



Draw-Cut-Glue: Comparison of Paper House Model Creation in VR and on Paper in a Museum Education Programme - Pilot Study

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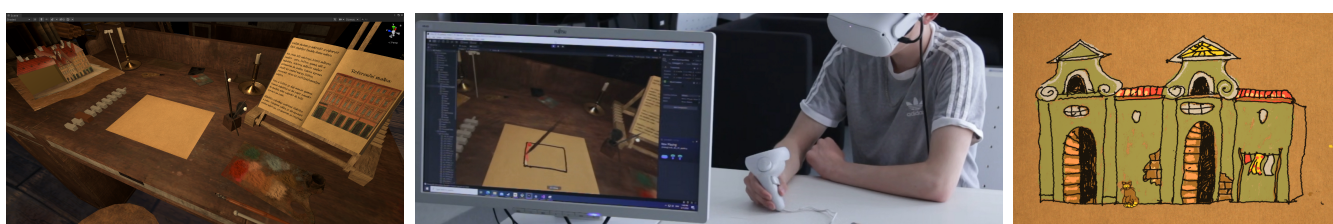


Figure 1: The virtual environment of Langweil's workshop; drawing a facade in VR; an example of free creation with our VR system.

Abstract

In this paper, we describe the integration of Virtual Reality (VR) into a museum education programme. The aim of the programme is to present the cultural heritage of Langweil's model of Prague in the context of author's life in the 19th century. For the programme, we developed a VR application in which students experience the creation of Langweil's model of Prague, more specifically, they virtually draw and cut out a facade of a house and insert it into the rest of the model. As part of the educational programme, the students also experience a similar activity with a paper model, which leads them to compare the creation in VR and in reality with real tools. The context of the author's life is covered by two additional programme activities using a budget simulation and a discussion using historical photographs. In a pilot study we evaluated the programme with 31 students and we describe the observed results from both the students' and the organisation's perspectives.

CCS Concepts

• **Social and professional topics** → *K-12 education; Informal education*; • **Applied computing** → *Interactive learning environments*; • **Human-centered computing** → *Virtual reality*; • **Computing methodologies** → *Virtual reality*;

1. Introduction

Museum education is a relatively young field both in the world and in the Czech Republic, but it has been developing rapidly in recent years and is looking for new ways of being involved [Šo12]. The term emphasises that the role of the museum is changing from an aesthetic role to an educational role, where educational specialists and educational programmes are used [Hei06].

One of the latest trends is the effort to include VR in museum education [SSL20, ZCW22]. It is no more used only for the visualisation of digitised museum collection items but is used as a specialised educational application. Nevertheless, in general terms, VR is still considered more as an entertainment element that can

enliven and make the content of an exhibition or exposition more attractive [BOPG19].

In line with recent research [DA20], appropriately used VR can become a valuable element of focused student work in the museum and can also bring the desired results in the newly applied research education, which is also beginning to enter the museum environment. Ideally, it can successfully link the goals of museums (to present and interpret cultural heritage) and the goals of school education (to build students' historical thinking through research education [SM12]). VR is attractive enough to enliven the educational process in the museum, but it also provides students with valuable insights, e.g., in simulating the use of different technologies, working procedures, or exploring variants of problem-solving tasks.

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1.1. Langweil's model of Prague as a historical source for museum education

Langweil's paper model of Prague is one of the most valuable collection items of the Prague City Museum [Pra23]. Its creator Antonín Langweil created it in the first third of the 19th century (1826-1837). It is a realistic model made of paper and homemade cardboard, using small pieces of wood and ivory on a wooden structure. It accurately depicts the appearance of pre-redevelopment Prague. The author succeeded in working on the Old Town of Prague, Lesser Town and Hradčany, but he could no longer work on the New Town of Prague; after eleven years of effort, his work was interrupted by death.

The explanatory value of Langweil's model of Prague is twofold. In terms of its content, it is a valuable document of the appearance of Prague before the redevelopment and thus provides valuable information, especially for historians and archivists, about what Prague looked like, including, for example, the still unregulated banks of the Vltava River, the network of natural roads in the Old Town of Prague, or details of the fortifications in some parts of Prague. But equally important is the technological evidence. The model itself faithfully documents the techniques used to create it, which at the time of its creation were of an extraordinary technical level. In addition, thanks to his education, Antonín Langweil showed extraordinary technical skill in the actual processing of the model, which may be of interest to today's creators of paper models.

