The Impact of Immersion on Cluster Identification Tasks
APPENDIX

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A PRE-STUDY

A.1 Pre-Study: Procedure

Table S1: Overview of the pre-study procedure.

Step	Name	Description
1	Welcome	Participants were welcomed and introduced to the study. Moreover, they were asked to give written informed consent and to fill in a questionnaire assessing demographic variables.
2	Training	Participants completed multiple training trials in each visualization design space until they fully understood the task.
3	Trial Block A	Participants completed four trials in a systematically assigned design space.
4	Measures of Immersion	Participants were asked to answer the single immersion question and the immersion questionnaire.
5	Trial Block B	Same as step 3, but with the next design space as prescribed by counterbalancing.
6	Measures of Immersion	Same as step 4.
7	Trial Block C	Same as step 3, but with the next design space as prescribed by counterbalancing.
8	Measures of Immersion	Same as step 4.
9	Trial Block D	Same as step 3, but with the next design space as prescribed by counterbalancing.
10	Measures of Immersion	Same as step 4.
11	Semi-Structured Interview	Participants were asked a predefined, but not limited set of questions.
12	Closing	Participants were thanked and paid.

A.2 Pre-Study: Overview of Collected Data

Table S2: Overview of all data collected throughout the pre-study.

Data Gathered	Description	Analysis
Single Measure of Immersion	Single question (Sect. A.4.1) on subjectively perceived immersion. Assessed after each design space / trial block.	Answers were given on a five-point rating scale from 1 (not immersed) to 5 (very immersed). Subsequently, statistical analyses were performed.
Multiple Measure of Immersion	Questionnaire consisting of 18 questions (Sect. A.4.2) from various immersion questionnaires	Immersion scores were computed by summing up participants' responses and statistical analyses were performed.
Semi-Structured Interview	In addition to more open questions, the interview included the collection of individual ratings for presence and abstractness (for which Likert scales ranging from 1 to 5 were used; see Sect. A.4.3)	Median abstractness and presence scores were evaluated quantitatively. Answers to open questions were evaluated qualitatively.

A.3 Pre-Study: Study Results

To evaluate differences in the level of immersion between design spaces, a non-parametric Friedman test was deployed ($\chi^2(3) = 24.23$, $p < .001$). We used a non-parametric test because of skewed distributions. Wilcoxon signed-rank tests were conducted as post hoc tests to follow up this finding. A Bonferroni correction was applied (to control for multiple testing) and so all effects are based on a significance level of $\alpha = .008$.

A.3.1 Pre-Study: Results - Single Measure of Immersion

Table S3: Immersion Question: Results of Bonferroni-corrected Wilcoxon signed-rank tests.

	design space	z	p	effect size (r)
Screen2D	Screen3D	-1.90	.055	-.27
	VRTable	-2.84	.001	-.41
	VRRoom	-2.75	.002	-.40
Screen3D	VRTable	-2.85	.001	-.41
	VRRoom	-2.61	.003	-.38
VRTable	VRRoom	-.75	.307	-.11

A.3.2 Pre-Study: Results - Multiple Measure of Immersion

Table S4: Immersion Questionnaire: Results of Bonferroni-corrected Wilcoxon signed-rank tests.

	design space	z	p	effect size (r)
Screen2D	Screen3D	-2.12	.016	-.31
	VRTable	-2.90	.001	-.42
	VRRoom	-2.90	.001	-.42
Screen3D	VRTable	-2.94	< 0.001	-.42
	VRRoom	-2.87	< 0.001	-.41
VRTable	VRRoom	-1.88	.031	-.27

A.3.3 Pre-Study: Results - Quantitatively Evaluable Interview Questions

Table S5: Interview questions about subjectively perceived presence and abstraction: Results of Bonferroni-corrected Wilcoxon signed-rank tests.

	design space	z	p	effect size (r)
Screen2D	Screen3D	-2.89	.001	-.41
	VRTable	-3.27	< 0.001	-.47
	VRRoom	-3.28	< 0.001	-.47
Screen3D	VRTable	-2.75	.002	-.40
	VRRoom	-2.97	.001	-.43
VRTable	VRRoom	-2.67	.005	-.39

A.4   Pre-Study: Questionnaires and Interview Structure

A.4.1   Pre-Study: Single Measure of Immersion (Immersion Question)

During the introduction to the study, participants were made familiar with the concept of immersion. The single measure presented below served as an additional measure for the assessment of subjectively perceived immersion.

