Course Lectures as Problem-Based Learning Interventions in Virtual Worlds

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Abstract. Virtual Worlds (VWs) present considerable potential as future learning platforms, but further studies are required to assess their effectiveness in constructivist and collaborative learning situations. The paper investigates the suitability of VWs as a platform for hosting PBL (Problem-Based Learning) activities and explores their affordances in terms of collaboration support and learning effectiveness. We have designed an educational VW and developed a number of tools that support collaborative learning activities. Using this environment, we have conducted a PBL intervention that required from students to collaboratively design the user interface of a multimedia kiosk. We performed a thorough, formative, multi-method evaluation of the learning activity. The results reveal several encouraging findings about PBL and collaboration mediated by VWs, and lead to a series of recommendations.

Keywords: Virtual Worlds; Problem-based Learning; CSCL; User Interface Design

1 Introduction

Virtual Worlds (VWs) are computer-generated 3D environments, in which multiple users navigate, interact and communicate having a form of embodied representation [1]. Given that this fairly new medium has significant differences and introduces novel affordances compared to traditional learning paradigms, researchers attempted to study its effects on the learning outcomes, and the circumstances and preconditions under which this new medium is to be used [2-4]. A number of prototypes and case studies have been setup in order to draw results on the use of VWs in education in the last two decades [4-7], starting from the early immersive VR systems to the current massive multi-user worlds. Although these studies vary in terms of configuration and types of educational activities tested within the 3D environment, the early results have shown that VWs have significant potential as a complementary educational medium [8,9].

Nowadays, a number of universities and high-schools are using VWs as part of their curricula.[1] However, the majority of them employ VWs simply for resource

[1] http://virtualworldwatch.net

sharing and conferencing, and the common activities that take place within the environment are text or voice-based communication, document storage and exchange, group discussions and presentations, e.g. [10-12]. These approaches do not exploit the powerful affordances of VW in presenting real-time simulations of custom environments, in which users can actively participate in an experiential and constructivist manner. We argue that VWs should be explored for setting up novel educational interventions that support and visualize evolving in-world activities with the presence and participation of people who construct and manipulate 3D objects and tools.

A learning approach that follows the principle of active and collaborative knowledge construction is Problem-based Learning (PBL). In PBL students learn by addressing authentic and open-ended problems and reflecting on their experiences, thus developing problem-solving strategies and building domain knowledge in a self-directed manner [13]. This approach has several advantages, as students are actively gaining transferable skills by investigating, explaining and resolving meaningful problems and the individual or group participation in problem-solving activities is highly motivating for them. However, there are only a few documented cases in which VWs have been used for collaborative PBL activities.

The aim of our work is to explore meaningful ways for the facilitation of collaborative PBL activities in VWs. We present the design and evaluation of a PBL intervention in a user interface design lecture. Our goal was to engage students in PBL activities through their collaborative design, experimentation and evaluation of user interface prototypes. We designed an educational environment on top of an existing VW platform, built a number of supporting tools for collaboration and prototyping, and facilitated a set of learning activities over an extensive lecture session. We performed a detailed evaluation of the activities, in which we combined various methods for data collection and analysis in order to explore dimensions of collaboration, learning and usability. The evaluation results reveal several strengths and weaknesses of VWs as potential PBL platforms.

2 Related Work

2.1 Problem-Based Learning

PBL is a learning and teaching approach that has been widely adopted in practice during the last 20 years in both traditional and online educational settings [14]. It incubates an experiential, social and active perspective to learning that contributes to the development of critical thinking skills. Typical PBL contexts require learners to work in small groups to investigate a real-life problem. The instructor acts as a facilitator of group work challenging students' learning and collaboration strategies, and may occasionally provide resources to help learners find a solution to the problem, despite that students are primarily responsible for finding their learning resources.

The collaboration and interaction of motivated students groups and the effective teacher facilitation of PBL activities are critical factors for the success of this approach in both traditional and online learning settings. With respect to online learning settings, several studies have attempted to implement PBL. Donnelly [15] integrated online PBL techniques with face to face learning. It was found that group activities were the most important parameter for the success of the process. Dennis [16] compared a face to face with online PBL settings. Results showed that the groups did not differ in learning performance but the online group spent more time for learning activities. Ozdemir [17] reported that students in a collaborative PBL environment outperformed those who were in an individual PBL environment as regards the development of critical thinking. In [18] it is suggested that only online courses with collaboration characteristics should make use of PBL.

