A Virtual Playground for the Study of the Role of Interactivity in Virtual Learning Environments

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Abstract

Interactivity is regarded as one of the core components of a successful Virtual Reality experience, and is promoted widely for its effectiveness, motivational impact, and significance for learning. The research described in this paper sets out to explore learner interaction in immersive Virtual Environments, focusing on the role and the effect of interactivity on learning and conceptual change. In order to examine this relationship, different environments (immersive and interactive, immersive but passive, and non-virtual) have been designed to support a set of tasks for primary school students between 8 and 12 years old. The tasks are constructive by nature, including such things as the assembly of columns from parts or the re-design of a playground, and require performing mathematical calculations. A set of qualitative observations have been made on a case-by-case basis, while the analysis is continuing to look at the various elements that form the complex relationship between interactivity and learning.

Keywords--- **Virtual Reality and Education, Interactivity, Evaluation**.

1. Introduction

Interactivity is undoubtedly one of the defining components of Virtual Reality (VR). In the context of a Virtual Environment (VE), interactivity is regarded as the process with which users can have a first-person experience, in other words, explore, act upon, control, and even modify the environment. Interactivity is also largely regarded as one of the fundamental requirements for presence within virtual reality [1] [2] , though specific studies on this are hard to find, other than studies that have been looking at the effect of body movement [3] .

In any case, the plethoric development of interactive virtual environments for rapid prototyping, industrial design, and training, to name just a few domains, and the evolution of the interfaces, emphasize the appeal of interactivity. Moreover, the proliferation of immersive systems in public spaces, such as museums and entertainment settings, and the growing sophistication of home gaming systems, advertise interactivity as a core attraction of the virtual experience. In all these contexts interactivity is being promoted widely for its effectiveness, motivational impact, and significance for learning.

Virtual environments, in general, have been valued as being extremely motivating for learners [4] , especially for those with non-traditional learning styles. Ongoing efforts at studying the other essential properties of VR, such as immersion and presence, are beginning to clarify their educational effect [5] . 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 behaviorist [6] to a constructivist and social constructivist approach [7] . We are interested in examining the effect of interactivity on conceptual learning, as opposed to factual learning. Conceptual learning is identified with deeper, transferable understandings of abstract knowledge; it has do to with logical thinking, the formation of scripts, stories, cases, mental models or constructs, concepts, associations, perspectives, strategies [8] [9] .

Similarly, the different definitions of interactivity, as encountered within different contexts (socially-based contexts, distance education, museum education, etc.), illustrate the fact that interactivity remains a vaguely defined concept, despite its implicit “hands-on” or “physical” nature [10] . Nevertheless, there have been a number of attempts to provide a structure by identifying types, levels, varieties, or degrees of interactivity in an effort to better define the role of interaction and interactivity within computer-mediated learning environments. 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. kinesthetically) 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 [12] have defined interactivity as *explorative*, *manipulative*, and *contributive*, categories which essentially correspond to the definition that we have adopted.

2. Previous research on VR and education

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 [13] . 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 [14] [15] . 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 [16] . Nevertheless, despite it being a very young field, virtual reality research in education has already produced a significant body of work that is also considering the longitudinal effects [17] .

However, 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 in VR. 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 [18] . 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 representation properties, task demands, and within-subject factors.

To summarize, VR projects developed for informal education or for other, research-based educational VR studies, have either not provided the analytical evidence to demonstrate learning as a result of interaction with the environment or, where an educational impact was perceived, there is no explanation of how and why. More importantly, the role of interactivity within learning has not been the focus of any of the evaluations carried out as such. 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 sections, we describe the design of our studies and the virtual environments created to support the studies, in an effort to provide some answers to the above methodological question.

