Can Interactivity in Virtual Environments Enable Conceptual Learning?

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Abstract
This research sets out to explore user interaction in immersive Virtual Environments (VEs), focusing on the role and the effect of interactivity on learning and conceptual change. The intention is to examine how interaction and conceptual learning are related in the context of virtual environments developed primarily for informal educational settings. In order to study this, different virtual environments have been designed for projection-based immersive Virtual Reality (VR) devices, such as the CAVE®, since these types of environments are increasingly found in real-world contexts. Pilot studies have been carried out with primary school students, while a set of main experiments are being planned. The participants in all studies are children between 8 and 12 years old, as this is the age in which concrete mental models are formed and, thus, best suited to study the development of learning. To date, the children who participated in the pilot studies were asked to carry out tasks, such as the assembly of ancient columns from parts, which were designed to promote constructivist learning. Their interaction in the VE was analyzed using an Activity Theory framework [5]. The result of this analysis has informed the design of the main studies, which is currently underway.

MOTIVATION AND RELATED WORK
The plethoric development of interactive systems for the broad public, the proliferation of immersive exhibits in museums, informal education institutions and entertainment settings, and the growing sophistication of home gaming systems, emphasize the appeal of interactivity, regarded as the process with which users can have a first-person experience, in other words, act upon, control, and even modify their own digital experience. In these contexts interactivity is being promoted widely, not only for its recreational potential but also for its significance for learning. This is even more prominent in the case of immersive virtual reality, since interactivity is largely regarded as one of VR’s essential properties. Virtual environments are valued as being extremely motivating for learners [2], especially for those with non-traditional learning styles. Ongoing efforts at studying the other essential properties of VR, such as immersion and the phenomenon of presence are beginning to clarify their educational effect [13]. However, when it comes to interactivity, there is a common belief that the effectiveness of a VE that provides a high degree of interactivity is substantially more than the effectiveness of a VE where interactivity is limited. Little systematic research is available to substantiate this assumption and, to date, no clear evidence exists that interactive VR applications can bring “added value” to learning, especially for children. Furthermore, it is not certain if interactivity alone, as an essential property of the virtual reality medium, can provide a strong effect upon learning. This problem is particularly acute where deep understanding, not behavior, is of concern. Hence, a central question emerges: does interactivity enable learners to construct meaning? This research is interested in examining the dimension of interactivity in a VR experience and, in particular, its potential and limitations for learning.

Defining learning is notoriously difficult. There are a range of different perspectives on learning and a great number of theories on how learning takes place. Moreover, the notion of what constitutes learning has evolved throughout the years from a behaviouristic to a constructivist and social constructivist approach. We are interested in examining the effect of interactivity on conceptual learning, as opposed to factual learning, and thus adopt the constructivist tradition as the theoretical model of learning for this work. Conceptual learning is identified with deeper, transferable understandings of generalisable, abstract knowledge; it has to do with logical thinking, the formation of scripts, stories, cases, mental models or constructs, concepts, associations, perspectives, strategies [12].

Similarly, the different definitions of interactivity, as encountered within different contexts, illustrate the fact that interactivity remains a vaguely defined concept, despite its implicit “hands-on” or “physical” nature. Nevertheless, there have been a number of attempts to provide a structure by identifying types, levels, varieties, or degrees of interactivity. At a minimal level, most of these attempts recognize gradations of interactivity, with some actions being more or
less interactive than others and the underlying assumption being that the higher the level of interactivity, the better the outcome. For this research, a working definition of interactivity which defines it as the process that actively involves the learner physically (i.e. bodily movement) and intellectually, is adopted. This refers to more than a one-to-one call-and-response and instead implies multiple decisions and components on different levels: on one end, spatial navigation, considered to be the lowest possible form of interactive activity, manipulation of the environment or parameters of the environment as the basic middle level of interactive activity, and, on the top end, the ability to alter the system of operation itself as the highest form of interactivity. Similarly, Pares and Pares [6] have defined interactivity as explorative, manipulative, and contributive, categories which essentially correspond to our definition.