On-line approaches to PBL may have positively assisted the processes, but there are still issues that need further improvement. Constructivist learning environments, according to Wilson [19] should contain "*a setting or a space wherein the learner acts using tools and devices, collecting and interpreting information, interacting perhaps with others, etc*". A more experiential and constructivist approach to PBL would need to include rich multimodal representations of the problem space and the ability to freely experiment with real-time interactive tools to construct possible problem solutions. VWs are a platform that can support such enhancements.

2.2 Designing PBL Interventions in Virtual Worlds

PBL has already been characterized as one of the most appropriate learning pedagogies in VWs, especially in Second Life [20]. Despite the large amount of work in combining PBL with online learning there are few studies of PBL in VWs. In [21] Second Life[2] (SL) is used to implement a collaborative PBL activity. The tutor intervened in the process by using scaffolding techniques in order to help students to achieve their goals. It has been reported elsewhere [22] that the use of scaffolding techniques is effective when collaborative learning occurs in a VW. In [23], the suitability of SL for PBL is demonstrated through the mapping of learning activities on to PBL goals as they have been stated in the framework of [13]. They used a machinima-based assessment technique where students worked in groups to create short video clips from their activities in SL. According to the findings it is supported that development of wider transferable skills can be realized effectively through VWs such as SL. In [24] findings from a case study with a PBL approach are reported, where students were tasked to create learning experiences within SL for external clients. The emphasis was mainly placed on the process of how students formed groups and created the interactive learning experiences by using the affordances of SL. It was found that SL can contribute to PBL as a pedagogical approach in several ways such as supporting the roles of tutors and students, facilitating their relationships, enhancing students' motivation and ownership of the project, as well as easing the assessment activities by the tutors. Similar results can be found in the study of [25], which refers to enquiry-based learning.

These studies are presenting the experiences of using VWs with a PBL pedagogy, however they do not yet propose an approach for the design of specific VW tools and PBL interventions in VWs or present a specific approach for the assessment of these interventions. Much of the relevant research on PBL is still conceptual and

[2] http://secondlife.com

information about detailed evaluation with regard to specific methods and practices is lacking.

2.3 Evaluation of PBL Activities in Virtual Worlds and Computer-Supported Collaborative Learning

The evaluation of PBL involves the intertwined dimensions of collaboration, interaction and learning, placing emphasis not only in the learning content but also in the assessment of more general skills like self-directed learning, intrinsic motivation and critical thinking. When PBL occurs in the classroom, various types of formative and summative assessment tools and methods are used encoded in complex assessment rubrics [26]. Despite that there is much work on the assessment of PBL in computer supported collaborative learning (CSCL) situations, the assessment of PBL activities in VWs is currently an open issue: there are too few studies of PBL in VWs and they have not yet developed specific tools for that purpose.

When a problem-based approach is employed in CSCL, the evaluation involves interaction analysis of the participating teams in order to clarify what types of collaborative interactions have occurred and what educational benefits have taken place [27, 28]. Interaction analysis is both a qualitative and quantitative process that can be performed with various instruments and methods that must also take into account the specific problem at hand. In [29] the evaluation of collaborative learning is described as "*placing strong emphasis on the situated nature of collaboration and the impact of certain situational factors (with a few or as little as possible a priori expectations)*". In [30] a principled framework for the study and analysis of group interaction and scaffolding is presented by combining different aspects and issues of collaboration, learning and evaluation. The evaluation happens with the qualitative inquiry of indicators about 'task performance', 'group functioning', 'social support' and 'help services'. The approach has been applied in e-learning course situations with large numbers of participants, and it can be extended to cover the particular issues of PBL interventions in single lecture situations. The interaction analysis framework of [31] is a tested approach which is appropriate for assessment of collaborative learning in the long-term on top of robust collaborative technology.

2.4 The Scope of Our Research

The aim of our work is to explore meaningful ways for the set up and facilitation of collaborative PBL activities in VWs. In our study, we describe an approach for the design and evaluation of PBL interventions in VWs that reports on the value of VWs as educational platforms for constructivist and experiential learning. The goals of this study were to: (a) design a learning intervention for a lecture of user interface design that includes a number of PBL activities; (b) facilitate the learning process, while keeping track of students' behaviour and performance; and (c) evaluate the learning process with criteria that stem out of the PBL philosophy, as well as the final outcome.