3. Studying interactivity in VR

3.1. Exploratory pilot studies

Since what is sought is to study learning as a result of the learner’s interaction with a virtual environment, a learning task had to be specified and an interactive virtual environment built with enough features as to invoke the aforementioned multiple levels of interactivity found in VR applications [12] . Our first idea, which was developed with consultation from supportive math and science teachers, was to create a task where the user had to build a temple by identifying and assembling its various parts. As an idea, the construction of a temple is advantageous because it encompasses an inherently activity-rich process, so it formed the basis for our 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 involving the assembly of ancient columns from parts in an immersive stereoscopic VR system (a CAVE®-like display) using a 3D joystick device with buttons for interaction. 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 [19] , 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 participant's behavior in the environment. The organizational framework of Activity Theory [20] 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 participants to change their behavior as well as revise their rules and conceptions, triggered by the rules set out by the system. The participants' 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.

To make the analytical methodology clearer, let us look at the example of 10 year-old John. John had started constructing a column from the capital (the top part), which he placed in the air and then begun building downwards by placing each one of the drums underneath. 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 John in changing his course of action.

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

John: It's the last piece.

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

John: 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.

John: [trying to pick up the last piece and realizing that it doesn't move] It is glued on the floor...

Observer: Why would it be glued on the floor?

John: [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, John 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 [21] .

Figure 1. The layout of the virtual playground (top) and a view of the virtual environment as displayed in a cubic immersive display (bottom).

Overall, the exploratory case studies set out to explore the research question (how to provide evidence that interactivity influences learning) and helped in clarifying issues concerning the methodology for working with children for this problem, while acting as a test bed for the application of the analytical framework. 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.

3.2. 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.

It became apparent that the column construction activity did not provide enough opportunities for conceptual challenge and could not be easily linked to the everyday life and interests of today's children between 8 and 12 years old. 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 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 [22] . 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.

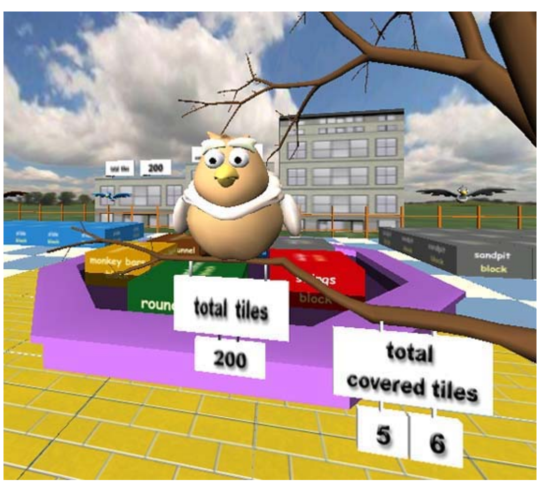

Figure 2. View of the virtual environment used for the main studies, in which children interactively design a playground based on the rules that are provided by expressive virtual characters. The owl is the main character that greets each participant and provides the general rules before the start of the design.

We decided to incorporate learning problems based on fractions into an engaging virtual reality application with a game-like scenario. Consequently, the idea of designing a playground emerged. We created both a Virtual Playground (Figure 1) and a physical model using LEGO™ bricks (Figure 4). The tasks designed for the virtual playground 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 color-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, by picking blocks from the central pool and placing them on the 4 tiles that need to be covered.

Figure 3. Different coloured birds represent each area that needs to be changed by the participant. When approached, the bird speaks out the rule, which requires performing fractions calculations, for its 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 (Figure 2) and six birds (Figure 3). When the correct area is formed, the user can press a button to switch to "playground mode", and immediately see the playground element appear correctly. If the area is not formed correctly, then the playground element will not appear and the user will be prompted to reconsider her actions. In addition to the switch between block mode (in which construction takes place) and playground mode, 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).

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).

4. Main Experimental Study

As already mentioned, the purpose of this research is to evaluate the value of user interaction in interactive virtual learning environments. Specifically, the goal 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 research question. Centered on this environment, an evaluation study was planned, which started in late 2004 and continues to run. At the time of writing, approximately 30 children, between 8 and 12 years of age, have participated in two of the three conditions of the study and another 15 have been planned to take part in the third condition (Figures 5-8).

