Problem-Based Learning for Design & Engineering Activities in Virtual Worlds

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Abstract. There is a growing number of Problem-Based Learning (PBL) studies in Virtual Worlds (VWs); however the suitability of these approaches is still unknown for particular knowledge domains and in full-time courses. In this paper we argue that VWs can support a constructionist approach to PBL for blended practice-based courses of design and engineering, and we describe an instructional design framework and its application at an HCI (Human-Computer Interaction) design course. The approach places emphasis in 'learning by doing' and enables students to collaboratively work in authentic and ill-defined situations, follow self-directed routes to address problems, and construct digital artifacts as candidate solutions. The proposed approach translates the principles of PBL into guidelines for setting up a VW as a learning environment, building supporting tools and implementing learning activities that require from students to create digital models that reflect their understanding about their learning. We have applied the framework in a blended postgraduate course in HCI Design that involved various PBL activities and the application of methods related to the lifecycle of interactive product development (including user research, conceptual design, prototyping and usability evaluation). The results were encouraging with respect to the applicability of the approach, students' acceptance as well as perceived usability of the VW environment and tools in the long-term.

Keywords. Virtual Worlds; Problem-Based Learning; Blended learning; Design & engineering; Human-Computer Interaction; Constructionism; Framework;

1 Introduction

VWs are characterized by an integration of unique affordances that can support constructivist learning, thus allowing students to develop their own understanding and to participate actively in the learning process. When users interact with a VW they get to some extend the feeling of 'being there', a sense originally referred as presence (Zahorik & Jenison, 1998) and more recently re-defined by Slater (2009) as the combination of the illusion of being located in the digital space (place illusion), and the illusion that what is happening there is real (plausibility illusion). This subjective state of mind leads to the perception of the VW as a space in which learners co-exist, rather than an external system they are interacting with, and the users' immersion in this digital environment may activate experiential and situated learning (Dede, 2009). The characteristic of persistence found in VWs allows users co-create the learning content, to construct their own meaningful structures, and to communicate them to their peers. The expressiveness of animated 3D graphics and real-time interactive simulations can be used not only to create realistic places and objects, but also to reify abstract or complex concepts using visual metaphors, or even to overcome physical limitations (e.g. by altering the rules of spatial proximity to transform social dynamics and improve learning (Bailenson et al., 2008)). Learners coexisting as avatars in the VW can define their own virtual identities (Junglas et al., 2007), interact with others in richer ways, and develop of a sense of community (Bronack et al., 2008).

There is a variety of alternative pedagogies related to constructivism, most of which have been implemented using VWs in experimental or applied educational settings with encouraging results. In Communal Constructivist approaches learners collaboratively construct knowledge, publish their findings in the environment and communicate them to future learners (Girvan & Savage, 2010). Inquiry-based learning approaches let students learn as they search for information expanding their knowledge about a subject and perform in-world activities in order to pursue some goal (Barab et al, 2005). In Experiential Learning approaches students learn new concepts through active experimentation in the environment, observation and reflection (De Freitas & Neumann, 2009). In Problem- and Project- based learning approaches, students learn through their collaborative work to solve some ill-defined authentic problem (Vosinakis et al, 2011; Jamon et al, 2008). In other cases, the adoption of a dominant pedagogy is avoided and a game-based learning approach is being followed: learners are placed in a gaming environment, in which the educational content is blended with the challenges they have to face during the game, and they learn as they play (Honey & Hilton, 2011).

Besides the variety in constructivist pedagogies, there are also noticeable differences in the ways these are implemented using VWs in terms of the presentation and affordances of the environment, the challenges posed to the students and the supported activities. These mostly fall under three generic categories, which are by no means mutually exclusive. The first is based on narrative, where learners assume specific roles in pre-constructed stories and learn through their exploration and interaction with the world's contents. This approach has been followed in the case of two successful educational environments adopting Inquiry-based pedagogies: Quest Atlantis (Barab et al., 2005), an imaginary environment in which children learn science by pursuing quests that require from them to perform activities in the virtual or the physical world and to publish their findings, and 'River City' (Dede et al., 2004), a multiuser environment for learning biology, which places learners in a storyline regarding the spreading of an illness in a 19-th century city. The second category is based on simulation and experimentation: students are asked to interact with a simulated environment through free or guided experimentation in order to enhance their understanding and reflect on their experiences. This approach has been followed in the early virtual reality learning environments using immersive hardware, such as ScienceSpace (Dede et al., 1996), a collection of VWs for experimenting with complex scientific concepts. A number of game-based learning environments focusing on training in simulated environments (Raybourn, 2007) also fall under this category. The third category is based on construction: student activities are focused on collaborative creation of new content, instead of exploring or experimenting with pre-constructed places and objects. A first example of a learning environment that included constructive activities was the NICE project (Roussos et al., 1999), in which children were free to plant a garden in a persistent immersive environment, and stories were automatically created and updated based on their actions. In another example (Barab et al., 2000) students learned astronomy by building models of the solar system in 3D.

The focus of our work is on the design and use of VWs for practice-based courses of design and engineering, in which students are required to construct some working prototype of a system or artifact (tangible and/or digital). In this sense, a constructionist problem-solving approach would be more appropriate as it may extend the ability of students to ‘construct’ from the mental space to the physical (and/or virtual) world. Therefore, we claim that Problem Based Learning (PBL) is a suitable pedagogy for virtual learning environments in these disciplines. In PBL (Hmelo-Silver, 2004; Wood, 2008; Kwan, 2008; Barrett & Moore, 2010) students learn by addressing ill-defined and open-ended, real-life problems, collaboratively, initially having little knowledge about the problem domain. During the problem-solving process students identify their knowledge deficiencies, decide what they need to learn, propose solutions, evaluate them and reflect on their experiences, thus developing problem-solving strategies and building domain knowledge in a self-directed manner (Savery & Duffy, 1995). In addition to the above, in practice-based courses of design & engineering students are also required to construct some working prototype of system or artifact (tangible and/or digital), therefore a constructionist (Papert, 1980) approach to PBL is required that extends the ability to 'construct' from the mental space to the physical (and/or digital) world.

The aim of this paper is to propose a novel approach and framework for the design and use of VWs for PBL activities in design & engineering education and to present its application in the context of a blended Human-Computer Interaction design course. The proposed approach translates the principles of PBL into guidelines for setting up a VW as a learning environment, building supporting tools and implementing learning activities that require from students to create digital models that reflect their understanding about their learning. We have followed this approach in a full-time, blended postgraduate course on HCI design, in which groups of students had to research, design, construct prototypes and organize the user-centred evaluation of public interactive installations by discovering, selecting and applying appropriate methods. The evaluation results and the experiences out of this course were very encouraging, as they indicate the potential of VWs to support constructionist PBL activities in the VW. However, a number of challenges related to technical or usability issues have been identified and are also discussed for further applications of this work.

2 Related Work and Scope

2.1 On the Foundations of Problem-Based Learning

Problem based learning is regarded by many as a total approach to learning (Barrett & Moore, 2010), as a philosophy about learning (Neville, 2009) and as a learning strategy (Kwan, 2008), rather than simply a method of teaching. The theoretical foundations of PBL can be traced to the traditions of constructivism, constructionism, situated learning and reflective practice.