This work can contribute to the current corpus of studies that aim to discover the extent in which VWs can support constructivist activities, to evaluate the learning results of their use, and to unveil critical problems related to student collaboration and learning.

3 The VW Environment and Tools

3.1 Configuration of the Virtual World with Open Source Software

The VW implementation (Fig. 1) has been based entirely on open source software. The world server was installed in a standalone PC using the OpenSimulator platform,[3] and the FreeSwitch server[4] has been set up and connected to the environment to provide voice communication support. We have created a small island and built a number of interior and exterior places for group collaboration and whole class activities. We implemented four additional collaboration tools in the LSL Scripting language. On the client side, the Hippo OpenSim Viewer[5] was running on PCs with standard keyboard and mouse equipment plus an additional headset with microphone for voice communication. No significant decrease in efficiency or loss of quality has been detected during the whole experiment.

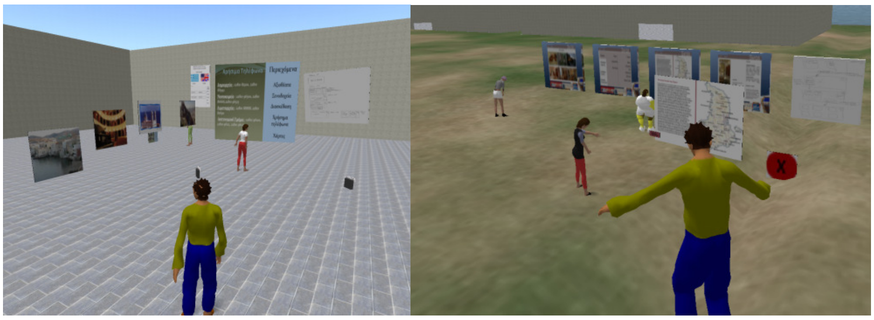

Fig. 1. Screenshots of the environment.

3.2 Design and Implementation of the Supporting Tools

Group educational activities in VWs have strong requirements concerning the communication and collaboration of remote students and teachers. For our study in the area of user interface design we have identified the following tasks in group-based PBL activities:

- In the early stages, students discuss about the problem, write down facts and reveal aspects for which further knowledge may be required.
- Then, they assign roles to group members, search for and share resources, and formulate, present and explain their ideas.
- Then, they collaboratively assemble a final solution and gradually refine it.

[3]http://www.opensimulator.org
[4]http://www.freeswitch.org
[5] http://mjm-labs.com/viewer

- Finally they present it to the class for further evaluation and feedback.

To support these tasks, the educational environment should provide the appropriate means for text and voice chat, and allow students generate and share public and private documents to exchange ideas and coordinate their activities. Also, students should be able to easily take notes during group discussions and chat sessions and share them with others. Groups should be able to collect and organize their common resources within the VW in order to use them for reference during their problem solving activities. Finally, the world should contain the building blocks to collaboratively construct a working prototype and to enhance it with further explanations about the design choices.

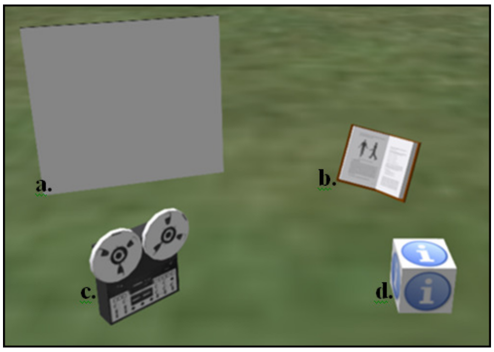

Fig. 2. The supporting tools of the environment. a. Interface Element, b. Resource, c. Comment Recorder, d. Annotation.

The platform employed for our study provided inherent support only for part of these tasks allowing for text and voice chat between users, but there is no support for offline messaging. Concerning resource management, one can only add geometric objects to the environment, whilst any other document type can only be placed in an object's contents. However, security reasons restrict other users besides the object owner to view its contents. Finally the construction of a working user interface prototype requires a lot of programming effort using the VW's scripting language, which was outside the scope of our learning session.