The original paper model was digitized between 2007–2010 and a faithful digital version was created with the help of 3D reconstruction [SBZ13]. The data created during this reconstruction was used in the framework of this project, i.e. "Langweil's model of Prague as a school historical source" [Pra23].

1.2. Goals of museum education using Langweil's model of Prague

The main goal of the museum education programme was to allow the students to get acquainted with Langweil's model of Prague. The secondary goal was to put the intentions and activities of the author in the broader context of everyday life in Prague in the first half of the 19th century.

We covered these goals using the following components of the programme:

- Work with Langweil model in VR - Investigation of the model, which is normally enclosed in a glass protective case, and simulation of drawing with tools that Langweil actually used and are now unavailable for everyday use, as well as Langweil's process of working on the model.
- Construction of the paper house model - approximation of work with Langweil model resembling same technological procedure with real material.
- Budget simulation - demonstration of everyday life by planning the weekly consumption of Langweil's large family.
- Housing in the 19th century - a discussion about living in the centre of Prague at the time, based on historical photographs.

The components were set up in the educational programme,

which is described in section 2. Fulfilment of the goals was evaluated using a qualitative pilot study with 2 student groups, as described in section 5. The main research questions evaluated in the pilot study were:

- RQ1 - Which activities of the educational programme will impact the students most - VR, paper model or other activities?
- RQ2 - What are the issues of the educational programme that needs to be changed before final deployment?

2. Description of education programme with VR

2.1. Objectives of the programme and target user group

There are several skills for students to develop in this education programme. From a cognitive point of view, students learn the basic facts related to Prague in the first half of the 19th century. They also put the personality of A. Langweil and his model in the contemporary context. On the personal-social level, they formulate their opinions in a group, present and argue in front of a larger group of classmates and, at the end of the programme, articulate the differences between working in real and virtual environments. In the affective area, through VR and working on a real model, students have the opportunity to better empathize with the personality of A. Langweil, to take their own stance on his work and art through their own experience, and hopefully to move up the personal value ladder.

The methods used in the programme include detailed observation, description of a collection object, presentation of own hypotheses, guided discussion, and practical activities related to the creation of a real model according to a model or a photograph (drawing, cutting, glueing, modelling), creative work (creation of a facade in VR), role-playing on different levels.

The education programme is targeted to two age groups of students - 11-15 years and 15-20 years, i.e. the second stage of primary school and secondary school students in the Czech education system. When referenced to the school education curriculum, the content of the programme corresponds to the subjects History, Education for citizenship, and Civic and Social Studies (social phenomena and processes). In the system of museum education, this education programme is based on object-based learning in the museum (interpretation of the collection object) and presents and makes accessible the collections in a form adequate to the age of the students. At the same time, it fulfils the principle of hands-on learning, which has been gaining more and more supporters in recent years.

2.2. Description of individual activities

The overall scheme of the educational programme is in Fig. 2. After a short common introduction at the beginning, the programme is carried out in four groups of students (max. 5 students in each group), which circulate between four lecturers, each of whom is in charge of a different site. The group of students stays at each site for 20 – 25 minutes. After the exchange of groups at all four sites, a joint reflection with evaluation follows. The estimated duration of the whole programme is 120 minutes, including a visit to the exhibition with Langweil's model of Prague. The venue will be the main building of the Prague City Museum.

1. Building model in VR: On this site, the student's task is to create the facade of one of the selected blocks of houses from Langweil's real model in the VR application (see example in Fig. 3). Additionally, he/she explores the environment in which Langweil created the model and the tools he used. At the same time, the student's work on the facade of the model is transmitted to the screen where the other group members with the lecturer could watch and comment on it, give advice to their classmates, etc.

2. Building paper model: On this site, students are creating a real paper model based on Langweil's model. This task is slightly different for each user group. The second-grade students of the primary school work with a model which has pre-printed outlines and cut-outs (see Fig. 4). It is one of the selected four blocks of houses they have already encountered in VR. On the other hand, students from secondary school are only given such a model as an example, and they form their model from scratch.

3. Weekly family budget simulation: On this site, students have to plan the family budget for one week. They have to cover food spending and also deal with unexpected situations in Langweil's life (e.g. the youngest daughter needs new shoes, a debt in a shop has to be paid, etc.). Moreover, students should spare money which Langweil could use to create his model. The whole activity takes the form of a simple game with cards showing products and their price based on a real and documented contemporary food basket. In the end, the groups present their budgets to the lecturer and defend them.