According to the tenets of constructivism, knowledge is not universal, but each person constructs his/her own representation (e.g. Duffy & Cunningham, 1996). Thus, constructivist approaches support that learning occurs when the learners' exploration uncovers inconsistencies between their knowledge representations and current experience, and when they develop mental models on the basis of their own backgrounds and skills. Papert (1980) has proposed constructionism as a particular approach within the constructivist tradition that requires from learners to additionally construct tangible artifacts to reflect their learning progress. He argues that "*building knowledge structures … happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity*" (Papert & Harel, 1991).

In situated learning (e.g., Lave & Wenger, 1991; Anderson et al, 1996) the main idea is that much of what is learned is specific to the situation in which it is learned. According to the situated learning approach, learning should occur in an authentic context related to practice and that the collaboration between groups of learners (as well as between learners and other potential involved partners like for example project clients) is necessary for ones learning. Situated learning shares much with reflective practice, which has been described by Schön (1987) as the iterative process of 'learning by doing' and 'reflection-in-action' that is followed by practitioners like architects, psychotherapists, engineers, planners and managers. According to Schön, *“practitioners themselves often reveal a capacity for reflection on their intuitive knowing in the midst of action and sometimes use this capacity to cope with the unique, uncertain, and conflicted situation of practice“*. The reflective practice approach for learning requires from the tutor to observe, discuss and review students’ practice when it occurs, and to intervene at the students’ zone of proximal development (Vygotsky, 1978), the point where practice is hard enough to learn without help but not too difficult to grasp through tutor critique, coaching and scaffolding.

2.2 Principles of Problem-Based Learning and Differences from Other Approaches

PBL has a long tradition in academic education and a number of universities and schools have adopted it as their principal learning strategy (e.g. McMaster Medical School, Maastricht University and Aalborg University). Savin-Baden (2007) presents a detailed history of how PBL spread internationally, first in medical schools and then other fields, including engineering, computer science, business, architecture, economics, educational administration and law, and refers to the adoption of PBL at universities in Denmark, Finland, France, South Africa and Sweden. The world-wide adoption of the PBL philosophy in distinct schools and courses has resulted to various methods to implement a PBL course, notably the “seven-jump” PBL tutorial applied at the Maastricht University, the 5-step PBL process proposed by Hmelo-Silver (2004) and others. The availability of different methods and models for PBL implementation has been identified since its initial descriptions as a distinct pedagogical approach by Barrows (1986). Nowadays, it is widely acknowledged that the exact steps of PBL implementation may be modified according to particular course requirements provided that the key principles of PBL are followed, which can be summarized to that: (a) students are provided with an authentic problem that is related to practice; (b) students work in groups; (c) self-directed learning occurs (beyond group work) and therefore students become responsible for their own learning; (d) the tutor acts as a facilitator pursuing students' deep learning.

More specifically, in PBL (e.g. Kwan, 2008; Wood, 2008; Hmelo-Silver 2004; Wood, 2003), students are presented with an ill-defined problem that is related to professional practice, for which they have to work in groups to identify the route to a solution. Group work identifies knowledge deficiencies and then self-directed learning is required from each student that rests on their individual student interests and skills, thus taking responsibility for their own learning. PBL must not be confused with problem solving, which involves the derivation of a single correct answer from a well-defined problem, using a formal and rigorous process. In sharp contrast, in PBL the problem is authentic and related to practice; the process of inquiry (or a methodology) needs to be identified by the learner; the outcome is essentially a unique proposal to tackle the problem. Furthermore, the role of the tutor in PBL is notably detached from student work: it is that of the facilitator of the process (Wood, 2008) that does not provide direct help or corrections but rather poses questions and challenges to provoke deep student learning.

PBL has often been related to Project-Based Learning (PjBL) (e.g. Krajcik & Blumenfeld, 2006; Capraro & Slough, 2009), mainly due to the realistic and authentic context for problems/projects provided in both approaches. According to Thomas (2000) "*projects are complex tasks, based on challenging questions or problems, that involve students in design, problem-solving, decision making, or investigative activities; give students the opportunity to work relatively autonomously over extended periods of time; and culminate in realistic products or presentations*". The PjBL tradition is common in schools of management, computer science, and engineering. The main differences of PjBL to PBL include that students are usually provided with methods or a methodology that has to be applied. In addition, the tutor can take up many roles during the lifetime of the PjBL course like: coach, project member, reviewer, etc., in contrast to PBL where she has to act as facilitator without coaching.

Inquiry-based learning (IBL) has also been compared to PBL much due to the open-ended nature of the problem/inquiry that is pursued by either approach. The main claim of IBL is that "*engaging learners in scientific processes helps them build a personal knowledge base that is scientific, in the sense that they can use this knowledge to predict and explain what they observe in the natural world*" (Van Joolingen et al, 2007). Thus IBL emphasizes scientific investigations that engage students into the processes of science (De Jong 2006): orientation, stating hypotheses, experimentation, creating models and theories, and evaluation. The main differences of IBL to PBL include that IBL emphasizes the use of scientific methods and usually requires rigor and documentation in contrast to PBL that emphasizes group work in problems of professional practice that may not require a scientific approach per se in favor of empirical and professional practices. Furthermore, in PBL that students are responsible for their own learning, while in IBL it is typical that tutors advise on scientific methods that should be employed.

2.3 Applications of PBL in the Classroom and in Blended Learning

The power of the PBL approach has been argued for teaching science, engineering, and the design of computer systems since the mid 90ies. According to Allan (1996) PBL "*provides a powerful alternative to the passive lecture tradition in introductory science courses in biology, physics, and chemistry*". PBL has been proposed as a vehicle to transform computer science education towards students' active learning and involvement into problems that are related to practice. Nelson (2003) argues that PBL can be employed to restructure computer science courses, programs of study, or entire institutions provided that professors conceptualize "*curriculum as problems, place students in the role of designers, and reconfigure classrooms as design studios*". Schultz & Christensen (2004) report on the implementation of the highly structured seven-step problem-based learning (PBL) procedure as part of the learning process in a human–computer interaction (HCI) design course at the Technical University of Denmark and conclude that the students "*definitely took a deep approach to learning, and … obtained competencies not only within the traditional HCI curriculum, but also in terms of teamwork skills*".

The traditional approach to PBL through classroom sessions has been subject to critique in terms of organizing and coordinating the process (Hoffman & Ritchie, 1997). To overcome these obstacles, a large portion of PBL courses are now blended with the use of various online technologies that support various aspects of the process in medical teaching (Moeller et al, 2010; Raupach et al, 2010), mathematics (Chang & Wang, 2011), electrical engineering (Montero & Gonzalez, 2009), information science (Bozic et al, 2009), computer science (Baturay & Bay, 2010; Chhabra & Sharma, 2010), software engineering (Richardson et al, 2011, Silva et al, 2011) and human-computer interaction design (Nordahl & Serafin, 2008).