Figure 1. Young users engaged in an ancient column construction activity during the exploratory studies which aimed at examining interactivity in an immersive virtual environment.

A number of educational VR research projects have been developed throughout the years, mostly in academic contexts, with a goal to apply and test the potential of virtual reality as a medium for educating students. In some projects, very specific applications of VR have been developed (i.e. in chemistry, physics, etc) that examine how students react to these and if they achieve the learning goal [3]. Although many interesting evaluation studies have been carried out as part of the various research efforts, these, unavoidably, produced limited or questionable results due to the fact that the complex nature of the medium was not taken into account and the evaluations isolated parameters neglecting important, in our view, contextual information. In other cases, the opposite holds, with exploratory studies that looked at general aspects rather than specific processes through which the systems cause learning [9].

In any case, very few studies single out and explore the influence of interactivity on conceptual learning or approach critically or even question the significance of interactivity as a facilitator of the learning process. Even fewer go further to consider which forms of interactivity, if any, are effective. A study which has tackled this question in the context of geometry teaching with diagrammatic representations, focused on the comparison between different graphical representations of the concept of stereographic projection and the effect that the addition of various interactive properties might have on the learning goal [6]. The results led to the conclusion that just adding interactivity did not seem to increase the efficiency of the learning environment since the interactive 3D environment did not seem to provide the expected learning gains. However, it was noted that the study was exploratory and additional investigation was required, since learning seemed to be affected by a complex interaction of representations’ properties, task demands, and within-subject factors.

To summarize, VR projects developed for museums or other, research-based educational VR studies, have either not provided the analytical evidence to demonstrate learning or, where an educational impact was perceived, there is no explanation of how and why. And more importantly, the role of interactivity within learning has not been the focus of any of the evaluations carried out. Hence, the research question that emerges is how interactivity in a virtual learning environment can influence learning. To answer this question, we first need to address how this can be studied, how we can provide evidence that interactivity in a virtual environment influences learning. In the next section, we describe an exploratory study, which was designed to provide some answers to the above methodological question.

**EXPLORATORY STUDIES**

A set of exploratory studies was carried out with three children between 8 and 12 years old. The children were asked to complete tasks, such as the assembly of ancient columns from parts, in an immersive stereoscopic VE (a CAVE®-like display) using a 3D joystick device with buttons for interaction (Figure 1). The learning goal was to understand the differences between columns of different order (Doric and Ionian) and symmetry. The tasks included selection, comparison, and resizing of the column parts in order to fit them to their correct bases. Since these studies
were exploratory, we followed a qualitative approach based on observation (aided by a think-aloud protocol) and informal interviews with the children. We observed the children’s activity in the VE and looked for the following different occurrences of learning for the purpose of analyzing our data:

- Conceptual change, where participants revise their conceptions or change their interpretation of something.
- Additive knowledge, where participants have added to what they have already experienced, as long as this involves some kind of reinterpretation of previous action rather than just the accumulation of information.
- Changes in behavior. Despite the constructivist focus of our study, changes in behavior were considered an important indication of learning simply because they were more likely to occur in the observational data of such a small study, than strong evidence of some internal understanding.

Similarly to [1], our method of analysis was based on supporting or refuting emerging hypotheses; we reviewed the video of all sessions and identified various points where interesting interactions seemed to occur. We then proposed a hypothesis concerning what we saw, explaining this in terms of learning. We chose to focus on points where participants made a statement that indicated they had changed their conception or where we could conclude things from our observation of the subject’s behavior in the environment. The organizational framework of Activity Theory [5] provided us with the conceptual vocabulary to help interpret these points qualitatively. Our findings indicated three kinds of instances where learning seemed to take place: learning about the system as a result of technical problems, learning caused by (unintentional) observer intervention and, to a lesser extent, learning arising from system feedback. The latter case of instances is what we are most interested in, since it involves interaction between the learner and the digital environment without human mediation. We thus focused on excerpts where such instances provoking internal contradictions leading to conceptual change seemed to occur. These caused the subjects to change their behavior as well as revise their rules and conceptions, triggered by the rules set out by the system. The subjects’ observation of the system’s rules guided them in evaluating their actions, assessing for themselves the contradiction within the system and resolving it in order to achieve the objective.