4. Housing in the 19th century: On this site, students learn about 19th-century housing options through images and historical photographs. The students from second-grade primary school take on the roles of the inhabitants of the houses. Based on their observations of source images, they pantomime and interpret the everyday activities of the house inhabitants. Together with the lecturer, they discuss the differences between life in A. Langweil's time and today. The secondary school students take on the role of researchers

(the so-called mantle of experts) and prepare a conference presentation about the level of housing in the first half of the 19th century based on their observations of the source images.

Discussion In the end, all four groups come together in one place and in a discussion led by the lecturer, the students reflect on their work on all sites. They discuss not only the content but also the form, especially they compare the creation of a model from paper and a model in VR.

3. Related work

3.1. Museum education with VR

The use of Augmented Reality (AR), Virtual Reality (VR) or Mixed Reality (MR) in museum education has shown an increase in the last 5 years, as documented by Zhou et al. in their meta-analysis [ZCW22]. The authors found an average of 5 articles per year between 2012-2017 and an average of 10 articles per year between 2018 and 2020 dealing with studies with VR, AR or MR devices in museum education. Most of these studies (40%) focused on education for the K-12 target user group, in which we can also include our programme. The main trend of the studies was the use of AR in science museums (18 studies), history museums (12 studies), and art museums (8 studies). Most studies also aimed to provide visitors with declarative knowledge (33 studies).

An example of a blended learning concept can be found at [LLJ*21], where students are introduced to pagoda architecture sequentially through a book, hands-on creation of a 3D physical model, similar model visualizations in AR, and a quiz. Testing confirmed the benefits of this approach over traditional print and video formats.

In our approach, we focused on a fully VR environment that should provide not only declarative knowledge but also procedural-practical knowledge, i.e. to try working in a historical context and in an environment simulating a certain historical period, which promotes imagination and inclusion in the context of the historical period. In terms of evaluating the benefits of AR, VR or MR for museum education, Zhou et al. [ZCW22] evaluated the benefits of

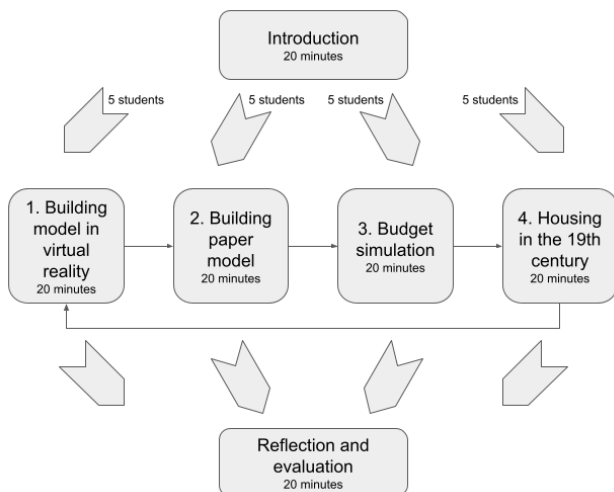


Figure 2: Scheme of the educational programme with Langweil's model of Prague.



Figure 3: A virtual model of a house from Langweil's model of Prague and a facade drawn in the VR application.



Figure 4: Paper model of a house from Langweil's model of Prague.

these technologies as significantly positive in the case of academic achievements, such as learning mathematics through AR exhibitions. In terms of perception, the results of the studies were rated as moderately effective. Surprisingly, only 1 study out of the 17 analysed compared the impact of VR and non-VR learning. Such a comparison is possible in our educational programme.

3.2. VR drawing apps

The main requirements for our application are the creation of an immersive environment where users are taken back to the era of Langweil's model and where they can work with the original tools in as realistic a way as possible. Important aspects in our case are the means for drawing contour lines with a nib pen, colouring with a brush and coloured inks and cutting the paper to the desired shape.

The currently available VR drawing apps can be divided into two groups. The first group are 3D drawing programmes, where the user creates spatial artwork using VR controllers. In this case, this is not the kind of work we are looking for, but we will nevertheless list the important representatives here. Examples include Google's Tilt Brush [Goo17], CoolPainterVR [Wil18] for PlaystationVR, Gravity Sketch [Gra23], SurfaceBrush; facilitating 3D VR freehand drawing for 3D printing [RRS19], SteamVR Home; the main hub for SteamVR [Val22] and even A-Painter [MOZ], an in-browser VR painting applet. We must also not forget to mention hardware solutions for VR drawing such as VR pens from Wacom [Wac23] and Logitech [log23]. The former uses a proprietary tracking system, while the latter uses the lighthouse SteamVR system.

