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Abstract

Immersive virtual reality (IVR) offers possibilities of creating a learner-centric environment that can provide more presence and engagement for students leading to an enhanced learning experience compared to conventional classroom practices. However, the potential of IVR in vocational education and training (VET) has not yet been explored in-depth, and it is an open question of whether it can effectively support learner creation in a designing task. In this paper, we present an IVR application developed to support gardener apprentices in designing gardens. Using this application, we conducted an experimental study with gardener apprentices to investigate the effect of the IVR interface compared to paper sketching and learner behavior on the proportion, composition, and creativity of the design outcome. Additionally, we investigated how it can be combined with a paper sketching activity to improve its effectiveness. Our analysis shows that the IVR interface can be more effective for the proportion aspect, but this may be limited to students that are able to use it after working with paper. In terms of the combination order, the effectiveness of IVR on the design quality was improved when it was done after the paper sketching and this ordering produced a more effective outcome for the proportion and composition aspects. Finally, our results show that IVR design quality is related to learner behaviors such as the time spent on designing and the number of simulations used. This study demonstrates the effectiveness of IVR applications in supporting designing skills and how effectiveness can be improved by combining it with a conventional method of practice.

Introduction

Virtual reality (VR) technology has become popular in recent years and its effectiveness has been demonstrated in various educational settings (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014). The main advantage of VR is that it encourages students to be active learners and promotes decision-taking by permitting autonomous exploration and learning by doing (Martín-Gutiérrez, Mora, Añorbe-Díaz, & González-Marrero, 2017). VR technologies are capable of promoting a full student-centered learning experience given that students are the main performers when experimenting and practicing with virtual objects (Winn, 2002). Previous studies show the positive effect of VR in terms

Practitioner Notes

What is already known about this topic

- The effectiveness of IVR has been reported in a variety of educational settings.
- IVR enhances learning through situated experience, multiple perspectives, and simulations that transfer to the real world.
- Most IVR applications for VET have focused on passive learning or basic procedural skills.

What this paper adds

- Design and implementation of an IVR application in VET to support design-related learning.
- The use of IVR may have a significant impact on the quality of design outcomes.
- The use of IVR after paper sketching may increase the quality of designs during IVR use.

Implications for practice and/or policy

- IVR can enhance the design outcome in terms of the proportion aspect, but this may be limited to students that are able to use it after working with paper.
- The design quality can be affected by the combination order between IVR and paper sketching where the effectiveness of IVR can be improved when it is done after paper sketching.
- The behavior of learners using IVR can be used as indicators of the design quality.

of academic performance (Alhalabi, 2016; Merchant et al., 2014), spatial skills (Gutierrez, Dominguez, & Gonzalez, 2015; Lee & Wong, 2014), social skills (Valmaggia, Latif, Kempton, & Rus-Calafell, 2016), motivation (Harris & Reid, 2005), and engagement level (Dede, 2009; Martín-Gutiérrez et al., 2017).

However, while many studies show the effectiveness of VR technologies across learning contexts and domains, the potential of VR for vocational education and training (VET) has not yet been explored in-depth. VET can provide a unique opportunity for learning through situated experiences. In VET, many learners may do an apprenticeship in companies and learning is often embedded in their workplace. For example, a florist should design a bouquet based on a specific request of a customer, or a carpenter should be aware of the safety information in a particular construction site. VR can offer possibilities of creating these situations for the learners in a safe, exploratory practice space (Le, Pedro, & Park, 2015). Particularly, immersive VR (IVR), compared to the conventional monitor-based low-immersion VR, can enhance learning through situated experience with greater immersion, learning through multiple perspectives, and transfer through simulations of the real world (Dede, 2009).

This work contributes to the use of IVR to support design-related learning, particularly in the context of VET. In this paper, we present an IVR application for VET, specifically gardener apprentices, and validate its effectiveness for supporting designing skills. Through an experimental study, we investigate the effectiveness of IVR compared to current paper-based practices and how they may be effectively combined to support design outcomes. We are interested in the comparison between IVR and paper since we believe that both interfaces have their own specific affordances that learners can benefit from. We also investigate the combination of the two in order to verify if the strengths may be complementary depending on how they are combined.

Related work

VR can provide learners with the opportunity to experience situations that cannot be accessed due to factors such as time problems (the inability to speed up/slow down or go back in time), physical inaccessibility (places or situations that one cannot be in), dangerous situations, or ethical problems

(Freina & Ott, 2015). In VET, this opportunity to experience inaccessible situations can be particularly effective for supporting learning. For example, VR can simulate dangerous tasks to support learning of construction safety (Le et al., 2015) or in the architecture-engineering-construction sector (Rahimian, Arciszewski, & Goulding, 2014). For corrosion prevention and control, Webster (2014) found IVR to be more effective for learning gains compared to traditional lecture-based learning. As these examples illustrate, VR technologies are capable of allowing VET learners explore the situations that are difficult to directly observe and experience in the physical world (Olympiou & Zacharia, 2012; Pyatt & Sims, 2012).

