# User Experiences and Lessons Learned from Developing and Implementing an Immersive Game for the Science Classroom

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## Abstract

We describe our experiences of the 2020Classroom, an on-going project to develop a three-dimensional immersive learning environment through a game called *Metalloman* to teach bioscience concepts to engineering undergraduate students. Specifically, this paper focuses on work towards the development of a methodology through the refinement of techniques from HCI, activity theory and digital game design to inform design and evaluation for enjoyable, engaging and motivating, as well as usable immersive learning environments. Using these methods, studies to evaluate usability and user experience to inform redesign are described and preliminary studies to assess learning outcomes are outlined.

## 1 Introduction

A review of the use and application of virtual reality technology and game engines shows a broad spectrum of projects ranging from teaching Newtonian physics and astronomy to museum applications. While exciting developments in virtual reality (e.g. surround screen, augmented, mixed, etc.) continue to emerge, the implementation of these systems is still quite expensive. Furthermore, besides the progress that has been made in multi-user virtual environments from research areas such as CVE and CSCW, the approach of virtual reality primarily focuses on single user environments making it difficult to assess its impact on potential classroom settings. In comparison, reduction in costs, availability, and ability to support collaborative interaction makes the approach of game engines an attractive alternative. Indeed, it can be argued that this is one of the main reasons for the recent enthusiasm in games design from academia and research, and their adoption in many real-world projects. For example, museums have examined using three-dimensional game engines to deliver photo-realistic simulations to desktop PCs (DeLeon and Berry 2000), small companies are using game engines to teach forensic science and areas of medical training (e.g. Games for health: Serious Games Initiative), and the US Homeland Security and government agencies are developing simulation games to train for real-world crises: ranging from disaster simulators for first responders and tactical language learning skills in combat situations (Tactical language training systems project – on-line). The next logical step would be to embrace the notion of games in the context of math and science education (Jenkins, Klopfer, Squire and Tan 2003), and to evaluate and identify promising features of games and gaming for learning.

The concept of educational computer games is not new. Their true potential as educational tools has only recently emerged. Our target audience is familiar with surfing the Internet to playing console video games and massively on-line collaborative games, and has high expectations for a visually appealing, Hollywood-like production. Consequently the responsibility is placed upon educators, researchers and developers to design educational games that students enjoy and motivate learning. This presents novel challenges to human-computer interaction. While some work in HCI has begun to address this imbalance, we are still some way off formulating a methodology appropriate for the design and evaluation of a range of educational digital games irrespective of configuration (i.e. supporting platform or enabling technologies). Therefore, there is a need for a methodology to inform design and evaluation throughout the development life-cycle.

In this paper we describe our experiences of the 2020Classroom project to develop an “immersive” learning environment through a game called *Metalloman* to teach bioscience concepts to engineering undergraduate students. While we have explored the used of various enabling technologies and configurations (e.g. projected and surround screen, desktop-based, etc.), the term “immersive” used herein refers to three-dimensional learning environments that allow students to navigate and interact with rich visual abstractions of the real world phenomena that they are studying. Furthermore, as the focus of this paper is on classroom use, most of our discussions refer to the Metalloman game running on desktop-based computers. The 2020Classroom multidisciplinary research effort is part of the Integrated Media Systems Center (IMSC), a National Science Foundation's (NSF) Engineering Research Center for multimedia and Internet research at the University of Southern California (USC). A description of earlier work carried out on the project can be found in: Wong, Kyriakakis, Carriazo and Lee (2003). The main objectives of our work are to: (*i*) identify the promising uses of distributed immersive technologies to enhance teaching and learning in today’s classrooms, (*ii*) identify how learning can be conveyed through games while concurrently maintaining students’ interest in the content and ensuring they can *play* with concepts central to the curriculum, and finally, (*iii*) address the new challenges that this presents for HCI. In particular, this paper focuses on work towards the development of a methodology through the refinement of techniques from HCI, activity theory and digital game design to inform design and evaluation for enjoyable, engaging and motivating, as well as usable immersive learning environments. We start in section two by briefly describing our previous work and lessons learned to develop immersive learning environments. Section three describes our experiences in developing the Metalloman immersive learning environment and steps towards formulating a methodological approach for its design and evaluation. Section four describes empirical pilot studies to test and inform redesign of the Metalloman game.