In the second group are VR applications that resemble drawing on paper or another 3D object. Applications in this category suffer heavily from the lack of proper haptic feedback, as the virtual surface the user is supposed to be painting on often does not correspond to a physical one. The same applies to the painting tool since VR controllers are not designed to function as one. Although difficult, overcoming these complications is not impossible through clever engineering. Examples for this category are Vermil-

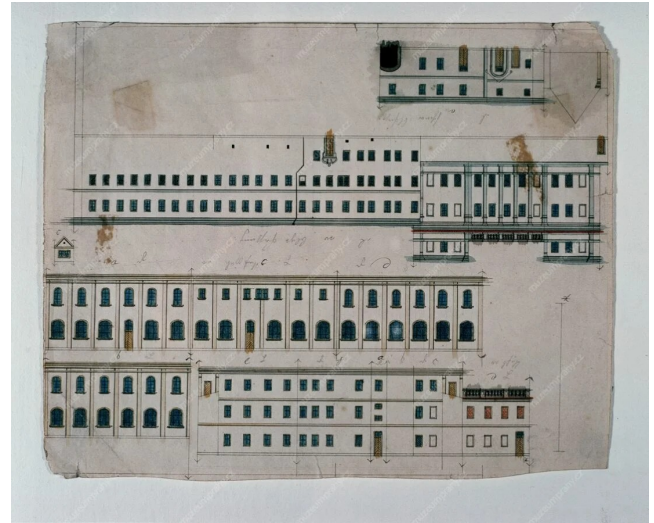


Figure 5: One of the three preserved sheets with drawn facades of the unfinished part of the model. We see auxiliary lines drawn with a pencil and black contours of individual parts of the facade drawn with a nib pen and coloured by a brush. Image source [Pra23].

lion VR [The21], a VR oil painting simulator, a VR painting sandbox PaintingVR [Ois22] and a small, yet very well-made part of Half-Life: Alyx [Val20]. In the AR domain, we can mention the work of [UFA22], who present virtual drawings on 3D-printed eggs (instead of virtual ones).

In the literature, we can name articles that use existing applications and form research questions about them, as well as papers describing VR software itself, where the user is usually placed in an environment that stimulates a specific situation. In the HandLeVR project [ZSW*20], the user is placed in a virtual car body paint shop and, through action-oriented learning, is asked to experience painting a car body. A more painting-like project is "Paint with me" [Ger17], which describes a two-user system where one is a painting teacher - he paints with real paints on a canvas, and this is captured by a stereo camera placed on his head. The second user is embodied in the tutor position using VR and can repeat the movements of the tutor, which are transmitted to him from the stereo camera. A study seeking to increase the interest of students of digital media design in 3D animation through VR experimentation with Google Tilt Brush was published in [HST19].

4. VR application description

We introduced existing VR applications that can realize our goal to some extent in section 3.2. Unfortunately, none of them fully allows the creation of our own environment or the implementation of our own working techniques for which we have specific requirements. Therefore, we decided to implement our own solution in the Unity game engine using the SteamVR library for the VR interface. In the following sections, we briefly describe the design and implementation of the VR application Langweil's Workshop, including two different implementations of interaction techniques.

The VR application is a specialized application that simulates work in Langweil's workshop. In the application, a specific task is prepared, the creation of one facade of a house, just like Langweil did, see Fig. 5. This task is described in a book within the app (see Fig. 6), so the user does not have to switch between the VR environment and the real world.

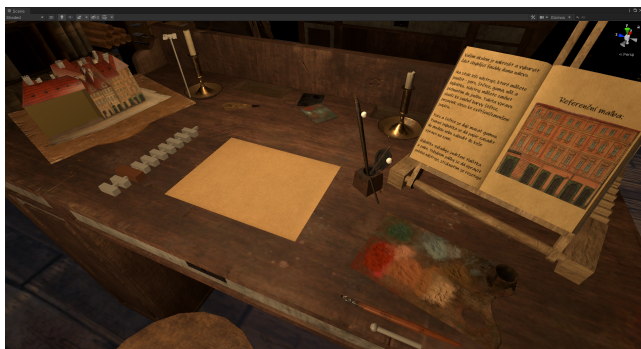


Figure 6: VR app environment. On the left is a model of a house that lacks a facade. In the centre is a piece of paper to draw the facade. On the right are the instructions for the task.