Particularly for designing skills, IVR has had positive effects. Researchers have demonstrated the effectiveness of immersive environments for designing airport interiors (Kefalidou, D'Cruz, Castro, & Marcelino, 2019), creative form-making in visual art (Keefe, 2009), designing DNA molecules (Schkolne, Ishii, & Schroder, 2004), and evaluating machinery designs (Aromaa & Väänänen, 2016). In these studies, the purpose of IVR was often the assessment of a design prototype or communication with customers. On the other hand, Rieuf et al. (2017) investigated the effect of IVR on the quality of design outcomes and found that the use of IVR for early-stage product design is effective for aesthetics and originality of the final design. However, their experiment was designed for experienced designers and the analysis focuses on the emotional influence of the IVR activity on the design outcome. It is still an open question of how IVR can support the design skills of novices as measured by the quality of the design outcome, which is the focus of our study.

This further investigation is particularly needed as there is conflicting evidence across domains as to the effectiveness of IVR. Previous research has shown IVR to positively influence motivation and attitudes towards learning (Lau & Lee, 2015; Makransky, Borre-Gude, & Mayer, 2019; Parong & Mayer, 2018). On the other hand, IVR has been reported to have negative effects on cognitive load (Makransky, Terkildsen, & Mayer, 2019). In terms of learning, IVR introduces possibilities for unique representations of situations that are not available in conventional methods currently used in classrooms, such as the standard of paper-based practice. IVR provides learners with the ability to change their perspective and frame of reference, which is a powerful means of understanding complex phenomenon or structures (Dede, 2009) and can improve learners' spatial understanding (Gutierrez et al., 2015; Lee & Wong, 2014).

Additionally, IVR supports the running of realistic simulations, which have shown to be as effective as physical ones (Klahr, Triona, & Williams, 2007; Zacharia & Constantinou, 2008). VR provides learners with the opportunity to manipulate factors that cannot be changed in real-life, such as the passage of time (Freina & Ott, 2015; Makransky, Terkildsen, et al., 2019; Parong & Mayer, 2018). In designing tasks in particular, these affordances may allow learners to focus on the spatial aspects of the design and how they may change over time (Gutierrez et al., 2015; Keefe, 2009; Lee & Wong, 2014) providing a strong case for the use of IVR in garden designs. On the other hand, paper sketches are a familiar medium to students, which can lower the extraneous cognitive load of students working with the material (Van Merrienboer & Ayres, 2005). With a lower cognitive load, learners have more opportunities to develop knowledge towards the learning outcomes (Makransky, Terkildsen, et al., 2019). These differences between IVR and paper interfaces may influence the effectiveness of the activity depending on how the affordances align with the goals of the task.

Moreover, these differences may provide complementary benefits depending on how the representations are combined (Ainsworth, 2006; De Vries, 2006). Combinations of VR with physical practice can be more effective than either one of them alone (De Jong, Linn, & Zacharia, 2013; Jaakkola, Nurmi, & Veermans, 2011; Kollöffel & de Jong, 2013). VR and physical practice each provide different representations that when combined can more effectively support learning (Ainsworth, 1999). Moreover, *how* the representations are combined, i.e., the order in which the learners interact with them, may influence learning (Ainsworth, 2006). In this case, it is not just a question of if a combination is more effective, but what order is most effective.

Research questions and hypotheses

For this study, we investigated how IVR can support the designing skills of VET learners. Specifically, we chose to work with gardeners as their work involves designing physical spaces, which aligns well with the affordances of IVR. We were interested in measuring the quality of the apprentices' designs using an IVR application compared to their current way of practicing designing, a paper sketch, and how the quality is affected by a different order in the combination of the two modalities. For this investigation, we formulated our research questions as follows:

- (RQ1) Can an IVR interface support designing skills compared to a paper interface and in which ways does it differ in terms of the quality of design outcome?
- (RQ2) In what ways do learners improve their designs with a chance to iterate and does the order in which they interact with the IVR compared to the paper sketching impact their design quality?
- (RQ3) What are the behavior features from IVR that are correlated to the design outcome?