Let us look at the example of 10 year-old Chris. Chris had started constructing a column from the capital, which he placed in the air and then begun building downwards by placing the drums underneath (Figure 1). He had managed to squeeze the last drum under the others and attempted to pick up the column base. The VE was not programmed to provide any explicit feedback; however, it was designed with certain features that provided intrinsic feedback, such as the fact that the column bases could not be moved. This was the only type of feedback that represented the system’s interactive capabilities and which implicitly aided Chris in changing his course of action.

**Observer**: How do you see that this piece goes at the bottom rather than the top?

**Chris**: It’s the last piece.

**Observer**: How do you know that it is the last piece?

**Chris**: Because I put that one [showing the bottom last column drum] and saw that there is no other one that fits below it... Anyway, you can tell it’s the last piece.

**Observer**: Why would it be glued on the floor?

**Chris**: [thinks for a moment] …Oh! So that I can put the other pieces here.

He then took apart the column he had constructed in the air and began constructing it piece by piece on top of the base by reversing the sequence in which he was placing the column drums until he reached the capital. The “Oh!” is the “Eureka” moment that both triggers his change in behavior and indicates a change in his conceptions. Furthermore, in the tasks that followed, Chris identified the bases immediately, having remembered from this first task that the bases do not move, and started constructing the columns from the bottom working up. For a detailed analysis of the exploratory studies using the Activity Theory framework, see [10].

Overall, the exploratory case studies set out to explore the research question (how to provide evidence that interactivity influences learning) and succeeded in clarifying issues concerning the methodology for working with children for this problem and the framework for analysis. They also allowed shortcomings of the task to be identified; the observed learning outcomes indicated that the learning goal of the tasks, to learn about the order and symmetry of ancient columns, was not easily quantifiable and did not provide enough opportunities for conceptual learning to occur and, consequently, to be assessed. This led to a re-design of the study, which required the design of a different virtual environment, as discussed in the following section.
THE VIRTUAL PLAYGROUND

Since what is sought is evidence of conceptual change arising from a process of scaffolding and feedback generated by the system, the experiment tasks had to be re-designed in order to foster such change and minimise the other kinds of learning, such as technical learning (i.e. learning how to use a system and how to perform a task) or learning as a result of external aid from the observer.

Therefore, a different learning domain was chosen that would allow us to exploit the capabilities of the VR medium in visualizing abstract and difficult conceptual learning problems and providing feedback. In order to examine “interactivity”, it was decided that varied levels of control over the parameters of the system should be provided through an experimental VE in which children will be asked to complete constructivist tasks (such as planning the layout of a playground) that are designed as mathematical fraction problems. Fractions were chosen as the learning topic due to the difficulty that primary school students have in understanding and connecting them to real-world situations [4]. In other words, fractions lend themselves to designing learning tasks that are, at the same time, conceptually difficult, abstract enough to justify representation via a VR simulation of a real-world situation, and can allow for a kind of varied and incremental interactive treatment.

We decided to incorporate learning problems based on fractions into an engaging virtual reality application with a game-like scenario. We thus created the Virtual Playground (see Figure 2). The tasks designed for this application involve modifying (resizing and placing) the various elements of the playground (swings, monkey bars, a slide, a roundabout, a crawl tunnel, and a sandpit). Each element covers an area which is colour-coded and represented by blocks. The area representing each playground element is initially incorrect (either too big or too small) and must be redesigned, according to rules that require fractions calculations. The swings, for example, initially cover a 3 x 4 area, that is twelve blocks. The children are told to increase the area by comparing two fractions (the fractions 1/3 and 1/4) and choosing the number that represents the larger amount. In this case, the fraction 1/3 which results in 4 blocks must be chosen and the 4 blocks must be added to the swings area.