The VR app is set in the era of Langweil's workshop. This corresponds to the overall space of the workshop, i.e., the type of table and the tools used. The user has two types of brush and a colour palette for drawing with colour, a nib pen for drawing contours with black ink, a tool for erasing, and a tool for cutting, see Fig. 7. These two tools do not fully correspond to the period characteristic, as the user-friendliness of the originally intended tool (scraping knife) was low and would have unnecessarily spoiled the user experience. It would also be difficult to distinguish the erasing knife from the cutting knife. The last part of the environment is part of Langweil's model with the missing wall, see Fig. 6.



Figure 7: Tools available in the VR app. From left to right: nib pen, thick and thin brush, cutting knife, move and glue tool, eraser.

We have created 2 variants of application control. The first variant of the application (Fig. 8) allows free grabbing of drawing tools (referred to in the following text as Version 1). Once grabbed, the tool is bound to the position of the controller, so drawing was dependent on the position of the tool and controller at the moment of grabbing.



Figure 8: Drawing using 1st variant, where drawing occurs when the virtual pen touches the virtual paper in the scene. The participant holds the controller in the air and draws with the virtual pen without haptic feedback.

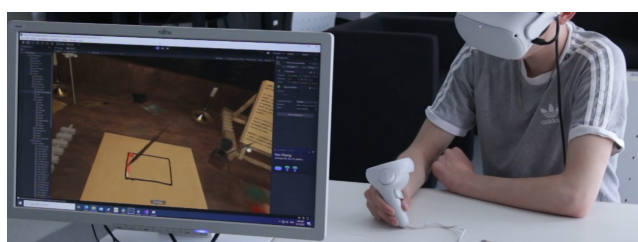


Figure 9: Drawing using the 2nd variant, where drawing occurs as the controller moves across the table. The participant holds the controller like a pen, naturally leaning on the table, which provides sufficient support and haptic feedback.

The second variant uses the table as an object both in the real world and in the virtual world, the so-called passive haptic feedback (see Fig. 9). In this variant (referred to as Version 2), the position of the tool is absolute with respect to the position of the controller, where the drawing tools pass through the longitudinal axis of the controller. The user is assumed to hold the VR controller in their hand like a pen - drawing with the lower end of the controller. This end slightly touches the table, and near the point of this contact, the drawing mode of the tool is activated. Switching between tools is done by touching the tools lying on the table; there is no need to press buttons on the controller.

5. Pilot study - evaluation of the education programme

In the pilot study, we evaluated the entire educational programme in the context of the research questions introduced in subsection 1.2. The aim was to evaluate students' reactions to the use of VR, compare the results with the creation of a paper model and observe feedback on the programme as a whole.

The study was conducted with two participant groups. The first group (Group P) consisted of 19 students (participants P1-P19) from the 5th and 6th grades of primary school, divided into 4 groups. The second group (Group S) consisted of 12 students (participants S1-S12) in the first year of a four-year secondary school, divided into 4 groups.

In the pilot study, the educational programme was run according to the overall scheme - see Fig. 2. In order to evaluate results, three methods were used:

- Questionnaire was used to collect previous experience of participants with VR and paper modelling and also feedback from the same tasks in the study.
- Observation was used to evaluate individual tasks at each site.
- Discussion was used to evaluate gained knowledge and gather feedback.

VR application evaluation procedure

The VR application was evaluated by 16 participants, 8 from Group P (P1-P8) and 8 from Group S (S1-S8). The remaining participants in the group were observers only. Most of the participants (15) were right-handed, and 1 was left-handed. The participants were divided into two subgroups according to which variant of the VR application control they were using, either variant 1 (P1-P4, S1-S4) or variant 2 (P5-P8, S5-S8).

The actual work in the VR application corresponded to the time designated for this task in the educational programme, which was 20 minutes. During this time, the participants had approximately 8 minutes to put on the VR headset, orient themselves in the scene, and try out the tools. For the next 10 minutes, participants drew the facade of the house and then had 2 minutes to cut out the facade and fit it to the rest of the model house.

At the end of the task, participants completed a questionnaire.

Paper models evaluation procedure

This task was evaluated by all the students in both Groups P and S. While the participants from Group P worked with a pre-prepared model of a house from Langweil's model of Prague, participants from Group S had to draw, colour, cut and glue their own 3D model of a house based on Langweil's model.

Similarly to the VR application, the participants had to get acquainted with the model and model building technique. Then they drew, coloured, cut and glued the model.

6. Pilot study results

6.1. Previous experience of participants

Prior to this study, 9 participants had never used a VR headset. The other participants reported using VR headsets very occasionally, at most a few times a year, using either standard controllers (4), dedicated controllers (1) or hands-free (2). Thus, we can label all participants as beginners in using a VR headset. Only one participant stated that he/she had experienced physical difficulties in the past when using a VR headset.