The first question investigates the feasibility of using IVR to support designing skills by comparing it to the conventional way of practice. We hypothesized that the IVR interface can better support the designing skills compared to the paper interface and improve the quality of the design outcome in terms of proportion, composition and creativity (H1). These criteria have been chosen with gardening teachers while considering the affordances of IVR in the domain and this hypothesis is based on the positive effects of VR on spatial skills and creative designs (Gutierrez et al., 2015; Keefe, 2009; Lee & Wong, 2014). The second question investigates how to combine IVR with conventional practice in order to maximize its benefit. We hypothesized that the quality of design would improve in the second activity compared to the first (H2a) and that learners would have a better design quality in IVR if it was done after the paper sketching (H2b). These hypotheses are based on the positive findings of Rieuf et al. (2017) on the effect of IVR in the design process. Finally, the third question is on the investigation of the learner's behavior while using the application. We hypothesized that the design quality is positively correlated to the time spent on designing, the number of objects placed in the design and the number of simulations run (H3).

GardenVR: Garden designing and exploration using IVR

Design

The IVR application used in this study, GardenVR, supports learners in practicing and developing designing skills through designing a garden and exploring it in an immersive environment. The workflow of GardenVR is shown in Figure 1. In order to maximize the benefit of IVR in a garden designing context, we developed GardenVR based on the following three concepts: (i) multiple perspectives, (ii) constructivism, and (iii) going beyond physical limits.

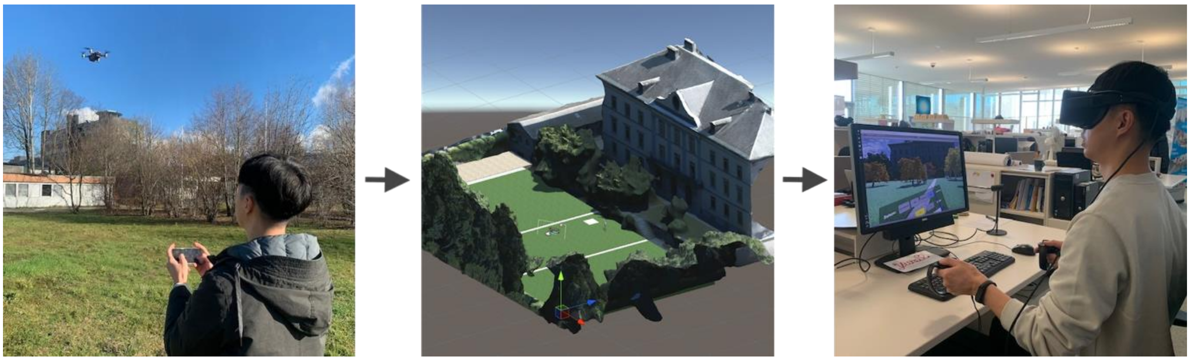

Figure 1: Workflow of GardenVR. Taking pictures of a garden with a drone (left), 3D reconstruction of the space (center), and designing activity in IVR (right)

Multiple perspectives: The benefit of having multiple perspectives in a creative task has been well reported in the literature (Anderson & Helstrup, 1993; De Bono, 1985) and the ability to change one's perspective in IVR is a powerful means of understanding complex phenomenon or structures (Dede, 2009). This is usually done by allowing shifting between exocentric and egocentric views. In GardenVR, we provide two modes for learners that they can switch between. The two modes, Design and Explore, are shown in Figure 2. The Design mode provides an exocentric view where the learners are given the top view of the garden and they can place objects such as trees in the garden. The top-view exocentric perspective for designing is inspired by how gardeners work with 2D top-view drawings on paper or in CAD software to represent a garden. On the other hand, the Explore mode provides an egocentric view where the learners are inside the garden that they designed. They can explore the garden by walking through it in a 360-degree 3D environment. By switching between the two modes, the learners can experience different perspectives on the design.

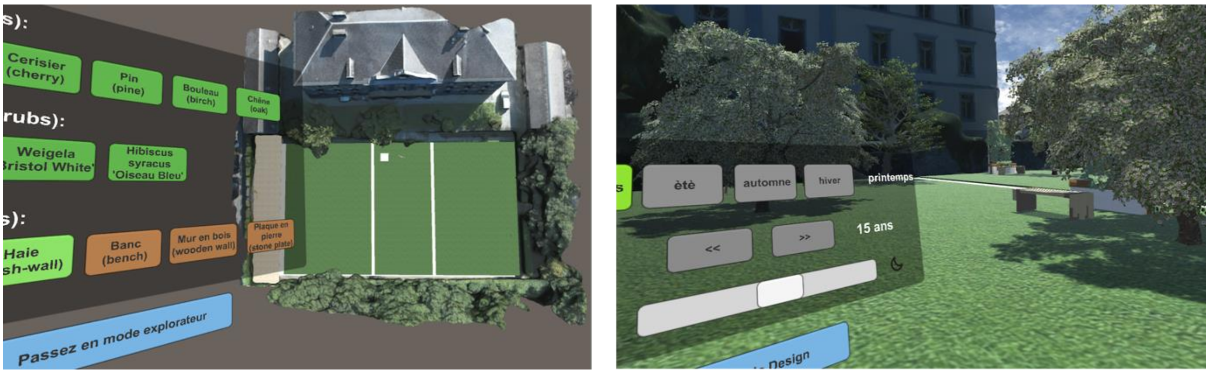

Figure 2: Design mode with an exocentric view (left) and Explore mode with egocentric view (right)