Various benefits of using online technologies with the PBL approach have been reported. In medical teaching Moeller et al (2010) report that blended PBL profits best from supporting asynchronous communication (i.e. Wiki), while synchronous communication components and hypothesis-driven information retrieval do not yield further improvements. In an introductory computer science course, Baturai & Bay (2010) report on a comparative distance learning study that investigates the effects of PBL on two student groups, the first using the standard online tutorials, and the second that worked with PBL project assignments; the results indicated that students who worked on problem-based projects felt much more ‘connected’ to other class members and achieved higher scores in the post-tests. In a study of a computer science source that followed PBL with blogging, Chhabra & Sharma (2010) conclude that a significant difference was seen between performance and attitude of the treatment group (PBL with blogging) and control group (only PBL) for lab sessions, and that teamwork and communication skills were also significantly improved in the case of PBL with blogging class.

2.4 Applications of Problem Based Learning in Virtual Worlds

A number of case studies have been presented in the last few years that involved PBL activities in VWs (Brown, et al, 2008; Good, et al, 2008, Omale et al, 2009, Vrellis et al, 2010, Vosinakis et al 2011). These studies present encouraging results of applications of PBL in terms of experimental course sessions and studies but they have not been applied to full-time courses.

Brown et al (2008) engaged students in machinima production in Second Life (SL), i.e. the generation of cinematic video by capturing in real-time the rendered screen of VWs and suggest that the development of wider transferable skills can be realized effectively through VW such as SL when a PBL approach is followed. Good et al (2008) reported findings from a case study with a ‘strong’ PBL approach where students were tasked to create learning experiences within SL for external clients. 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. Vrellis et al (2010) used SL to implement the collaborative problem-based learning activity of a simple physics experiment, which involved the calculation of the direction of a bullet in a shooting task by pairs of students using the tools of a calculator, two rulers and a shared whiteboard. The empirical results highlighted several advantages of VWs for constructivist learning, such as the persistence of the environment, the in-world object manipulation and the use of learning tools. Vosinakis et al (2011) presented an exploratory study of PBL in user interface design of a multimedia kiosk that occurred in the VW with specific collaboration and development tools, and they have identified several positive outcomes regarding the impact of the approach on student collaboration for idea generation, co-creation and the final outcome of the design activity.

Notwithstanding the value of these approaches for investigating the appropriateness of VWs as constructivist learning environments, most of these do not fully conform to important PBL principles mainly because they do not pose authentic, ill-defined problems to students who in turn are not engaged in self-directed learning and deep critical thinking. In some cases the problem domain was related to activities that are inherently supported by VWs, e.g. machinima production or construction of learning spaces, and in other cases the 3D environment has been mainly used for group discussions and brainstorming. In many cases, the use of tools designed specifically to experiment with various problem solutions have not been included and the open-ended environment of Second Life (SL) has been used as is; however, VWs are not learning platforms per se but they need to be designed as such. Finally, most studies are limited in time and exploratory in nature calling for wider implementation of the approach.

2.5 The case of Problem-Based Learning for Design & Engineering Education

In design & engineering education students are expected to apply their theoretical knowledge in problems that they will encounter in their professional life. Much of what is taught in these disciplines is related to examples from professional practice presented by their teachers in the classroom and to problem-solving in the form of exercises in the lab. However, what is more important is to engage students in authentic situations and projects in between the classroom, the lab and the field. According to Jonassen et al (2006) "*learning to solve classroom problems does not necessarily prepare engineering students to solve workplace problems*". If we place design engineering students into an authentic problem situation, they are immediately encountered with decisions about (among others) form, function, materials, mechanics, software, ergonomics and usability, in unique conditions related to the particular knowledge and skills of the design team, client requirements, user group characteristics, time constraints and costs.

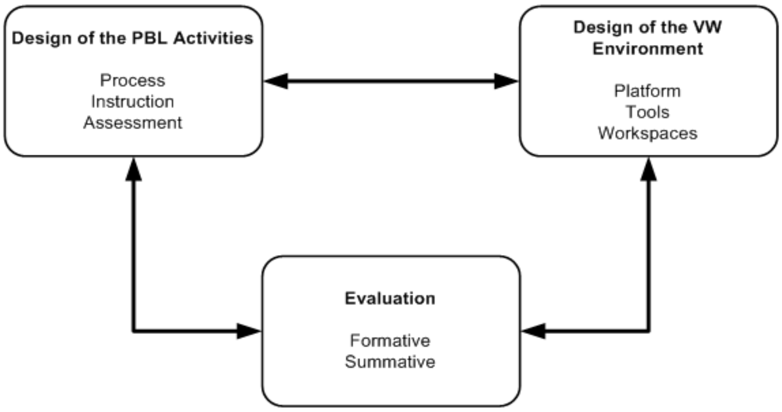
An additional requirement for design & engineering education is that students should be capable at some point of developing tangible (including digital) artifacts (prototypes) that reflect their decisions and practice; this typically happens in their thesis work - but it may certainly happen at problem- (or project-) based courses at their later years of study. These artifacts are subject to multiple evaluations and experimentation with both objective and subjective criteria that are identified during the design and development process which is typically conceived as iterative and incremental. This requirement of design & engineering education is unique with respect to other practice-based disciplines (like for example medicine and law) in which rational decision making is more important, and there is limited, if any, room for construction and experimentation of solutions or prototypes.

PBL is a suitable approach for design & engineering education because it requests that students are presented with an authentic problem; they must work in groups (this is also a requirement for design & engineering practice); they are empowered to take responsibility for their decisions and their learning in a self-directed manner according to their interest and skills. In addition the PBL approach needs to ensure that students work in an environment that allows them to construct and test prototype solutions for the problem given.

Certainly, a modern approach to design & engineering education requires that students work in a digital environment that can complement field work and physical communication with computer tools for asynchronous and remote work and digital modeling and evaluation of artifacts. PBL may certainly supported with a combination of web technologies and tools for communication, collaboration and 2D/3D digital modeling, which is closer to the professional practice of a design engineer, but still requires proficiency in using multiple technologies and tools which pose particular burdens to students. An alternative technological approach is to design and develop PBL in VWs. This fairly new medium may not have yet reached the level of maturity of other, more popular solutions and may still not be as robust and usable. The quality of avatar-based communication is not comparable to video-conferencing, its use as a modeling and visualization tool lacks the detail and visual quality of professional modeling applications (Koutsabasis et al., 2012), and it cannot offer the level of organizational support found in Learning Management Systems. However, VWs integrate unique affordances that allow for activities that are not easily found, if at all, in the web, like co-presence, role-playing, co-construction and simulation. These affordances are of particular importance for a blended, constructionist approach to PBL in design & engineering practice-based courses.

3 A Framework for the Instructional Design of Problem-Based Learning Activities in Design & Engineering Courses in Virtual Worlds

We propose an approach for the instructional design of practice-based Design & Engineering courses in VWs (Figure 1) following a PBL pedagogy that consists of 3 intertwined stages. The first stage is the *design of the PBL activities.* During this stage designers decide about the organization and support of the student activities throughout the course, the scaffolding and technical assistance by the instructors, and the assessment of the students' work. The next stage is the *design of the VW environment*, which involves the selection of the platform that is going to be used, the interactive tools that will be developed to support the learning activities, and the construction and configuration of the in-world learning workspaces. The final stage is the *evaluation* of the instructional design process that provides formative and/or summative feedback on the environment and activities.