The system provides both visual and audio feedback to respond to the children’s activity, including feedback on the rules of the task provided by virtual characters, such as an owl and six birds (see Figure 3). When the correct area is formed, the user will immediately see the playground element appear correctly. Additionally, the system provides a number of other tools to facilitate the user’s activity, such as the ability to switch between multiple views (ground view or top-down view) and modes (block mode or model mode).

It is important to note here that the Virtual Playground is not designed as an instructional environment following specific pedagogical models for teaching fractions, but as an evaluation environment. Hence, the characters (owl and birds) are neither avatars nor intelligent agents that respond to the user’s actions and questions. They are merely “rule providers”, meaning that they simply state the rules of the tasks that must be performed (in place of a written instruction sheet, for example).

Pilot experiments with the Virtual Playground were carried out in October and early November of 2004, with the participation of four children, one girl and three boys, aged between 7.5 and 12 (Figure 4).

The main goal of the pilot studies was essentially to improve the usability of the VE and allow us to reflect on the overall process of the evaluation, so as to prepare the main
evaluation. However, a number of interesting observations were made on a conceptual level. The chief finding from these pilot studies, apart from the practical and technical issues with the interface, has been the confirmation of the difficulty that children have when asked to compare fractions.

**Figure 3.** Views of the virtual environment used for the main studies, in which children interactively design a playground based on the rules that are provided by expressive virtual characters, such as an owl and birds, and which require performing fractions calculations.

In many difficult problem solving situations where the children’s answers were correct, the decisions seemed to be made intuitively, supported also by the cues provided by the environment (the shape of each area and the surrounding space). It is possible that this intuitive action is closely linked to the form of the representation (VR) of the problem and, consequently, the value of VR over formal, abstract instruction as a way of supporting learning. Our goal in the main studies will be to capture and isolate activity that seems to be a result of system feedback and intuition, and carefully juxtapose it to the results of the pre- and post-tests.

**MAIN EXPERIMENTAL WORK**

As mentioned, the goal of this work is to evaluate if children learn better by interacting in (i.e. exploring, reacting to, and acting upon) an immersive virtual environment, or, if their interaction enhances conceptual learning of a subject matter. The Virtual Playground environment was designed as the vehicle for the evaluation of our hypothesis. Hence, a set of main experiments have been planned and will be carried out in the next few months. These experiments are informed by the observations of the exploratory studies and the pilot studies with the Virtual Playground.

The experimental method will include observation, interviews and pre- and post-test questionnaires, designed in collaboration with math teachers, for three different participant groups (two experimental and one control). Each study will be conducted with one participant at a time. The duration of the study will be 2 hours for each child. In the first part of the study, the participant will be asked to fill out a questionnaire with math questions similar to those asked in the Key Stage 2 SAT math test. This part of the study will take place a few days before the experiments in the laboratory. After all questionnaires have been collected, each child will be assigned to one of three groups in an even spread according to aptitude, gender, and condition.

**Figure 4.** Children between 7.5 and 12 years old, while interacting with the Virtual Playground in an immersive display during the pilot studies.

The participant of the first experimental group will be immersed in the 3D re-construction of the playground in virtual reality and will be asked to design the playground in this 3D space. In this case, the participant actively designs the playground, having full control over the interactive features of the system. The experience will require that the child actively explores the virtual surroundings and explains her/his actions to the observer.
The participant of the other experimental group will also be immersed in the Virtual Playground but only as a passive observer (they will not have the ability to interact).