Constructivism: VR technologies encourage students to be active learners by promoting decision-taking, permitting autonomous exploration, creating new experiences, and learning by doing (Martín-Gutiérrez et al., 2017), thus aligning with the constructivist approach (Winn, 2002). In GardenVR, learners are given a practical task of designing a garden where they are the main performers of the task. They create a garden and experience it themselves, which is very similar to their real-world work. However, an advantage of the virtual environment is that learners can easily undo an action allowing them to practice trial and error as the main performer. They can try an action (such as the planting of a tree), observe the consequence, and undo the action. For a profession like gardeners, it is not feasible to take this approach for training in the real world, if not impossible.

Going beyond physical limits: One of the motivations for the use of VR is the opportunity to experiment with those situations that cannot be accessed physically. For GardenVR, we focus on the time dimension. One of the skills that gardener apprentices need to acquire is the ability to consider the evolution of the garden over time. In garden design, there are three important time scales: daily changes of the Sun's position and the shadows, seasonal changes of plants, and the growth of trees in years. GardenVR provides the functions of daily, seasonal, and yearly changes of the gardens. Learners can fast-forward the time to visualize the evolution of the garden supporting the advantage of VR-based simulations to reduce the time demand for experiments (Makransky, Terkildsen, et al., 2019).

Interface and implementation

The interface of GardenVR is designed for a head-mounted display with two controllers for both hands. Using the right-hand controller, one can point at an object and interact with it. On the left-hand controller, a menu is attached that shows the available functions. In the Design mode, the menu shows the objects that can be placed in the garden, and in the Explore mode, it shows the options to explore the designed garden including changing seasons and growing trees. In the Explore mode, one can also move around in the garden using the thumb stick on the left-hand controller. The GardenVR application was developed for Oculus Rift[1] using the Unity environment[2]. The 3D models of the trees are created using SpeedTree[3].

Methods

Research design

In order to test our hypotheses, we conducted an experiment with a 2×2 mixed-subjects design where the interface (paper or IVR) was the within-subjects factor and the order of the interfaces was the between-subjects factor. The participants were assigned randomly to either paper-first condition or IVR-first condition. The task given to them was to design a garden room in their school garden. The participants were asked to do the task using the two interfaces and the order was based on the conditions in which they were assigned.

Participants

We conducted the experiment with 30 gardener apprentices from two schools in the dual-track VET system in Switzerland. Considering the relevance of the task to the curriculum, we only recruited students who are specializing in landscaping, but not in plant production. We also limited our sample to the second-year students in the three-year curriculum for the homogeneity of the population. Our sample accounts for around 10% of the total target population (Swiss federal Statistical Office, 2020), which were the schools that agreed to participate in the study.

The participants were aged between 16 and 30 (M = 20.2, SD = 4.16) and 26 of them were male. The unbalanced gender ratio comes from the nature of the profession. They have learned the design rules for gardening for two semesters, but have limited experience in designing gardens themselves. Among the 30 participants, we randomly assigned 14 to the paper-first condition and 16 to the IVR-first. There was no significant difference between conditions with respect to age range, $F(1,28) = 0.980$, $p = .33$. All participants were made aware of their rights before participating in the study and consent was collected in accordance with the Human Research Ethics Committee of EPFL.

[1] Oculus Rift: https://www.oculus.com
[2] Unity: https://unity.com
[3] SpeedTree: https://speedtree.com

Experimental procedure

When the participants arrived, we gave them a general introduction to the study and asked them to read and sign the consent form. Before working with either of the interfaces, the participants read through an instruction sheet that described the task – to design a garden room for an empty space in the school garden. They were also given a set of trees and objects that they could use in the design. The participants were asked to do the task using the two interfaces based on the order to which they were assigned. For the paper interface, they were given a sheet of paper with the design area marked as a rectangle and the scale information. They used a normal pen or pencil to make a sketch. For the IVR interface, they were given a short tutorial on how to use the IVR device in order to design a garden. For each interface, they were given 25 minutes in which to design their garden.