Thus, we have designed and implemented a number of additional tools that were available to students during the study in order to overcome these obstacles and to enhance the collaboration affordances of the environment. The implemented tools were:

- *Resource*: an object that links to external web resources
- *Comment Recorder*: a tool to record and playback user messages
- *Annotation*: an object that contains a written message
- *InterfaceElement*: an object with scripted behavior that can be used as a user interface component in the working prototype

The aforementioned objects were provided to each student on initialization and they could insert multiple copies of them inside the environment (Fig.2).

The “Resource” object is the equivalent of a hyperlink. It has the form of an open book and it opens a web resource in the default browser upon mouse click. It can be used by the teacher(s) in order to provide some initial resources to the students (guidelines, design patterns, templates, etc.) to aid them during their tasks, and by the student groups in order to share and organize the resources they found in their self-directed learning activities.

The “Annotation” object allows students to post annotations within the environment. If any user clicks on it, a text message is opened and may be saved in his/her inventory for later use. In the context of the PBL activities, annotations may be used for the asynchronous collaboration between group members (e.g. in the form of comments, notes about things to be done, role descriptions, etc.) or they may be attached to the user interface prototype as further notes or explanations of design choices.

The “Comment Recorder” object can record and playback user messages on demand by sending special commands to the text communication channel. It can be used to take notes from conversations during the early collaboration stages and also as a tool to record viewer comments during the final evaluation stage.

Finally, the “Interface Element” object is the principal design element of the user interface prototype. Its look and behavior can be configured using a simple set of commands and, depending on its configuration it can:

- show or hide in the environment as a result of an external event,
- operate as a button that will generate a batch of events if pressed, which may affect the status of other interface elements or itself
- contain a number of images (faces) that may change dynamically its appearance as a result of an external event, and
- operate as a container that forwards events to its contents

Students can combine and configure copies of the “Interface Element” object in order to design buttons, windows and image containers during the final stages of the learning activity and collaboratively construct an interactive user interface prototype.

4 Facilitation of the Learning Intervention

4.1 Course Lecture and Participants

The learning intervention was offered as an introductory, optional joint lecture for the courses of Advanced User Interfaces and Virtual Reality at the department of -omitted for anonymity-. The participants of the study were ten students (3 male, 7 female). All participants had attended a number of related lectures like HCI (Human-Computer Interaction), Interaction Design and Multimedia Design. They were all proficient computer users, but only three of them had some experiences with VWs.

The participants were allocated in three balanced groups in terms of their experience in VWs and their user interface design skills. The team mates had to perform all activities through the VW, to simulate remote collaborating conditions. Their seating positions had a certain distance from each other, and they were not allowed to communicate face-to-face during the activities. The teaching team comprised of the authors themselves, who also provided technical support and facilitated the collaboration and learning activities during the whole intervention.

4.2 PBL activity and goals

The lecture was organized around an authentic, ill-defined problem according to the tenets of PBL, which was given to the students in the following statement of a ‘design brief’: “*Design the user interface of a multimedia kiosk system for browsing available rooms to let in the island of Syros. The intended users are tourists (Greeks and foreigners), who can access the system from the harbour of Syros. You should take into account usability guidelines for multimedia presentations and information seeking. You should design the 5-7 most basic screens of the system, in wireframes*”. In addition, the participants were presented with an abstract work plan that included tasks that they could choose to follow with indicative times for completion.

Fig. 3. Group presentation inside the VW.

The learning goals of this learning intervention were: a) to discover the usability and accessibility requirements of touch screen interfaces, b) to understand the differences in the design of such interfaces compared to other, more conventional cases, and c) to apply this knowledge in a specific practical context. Following the principles of the PBL approach, the learning session has been applied as follows:

1. The students were given an introductory session in the VW to familiarize with the interface.
2. The supporting tools were presented to the students accompanied by specific use cases.
3. Students worked in groups inside their allocated workspaces. They analyzed the problem, shared ideas and gathered resources.
4. Each group assigned roles and/or tasks to its members. They proposed and argued about concepts, designed the appearance of the user interface elements using in-world and external tools, and collaboratively constructed their prototype as a proposed solution
5. Once the group agreed on the final prototype, they attached explanatory annotations to justify their design choices and presented it to the whole class (Fig.3)

6. Students and teachers were then free to test each interface prototype themselves and leave comments and suggestions concerning the appropriateness of the solution.