In terms of drawing and graphics design, 6 participants reported that they draw frequently (at least once a month), 6 participants reported that they draw occasionally, and 4 reported that they do not draw at all. When asked if they had ever created a paper model, 1 participant said he/she creates paper models often, 7 participants said that they had created models several times, and 8 never created any paper model. For drawing, participants used common graphics editors and a mouse (4). Two participants mentioned drawing on a tablet without a pen and one with a pen. The participants' responses do not show a link between creating models and drawing. In general, participants had more experience with drawing and creating paper models than with using a VR headset.

6.2. Results of participants' work with VR application

All participants managed to draw at least a basic structure of the facade, see Figs 10–13 (the images are taken from a video recorded during the study). From the results, it can be observed that Version 2 allowed participants to draw richer and more elaborate facades than Version 1. It was also evident from the video recordings that drawing and colouring in Version 2 required less effort than the same work in Version 1. Therefore, only Version 2 will be used for the final deployment of the educational programme.

The overall evaluation of the VR application by the participants based on the questionnaire was positive (8), and neutral (7) but also negative (1). The participants liked both the workshop environment and the work with the individual tools. Participants made the most negative comments about the cutting tool, which still needs to be improved. Among other things that could be improved or added to the application, participants also mentioned the paper handling (lifting, enlarging) or the richness of the colour palette. When assessing the similarity between drawing in VR and creating paper models, participants were unable to decide. Physically, most participants felt comfortable. Only 2 participants reported having mild dizziness or a headache.

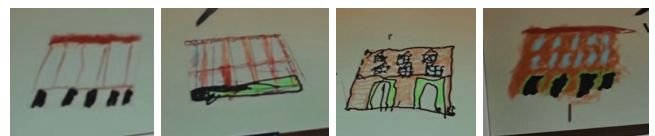


Figure 10: Facade created using VR application Version 1 - primary school students P1-P4.

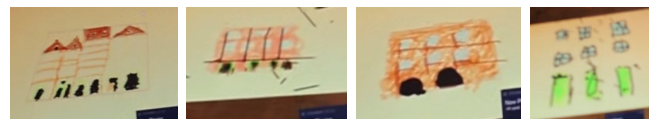


Figure 11: Facade created using VR application Version 1 - secondary school students S1-S4.



Figure 12: Facade created using VR application Version 2 - primary school students P5-P8.

6.3. Results of participants' work with paper models

Participants from Group P first coloured the house with crayons. Some of them (mostly girls) coloured with great enthusiasm, but the desire for the most beautifully coloured and shaded house (see examples of models in Fig. 14) led to the fact that they spent most of their time on this activity and then had little time for cutting and gluing. Some participants needed advice on which edges to bend



Figure 13: Facade created using VR application Version 2 - secondary school students S5-S8. The first facade from the left is placed together with the model in Fig. 3.

and which areas to glue, while some participants used a triangle or ruler to bend the edges by themselves. Not everyone was able to meet the 20 minute time limit, but most did. It was clear that participants had fun during the activity. They were delighted with their houses, which they were happy to take home.

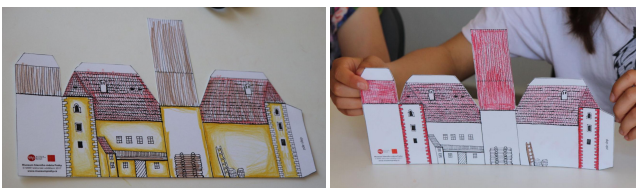


Figure 14: Example of paper models of participants from Group P (primary school students)

The reaction of many participants from Group S at the beginning of the activity was that "they cannot make it"! Then they started the activity with great enthusiasm. Most of them created traditionally shaped models, but one participant decided to create a cylindrical rotunda house (see Fig. 15). Some participants tried to make the dimensions of the house as close to Langweil's model as possible, creating really tiny models. Apart from the rotunda, none of the participants attempted to create a model with more sophisticated shapes, like a gabled roof, etc. Not all of the participants managed to meet the time limit of 20 minutes, but most of them did. The participants from Group S also worked with great enthusiasm and definitely enjoyed their work. However, they were not so keen to take their paper models home with them.