Dependent measures and logs

We were mainly interested in the quality of the garden design created by the participants as a measure of performance. In order to quantify the quality of the designs, we used the evaluations of domain experts as they play an important role in evaluating creative work (Kaufman, Baer, Cropley, Reiter-Palmon, & Sinnett, 2013). We asked two gardening teachers from a Swiss vocational school who had more than ten years of experience in the field for grading. They had a design review meeting and agreed on the grades for each design in three criteria: proportion, composition and creativity. Proportion refers to the spatial relationship among the objects, composition is about the appropriateness of the selection of the objects, and creativity is about how creative the design is within the boundary of the basic design rules. The first two criteria, proportion and composition, directly involve domain-specific knowledge. For creativity, previous research shows that domain-specific expertise is crucial for creativity assessment (Baer, 2015). For each criterion, a grade was given from 0-7. During the meeting, any grades that were inconsistent between the two teachers were discussed until agreement was reached.

In addition to the design outcomes, we collected log data while the participants were using GardenVR. The log data included all the interactions of the participants with the application. Each action of a participant was recorded as one line in the log file and it included timestamp, type of the action, objects involved in the action, and the mode in which the action occurred. In addition to the action logs, we also recorded the 6-DOF positions of the participant's head and the two hands in the virtual space. The position log was recorded every second.

Analysis

To investigate the effect of the interface and the order on the quality of the design outcome, we conducted a repeated measure ANOVA analysis. We analyzed the difference between the two interfaces as well as the effect of the order of them while considering the interaction effect. To assess the combination of the IVR and paper activities, we conducted a t-test to compare the performance between order groups on the second activity. We used the *p*-value of .05 for the significance level and we measured the effect size using partial eta-squared (η^2) value where 0.01 is considered a small effect size, 0.09 a medium effect size, and 0.25 a large effect size.

In order to investigate the behavior of the participants using GardenVR, we analyzed the log data collected. From the log data, we extracted a number of process variables including the time spent in the two modes measured in seconds, the proportion of the time spent in the two modes, number of objects placed in the design, number of revisions of the design, and the number of simulations executed in the Explore mode. Using Pearson's correlation, we investigated how these variables are related to the quality of the design outcome.

Results

Hypothesis H1: Effect of IVR interface

We first investigated the effect of the interface on the grades in the three criteria. For the proportion grade, the results indicated a main effect of the interface ($F(1, 27) = 8.92$, $p < .01$, $\eta^2 = .24$) with the IVR condition outperforming the paper. For the composition grade, there was not a significant effect of the interface ($F(1,27) = 0.27$, $p = .61$). For the creativity grade, we observed a main effect of the interface ($F(1,27) = 13.17$, $p < .01$, $\eta^2 = .32$) with the paper condition outperforming the IVR. However, we observed significant interaction effects between the two factors in all three criteria (for proportion, $F(1,27) = 14.24$, $p < .001$, $\eta^2 = .43$; composition, $F(1,27) = 23.04$, $p < .001$, $\eta^2 = .50$; creativity, $F(1,27) = 24.28$, $p < .001$, $\eta^2 = .50$). As shown in Figure 3, the quality of design within an interface changed depending on the order. In this case, we cannot claim that IVR or paper outperforms the other on proportion or creativity respectively as there may be a confound of the combination. As the analysis comparing the outcomes of the second activity to investigate the impact of the combination orders will occur to answer H2b, we only conducted a post hoc analysis to compare the outcomes of the interfaces after the first activity. We found no significant difference in terms of proportion $t(28) = 1.51$, $p = .14$. However, we found a significant difference for both composition ($t(28) = 4.42$, $p < .001$, $\eta^2 = .41$) and creativity ($t(28) = 6.00$, $p < .001$, $\eta^2 = .56$) with paper outperforming IVR. In summary, our analysis showed that the IVR interface can be more effective for the proportion aspect, but this may be limited to students that are able to use it after working with paper. On the other hand, the paper interface was better for the creativity of the design only partially confirming our hypothesis (H1) around the benefits of IVR compared to paper.