Finally, the participant of the control group will take part in an activity using LEGO bricks. The activity will be hands-on, involving the design of a playground on a grid-like floor plan, similar to the top-down view of the virtual reality environment (Figure 5). As in the Virtual Playground, the differently coloured bricks represent the swings, slides, etc., which the participant must position according to the requirements/specifications provided. However, the participants in this condition will not have any interaction with a digital environment. Each participant will be actively involved in designing the playground and no interactivity in the form of intrinsic system feedback will exist. The control study has been piloted with three participants (Figure 6).

Figure 5. The control group will engage in a hands-on playground design activity using actual (physical) LEGO bricks (top photograph). A similar top-down view of the playground is also provided in the virtual environment (simulator image on bottom).

The age of the participants sought for the studies is between 8 and 12, that is 4th to 6th grade or the grades in which different concepts of fractions are taught in school. According to Piaget’s theory on the cognitive development of humans [6], children in elementary and early adolescence (the age group we are targeting) are in the concrete operational stage, in which intelligence is demonstrated through logical and systematic manipulation of elements related to concrete objects and in which operational thinking develops. This reinforces our choice of individuals in this age group in order to best study the development of learning.

However, age can not be a determining factor in the analysis phase of the research, since the understanding of fractions may vary greatly between participants of the same age. Also, the ability that students have to solve fractions problems may range between the different ages, the different school systems, and the different teaching approaches. For this reason, each student’s ability, as judged from the results of the pre-test and the information collected from the parent or teacher, will be the main defining factor. Based on this data, students will be ranked and assigned into categories. For instance, they may be assigned to two categories, based on their average mark (top half and bottom half), or to three (classified into advanced students, mid level, and low level). This classification will also help to avoid a ceiling effect, where the participants find the exercises to be too easy.

**EXPECTATIONS FROM STUDIES**

As with the exploratory studies (constructing columns) and the pilot studies with the Virtual Playground, a number of methodological and practical issues are expected to emerge when carrying out the main studies. The focus of the studies will be to capture behavioural and conceptual change, which can lead to indications of learning triggered by interactive activity in the virtual environment. To identify this change a number of measures have been taken. Different conditions result in a between-groups design, attempting to cover the different combinations of activity, interactivity and immersion. Then, multiple different methods of testing have been designed, ranging from the quantifiable pre- and post- questionnaires to the more qualitative observations and interviews. This is to ensure that the data collected will result in a wealth of information, which we can meaningfully combine and analyse. On the other hand, this wealth of information is a double-edged sword, as one can easily become distracted in a labyrinth of qualitative and anecdotal data of uncertain value. The use of an analytical framework such as Activity Theory, as used for the exploratory study, can help us identify the critical incidents and thus focus the analysis on these.

Overall, we hope that the main studies will enlighten our understanding of children’s activity and, through this, our understanding of their emerging knowledge of fractions. However, to be realistic, a short experience in a virtual environment which incorporates an alternative representation of a difficult problem is unlikely to provide us with groundbreaking evidence of conceptual learning. What we hope to achieve is to gain an insight that will help us draw some conclusions about the effect of the interactive features of an immersive environment on something so broad, deep and undefined, as learning is.
In this sense, this research is expected to contribute to the understanding of the complex relationship between interactivity in advanced technological environments and learning. The experiments designed and carried out, should provide insights as to how people interact and learn in virtual environments and lead to recommendations on how interactivity should be designed in order to achieve meaningful learning experiences. From a computer science and human-computer interaction point of view, it is expected that the results of this research will contribute to a broad and interesting problem domain, namely, the design and development of better user interfaces and interaction methodologies, especially for immersive VR environments.

The understanding of how humans interact in immersive digital environments can aid the broader community and practitioners in designing and engineering interactivity for training as well as formal or informal educational systems and contexts. This is increasingly important in a world where VR systems are becoming commonplace, especially in learning and leisure-based contexts. It is believed that VR research, an inherently interdisciplinary domain, will encompass even more and diverse research strands in the future. This work aims at advancing the study of future virtual reality systems by bringing together a number of separate yet intertwined areas that should be explored, synthesized, and translated into practice.

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