5 Evaluation

5.1 Data Collection and Analysis Method

We have constructed a mixed (qualitative & quantitative) method for interaction analysis of problem-based CSCL in VWs. More specifically, we used the following methods:

- Automated monitoring of student behaviour: this was achieved by video capturing of the activity within the VW, logfile analysis with respect to the use of the tools, and observation of the state of the world during and after the exercise.
- Dialogue analysis: voice chat was recorded for most of the exercise and an analysis of utterances was performed. We followed the taxonomy of [32] who classify utterances in one of the following content categories: Procedure, task status, reference, internal state and acknowledgement.
- Students' self-reporting: we used a questionnaire that investigated several aspects of the problem-based CSCL experience, as well as follow-up discussion.
- Tutors' evaluation of the outcome: this was performed during the activity and also after the experiment taking into account all data gathered.

The method for interaction analysis explores the dimensions: 'task performance', 'group functioning', 'social support', and 'learning performance and outcome'. The first three dimensions are those proposed by [31], while the fourth dimension was added to investigate issues of particular PBL process. Thus, the evaluation method employs a number of established dimensions and indicators for interaction analysis in CSCL and extends these to support evaluation of PBL situations. A large corpus of data can be collected for each indicator involving at least two related methods, allowing for cross-examination of the results. Table 1 illustrates the dimensions and indicators of interaction analysis performed for this exploratory study and the corresponding data collection methods.

5.2 Results

The overall result of the learning interventions was that all student groups proved capable of constructing functional user interface prototypes using the in-world tools as well as of instantly testing and evaluating their solutions. The prototypes were particularly interesting, while all learning activities were conducted in an engaging, enjoyable and satisfactory manner.

The learning intervention lasted for a total time of 6.5 hours, which was about 1.5 hour more than initially estimated. The first 2 hours were devoted to the tutorial about the use of the VW. Then, a total of 3.5 hours were devoted to the activity of user interface design, presentations and follow-up, while a total of 1 hour was allocated to the breaks. Participants were asked how much time they would need to carry out the user interface task in a 'face to face' situation and deliver at the same quality: some of them answered about the same time (3.5 hours), others said about an hour less. This is a quite interesting result considering other time consuming activities in face to face situations like for example time arrangements. All teams made use of the tools provided in the environment to document on the design process (Table 2).

Table 1. Dimensions and indicators of interaction analysis and corresponding data collection methods

Interaction Analysis Indicators	Action monitoring	Dialogue analysis	Self-reporting (question-naires)	Post evaluation (observation, follow-up)
Task performance				
TP1. Problem-solving capabilities and learning outcomes	X	X		X
TP2. Contributing behaviour during tasks	X	X		X
TP3. Performance in terms of self-evaluation		X	X	
Group functioning				
GF1. Active participation behaviour	X	X		X
GF2. Social grounding	X	X	X	X
GF3. Skills that monitor and facilitate the group's well-being		X		X
GF4. Group processing		X	X	X
Social support				
SS1. Commitment toward accomplishment of the common goal	X	X	X	X
SS2. Level of peer involvement	X	X	X	X
SS3. Achievement of mutual trust		X	X	
SS4. Motivational and emotional support to peers		X	X	
SS5. Conflict resolution		X	X	X
Learning performance and outcome				
LPO1. Flexible knowledge about the problem at hand	X	X	X	X
LPO2. Effective problem-solving skills		X	X	X
LPO3. Self-directed learning skills		X	X	X
LPO4. Intrinsic motivation		X	X	X

Table 2. What tools of the VW contributed to the development of your knowledge about the problem? (Bad 1 2 3 4 5 6 7 8 9 10 Excellent).

	Average	Median	Mode	St.Dev.
Resources	5,5	7	7	2,9
Annotations	6	6	6	1,6
Comment listener	4,1	5,5	0	3,7
Interactive objects	6,7	7	7	1,4
Chat (text)	7,5	8	9	1,9
Voice Chat	9	10	10	0,5

5.2.1 Task Performance

With respect to the problem-solving capabilities demonstrated and related actions taken, we observed that students devoted a large portion of their available time to discuss about the understanding of the design problem. These were intertwined with intervals of self-directed learning, which occurred either from ‘assignments’ or ‘requests’ by other team mates (e.g. “will you find photos and content about hotels?”) or from individual initiative (e.g. “I can find some text to write about Syros history”). This was also identified by the dialogue analysis (Fig. 4): most of discussion was about the procedure and task coordination (38.7%) and acknowledgements (24.0%), while less time was devoted to discuss about the task status (6.2%) and to refer to virtual objects and tools (11.0%).