How immersed did you feel in the virtual environment? *

○ very strongly immersed

○ strongly immersed

○ immersed

○ not very immersed

○ not immersed at all

○ I don't know

A.4.2   Pre-Study: Multiple Measure of Immersion (Immersion Questionnaire)

The second measure was a questionnaire on immersion which combined various questions on immersion from established questionnaires. We used all questions from the Igroup Presence Questionnaire (IPQ) [3] in its original form, except for one question that caused confusion in the pilot study, namely SP3. Moreover, we included questions from Witmer and Singer [4] (PQ), Lessiter et al. [2] (ITC) and Jennett et al. [1] (IEQ). We carefully selected questions from immersion questionnaires that fit our task and scenario. Another requirement was that they had to be suitable for both conditions: Screen and VR. Questions like "I did not feel as if I was moving through the game according to my own will." (S19 from IEQ) were therefore excluded. Immersion scores were computed by summing up participants' responses to all 18 questions.

In the computer generated world I had a sense of "being there". *

	1	2	3	4	5	6	7	
not at all	○	○	○	○	○	○	○	very much

Somehow I felt that the virtual world surrounded me. *

	1	2	3	4	5	6	7	
fully disagree	○	○	○	○	○	○	○	fully agree

I felt like I was just perceiving pictures. *

	1	2	3	4	5	6	7	
fully disagree	○	○	○	○	○	○	○	fully agree

I had a sense of acting in the virtual space, rather than operating something from outside. *

	1	2	3	4	5	6	7	
fully disagree	○	○	○	○	○	○	○	fully agree

I felt present in the virtual space. *

	1	2	3	4	5	6	7	
fully disagree	○	○	○	○	○	○	○	fully agree

How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)? *

	1	2	3	4	5	6	7	
extremely aware	○	○	○	○	○	○	○	not aware at all

multiple measure of immersion page 1

I was not aware of my real environment. *

	1	2	3	4	5	6	7	
fully aware	○	○	○	○	○	○	○	not aware at all

I still paid attention to the real environment. *

	1	2	3	4	5	6	7	
fully disagree	○	○	○	○	○	○	○	fully agree

I was completely captivated by the virtual world. *

	1	2	3	4	5	6	7	
fully disagree	○	○	○	○	○	○	○	fully agree

How real did the virtual world seem to you? *

	1	2	3	4	5	6	7	
completely real	○	○	○	○	○	○	○	not real at all

How much did your experience in the virtual environment seem consistent with your real world experience ? *

	1	2	3	4	5	6	7	
not consistent	○	○	○	○	○	○	○	very consistent

How real did the virtual world seem to you? *

	1	2	3	4	5	6	7	
about as real as an imagined world	○	○	○	○	○	○	○	indistinguishable from the real world

The virtual world seemed more realistic than the real world. *

	1	2	3	4	5	6	7	
fully disagree	○	○	○	○	○	○	○	fully agree

multiple measure of immersion page 2

How completely were all of your senses engaged? *

	1	2	3	4	5	6	7	
not engaged	○	○	○	○	○	○	○	completely engaged

How closely were you able to examine objects? *

	1	2	3	4	5	6	7	
not at all	○	○	○	○	○	○	○	very closely

How well could you examine objects from multiple viewpoints? *

	1	2	3	4	5	6	7	
not at all	○	○	○	○	○	○	○	extensively

How involved were you in the virtual environment experience? *

	1	2	3	4	5	6	7	
not involved	○	○	○	○	○	○	○	completely engrossed

Were you involved in the experimental task to the extent that you lost track of *
time?

	1	2	3	4	5	6	7	
not at all	○	○	○	○	○	○	○	completely

A.4.3 Pre-Study: Semi-Structured Interview

After all trials were completed, we conducted a semi-structured interview following the structure described below. We noted down answers to open questions and justifications given by participants for their answers. The structure was intended for the study supervisor to have a guideline at hand for the overall interview.