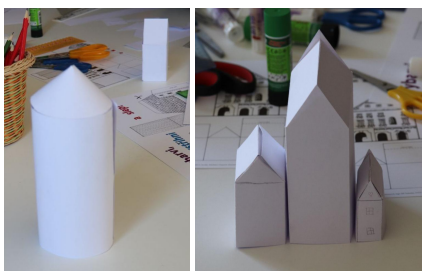


Figure 15: Example of paper models of participants from Group S (secondary school students)

6.4. Post-test discussion of the educational programme

After the end of the education programme, lecturers from the Prague City Museum conducted a final discussion of the education

programme with both participant groups. The main purpose was to evaluate which activities impacted the participants most (RQ1). The participants' answers were recorded, then transcribed and summarized for the purpose of this article.

The participants from Group P were clearly interested in VR and working within this so much, that they kept referring to VR throughout the final discussion. The girls, in particular, were also interested in making a simplified paper model. The other two activities were surpassed by the experiences of the first two modelling activities. One student also recalled a 19th-century consumer basket.

The opinions of the participants from Group S were more diverse. They were not limited to virtual reality but also recalled the construction of a paper model, a consumer basket from the first half of the 19th century, and when they formulated what they were taking away in their minds, it was most often the information they became aware of during the activity dealing with housing in the first half of the 19th century, which some initially said they were not interested in.

6.5. Observed issues and improvements from the educational programme evaluation

From the participants' first reaction, we see that the pilot study was successful and its objectives were met. However, we nevertheless identified several issues and possible improvements that should be considered, before the final educational programme will be deployed (RQ2):

- In the VR application, cutting and paper manipulation should be improved.
- There are strict time constraints which are important to follow. There should be proper time warnings for students to progress, especially during the modelling activities.
- During the modelling activities, participants asked follow-up questions, e.g. about chimney shapes, piles of wood, house extensions, etc. This is both a great opportunity and also a responsibility for the lecturer to answer questions correctly.
- Participants asked not only about the history, but they asked about technical issues, e.g. how to bend a paper and which sides to glue. Some kind of training for lecturers may be also beneficial.
- Paper models may be simplified or improved to be easier for participants to build. Also, best practices should be provided to lecturers, e.g. to start with model cutting and continue with drawing to meet the activity time limit.

7. Conclusions

Our work aimed to prepare a museum educational programme, where students get acquainted with Langweil's model of Prague in the context of the author's life. The programme targets second-grade primary school students and secondary school students. It allows them to compare the two ways of working on a paper model, both in an attractive virtual reality environment as well as in a real-life environment with real materials and tools. The secondary goal of the educational programme was to place the work with Langweil's model in a contemporary context and to provide students

with a more accurate impression of everyday life in Prague during the first half of the 19th century. This goal was fulfilled by additional activities of the educational programme, namely the budget simulation and the housing in the 19th century.

To meet the educators' requirements, we created a new VR application called Langweil's Workshop. The application targets the requirements for the plausibility of the VR environment, the suitability and functionality of the chosen tools for simulating tools from the 19th century and the similarity of working with them, to the actual use of these tools.

Validation of the educational programme was done in a pilot study. First of all, the results answered the research question RQ2 that the programme can be deployed for general public use after minor issues and improvements are resolved. Next, the result also answered research question RQ1, which differs between the two target user groups. For participants from Group P (second-grade primary school students), the VR application was the most interesting activity. On the other hand, participants from Group S (secondary school students) had more diverse opinions and they recalled all of the activities from the educational programme.