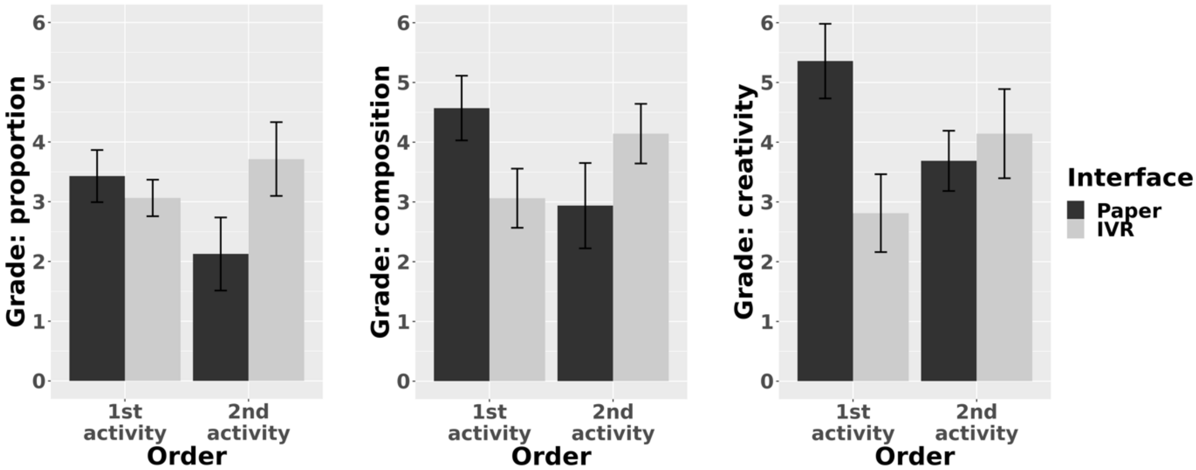

Figure 3: Comparisons of grades in three criteria over time

Hypothesis H2a: Design improvement with iteration

Our second research question was whether learners improve their designs with a chance to iterate. In other words, did they improve from the first to second activity. The results indicated that there was not a significant difference between the grades of the first and second activity in any of the criteria (for proportion, $F(1,27) = 2.35$, $p = .14$; composition, $F(1,27) = 1.16$, $p = .29$; creativity, $F(1,27) = 0.35$, $p = .56$). With this result, we reject our hypothesis on the improvement of the quality of the design outcome (H2a).

Hypothesis H2b: Order between IVR designing and paper sketching

In order to test our hypothesis on the effect of the combination order, we analyzed the final product that the students produced after both iterations using a t-test. We observed significant effects for proportion

($t(28) = -3.91$, $p < .001$, $\eta^2 = .35$) and composition ($t(28) = -2.88$, $p < .01$, $\eta^2 = .23$) with IVR outperforming paper. We did not find a significant difference in creativity, $t(28) = -1.11$, $p = .28$. Furthermore, the differences between performing IVR first or second were significant for all three criteria (for proportion, $t(28) = 2.12$, $p < .05$; composition, $t(28) = 3.28$, $p < .01$; and creativity, $t(28) = 2.89$, $p < .01$). On the other hand, the grades from the paper sketching were lower for the second activity than the first activity for all three criteria (for proportion, $t(28) = 3.61$, $p < .01$; composition, $t(28) = 3.81$, $p < .001$; and creativity, $t(28) = 4.51$, $p < .001$). In summary, the effectiveness of IVR on the design quality was improved when it was done after the paper sketching and this ordering produced a more effective outcome for two of the three criteria supporting our hypothesis (H2b).

Hypothesis H3: Behavior in IVR

In order to investigate the effect of the behavior of learners while using the IVR application on the quality of the design outcome, we extracted and analyzed a number of process variables from the application log data. The behavior features we extracted included some time-related features such as the time spent in each mode, some design-related features such as the number of objects placed, and some simulation-related features such as how many times they simulated the designed garden. Table 1 below shows the correlations between the behavior features and the grades in the three criteria.

Table 1: Correlations (Pearson's r) between behavior features and grades

		IVR as first activity			*IVR as second activity*		
Row No.	*Behavior features*	*Proportion*	*Composition*	*Creativity*	*Proportion*	*Composition*	*Creativity*
1	Duration total	0.169	0.024	0.029	0.038	0.209	0.230
2	Percentage Design mode	0.295	0.268	0.300	0.393*	0.409*	0.426*
3	Number of objects in design	0.046	0.207	0.119	0.248	0.455*	0.350
4	Number of mode switching	–0.159	–0.184	–0.184	0.130	0.283	0.049
5	Number of daytime change simulations	–0.380*	–0.426*	–0.470*	–0.244	–0.079	–0.044
6	Number of season change simulations	0.017	–0.188	–0.142	0.187	0.179	0.291
7	Number of tree growing simulations	–0.126	–0.300	–0.461*	0.149	0.264	–0.056
8	Total number of simulations	–0.232	–0.363	–0.439*	–0.059	0.032	–0.043

* $p < 0.05$

From the results, we observed that the quality of the design was correlated to the percentage of the time spent in the Design mode in all three criteria when IVR was the second activity to the paper sketching (row 2) and hence negatively correlated to the percentage in the Explore mode. For the number of objects placed in the design, we observed a correlation with the composition grade of the design when IVR was the second activity (row 3). When IVR was the first activity, we did not find any significant correlations for these features. On the other hand, we observed that the simulation-related features were negatively correlated to the design quality, particularly for creativity, when IVR was the first activity (row 5 to 8). But the correlations were not present when it was the second activity. These results partially support our hypothesis on the positive correlations with the time spent on designing and the number of objects placed, but not for the number of simulations run (H3) while the order between IVR and the paper sketching had an effect on these correlations.