Final Interview

Participant ID

Kurzantwort-Text

Comment

Langantwort-Text

Order by Difficulty

1 easy to 4 hard

2D Scatterplot-Matrix

Kurzantwort-Text

3D Scatterplot

Kurzantwort-Text

VR Table

Kurzantwort-Text

VR Room

Kurzantwort-Text

Comment

Langantwort-Text

Order by Preference

1 not preferred to 4 preferred

2D Scatterplot-Matrix

Kurzantwort-Text

3D Scatterplot

Kurzantwort-Text

VR Table

Kurzantwort-Text

VR Room

Kurzantwort-Text

Comment

Langantwort-Text

Order by Presence

1 not present to 4 present

2D Scatterplot-Matrix

Kurzantwort-Text

3D Scatterplot

Kurzantwort-Text

VR Table

Kurzantwort-Text

VR Room

Kurzantwort-Text

Comment

Langantwort-Text

Order by Confidence

1 not confident to 4 confident

2D Scatterplot-Matrix

Kurzantwort-Text

3D Scatterplot

Kurzantwort-Text

VR Table

Kurzantwort-Text

VR Room

Kurzantwort-Text

Comment

Langantwort-Text

Rate Abstractness

1 least abstract to 5 very abstract

2D Scatterplot-Matrix

	1	2	3	4	5	
not abstract	○	○	○	○	○	very abstract

3D Scatterplot

	1	2	3	4	5	
not abstract	○	○	○	○	○	very abstract

VR Table

	1	2	3	4	5	
not abstract	○	○	○	○	○	very abstract

VR Room

	1	2	3	4	5	
not abstract	○	○	○	○	○	very abstract

Comment

Langantwort-Text

Rate Presence in Virtual Environment

1 least present, 5 very present

2D Scatterplot-Matrix

	1	2	3	4	5	
not present	○	○	○	○	○	very present

3D Scatterplot

	1	2	3	4	5	
not present	○	○	○	○	○	very present

VR Table

	1	2	3	4	5	
not present	○	○	○	○	○	very present

VR Room

	1	2	3	4	5	
not present	○	○	○	○	○	very present

Comment

Langantwort-Text

General Comments

VR Table vs. VR Room - Preference? Why?

Langantwort-Text

Comment

Langantwort-Text

B MAIN STUDY

B.1 Main Study: Procedure

Table S6: Overview of the main study procedure.

Step	Block	Name	Description
1		Welcome	Participants were welcomed and introduced to the study. Moreover, they were asked to give written informed consent and to fill in a questionnaire assessing demographic variables.
2	A	Training	Participants completed multiple training trials in the visualization design space of this block until they fully understood their task.
3	A	Trials	Participants completed eight trials in a systematically assigned design space.
4	B	Training	Same as step 2.
5	B	Trials	Same as step 3.
6	B	Memorability Assessment	Participants completed the memorability questionnaire concerning the last completed trial. This was only assessed for one single task to avoid learning effects. Participants did not know that they have to recall the dataset after the trial.
7	C	Training	Same as step 2.
8	C	Trials	Same as step 3.
9	D	Training	Same as step 2.
10	D	Trials	Same as step 3.
11		Final Questions and Open Discussion	Participants were asked a predefined, but not limited set of questions.
12		Closing	Participants were thanked and paid.

B.2 Main Study: Overview of Collected Data

Table S7: Overview of all data collected throughout the main study.

Data Gathered	Description	Analysis
Video & Audio	Participants were recorded during the trials.	Recordings were used in the video analysis process to count errors and find recurring patterns in user behaviour.
Error Rate	Participants were asked to point to clusters in the inspected scatterplot visualizations (with the mouse or VR controller) and to inform the study supervisor that they had found a cluster. In addition, they were asked to sum up the total number of clusters found at the end and to communicate their result to the study supervisor.	Throughout an exhaustive video analysis, a minimum of two persons encoded the clusters found by participants. The error rate was calculated as the number of clusters found divided by the overall available amount of clusters. Subsequently, the results were statistically evaluated. In the scope of the video analysis, we also encoded deviations from the amount of clusters actually found and the reported amount of clusters found. Moreover, we looked for common mistakes or pitfalls the participants made when solving the task (e.g., loss of orientation and double counting clusters).
Task Completion Time	The task completion time was logged as the time from the appearance of the scatterplot to the participant's statement that he/she had finished the task.	Task completion times were evaluated statistically.
Memorability Score	After the second trial block, participants were asked to complete a memorability questionnaire in which they had to recall the dataset/scatterplot from the previous trial and write down the number and shape of clusters found.	We created the memorability rate by comparing the recalled cluster shapes with the actually available cluster shapes in the dataset.
Body & Head Movement	For the immersive environments, we tracked the movement of the participants (position and head orientation).	The total distance, participants walked, and the total amount of head rotations were evaluated.
Subjective Preference	After all trial blocks were completed, we asked the participants several questions. They were asked to rank the four design spaces by difficulty and state the preferred design space. This was followed by an open discussion about the study.	Average preference ratings as well as the distribution of responses given were analyzed.