# 2 Previous Work

Prior work conducted in the area of education at IMSC examined how to bring immersive technologies to the classroom. As educators increasingly look to technology to meet the challenges of teaching and learning in a rapidly changing educational environment, the field of *interactive visualization* – illustrating educational concepts through visual, interactive applications, and simulations – presents a promising and emerging paradigm for learning and content delivery. *Interactive visualization* puts students and their teacher in the picture of what they are studying, supporting them as they interact with content material, explore new challenges, and perform simulations. Specifically, BioSIGHT$^{TM}$’s prototype *Immunology* module was designed, developed and assessed to identify a pedagogical goal of interactive scientific visualization as a tool to promote the formation of visual metaphors for abstract concepts that are inaccessible because of temporal or spatial scale (BioSIGHT on-line). This element served as the foundation for the identification and development of appropriate *Immunology* visual content. One component of the BioSIGHT$^{TM}$ *Immunology* module that was developed is called the Exploratory Challenge. It is a computer game-like simulation that introduces students to the visual and spatial concepts that must be understood before the learner can successfully visualize the topic. In addition, concepts were treated in purely abstract ways, presenting a key idea without explicit reference to the biological subject. Challenges are presented that easily engage students without requiring lengthy preparation and are self-motivating. The Exploratory Challenge component was found to be effective in conveying the concept that immune response represents an entire system with distributed quality and achieves dynamic steady-state (Kozma, Hoadley and Hinojosa 1999). More importantly, the Exploratory Challenge component was effective in generating dialogue and discussion among students and their teacher.

To further extend the work conducted on *interactive visualization* at IMSC, immersive learning environments were designed and developed to examine how to convey complex scientific concepts to a novice target audience as well as how they might influence the teaching and learning processes within immersive learning environments. An underlying approach to such environments involves the notion of how students can *play* with ideas or concepts central to the curriculum. For example, some of the game logic that we have used includes answering questions correctly for points to acquire new capabilities as well as achieving a specific task. Learning activities in the subject of *Immunology* were developed that provided an opportunity to collect data for informal student usage, environment design issues, as well as classroom implementation. Although while pursing learning activities students are able to query dynamic moving objects and receive information through text, narration and animations, pilot tests revealed that despite students’ familiarity with computer games, our user population of biology high school students was overwhelmed with information, and exhibited a fairly high level of frustration navigating through the environment. Therefore, the need for more considered design and evaluation methods is apparent.

## 3 Development of the 2020Classroom Immersive Learning Environment

The 2020Classroom is a multidisciplinary research project to apply distributed immersive and serious games to learning. The objective is to design, implement, and evaluate the role of compelling games in transferring science concepts by allowing students to navigate and interact with rich visual abstractions of the real world phenomena that they are studying. This involved the transformation of learning materials that are traditionally conveyed in a sequential manner into fully navigational learning activities. In general, the research goals are to: (i) create novel curriculum material and a prototype of immersive collaborative distributed learning environment; (ii) develop new methods for objective and subjective evaluation of learning; and (iii) evaluate the degree to which gaming and immersion affect learning. Our challenge was to create a compelling environment for students to: (i) engage in activities that convey fundamental principles; (ii) form robust visual models of complex processes; (iii) capture and sustain their attention; and (iv) pique their natural curiosity.

Using the Torque game engine (GarageGames®), the prototype game called "Metalloman" that is under development consists of a set of *perspectives* of the human body. The overall motive given to students through the Metalloman backstory is to save humankind by keeping a world-renowned scientist (Dr. Metal) alive so that he can continue to perform essential research. Under the context of this backstory, students "travel" and "perform vital functions" to complete mission objectives, and these encounters help drive the game by providing a non-educational reason for interaction within a human body. To help in the creation of a backstory for Metalloman that would engage students, a user-centered design approach was adopted, as described in section 3.1.