We further looked into these behavior features and investigated how they are different based on whether the IVR designing was done before or after paper sketching. Figure 4 shows the comparison of the behavior features in the two conditions. The percentage of time spent in the Design mode was significantly higher when IVR was after paper sketching (*M* = 62.0, *SD* = 19.6) compared to before (*M* = 33.6, *SD* = 11.3), $t(28) = 4.93$, $p < .0001$. Similarly, the number of objects placed in the design was higher when IVR was after paper sketching (*M* = 65.6, *SD* = 21.0) compared to before (*M* = 26.4, *SD* = 8.47), $t(28) = 6.87$, $p < .0001$. For the total number of simulations, there was no significant difference between when IVR was after (*M* = 46.2, *SD* = 22.4) and before (*M* = 58.3, *SD* = 32.4), $t(28) = -1.17$, $p = .25$. Considering the positive correlations of the first two features to the design quality, these findings help explain why the grades were higher when the IVR designing was done after the paper sketching.

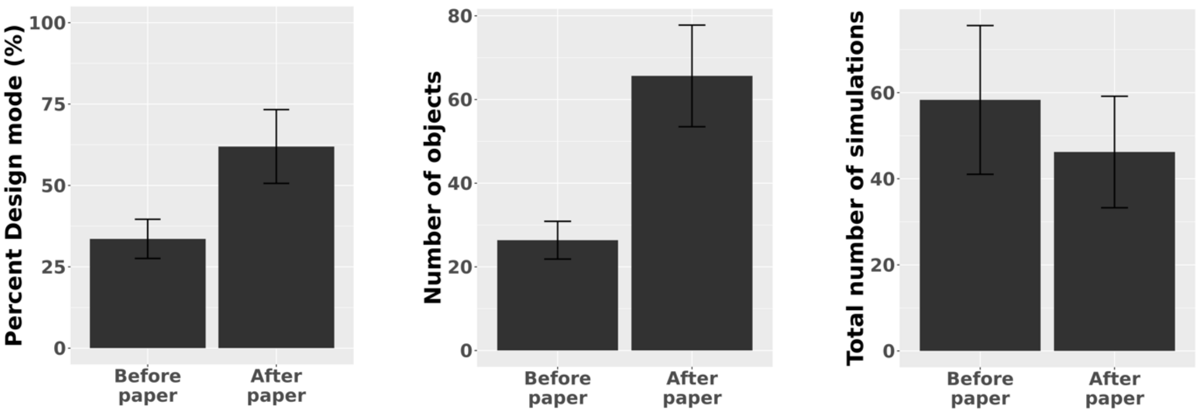

Figure 4: Comparison of the behavior features from IVR in the two conditions

Discussion and Conclusions

The goal of this study was to investigate the effectiveness of an IVR application in the context of VET, specifically for supporting designing skills. Using the application developed for gardener apprentices, an experimental study was conducted in order to answer three research questions on the effect of the IVR interface on the design outcome, how the IVR designing can be combined with the paper sketching in order to improve the effectiveness, and how the behavior in the IVR application is correlated to the design quality.

Regarding the first research question, we hypothesized a positive effect of IVR on the quality of the design outcome. In terms of overall performance, the findings from the experiment support our hypothesis in only the proportion of the design. Furthermore, in a post hoc analysis we found that this result may have been limited to only students who used the IVR after paper. One possible explanation can be that by using the IVR after having an initial sketch, the time spent in the design mode could be focused on the proportions rather than an initial design. As we see from our correlations, the time spent in the design mode when IVR is the first activity is not correlated with the proportion grade but it is in the second, supporting that having this extra time may allow students to focus on these features. However, the higher proportion score in the second IVR could be due to the learners having an opportunity to refine their designs. In this case, we would expect to see an increase in the proportion scores overall for the second activity, which we do not. Rather, the 3D representation of the design provided in IVR may support learners' designing skills in terms of the proportion, which is a spatial-related criterion (Gutierrez et al., 2015; Lee & Wong, 2014).