Self-evaluation of individual and group performance was quite similar for all participants. The average self-rating of their individual performance regarding the use of the system was: 7 (1: Bad – 10: Excellent) (st.dev.: 1.1). That was pretty much their rating about their team’s performance, i.e.: an average of: 7.1 (st.dev.: 1.3). Their responses varied more, when they were asked about their performance with respect to the task of user interface design: they rated their individual performance with an average of 6 (st.dev.: 1.8) and their team’s performance with an average of 5.9 (st.dev.: 1.9). Given that we closely observed the process, we consider these as rather misbalanced self-assessments: in fact, students faced many difficulties in using the VW, and the fact that they finally achieved to make use of the tools encouraged them to rate their performance rather highly than appropriate. On the other hand, the final outcome of the process was interesting from many aspects. Students have underestimated their performance in this respect because they needed more time for improvements.

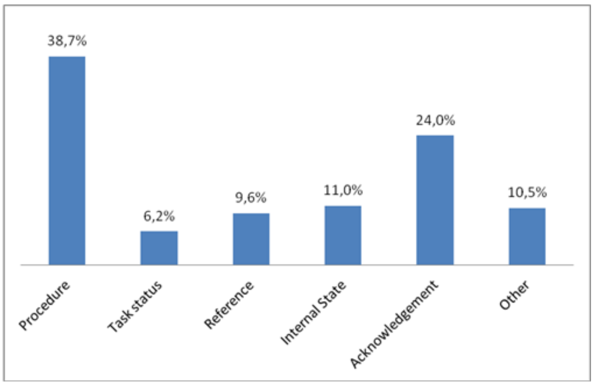

Fig. 4. Types of utterances.

5.2.2 Group Functioning

With regard to active participation, we observed (mainly from dialogue analysis and self-reporting) that all participants were actively involved in the collaboration and conversations, especially in the first phases of the collaborative activity. However, there were 2 students that gradually decreased their contributions. They reported that the experiment lasted too long, and they were tired by the process, despite that they enjoyed the experience overall.

All teams exhibited active interaction skills with respect to monitoring the progress of group work; this was evident especially from dialogue analysis: a rather large number of utterances were questions about how to proceed with the activity and specific tasks (14.1%), while there were also a large number of acknowledgements (24.0%) of group work. Each team used a different style of coordination of the work. Team 1 demonstrated a totally balanced coordination scheme without someone taking up a leading role. The other two teams quickly established a leader (in both cases the person who had more experience with the use of the VW) and allocated roles during the collaboration: the main roles were those of the 'visual designer', who also sketched the layout of the screens and the 'content designer' who located and edited content (mainly images and text). All participants reported that the result of their work was a collaborative product and that the environment contributed to their collaboration.

5.2.3 Social Support

All participants and teams performed very well with respect to social support: they were all highly motivated students, who were acquainted to each other. More specifically, they rated their commitment towards the achievement of their goal at an average of 7.5 (1: Poor – 10: Excellent), and the main reason for this rating not being higher was that some of the participants got carried away out of their curiosity to explore the VW! When they had to wait for other team mates, they kept exploring the world in a playful manner.

Regarding conflict resolution, we identified that there were several disagreements during the learning task about aspects of the design. This was natural since that all participants were mature design students and had their own different opinions on the design; however, these were openly expressed, discussed and quickly resolved. This is a positive finding: the collaborating participants in the VW seem to be encouraged to individually contribute to group work as well as to constructively resolve conflicts that may arise.

5.2.4 Learning Performance

Regarding the learning performance and outcomes, the main result was that all three teams achieved the goal of the exercise (i.e. to provide the design of the user interface of an information kiosk), at a fairly satisfactory level. All teams demonstrated interesting designs that took related guidelines and content into account. However they all reported that they would need more time to elaborate their design solutions.

The participants reported that they gradually developed their knowledge about the activity at hand to a considerable extent (an average of 6; 1: Bad – 10: Excellent; st. dev.: 1.2). They also reported that they devoted about half of the time in self-directed learning: an average of 4.4 (1: None – 10: All; st.dev.:2.3). Also, when asked in which situations they best contributed to the team as with respect to whether they followed the agreed plan, they admitted that their contributions were more suitable when they stick to the plan (an average of 7.2; 1: Alone – 10: "I stick to the plan"; st. dev.:1.9).