The approach taken in the design and evaluation of the 2020Classroom consisted of: paper prototypes, alpha and beta iterative design and in-house bug testing, and empirical evaluations to inform redesign. Furthermore, the 2020Classroom project incorporates a novel technique for analyzing user learning behaviors and outcomes derived from *immersidata*, data collected within an immersive environment (Shahabi 2003).

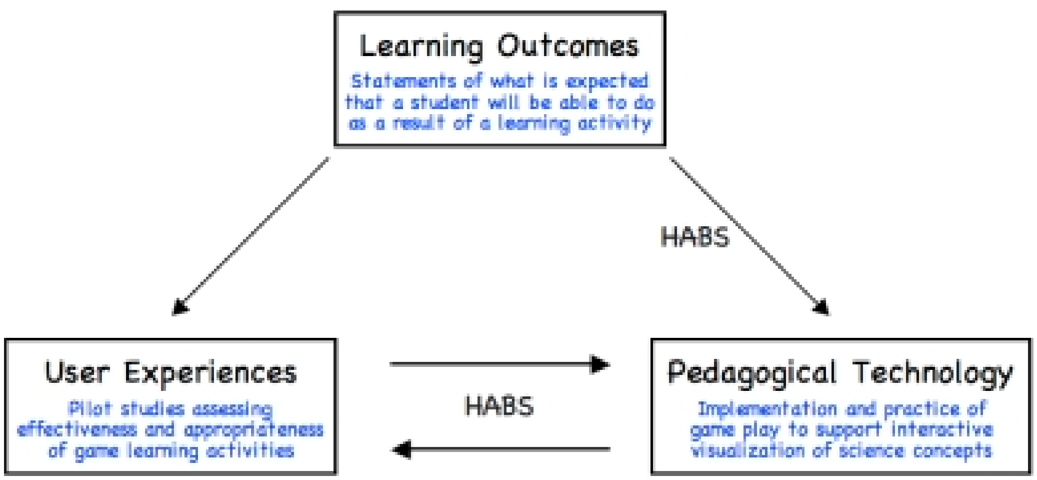


**Figure 1:** Development lifecycle for 2020Classroom

As illustrated schematically in Figure 1, the development life-cycle adopted in the 2020Classroom involved: (i) mapping learning outcomes to the design of content and tasks; (ii) materializing / implementation of content and task design into functional software; and (iii) iterative development and evaluation of content, graphics and tasks to provide learning outcomes. In this section we describe the refinement of techniques from HCI and activity theory to support this process throughout the development life-cycle for enjoyable, engaging and motivating, as well as usable learning environments.

## 3.1 User-Centered Design Approach to Backstory Development

A number of features are necessary to transform a three-dimensional immersive educational environment into an appealing game that motivates students to continue to play and want to play again. Metalloman allows users to experience simulations and representations of the human body from organ to cell-level, and select cells and fluids and place them in their appropriate location to initiate bodily functions. For example, collect and place insulin to decrease blood sugar level. In addition, essential game features are the narrative (see section 3.2) and backstory. The backstory is the underlying story that helps drive the game by providing an objective or reason for users to interact within a human body, other than educational. The backstory is a key feature that moves a three-dimensional virtual environment from being purely educational to one that incorporates a sense of challenge to stimulate users for continued gameplay. However, story development is arguably a creative and artistic process rather than scientific. While theories and models are being adapted to address the non-linear narrative nature of interactive media, the lack of design methodologies to inform the development of a creative story to fulfill these requirements is problematic. The next section describes progress towards a user-centered approach to overcome this challenge.

### *3.1.1 Method*

A study was carried out to choose an appropriate backstory for the environment developed by the 2020Classroom project. Due to the limited availability of typical end users (bioscience undergraduates) to employ in studies (other than the end user group that the game is being developed for), the study was undertaken in three separate locations of the university campus with the aim of obtaining subjects from diverse fields of studies and a user population as close as possible in age and educational level to that of the typical end users. A statement explaining that we are developing a digital game that allows players to explore and interact with organs in the human body and need help in selecting and adapting a backstory was read to subjects. Five scenarios or backstories created by different members of the 2020Classroom project team and ranging in style and complexity were presented to subjects. The order of stories was rotated. Subjects provided answers to eleven questions after they had read each of the backstories. Seven of the questions were rated on a scale from one to seven, asking if they found the backstory: engaging, interesting, understandable, plausible, memorable, exciting and dramatic. They were then asked what they liked and disliked about the backstory, if it would tempt them to play the game, what age range they thought the game was aimed at and their preferred story. Finally, they were asked to suggest ways in which we could improve their preferred backstory.