Prior to the main study, a set of pilot studies were carried out, aiming at improving the usability of the VE and allowing us to reflect on the overall process of the evaluation, so as to better prepare for the main study.

4.1. Experimental procedure

The study is being conducted with one participant at a time. The duration of the study is approximately 2 hours for each child. The nature of the study is such that the child is free to act or interact for as long as she wishes with the playground, be it the virtual or the LEGO playground.

In the first part of the study, the participant is asked to fill out a questionnaire with math questions that are based on the fractions questions found in standardized tests. A user profiling questionnaire is also given at this time. This includes questions that attempt to draw a picture of the child's familiarity with computers, frequency of computer game play, and understanding of or prior experience with virtual reality.

After the questionnaires have been collected, each child is assigned to one of three experimental conditions; either the control condition or one of two experimental conditions, in an even spread according to aptitude and gender (Table 1).

Table 1

condition	form of activity	interactivity	immersion
control	active	no	no
interactive VR	active	yes	yes
passive VR	yes*	no	yes

(*) in the case of the passive VR condition, interactivity is not directly experienced by the participant, but "through the eyes" of an invisible person who interacts with the VE while the participant watches.

If assigned to the control condition, the participant will take part in an activity using LEGO bricks. The activity will involve the design of a playground on a grid-like floor plan, similar to the top-down view of the virtual reality environment. As in the Virtual Playground, the differently coloured bricks represent the swings, slides, etc., which the participant must position according to the requirements and specifications provided. This condition does not take place in a digital environment. Thus, although, each participant is actively involved in designing the playground no interactivity (system feedback) exists.

If assigned to the interactive VR experimental group, the participant takes part in a similar activity, in a typical CAVE-like system consisting of four projection surfaces (three walls and the floor). The participant views the projected stereoscopic images by wearing a pair of active stereo glasses and can move around freely to interact with the environment by using a wireless wand which contains a joystick and buttons. The wand is used to navigate around the virtual world, and to select and manipulate virtual objects within that world. A wireless head tracker is specially adjusted on a cap that is worn by the participant, thus relaying the head position and orientation to the computer.

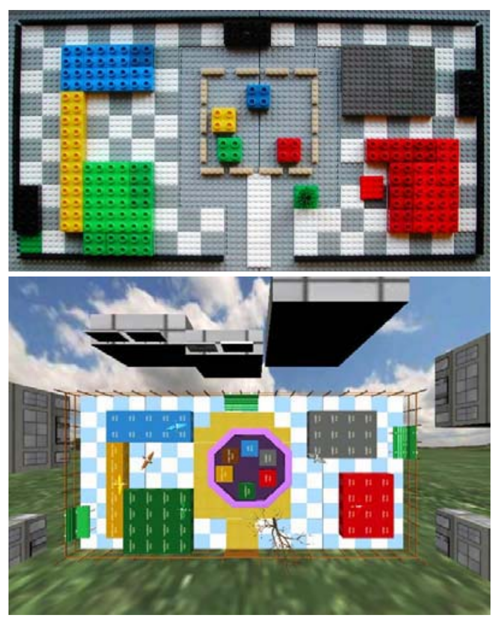

Figure 4. In the control condition, children engage in a hands-on playground design activity using actual (physical) LEGO bricks (top photograph). A similar top-down view of the playground is also provided in the virtual environment (simulator image on bottom).

In other words, the participant is immersed in the 3D re-construction of the playground in virtual reality and is 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 requires that the child actively explores the virtual surroundings and explains her/his actions to the observer. The task is similar to playing with a computerized construction kit or a computer game. Before starting, the task is explained to the participant who has a chance to practice moving objects around in the virtual space of a training environment.

Finally, the third condition is that of a "passive VR" experience, where the re-design of the playground is played out as in a video sequence without allowing the participant to act.