Regarding the issue of developing problem-solving skills, students first reported on a number of problems faced: most students reported difficulties in using the VW, and a few found it difficult to document their design choices and their opinions with some of the tools provided. Then they reported on their ability to overcome these, an average of 5.2 (1: Bad – 10: Excellent; std. dev.: 2.4). The main reason for not performing better in this respect was that they had limited experience with previous use of VWs. However, we note that the final outcome of the activity, i.e. the user interface design was quite satisfactory for all teams.

6 Discussion

The experience had several positive aspects. The fact that users had a shared persistent workspace was perhaps their most important and recognized advantage of the system. All students reported that they felt engaged and motivated to work towards their common goal. They highlighted the fact that they could easily log off or postpone some of their activities in the world (especially when they performed self-directed learning activities) and they were able to see their other mates' progress when returning to the world. Discussions about the problem and tasks were easy to carry out in the VW, since they all had their own material uploaded on the shared space. Also, it was natural to compare design ideas and comment on others' work. Students arranged user interface screens in some logical order and organized discussion sessions for each screen as well as all-together. The environment was fun and kept them occupied all the time, even at times when they had to wait for other team mates to deliver their parts of the work. Finally, the increased awareness of others' work and activity and progress was also reported as a positive aspect of the environment, mainly as a motivating factor to one's own work.

On the other hand, a number of problems and drawbacks have been identified. First of all, collaboration without voice seems to be a problem. There were a couple of situations when only text chat was available (due to temporary problems of the voice server), and participants felt quite restricted in their communication. Also, a few users reported that their attention was more on the difficulties of using the environment, especially in the beginning, rather than on the user interface design task. The teams discussed and planned their activities, but they did not manage to keep track of all their coordination decisions. Despite that there were available tools in this respect, some of them found it hard to use them. Some students did not like the fact that the roles of each participant were not visible by their avatars and they also wished for more '2D functions', e.g. the possibility to embed applications from their desktop environment to the VW. Finally, perhaps the most important problem for this study was the lack of familiarity with the environment. Students faced several problems during the use of the environment and often asked how to perform certain functions. They felt that if they were more familiar the final result would be much better.

The main recommendations made by the students are the following:

1. Shared whiteboard for sketching. Sketching is an important tool for collaborative design activities and was not supported by the VW. Some participants sketched on paper and scanned their drawings, while others used

external drawing applications. The sketches were then uploaded as images in the world.

2. Tools for organization and coordination of team work. Some form of a shared agenda as well as the direct visibility of roles (e.g. as part of their appearance) would be an asset.
3. Tools for collaborative writing in the world. Shared boards for presenting and editing notes and comments would also be helpful tools during design activities.
4. More privacy. Some users reported that they needed to chat directly to their team mates, without others hearing and interfering with their discussion.

7 Conclusions

In this paper we presented the design, facilitation and evaluation of a problem-based learning activity in an open source VW platform that took place in the form of an academic lecture. The current state of the art includes too few studies of PBL in VWs with work that is still conceptual, while information about detailed evaluation with regard to specific methods and practices is lacking.

The application of PBL in VWs revealed quite encouraging results. The learning session managed to capture the attention of students, to trigger self-directed learning activities, and to foster collaboration and discourse between them. The study also highlighted a number of problems that were mostly related to activity awareness, resource sharing and coordination issues. Some of these obstacles are based on inherent deficiencies of the specific platform that we used and have been tackled in other multi-user virtual environments and in own current work (e.g. the use of a shared whiteboard); while others are still open issues. Further research is needed towards the design and evaluation of novel metaphors, tools and paradigms for student collaboration in learning activities in order to overcome these difficulties and to improve the effectiveness of VWs as learning environments.

As to the nature of the issues explored, we are applying and refining our approach in other courses and contexts that involve more VW tools, longer assessments, more student groups and different problems [33,34]. We are also working to address several of the issues identified, mainly those related to creating a more realistic context of the collaborative work situation: mainly with respect to remote collaboration work (i.e. connection to the VW from the pragmatic work environment) and real projects that will also include customers. The virtual environment presented can support real interactions and collaborative work situations and can contribute to effective constructivist learning, provided that a couple of other relevant tools are built-in and some privacy issues are addressed.

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