### *3.1.2 Results*

Twenty subjects (11F, 9M), majoring in various fields of study including, cinema, journalism and electrical engineering, took part in the study. Seventeen were in the age range 18-22. All subjects had no difficulty providing responses to all questions with the exception of how "plausible" they thought the backstory was, with many asking for further explanation. Therefore, responses for "plausible" were excluded from the results. Of the remaining six questions rated from one to seven, backstory "4" had the highest mean rating for four questions, followed by backstory "1" with two. Eight subjects (the highest number) preferred story "4", in contrast to four subjects who liked story "1" and three who liked story "2". The highest number of subjects (six) said they would be tempted to play the game relating to backstory "4" and the highest number of subjects (eleven) rated story "4" as appealing to our typical end users' age-range.

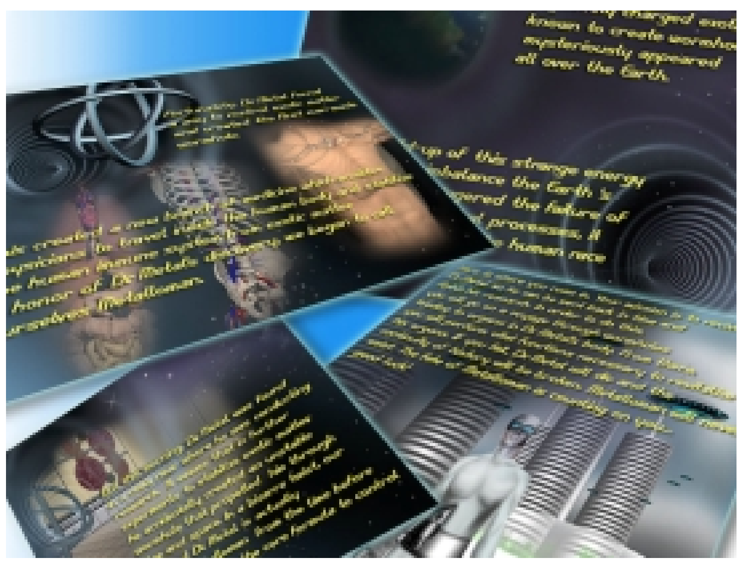

**Figure 2:** Graphical representation of the Metalloman backstory.

### *3.1.3 Discussion*

Of the five backstories, backstory "4" was consistently the clear favorite. Backstory "4" was given the highest rating in four out of six questions, it was chosen as being the most preferred by subjects, more subjects said they would be tempted to play the game relating to the backstory and most subjects said it would appeal to our typical end user's age range. Following further improvements suggested by subjects and in-keeping with features and objectives of the design, the backstory was implemented to create the "Metalloman" game environment. This was achieved by interweaving the story into the environment at the beginning to set-up the objective of the game, throughout the game by relating aspects of the environment to the story and at the end of the game by providing users with a statement of how well they achieved their objective. Figure 2 shows sections of the Metalloman introductory backstory consisting of screens that display the story in text and supporting graphics. In addition, while the introductory screens are displayed in a linear manner at the beginning of a game, a voice narrates the backstory and accompanying atmospheric music is presented to users.

## 3.2 Outline of Hierarchical Activity-Based Scenario (HABS) Approach

To support design and evaluation throughout the development life cycle of Metalloman, the hierarchical activity-based scenario approach (HABS) based on activity theory was adopted (Marsh 2001, 2002, 2003). HABS is a development tool that allows us to plan and model scenarios and narratives to any level of complexity in a hierarchical structure (from high-level *activities/objectives*, through *actions/goals* to low-level *operations/conditions* of physical/virtual artifacts) and trace user's progression/interactions in this scenario during use/game play. Any disruption from input interactive devices or design features can be identified using HABS through shifts between levels from operations to actions. In addition, HABS incorporates a method to structure and reason about the success of the *Metalloman* backstory objective, as well as the success of learning objectives through the objective outcome of activity coinciding with motive.