In all cases (activity with LEGO bricks, activity in the interactive VR scenario, and participation in the passive VR scenario), the participant is asked to complete a post-test with questions related to fractions, similar to the pre-test. Finally, every participant is interviewed about his/her experience by an observer who has noted the specific actions in which the participant has had problems with, and can direct the participant to reflect on these accordingly.

5. Preliminary observations from the study

Although the study has not been completed, a number of interesting observations have been made on a conceptual level and can be reported at this stage.

5.1. The problem of comparing fractions

The chief finding from the study thus far has been the confirmation of the difficulty that children have when asked to compare fractions. This was a consistent finding across most participants. Jack, for example, was able to solve almost all of the simpler exercises with relatively minimum help from the observer. When he got to the last exercise, which involved increasing the area of the swings (currently a 3 x 4 area of twelve blocks) by comparing two fractions (the fractions 1/3 and 1/4) and choosing the number that represents the larger amount, he immediately replied that he would increase the area by 1/3. However, when asked by the observer how he came up with that result, in other words, how many blocks he believed that 1/3 represented, he replied that 1/4 is four blocks and 1/3 is five blocks. This explained why he chose 1/3. The observer let him continue with his decision to add five more blocks to the swings area. When he completed the placement of the blocks (inevitably creating a non-rectangular area), he clicked on the red button to switch to "playground mode" and see if his decision was correct. When he saw that it was not, he understood that the area "did not have the right shape", but required help from the observer in order to correct it.

Mark, on the other hand, is a 9 year old boy who was very good in solving the individual fractions exercises in the pre-test. When he got to the swings, he immediately responded that 1/3 would make the swings area bigger. However, when the observer asked him how he came up with that response so quickly, he had difficulty in explaining his thought process. He eventually was able to explain that 1/3 of twelve is four, but it did not seem that he had consciously made his decision after performing the calculation; rather his decision was intuitive and seemed to be triggered by the shape of the swings area and what would look more correct.

Figure 5. A 12 year-old boy in the Virtual Playground.

It was later revealed, when talking with the parents and teachers, that both Jack and Mark had not been explicitly taught how to compare fractions in school yet, so their responses were, in some cases, random. This reinforces our observation that some decisions were 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 of the problem and, consequently, the value of VR over formal, abstract instruction as a way of supporting learning. Our goal in the analysis of the remaining cases will be to capture and isolate activity that seems to be a result of intuition, and carefully juxtapose it to the results of the pre- and post-tests.

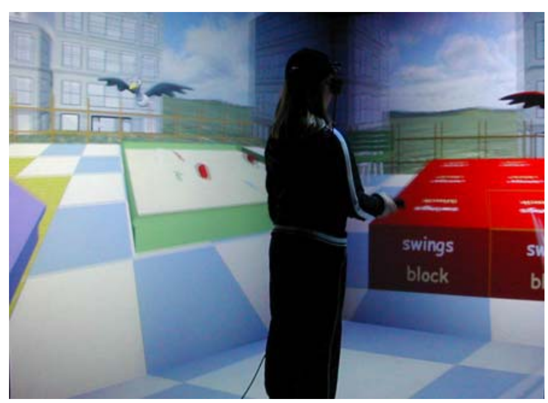

Figure 6. An 11 year-old girl exploring the Virtual Playground.

Similarly, Lisa, a 10 year old girl who has been taught most fractions in school, made some decisions based on what "looked right". These decisions were evident in two cases, in which she made mistakes with her fractions. In the case of comparison between 1/3 and 1/4, she decided to increase the swings area by 1/4. When asked why, she replied: “because I counted them and they are twelve, so divided by three they will not be enough... so... [I decided that it will be] four”.

Observer: So you decided to increase by 1/4...
Lisa: yeah.

Observer: And how many blocks is that?

Lisa: uhm... [distracted by what she was doing], four.