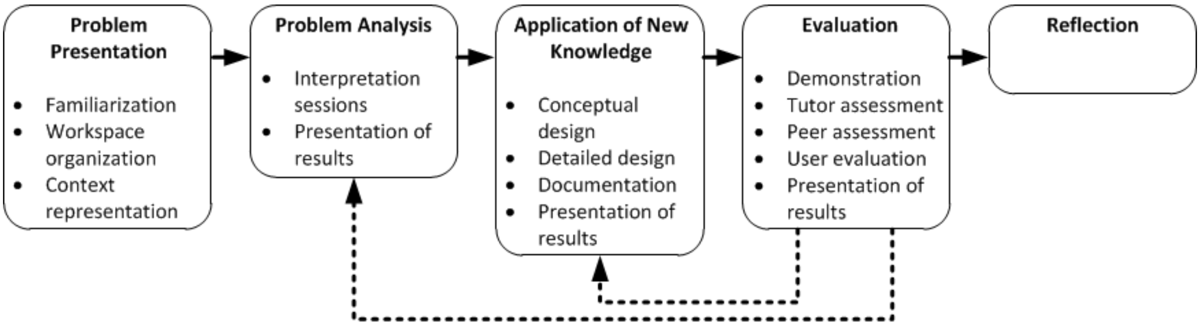


3.1 Design of the Problem-Based Learning Activities

The first stage of the framework is the design of the learning activities, which is described in terms of process, instruction and assessment.

3.1.1 The Process of Problem-Based Learning

The proposed approach to implementing the PBL process in a VWs is based on the learning cycle presented by Hmelo-Silver (2004), extended with technologically-enhanced approaches to constructivist learning (e.g. Harper & Hedberg, 1997; Lefoe 1998) and taking into account the affordances of VWs (Figure 2). It includes the stages of: problem presentation, problem analysis, application of new knowledge, evaluation and reflection.



Problem presentation. The PBL process starts with the presentation of an authentic, ill-defined problem by instructors to groups of students. The nature of the problem is such, that it requires the construction of some complex environment, system, artifact or process as part of its solution, e.g. an authentic problem in service design would be to re-design and re-organize the customer support service of a bank. The initial status of this problem can be presented in the VW by building a realistic context (e.g. the bank environment) and by enhancing the environment with documents (text, images) that present the initial information about the problem. The proposed student activities to be carried out in this stage are:

- Familiarization: the VW platform is introduced to the students and they familiarize themselves with the provided tools and places
- Workspace organization: students organize their personal and group workspaces by adding the appropriate collaboration tools and arranging the places to host group meetings and to publish the intermediate deliverables of the project
- Representation of problem context: the physical (3D) and abstract space (e.g. specifications) describing the problem context is further constructed and specialized based on students' understanding of the problem brief.

Problem analysis. Students work in groups to further understand the problem, discover their learning needs and design action plans. They can meet in the VW in order to identify the facts of the problem, to form new hypotheses, to detect knowledge deficiencies and to decide about future actions. Log files and minutes of their discussion may be stored for later reflection and published in whiteboards or as external links. The proposed student activities to be carried out in this stage are:

- Interpretation sessions: group meeting for problem analysis, in which students interpret and analyze the problem, identify issues that need to be further explored and researched (e.g. theoretical information about the problem, selection of appropriate methods, etc), and plans for future actions including self-directed learning assignments.
- Presentation of results: publishing of deliverables and resources (e.g. discussion logs, reports, external links) in the VW, possibly organized in chronological order and grouped by similarity; publishing of plans of actions.

Application of New Knowledge. In this stage, students are engaged in self-directed learning activities to address their knowledge deficiencies and then come back to the group to apply this into the construction of a solution to the problem. The problem solution is initially constructed in some conceptual form that outlines its' most basic features and then iteratively refined with more details, and presented in a realistic context with simulated behavior in the VW. The design choices can be explained and justified by attaching annotations in (parts and aspects of) their constructed solution. The evolution of the proposed solution, the design choices and the methods that have been applied may be depicted by publishing and organizing intermediate results and reports inside the virtual workspace. The proposed student activities to be carried out in this stage are:

- Conceptual design: collaborative creation of concepts (sketches, drawings, scenarios, etc); machinima may be also used for scenario-based design.

- Detailed design: collaborative construction or assembly of candidate solution using the tools provided
- Documentation of the design rationale: publishing of design choices and methods used for respective parts of the solution
- Presentation of results: grouping and organization of deliverables in workspace

Evaluation. The proposed solution is presented to the instructors and possibly peers, who can inspect the intermediate deliverables and the course of actions and choices that led to the solution. Comments and request for further explanations are posted in the environment by instructors and fellow student groups. In some disciplines, the solution may need to be evaluated by prospective users, e.g. if the usability of the proposed solution is in question. In these cases students may organize user evaluations in the VW. The evaluation in this stage is formative, and the group attempts to identify drawbacks in their solution and to propose alternatives. In some cases the evaluation results may reveal further knowledge deficiencies or alternative ways of applying new knowledge and make the group move back to the previous stages of the process to revise their work. The proposed student activities to be carried out in this stage are:

- Demonstration of solution: the proposed solution with its rationale and the intermediate design stages are publicly presented
- Tutor assessment: Tutors go through proposed solutions and provide questions and comments to facilitate deep student learning
- Peer assessment: Students inspect fellow groups' solutions and post comments and questions

- User evaluation: indicative users interact with the designed system or artifact to evaluate its usability
- Presentation of results: students publish evaluation results and plans for further actions, if required.

Reflection. In the final stage, students reflect on the abstract knowledge gained during the PBL process by creating reports in the form of resources or attachments that explain their design choices and address the questions raised during the evaluation. No specific activities are required in the VW.

3.1.2 Instruction

In PBL, instruction focuses on asking questions that challenge students' progress, knowledge and critical thinking, thus pursuing deep learning (Azer, 2009). Instructors act as facilitators who keep the PBL process running and mediate within student groups to help overcome difficulties identified during the research and self-directed study; however avoiding coaching and correcting students' work. Therefore, instruction in PBL has to follow a number of principles and strategies to support the students become self-directed learners while maintaining a student-centered learning process (Hmelo-Silver & Barrows, 2006).

In the VW, activities that can be set up to enable PBL facilitation include:

- Whole-class meetings: Instructors can schedule regular meetings in the VW, where the groups will present their progress and the whole class will discuss about the work presented and reflect on the discussions and comments.
- Building resource lists and showing examples of problems and solutions: Instructors may further assist the process by directing students towards specific resources or resource collections and by presenting other working examples.

- Group Meetings with Instructors: Additionally, they can organize meetings with each of the groups to be informed about the role assignments and the planned actions and to make sure that the groups are collaborating without problems.
- Asynchronous reviews of student work: Instructors may also review the groups' work by visiting their in-world workspaces and inspecting their messages, drawings and solutions. In this case they may attach annotations asking for further clarifications when needed.
- Technical assistance: For all activities, it is important to schedule specific hours on a regular basis for technical assistance. Given that users with less experience in 3D environments are expected to have difficulties using the VW platform and the tools provided, assistance by the instructors will be necessary to overcome technical difficulties.