Central to activity theory is Leont'ev's hierarchical framework of activity composed of: *activity, actions* and *operations,* characterized by *objective, goals and conditions,* respectively (Leont'ev 1981). In reference to figure 3, the *activity* is directed towards achieving an *object* or *objective.* The term "object-oriented" is widely used to denote this. The objective is a process characterizing the activity as a whole. For example, in a virtual library the objective may be to find a book. Objective is closely related to motive and both have to be considered in the analysis of activity (Leont'ev 1981), the smallest meaningful unit of analysis in activity theory (Kuutti K. 1996; Leont'ev 1981). Marsh (2002, 2003) identified that little, if indeed any, work in HCI appears to deal with these separately, either suggesting analysis of "object or motive" (Kaptelinin, Nardi and Macauley 1999), linking them together as illustrated through "objectified motive" (Christiansen 1996) or not dealing with motive at all. This is a very important concept that provides the basis for experiential analysis of "activity proper" (Leont'ev 1981).

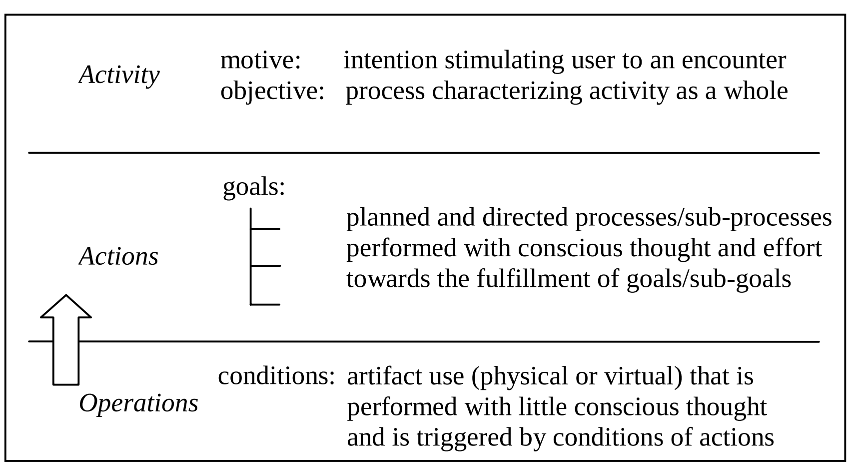


**Figure 3:** HABS: hierarchical activity-based scenario

Say in a virtual library example the motive is to find an article, reference or poem in the book. If the article, reference or poem is not in the book, the book is unavailable or cannot be found, then the outcome does not coincide with the motive, in which case it is not an "activity proper". On the other hand, if the objective outcome of processes is to find the article/reference/poem then this coincides with the motive and is "activity proper", at which point the activity ends. How this can be used in the assessment of user experience is described in section 3.2.1.

Activity is made up of one or a combination of a*ctions/tasks*. Actions are processes carried out with conscious thought and effort, and are planned and directed towards achieving a *goal*. Actions may be made up of sub-actions directed towards sub-goals. Their collective outcome is the activity's objective. For example, the action of scanning the virtual library shelves for the book is made up of sub-actions/goals such as, finding the book's subject category, locating the book's catalogue number, and so on. Each sub-action/goal has to be fulfilled in order to fulfill the higher-level action.

Actions are performed by a combination of *operations.* Operations are processes performed with little thought or attention in the use of artifacts both physical (e.g. keyboard, mouse, novel devices) and virtual (e.g. tools, objects, environment) triggered by conditions of actions. The early phases of learning to use an artifact will have been performed with deliberate and conscious attention. At this point they are actions. When they become well-practiced and experienced, actions become routine. That is, they do not need to be planned and at such a point are performed with little conscious thought or effort (i.e. actions become operations). These are issues relating to the mastery of devices and artifacts/tools. Conversely, operations become actions when something breaks down and/or impedes execution as represented by the vertical arrow in Figure 3.