Further, we observed the opposite result for the creativity of the design with the paper interface being more effective. These results relate to previous work in which the immersion of VR adds more presence, but also significantly higher cognitive load and it can overload and distract the learners, resulting in less opportunity to build learning outcomes (Makransky, Terkildsen, et al., 2019; Norman, 2014; Sweller, 2011). Interestingly, IVR did not seem to restrict creativity that was already present in a design as indicated by there being a significant difference between IVR and paper in the first designs but not the second. Students appeared to be able to carry over their creativity from their paper design as there was not a significant difference in creativity over time. Our results suggest that the increased cognitive load and the additional constraints from the interface of IVR can act as barriers against creative designs, but can be overcome by engaging in a more creative medium first (Anderson & Helstrup, 1993).

For our second research question, we did not find support for our hypothesis that the students would improve their designs in the second activity. However, we did find that the combination order of the two interfaces had a significant effect on the design quality as we have begun to discuss above. For the paper sketching, the design quality was significantly lower if it was done after the IVR activity than before with the opposite effect with the IVR. One possible explanation for the decrease in the paper is that the motivation of the learners in the paper sketch as the second exercise to the IVR can be lower (Harris & Reid, 2005). On the other hand, for the IVR, our results show that an appropriate preparation step before an IVR activity – a sketch on a paper in our study – can lead to an improvement of the effectiveness of IVR on the design quality.

Furthermore, in connection to our findings for the first research question, we believe that both interfaces have their own advantages and it is more meaningful to investigate how they can be combined together rather than simply comparing the two. Unlike with proportion and creativity, we did not find an overall difference in the composition scores between the paper and IVR activities. However, with further analysis, this difference may have been due to the combined ordering of the interfaces. Our results indicated in the first activity the paper interface performed better while in the second activity the IVR did. In other words, the learners that had a high composition with paper tended to keep that high composition in the IVR, and those who started with the IVR had a low composition and it stayed low when they switched to paper. One possible explanation is that the composition aspect of the design was fixated through the iterative process (Zhang, Xie, & Nourian, 2018) and it emphasizes again the importance of the combination order on the design quality.

Regarding the third research question on the behavior of learners using IVR, our results show that the quality of the design outcome was positively correlated to the percentage of time spent in the Design mode and the number of objects placed in the design. These factors are related to the effort spent in designing. It is not surprising that more time and effort spent in an activity results in better outcomes.

What is interesting is that the values of these behavior features were significantly higher when IVR was after the paper sketching and, therefore, the design quality was significantly better. On the other hand, we found that the number of simulations is negatively correlated to the design quality, particularly when IVR was the first activity. Although the time change simulation available in IVR is one of the core features of our application, the results suggest that simulations without sufficient effort on designing are not effective as has been found in previous work around the limited effectiveness of simulations alone (Garden, Le Fevre, Waddington, & Weller, 2015). One approach to address this issue can be to introduce control over the simulation functions by only letting the learners simulate the design once they spent enough effort on designing (Perez et al., 2017). An interesting direction for future work would be to investigate the effect of reflective prompts in the application that encourage reflection during the simulations.

Although this work contributes to our understanding of using IVR to support design tasks, there are limitations to the study that should be considered and addressed in future work. First, given typical effect sizes in educational research, our sample size is small. This was mainly due to the fact that we focused on a group of students that are high in homogeneity, but small in the total number. The small sample size may impact the generalizability of our results in that it may not be representative of the general population of design-related professions. Building upon the findings of this study, we could consider two ways for the future work in order to extend it in terms of the generalizability. First, the future work could extend the study at different levels of learning within the same profession. This extension would increase the sample size but create greater differences among the students in terms of the prior knowledge, which is another factor that would need to be considered. Secondly, the future work could also consider extending the study to other professions. While the current study focused on gardener education, there are many design-related professions that could benefit from supporting the design skills and it would be interesting to investigate the cross-professional generalizability of the results. Another limitation of the current study is that the age range of the participants was rather wide and it might have affected the results. Although all of them were in the same year in the Swiss VET system and there was no difference in the age distribution of the two groups, a pretest that ensures the same knowledge level could have strengthened the results.

This paper demonstrates how an IVR application can support the designing skills of the learners, particularly in VET. It contributes to the learning experience by demonstrating the effectiveness of IVR in supporting learners for a designing task. Our results show that the IVR interface can be effective for the spatial-related quality of the design, but it can also act as a barrier to creative design without sufficient preparation. We also demonstrated how the effectiveness of an IVR activity can be improved when it was done as the second activity to a conventional practice. The results support the potential of IVR in supporting designing skills while emphasizing the importance of the careful design of the learning activity within and around the application.

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Statements on open data, ethics and conflict of interest
The raw data collected in this study can be provided upon request. The design of the experimental study in this paper has been reviewed and approved by Human Research Ethics Committee (HREC) of EPFL. There is no potential conflict of interest in this study.

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