3.1.3 Assessment

The assessment of the PBL process refers to the intermediate learning results and outcomes from every course lecture. The scope of assessment in a PBL process is to measure the extent to which the content learning objectives of the course have been reached by the students, as well as to assess if higher-level skills like critical thinking, group work and communication skills are exhibited. During assessment, instructors have to track the work progress of student groups as well as the atomic contribution of students in group work. For design & engineering problems, work progress can be mapped onto milestones or phases of a typical model of the development lifecycle, which can be defined by students themselves and help them to plan their actions and keep track of their progress.

The VW may provide useful information towards assessment of PBL sessions by supporting the following activities:

- Review of problem solution and quality assessment: Reviewing student work and assessing its quality is typically made by the instructor in an empirical manner, with the use of synchronous and asynchronous tools. In addition, peers can also provide reviews in sessions organized according to a particular method like for example (remote) usability testing for the evaluation of user interfaces (Madathil & Greenstein, 2011).
- Action/work planning: Instructors can provide rough work plans in the VW – or ask students to do so, in order to keep track of work progress and milestone achievement.
- Collection and processing of comments, annotations and presentation logs about individual and group effort during the PBL process: This can happen automatically by the VW to some extent, however it is important for instructors to inspect the quality of these data in order to provide assessments about the abstract knowledge gained by the student or group.
- Traditional assessment methods: such as oral and written examinations can be also set up and conducted in the VW.

3.2 Design of the Virtual World Environment

Initiating from the fundamental concepts of PBL and constructivism and taking into account the affordances and limitations of VWs, we propose that the design of the VW environment should emphasize in (a) the selection of VW platform, (b) the design of VW tools, and (c) the design of learning spaces.

3.2.1 Selection of Virtual World Platform

The VW environment should include a number of characteristics that are considered important for collaborative constructivist learning:

- Avatar customization: this feature will let students develop a sense of identity in the mediated space, which is expected to enhance their presence and engagement (Junglas et al, 2007).
- Verbal and non-verbal forms of communication: features such as text and voice chat, pointing at objects or places, and performing gestures are essential for supporting distant real-time communication between learners (Davis et al, 2009).
- User-generated content: the environment should allow users to insert their own content in the form of 3D objects, media or links to external resources. This will help them re-structure their space, explore creative ways to present and communicate their knowledge and to collaboratively construct problem solutions (Antonacci & Modress, 2008).
- Public and private spaces: the existence of private (restricted access) spaces will allow individuals organize their own resources and test and develop their own ideas in private before presenting it to the rest of the community.
- Programming / scripting language: the ability to program the real-time behavior of the world's objects is essential for implementing simulation environments and interactive tools that will be used during the problem-solving processes.

Nowadays the most popular world is Second Life, which has over 20 million registered users and has been used extensively as an educational tool. Second Life supports all of the above characteristics. However, its embedded scripting language (LSL) is not suitable for CPU-demanding behaviors, such as complex real-time simulations or intelligent virtual agents. In these cases, more sophisticated solutions such as Game Engines or Collaborative Virtual Environment platforms (e.g. OpenWonderland, Croquet) could be preferred.

3.2.2 Design of Virtual World Tools

A VW platform alone does not suffice as a constructivist learning environment. It has to be extended with the appropriate functionality to support the required student activities. We suggest a number of indicative tools that can be implemented in VWs to support the collaborative and PBL activities identified in the proposed process. These suggestions are based on the facets of constructivist learning environments proposed by Perkins (1999) and the PBL whiteboard proposed by Barrows (1992), and are adapted according to the needs of the PBL activities and the affordances of VWs. The list is indicative; depending on the problem domain and on the learning goals, some tools may be altered or the list may be further expanded. The suggested tools are:

- Resources: objects that point to or contain resources provided by the instructors or found by the students. They might provide links to external URLs or allow reading and editing of documents in the VW.
- Message boards and Drawing boards: tools to collaboratively post and edit messages and create sketches and diagrams
- Building blocks: primitive objects related to the problem domain (e.g. mechanical parts in an engineering problem), which learners manipulate to construct new concepts, artifacts or systems.
- Simulation objects: objects with scripted behavior that can be used to simulate the functionality of a system
- Annotations: tools for adding comments and explanations on constructed objects or parts of the environment
- Discussion logs: tools for storing and reproducing discussions

- Interactive presentation boards: tools for presenting in-world during remote meetings
- PBL whiteboard: an object presenting the Facts, Ideas, Learning Issues and Action Plan of the problem solving process

3.2.3 Design of Virtual World Workspaces

A number of pre-constructed spaces can be provided to the learning community to be used during the various tasks of the collaborative problem-solving processes. Redfern & Naughton (2002) propose three types of places in collaborative virtual environments to support constructivist learning communities: a) Collaborative Zones, in which the groups share resources and collaborate, b) a Campus for informal interactions between the learning community, and c) Lecture rooms as a formal environment for lecturing. Extending these categories to support the identified PBL activities, we propose the following places:

- Simulation place: the environment in which the problem context and the candidate solutions will be presented
- Group collaboration place: the workplace for each student group that will be used for resource sharing, group discussions and collaborative design of the solution and posting of intermediate deliverables
- Class meeting place: a formal place for class presentations, discussions with the instructors, common resource sharing and announcements
- Personal place: a personal workspace for each student to collect and organize resources and to try alternative solutions

The design of each place and the interactive tools to be included, again, depends on the problem domain and the typical tasks related to that domain. Prasolova-Forland (2006) presents a number of possible place metaphors for educational VWs that can be used for the construction and configuration of the above-mentioned places.

3.3 Evaluation

The evaluation of the instructional design of PBL in VWs rests on work from the fields of PBL and CSCL (Computer-Supported Collaborative Learning). The evaluation of PBL is generally dealt with various types of formative and summative tools and methods usually encoded in complex assessment rubrics (O'Grady, 2004). 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 (Dillenbourg et al, 2002; Dimitrakopoulou & Lars, 2006).

The purpose of the evaluation may be formative or summative depending on whether we want to facilitate or judge the learning progress and outcome. In a holistic approach of evaluating PBL activities in VWs all these facets of evaluation have to occur and results should be aggregated. Furthermore, evaluation methods should allow for repeatability within the project of the course and between courses (Waters & McCracken, 1997). More specifically:

- Formative evaluation occurs throughout the lifetime of the course. The focus of the evaluation is on the PBL process as facilitated by the VW, and typical evaluation criteria include the high-level goals of PBL like: critical thinking, active learning and group work. It is mediated by various VW tools like: comments, questions (and short questionnaires), annotations, presentation logs, etc. These tools can be used in subsequent lectures to track down the learning progress. The evaluators are not only the tutors, but also peers (students). Tutors facilitate the higher level goals of PBL, while peers typically provide questions, opinions and feedback to their mates both in-the-group and within-groups about both the learning process and (intermediate) outcome(s). One dimension of this evaluation should involve the VW affordances and tools themselves; in this case the aim is to provide improvements during the lifetime of the course.

- Summative evaluation occurs at the end of the course or of a PBL activity within the course. The primary goal is to judge the learning process that took place and the final (or intermediate) outcome(s). Previous assessments can be aggregated in this type of evaluation, which concerns both groups and individual students. In PBL it is often that peer evaluation occurs in this type of evaluation to some degree. Summative evaluation also examines the use of VW tools for mediating PBL activities. In this case, usability is the primary focus of the evaluation that can take place with user testing methods.