Lisa made the common mistake (identified by [23]) of choosing 1/4 as the fraction that results in the larger number. However, she correctly added four blocks (the result of 1/3, not 1/4) to the swings area. This correct action seems, in part at least, to be attributed to her intuition rather than her calculations.

Figure 7. An 11 year-old boy placing a block in the Virtual Playground.

5.2. The power of the real world

Another interesting situation occurred with the monkey bars. In their incorrect version the monkey bars occupy an area of six blocks, placed in a long strip. The rule communicated to the participant states that the current area is too long and that it must be decreased by 1/6 of the area of the sandpit. David, an 11 year-old, immediately went to the sandpit (which occupies twelve blocks) and decided that the answer is six (another common mistake made by more than half of the participants in the study).

David: ...it’s too long [the monkey bars].

Observer: What did the bird tell you?

David: That they have to be 1/6 of the area of the sandpit...

Observer: How much is that?

David: Six.

He was certain that six was 1/6 of twelve. However, the playground confused him, since the monkey bars were already six blocks long, so if he took out six this would leave no blocks on the ground. He was stuck so the observer suggested that he try removing some blocks to see what happens. He then removed two blocks, and then another two, at which point he got it right and exclaimed that he had known all along that the correct answer was two but hadn’t thought of it from the start. When asked later why he was confused even though he knew that 1/6 of 12 is two, he responded that the correct result (two blocks) did not make sense to him, because “in real life the area for the monkey bars could not have been so short”. In this sense, it could be argued that the realistic representation of the learning task provoked “common sense”, which stood as an obstacle to conceptual change.

5.3. The choice of different views

Another interesting observation concerns the choice of views within the virtual environment (ground view or top-down view), which are provided by the design. No participant, except for one who is an avid computer game player, chose to use the top-down view of the playground (which resembles an architectural plan), even when counting the blocks in an area. Many different explanations may be given to this, either because they simply forgot about it, or because they are not used to using alternative tools that may simplify their task when a task can be performed in one way. Nevertheless, this may be interesting to follow up in the main studies, where we are considering including a reminder that will prompt the children to use the top-down view.

In summary, some generalizations have emerged from the preliminary informal analysis of the different cases, especially when examining each child’s activity and reaction to individual problems. Although we have not yet proceeded in examining where added learning value or conceptual change may have occurred, we have identified the individual sections where interesting contradictions seem to have occurred.

Figure 8. Children construct the LEGO playground as part of the control condition.

Conclusions

During the exploratory studies (constructing columns) and the pilot studies with the Virtual Playground, a number of methodological and practical issues emerged related to the challenges of designing and evaluating technology for and with children. For the main studies, the focus has been to capture behavioral 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 analyze. 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.

At the same time, the studies have so far highlighted some of the inadequacies of the methods used to collect and interpret the data. The participants, being young children, have difficulty in explaining their actions and, most of all, externalizing their thought process, while direct observation alone is unable to provide adequate insights into these internal thought processes. The think-aloud protocol that we used to obtain verbalization data can be somewhat effective, but this largely depends on the participant's learning style, capacity to verbalize, level of extroversion, or even gender [25] . Also, we hope to be as unobtrusive as possible during observation of each child's experience but it proves difficult given that the participant has to be asked questions while interacting with the virtual environment. This is a particularly common problem, especially in VR where achieving presence is paramount to the success of an experience and any direct method of eliciting information from the user during the experience can cause breaks in the user's sense of presence [26] . Nevertheless, our observations so far with the children that have interacted in the Virtual Playground indicate that not only do children feel comfortable and interact naturally with the environment after only about 2 minutes of training, but they also display a high level of presence throughout, illustrated by their movement (trying to touch the birds or sit on the swings) and comments such as "oh I keep on forgetting that I am not in a real playground!" (Figure 9).

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.

Figure 9. Children attempt to ride on the roundabout, following their successful re-design of the Virtual Playground.

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. 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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The studies for this research have been approved by the UCL Committee on the Ethics of Non-NHS Human Research, Study No. 0171/001.

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