8. Acknowledgement

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References

- [ĐA20] ĐURKOVIĆ Đ., ALEKSIĆ V.: The secondary school student's interest in virtual reality. In *International Scientific Conference Technics and Informatics in Education* (09 2020), pp. 255–260. 1
- [BOPG19] BETTELLI A., ORSO V., PLUCHINO P., GAMBERINI L.: An enriched visit to the botanical garden: Co-designing tools and contents. In *Proceedings of the 13th Biannual Conference of the Italian SIGCHI Chapter: Designing the next Interaction* (New York, NY, USA, 2019), CHIItaly '19, Association for Computing Machinery. URL: <https://doi.org/10.1145/3351995.3352034>, doi: 10.1145/3351995.3352034. 1
- [Ger17] GERRY L. J.: Paint with me: stimulating creativity and empathy while painting with a painter in virtual reality. *IEEE transactions on visualization and computer graphics* 23, 4 (2017), 1418–1426. doi: 10.1109/TVCG.2017.2657239. 4
- [Goo17] GOOGLE: Tilt Brush. <https://www.tiltbrush.com/>, 2017. (Accessed on 11/02/2023). 4
- [Gra23] GRAVITY SKETCH: Gravity Sketch. <https://www.gravitysketch.com/>, 2019–2023. (Accessed on 11/02/2023). 4
- [Hei06] HEIN G. E.: *Museum Education*. John Wiley & Sons, Ltd, 2006, ch. 20, pp. 340–352. doi:<https://doi.org/10.1002/9780470996836.ch20>. 1
- [HST19] HO L.-H., SUN H., TSAI T.-H.: Research on 3d painting in virtual reality to improve students' motivation of 3d animation learning. *Sustainability* 11, 6 (2019), 1605. doi:10.3390/su11061605. 4
- [LLJ*21] LEE J., LEE H.-K., JEONG D., LEE J., KIM T., LEE J.: Developing museum education content: Ar blended learning. *International Journal of Art & Design Education* 40, 3 (2021), 473–491. doi:<https://doi.org/10.1111/jade.12352>. 3
- [log23] LOGITECH: VR Ink Pilot Edition. <https://www.logitech.com/en-eu/promo/vr-ink.html>, 2023. (Accessed on 11/02/2023). 4
- [MOZ] MOZVR: A-Painter. <https://aframe.io/a-painter/>. (Accessed on 11/02/2023). 4
- [Ois22] OISO: PaintingVR. <https://www.paintingvr.xyz/>, 2022. (Accessed on 11/02/2023). 4
- [Pra23] PRAGUE CITY MUSEUM: Langweilův model Prahy. <https://www.langweil.cz/>, 2023. (Accessed on 06/02/2023, in czech). 2, 4
- [RRS19] ROSALES E., RODRIGUEZ J., SHEFFER A.: Surfacebrush: From virtual reality drawings to manifold surfaces. *ACM Trans. Graph.* 38, 4 (jul 2019). URL: <https://doi.org/10.1145/3306346.3322970>, doi:10.1145/3306346.3322970. 4
- [SBZ13] SEDLACEK D., BURIANEK J., ZARA J.: 3D Reconstruction Data Set - The Langweil Model of Prague. *International Journal of Heritage in the Digital Era* 2, 2 (2013), 195–220. doi:10.1260/2047-4970.2.2.195. 2
- [SM12] SEIXAS P., MORTON T.: *The Big Six Historical Thinking Concepts*. Nelson, Toronto, 2012. 1
- [SSL20] SHEHADE M., STYLIANOU-LAMBERT T.: Virtual reality in museums: Exploring the experiences of museum professionals. *Applied Sciences* 10, 11 (2020). doi:10.3390/app10114031. 1
- [The21] THE AVIARY: Vermillion VR. <https://vermillion-vr.com/>, 2021. (Accessed on 11/02/2023). 4
- [UFA22] URECHE A.-M.-C., FRYAZINOV O., ANDERSON E. F.: Traditional Romanian Egg Decoration in Augmented Reality with 3D Printing. In *Eurographics Workshop on Graphics and Cultural Heritage* (2022), Ponchio F., Pintus R., (Eds.), The Eurographics Association. doi:10.2312/gch.20221222. 4
- [Val20] VALVE: Half-Life: Alyx. <https://www.half-life.com/alyx/>, 2020. (Accessed on 11/02/2023). 4
- [Val22] VALVE DEVELOPER COMMUNITY: SteamVR Home. https://developer.valvesoftware.com/wiki/SteamVR_Home, 2022. (Accessed on 11/02/2023). 4
- [Wac23] WACOM: Wacom VR Pen. <https://developer.wacom.com/en-us/wacomvrpen>, 2020–2023. (Accessed on 11/02/2023). 4
- [Wil18] WILDBIT STUDIOS & SINGULAR PEOPLE: CoolPainter VR. <https://coolpaintrvr.com/>, 2018. (Accessed on 11/02/2023). 4
- [ZCW22] ZHOU Y., CHEN J., WANG M.: A meta-analytic review on incorporating virtual and augmented reality in museum learning. *Educational Research Review* 36 (2022), 100454. doi:10.1016/j.edurev.2022.100454. 1, 3
- [ZSW*20] ZENDER R., SANDER P., WEISE M., MULDER M., LUCKE U., KERRES M.: Handlevr: Action-oriented learning in a vr painting simulator. In *Emerging Technologies for Education: 4th International Symposium, SETE 2019, Held in Conjunction with ICWL 2019, Magdeburg, Germany, September 23–25, 2019, Revised Selected Papers 4* (2020), Springer, pp. 46–51. doi:10.1007/978-3-030-38778-5_6. 4
- [Šo12] ŠOBÁŇOVÁ P.: *Muzejní edukace [Museum Education]*. PhD thesis, Palacký University Olomouc, 2012. in Czech. 1