4 Case Study

4.1 Course and participants

We have applied the proposed framework in the context of a blended HCI Design Studio course in which we used a VW environment to support the PBL process. The course is offered at the MSc program of Design of Interactive and Industrial Products and Systems, at the University of the Aegean, Greece. The goals of the HCI design studio are to:

- Cultivate high-level skills to students like: a) critical thinking and reflection on the use of HCI and design, b) working in groups, and c) development of responsibility about learning;
- Develop a design project from ideation to user evaluation that is authentic and related to practice requiring field research and design work.

- Make constructive use of a number of technologies to improve students' digital design competence (Arvola & Hartman, 2008).

This was a 3-hour course for 12 weeks. All sessions were blended including about half of the time in the VW. In addition we held another 4 sessions in the VW to catch up with intermediate project deliverables. A total of 10 students participated in the course in 2 groups of 5 students with ranging backgrounds selected by the instructors.

4.2 Design of the Problem-Based Learning Activities

The proposed PBL process was followed according to the following schedule:

1. *Introduction and Problem Presentation (1 week).* The first week of the course was used to explain the approach and technology, and to provide context to the design project for each group. Students familiarized with the VW and the supporting tools.
2. *Problem Analysis (~3 weeks).* In this phase the students had to select appropriate HCI research and requirements methods and apply them to the problem. They were provided with initial bibliography, and they had to do their own study in order to specify and refine their methodology and to use it to come up with specific requirements. The results of the analysis should be posted in the VW and presented in class.
3. *Application (~ 5 weeks).* This phase requires the use of HCI and design methods for articulating design concepts and solutions. Students proposed problem solutions as designed products using the results of their own analysis and appropriate design methods. They also built an interactive prototype in the VW using the interface objects provided. All important design decisions of the group had to be justified using annotated explanations.

4. *Evaluation (~ 2 weeks).* During the evaluation phase, students had to select and use appropriate evaluation methods in order to assess the quality of the problem solution. Evaluation methods that required end-user involvement could took place in the VW using the virtual prototype. Additionally, students and instructors could use and test the prototypes and post their questions comments in the form of annotations.
5. *Final presentation and abstraction (1 week).* The last week of the course was devoted to the final project presentation in which students had to present their solution and discuss about the abstract knowledge gained from the process.

The problem presented to students was defined as follows:

> *Design a (multi-) touch interactive table or kiosk for a public place like a cafeteria, cinema or theatre. Consider alternative installations, e.g. on top of cafeteria tables or cinema seats, at the entrance, etc; the location of the installation will affect the utility of the installation and goals of the software multimedia application. The design should take into account "tangible requirements" like table form, dimensions, etc.; however it should focus on the aspects of the user interface and interaction. You should make careful and justified use of HCI design methods and deploy an evaluated prototype of the designed artifact in the VW.*

A considerable time of each classroom session was devoted to collaborative work on the identification of areas of further study and the assignment of atomic research and learning tasks for each student by all group members. All course activities required self-directed learning that occurred during the week interval. Student groups also had several in-world meetings without the instructors in their collaborative rooms.

4.3 Design of the Virtual World Environment

The VW platform was deployed entirely in open source software: the OpenSimulator application server[1], with a MySQL database and the Freeswitch[2] voice server, and the Hippo[3] viewer. This environment includes all required characteristics like avatar customisation, verbal and non-verbal communication, etc. We used OpenSimulator instead of the most popular SL, because: (a) we had more freedom to configure the environment, control user access and store user-generated content for future reference; (b) the nature of the HCI design studio requires a lot of images to be uploaded to the VW (e.g. sketches, models, concepts, prototypes) and SL charges a price per image upload; (c) most of the features of SL are already supported by the OpenSimulator platform. We kept our VW standalone, isolated from other regions to provide restricted access to students and tutors only.

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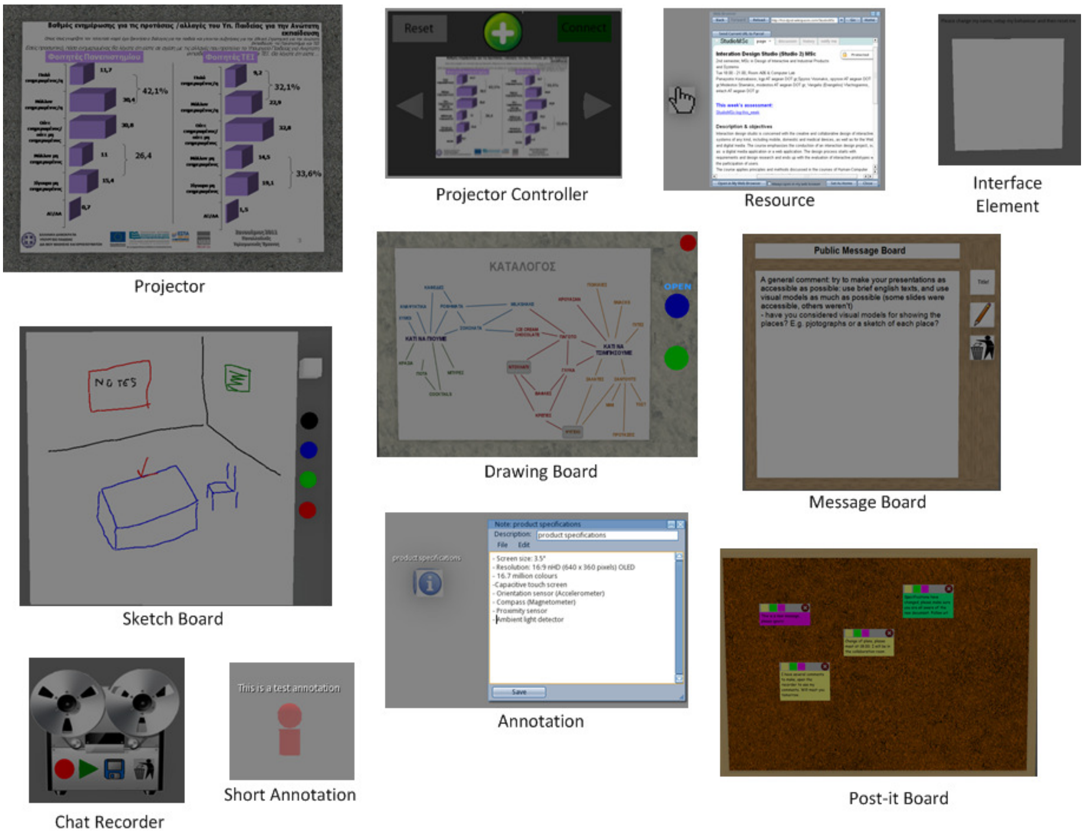
[1] http://opensimulator.org

[2] http://www.freeswitch.org

[3] http://mjm-labs.com/viewer/ - any other SL-compatible browser can be used as well with this configuration



A general comment: try to make your presentations as accessible as possible: use brief english texts, and use visual models as much as possible (some slides were accessible, others weren't)
- have you considered visual models for showing the places? E.g. pjotographs or a sketch of each place?