B.3 Main Study: Study Results

B.3.1 Main Study: Results - Error Rate by Visualization Design Space

Table S8: Error rate by visualization design space. Results of Bonferroni-corrected post hoc tests (Wilcoxon signed-rank tests).

design space		z	p	effect size (r)
Screen2D	Screen3D	-3.95	< 0.001	-.47
	VRTable	-4.87	< 0.001	-.57
	VRRoom	-4.57	< 0.001	-.54
Screen3D	VRTable	-1.36	1	-.16
	VRRoom	-0.23	1	-.03
VRTable	VRRoom	-1.13	1	-.13

B.3.2 Main Study: Results - Error Rate by Noise Level

Table S9: Error rate by noise level. *Difference* indicates the increase in the error rate when comparing the low noise condition with the high noise condition. Results of t-tests.

design space	$difference$	$t(17)$	95% CI	p	r^2
Screen2D	6.54%	-2.01	[-.34%, 13.43%]	.06	.19
Screen3D	1.3%	-.39	[-5.96%, 8.63%]	.70	.01
VRTable	5.74%	-2.27	[.40%, 11.08%]	.05	.23
VRRoom	5.54%	-2.19	[1.21%, 9.88%]	.05	.22

B.3.3 Main Study: Results - Task Completion Time by Visualization Design Space

Table S10: Comparison of the task completion time between the visualization design spaces.

design space		average difference	95% CI	p
Screen2D	Screen3D	-.141	[-.288, .006]	.066
	VRTable	-.066	[-.177, .045]	.565
	VRRoom	-.087	[-.180, .005]	.072
Screen3D	VRTable	.075	[-.056, .205]	.633
	VRRoom	.054	[-.072, .180]	1
VRTable	VRRoom	-.021	[-.104, .062]	1

B.3.4 Main Study: Results - Body and Head Movement

Table S11: Comparison of the two VR visualization design spaces with regard to the covered distance and head rotations. Results of t-tests.

VRTable vs. VRRoom	$t(17)$	p	r^2
Distance	-8.80	< 0.001	.82
Head Movement	-8.80	< 0.001	.82

B.4 Main Study: Questionnaires

B.4.1   Main Study: Memorability Assessment

Memorability Assessment

ParticipantID

_____

Number of Clusters: _____

How were the clusters shaped?

Final Questions

Please order the four different visualization design spaces by difficulty.
Assign ranks from easiest (1) to hardest (4).
Please use all ranks only once.

Scatterplot-Matrix: _____

VR-Table: _____

Scatterplot-3D (Screen) :   _____

VR-Room: _____

Which visualization design space did you prefer?

O   Scatterplot-Matrix

O   VR-Table

O   Scatterplot-3D (Screen)

O   VR-Room

REFERENCES

[1] C. Jennett, A. L. Cox, P. Cairns, S. Dhoparee, A. Epps, T. Tijs, and A. Walton. Measuring and defining the experience of immersion in games. *International journal of human-computer studies*, 66(9):641–661, 2008. doi: 10.1016/j.ijhcs.2008.04.004

[2] J. Lessiter, J. Freeman, E. Keogh, and J. Davidoff. A cross-media presence questionnaire: The itc-sense of presence inventory. *Presence: Teleoperators & Virtual Environments*, 10(3):282–297, 2001. doi: 10.1162/105474601300343612

[3] H. Regenbrecht and T. Schubert. Real and illusory interactions enhance presence in virtual environments. *Presence: Teleoperators & Virtual Environments*, 11(4):425–434, 2002. doi: 10.1162/105474602760204318

[4] B. G. Witmer and M. J. Singer. Measuring presence in virtual environments: A presence questionnaire. *Presence*, 7(3):225–240, 1998. doi: 10.1162/105474698565686