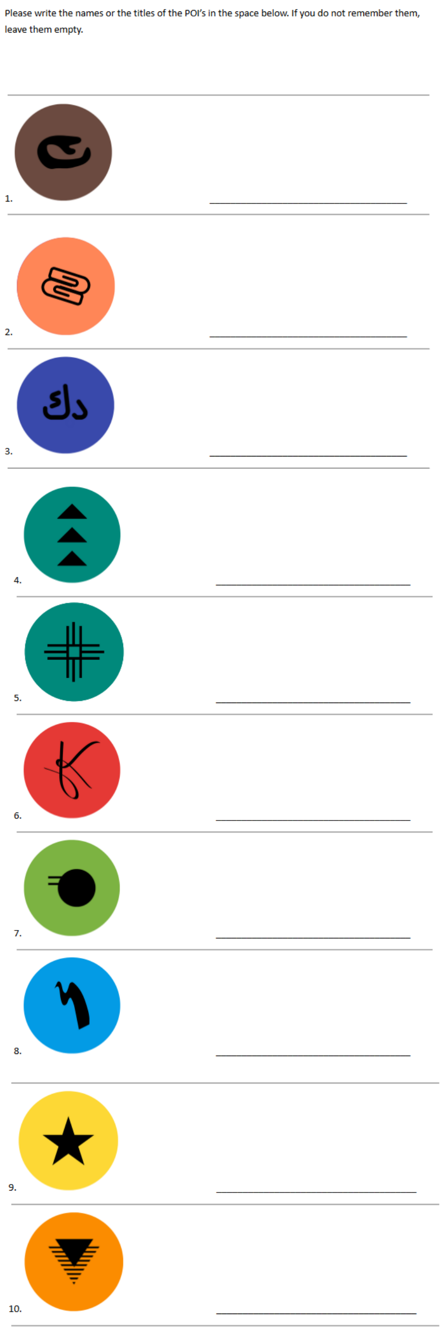


C Spatial Assessment

Please draw or position (using a line) the 10 POI's in their appropriate blank slot in the map.



D Textual Assessment



Please write the names or the titles of the POI's in the space below. If you do not remember them, leave them empty.

1. ____________________

2. ____________________

3. ____________________

4. ____________________

5. ____________________

6. ____________________

7. ____________________

8. ____________________

9. ____________________

10. ____________________

E Moderator Protocol 1

1. Moderator assigns the condition (these are counterbalanced and is determined in random) that the participant will work on, before they arrive. Moderator prepares the corresponding materials - orientation video, shortcut to forms, etc.
2. Participant is invited to enter the room by the moderator.
3. Moderator plays the appropriate orientation video to the participant that explains the prototype, the protocol and objectives. **OR** Moderator themselves provide an explanation of the prototype, the protocol, and the objectives
4. Moderator gives them the participant kit (Informed Consent Form, demographic information, etc.)
5. The moderator collects the participant kit after they fill them up.
6. Moderator assigns the Participant ID and writes them in all forms. The participant is notified of their condition.
7. Moderator invites the participant to stand in front of the touchscreen display. Moderator begins video recording.
8. Moderator starts the training application and invites the participant to follow the instructions based on the video.
9. Participant begins with the training task.
10. Once they are done with the training task, the Moderator invites them to click "NEXT" to proceed to the interaction task. Moderator begins the 6 minute timer.
11. Participant begins with the interaction task.

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12. **Puzzle condition** ->Participant is assembling the **Main Scene** puzzle, afterwards they look and memorize the locations of abstract symbols. <u>No interaction with the abstract symbols here.</u> After the Participant decides to move on with the assessment tasks, Moderator guides the Participant to the tests:
    a. Moderator invites the participant to complete the NASA-TLX form.
    b. Moderator collects the form.
    c. Moderator invites the participant to complete Instrument A - Memorising Abstract Symbols.
    d. Moderator collects the form.
    e. Moderator invites the participant to complete Instrument B - Recalling Position of Abstract Symbols in a Map.
    f. Moderator collects the form.
13. After that, the Moderator invites the Participant back in front of the touchscreen display.
14. Moderator instructs the Participant that they are able to click on the abstract buttons.
15. When the participant finishes with the task they press the "SAVE" button on the screen.
16. Moderator invites the participant to complete Instrument C - Recalling Information Behind Abstract Symbols.
17. Moderator collects the form.
18. Moderator stops the timer, closes the application, and ends the video recording.
19. Moderator thanks the participant for completing the study.

F Moderator Protocol 2

20. **Map condition** -> Look and memorize the locations of abstract symbols on the **Main Scene**. No interaction with the abstract symbols here. After the Participant decides to move on with the assessment tasks, Moderator guides the Participant to the tests:
    a. Moderator invites the participant to complete the NASA-TLX form.
    b. Moderator collects the form.
    c. Moderator invites the participant to complete Instrument A - Memorising Abstract Symbols.
    d. Moderator collects the form.
    e. Moderator invites the participant to complete Instrument B - Recalling Position of Abstract Symbols in a Map.
    f. Moderator collects the form.
21. After that, the Moderator invites the Participant back in front of the touchscreen display.
22. Moderator instructs the Participant that they are able to click on the abstract buttons.
23. When the participant finishes with the task they press the "SAVE" button on the screen.
24. Moderator invites the participant to complete Instrument C - Recalling Information Behind Abstract Symbols.
25. Moderator collects the form.
26. Moderator stops the timer, closes the application, and ends the video recording.
27. Moderator thanks the participant for completing the study.

G User Studies