Description: product specifications

- Screen size: 3.5"
- Resolution: 16:9 nHD (640 x 360 pixels) OLED
- 16.7 million colours
-Capacitive touch screen
- Orientation sensor (Accelerometer)
- Compass (Magnetometer)
- Proximity sensor
- Ambient light detector

We have designed and developed a number of interactive tools based on the categories presented in 3.2 in order to aid students through their PBL activities (Figure 3). The tools were freely available in a reserved place in the class meeting room, and any student could take them in their own inventory, make copies and use them. The tools include:

- The **Projector** and the **Projector Controller** were used to prepare and show presentations in the VW.
- The **Annotation** stores notes or comments in the 3D environment and others can click on it to open the note. For simpler one or two-line notes the **Short Annotation** object could also be used, which displays the message floating above it.
- The **Message Board** is a collaborative text-only whiteboard, and it could be used for storing ideas, facts or simply group meeting notes.

- The **Sketch Board** allowed free form sketching (with the mouse) on a white surface and allowed students to quickly present concepts to each other. In addition, if more sophisticated and accurate drawings were required, students could use the **Drawing Board** that displays Google Docs drawings in the VW (they had to edit them outside the VW).
- The **Post-it Board** was used to add new text messages.
- The **Chat Recorder** allowed students to record chat sessions, play them back, or save them as annotations.
- The **Resource** allowed students to store a short description of a Web document including a hyperlink in a new browser window when clicked.
- The **Interface Element** tool was designed to be used as a building block and simulation object for the implementation of a functional user interface prototype. Using multiple copies of this object, students can progressively construct windows containing elements such as buttons and images and define their behavior using simple commands. Thus, the Interface Element could be designed by students (a) as a button (which can send events to other elements (or to itself) when clicked), (b) as a Window, which can contain other elements, and be visible or hidden and (c) as an Image Container.

Class meeting

Collaboration room

Collaboration room

Simulation

Furthermore, a number of workplaces (Figure 4) have been constructed in the VW according to the proposed framework:

- **The class meeting place;** a large classroom with table, chairs and a projector.
- **The collaboration rooms** for each one of the groups. Only group members had access to configure these rooms by inserting and arranging constructed elements and tools.
- **The simulation places** for each one of the groups; in here they constructed and evaluated their interactive prototype.
- **The personal places** for each one of the students, i.e. small rooms whose doors could be opened or closed only by the owner.

4.4 Evaluation

The evaluation process followed for the HCI design course was formative and summative regarding both the PBL activity and the VW environment.

4.4.1 Evaluation of the PBL activity

The evaluation of the PBL activity was both formative and summative. Formative evaluation occurred periodically in every lecture by both teachers and students, while summative evaluation occurred at the final course session.

In formative evaluation, the aim of the tutors was to facilitate the PBL process mainly in terms of asking questions about students' progress and providing resources. Students' evaluation included comments, questions and ideas on peers during the presentations of their work. Overall, we were very pleased with the process followed. The PBL approach enabled students to take responsibility for their own study and follow different routes to their learning and project development. These different routes to research allowed students and groups to contribute with different methods to the course content corpus. Students were also very positive about the process recognizing its novelty, although a couple of them complained at first about the 'lack of guidance' and 'lack of corrections' on their work; however they got used to the approach especially after they saw their team mates to cope well. The main VW tools used for formative assessment were: message boards, annotations, the comment recorder and the PBL whiteboard.

For the summative evaluation of the PBL course, we articulated a mixed schema that consisted of two types of assessment including project assessment (60%) and assessment of individual student skills and attitudes (40%).

- Project assessment was provided by the teachers of the course on the basis of a weighted set of criteria reflecting the whole process, method use and outcome and qualitative explanations. Therefore, students received a final written review of their work on the basis of these criteria from each tutor.

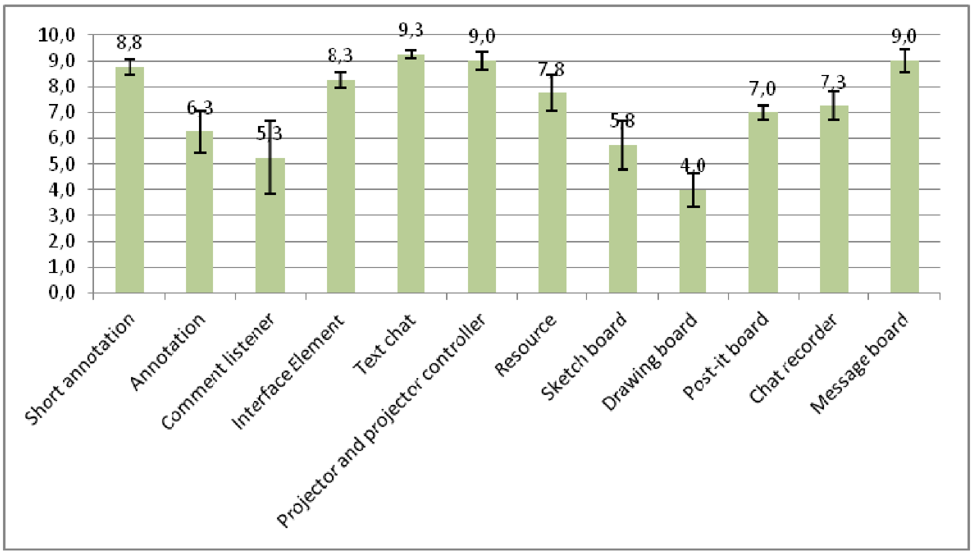
- The assessment of individual student skills and attitudes was provided partly by the teachers (10%) and largely (30%) by the students themselves who provided peer and self assessments for their groups on the basis of the high-level skills cultivated by PBL like critical thinking, self-directed learning and group work. Students and teachers filled in a PBL rubric of qualitative criteria adapted from (Yip & Ghafarian, 2000). Only the summary assessment was provided to students, not the detailed responses of peers.

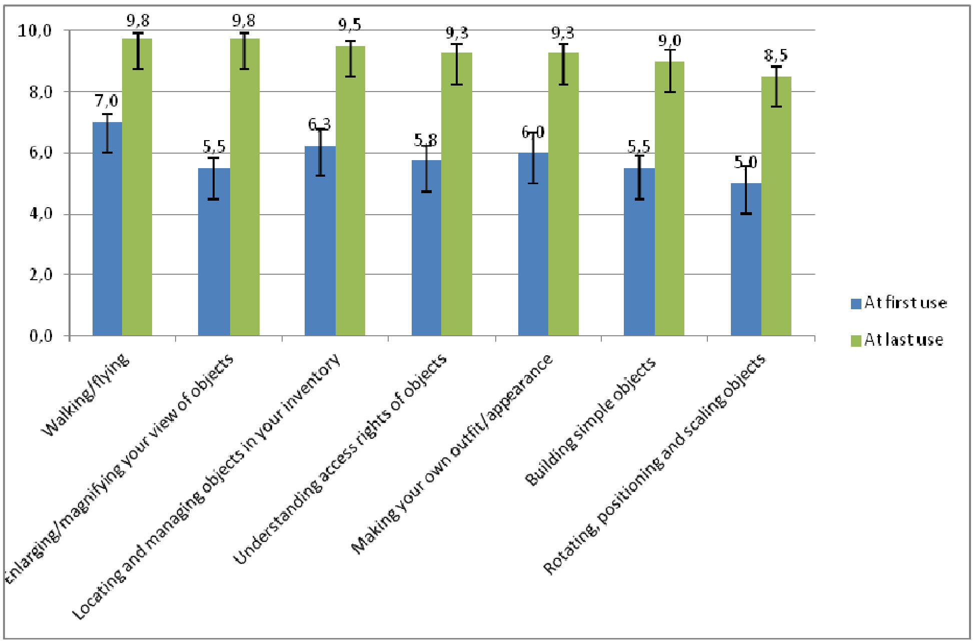
4.4.2 Evaluation of the VW Environment: Perceived Usability of VW Tools and Affordances for Design & Engineering

The evaluation of the VW environment also occurred throughout the course on the basis of student comments and requests for technical assistance that required a number of improvements. In addition to the technical support, we investigated the perceived usability of the VW with short questionnaires and interviews at the end of the course.

In the evaluation of perceived usability of the VW tools, students were first asked to rate their task performance regarding the use of each one of the tools. Students' responses (Figure 5) indicate that they managed to make good use of most of the tools. Furthermore, we investigated their perceived learning performance with respect to general skills and competences of using the VW. We were pleased to see that all students progressed significantly with the skill development in the use of VW (Figure 6). These results were also validated by our personal observations of students' use of the VW tools throughout the course.

In addition, students were asked about whether VWs can effectively support their specific problem of design & engineering. Their responses were overall positive especially for learning activities that are situated at the conceptual phases, where collaboration is intense in the exchange of ideas and determining courses of action. It was also widely reported that VWs can easily be employed in the evaluation of proposed solutions. However the granularity of solutions cannot develop in detail within this VW, and they would require other tools for that purpose. These results and experiences are similar to other studies of employing VWs in collaborative design tasks (Koutsabasis et al, 2012) that examined the use of VWs in architectural, interior and user interface design and suggest that VWs can effectively support conceptual design, design review and customer-centred evaluation in these domains, as well as offer an engaging user experience to designers and clients, however they may not adequately support detailed design activities.





5 Discussion and Conclusions

The paper presented a constructionist approach to PBL in VWs for practice-based design and engineering courses. In design & engineering education, students are expected to apply their theoretical knowledge in problems that they will encounter in their professional practice, where they will be confronted with decisions about (among others) form, function, materials, mechanics, software, ergonomics and usability, in unique conditions related to the particular knowledge and skills of the design team, client requirements, user group characteristics, time constraints and costs. An additional requirement for design & engineering education is that students should be capable at some point of developing tangible (including digital) artifacts (prototypes) that reflect their decisions and practice.

In contrast to other approaches like Inquiry-Based Learning, Guided Discovery, Game-Based Learning the proposed PBL approach does not necessarily place learners in a predefined narrative, in which they learn by observing and interacting with the content and possibly apply this knowledge to solve a problem whose solution is often pre-constructed in the environment. These approaches are appropriate for disciplines with well-defined problems that usually have a unique (set of) solution(s), like for example many scientific problems in physics, mathematics, etc., and are most usually employed in secondary education and entry-level university students. Furthermore, in contrast to Project-based Learning (e.g. Krajcik & Blumenfeld, 2006; Capraro & Slough, 2009), PBL promotes and cultivates self-directed learning and thus requires from students to 'learn how to learn' and to expand their knowledge rather than focusing on applying it with rigor. However, it requires that students are self-acting and motivated to take responsibility for their own learning, which makes it applicable for academic - rather than secondary - education.

The proposed framework aims to guide instructional designers, educators and VW/VR researchers to the preparation of the environment and supporting tools, and to the application of learning activities within it. It defines the intertwined stages of: (a) the design of the PBL activities, (b) the design of the VW environment and (c) evaluation; and within each stage a number of prospective activities, tools and workspaces are proposed. The design of the PBL activities is about the conduction of the PBL process followed (we propose a 5-step process and related activities), instruction and assessment. The design of the VW environment includes a number of suggested characteristics of the selection of the VW platform, learning tools, and workspaces where the learning will be carried out. The evaluation of the instructional design of PBL in VWs is both formative and summative and does not only examine the learning outcomes in terms of content but also includes the appreciation of higher-level skills gained by students and the user experience in VWs. The proposed approach and framework might be more appropriate for open-ended VW environments in which users can develop their avatar representations, interact with each other and collaboratively create 3D content, like SL and Opensim.

A blended, postgraduate HCI design course has been carried out following the proposed framework, and the evaluation results are quite encouraging. The VW has been used successfully during the course as a learning environment supporting collaborative work and prototyping. A notable advantage of the use of the VW compared to other technology-mediated approaches to PBL lies in the awareness and integration. The group progress was visible to all, so both the tutors and the groups could be aware of the activities that took place, observe and comment on the documents and solutions that were proposed. This integrated environment allowed remote users to collaboratively construct solutions and communicate in real-time using voice or text chat (in this case they could also record their discussion for later use). Furthermore, the VW and the tools created for the course offered various collaboration capabilities that allowed the group to work on their solution in parallel and exchange opinions and ideas through messages, drawings and sketches. Finally, the creative freedom offered by the VW in the sense that students could modify their appearance and construct and decorate their own collaborative space was highly engaging for most of them. These results comply with the claims that VWs have significant potential as constructivist learning environments.

On the other hand, a number of technical issues were faced during the use of the VW. Some students had difficulties to use the VW or the implemented tools for some time during the course, and kept asking for technical assistance. In a few cases we had to debug or extend the functionality of the supporting tools by request of the students. Additionally, the 3D modeling capabilities of the environment were not as sophisticated as in commercial applications and the rendering quality was significantly lower, as expected. This difference caused some frustration to the more experienced students with background from the arts or architecture. Some students felt that there was extra burden to convert and upload to the VW the documents that they created using familiar applications, such as Powerpoint and Photoshop and they would like to have a less complicated interface between the VW and external applications. Finally, some users found the Interface Element tool difficult and time-demanding to use, because every single component of each screen should be represented as a different object having its own behavior, and this process could be quite painstaking in the case of more complicated user interfaces. We have to note that most of these issues were strongly related to the selected VW platform and its scripting language.

We are currently applying and refining our approach in other courses and contexts that involve different VW tools, student groups and problems in the areas of interactive product design, architectural and service design. We are also working to address several of the issues identified and to set up learning and design problems that will also include customers as users of the environment. We expect that in the near future the overall picture of research in constructivist learning in VWs will be that of experiential use of designed VW platforms, in which a new breed of instructional designers will work on the creative introduction of tools and processes that facilitate constructivist learning. Furthermore, we envisage that particular methods and methodologies for constructivist instructional design in VWs will be further explored in order to allow designers to document and explicate their work to educators, students and clients.

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List of Figure Captions

Figure 1: Overview of the instructional design process of PBL in VWs.

Figure 2: A generic process for PBL activities in the VW, adapted from Hmelo-Silver (2004).

Figure 3: The implemented VW tools

Figure 4: Screenshots of various workplaces in the VW

Figure 5: Students' responses on their perceived task performance regarding the use of VW Tools (How would you rate your performance regarding your use of the tools? (1:Terrible; 10: Excellent)).

Figure 6: Students' responses regarding their perceived learning performance with respect to their skills and competence in making use of the VW (Q: Learning to interact with Virtual worlds: How would you rate your ability/skills with respect to…? (1:Terrible; 10: Excellent)).