### *3.2.1 Assessing appropriate or stimulating experience: objective outcome coincides with motive*

The degree to which an encounter provides users with experience that is appropriate, matches their expectations/intentions and/or is stimulating gives an indication of its success. For example, a user's motive for using technology may be, for example, for "some special need", interest, "to understand", "to comprehend", to learn, to feel emotions, for fun, enjoyment or pleasure. If the objective outcome of performing processes of an activity with technology is the inducement of appropriate and/or stimulating experience, the objective will coincide with the motive that stimulates the user to an encounter. Consequently, users' attention is maintained in pursuing their objective outcomes (i.e. continue the experience e.g. stimulating computer game) or an encounter has fulfilled a user's intention that drove them to the encounter in the first place (e.g. the book in the virtual library contains the article/reference/poem). Either way, the encounter is successful. Conversely, if the objective outcome does not provide appropriate and/or stimulating experience because it doesn't match up/deliver on expectations or purpose, or it is dull, boring, uninteresting, then it does not coincide with motive. Likewise, if technology is difficult to use, then again attempts to fulfill objectives are frustrated. In either of these circumstances an encounter or use will either have been unsuccessful or have frustrated attempts to fulfill objectives.

### *3.2.2 Design of Narrative in 2020Classroom using HABS*

Table 1 illustrates the hierarchical activity-based scenario approach for Metalloman, where activities are equivalent to missions. Metalloman consists of three missions: a training mission, control systems for blood sugar levels, and digestive processes and adsorption. The hierarchical structure and gaming backstory for Metalloman ingeniously provides an overall motive for students to interact with the game (i.e. help to save humankind by keeping Dr. Metal alive) while at the same time fulfilling the requirements of the educational or learning outcomes (i.e. to understand the problem of moving substances and molecules across cell membranes during the digestion process and how blood sugar levels are stabilized by hormones). To keep Dr Metal alive requires students to perform objectives (e.g. "regulate available blood sugar and restore systems that maintain blood glucose levels"). To fulfill objectives, students perform a number of actions/tasks towards the fulfillment of goals (e.g. "unlock wormholes") and sub-goals (e.g. increase and decrease glucose by breaking down or polymerizing glycogen respectively). If they perform goals successfully then the objective outcome is successful. According to the backstory, this will revive Dr. Metal and allow him to continue his research to save humankind. Thus, objective outcome and motive coincide and is "activity proper" (Leont'ev 1981). To assess how much students have learnt from performing missions/activities and to provide a way to reason about the extent to which Metalloman fulfills learning outcomes, pre and post study questionnaires were administered in empirical studies as described in section 4.

As mentioned, actions are performed by a combination of operations that are performed with little thought or attention in the use of artifacts (physical and virtual) triggered by conditions of actions. While Metalloman was developed to run on a variety of platforms and configurations (e.g. projected and surround screen, desktop-based), our overriding intention for the present design is for student use in their natural classroom environments. That is on standard desktop computers and therefore, physical operations are performed with keyboard and mouse, and linked to virtual operations including: navigation, selecting and placing objects, etc. When something impedes interaction or design behaves inappropriately, operations become actions (represented by the vertical arrow in Figure 3). Referred to as breakdown or breaks, they disrupt user experience and so provide ways to identify problematic interaction (with and between the physical and the virtual) and design (Marsh 2001). In the 2020Classroom project steps towards automating the identification of breaks in user experience in a continuous and unobtrusive manner through the capture and query of user behavior (e.g. directional and angular movement and events) and represented as a data schema termed *immersidata* (Shahabi 2003), are already underway (Marsh et al. 2005).

**Table 1:** Overview of activities in Metalloman

| Missions | Objectives | Goals | Sub-goals | Sub sub-goals |
|---|---|---|---|---|
| Body travel training | | | | |
| | Practice essentials of body travel | | | |
| | | Unlock wormholes | | |
| | | | Collect ATP and correctly place in "receptor" | |
| Control systems for blood sugar levels | | | | |
| | Regulate available blood sugar and restore systems that maintain blood glucose levels | | | |
| | | Unlock wormholes | | |
| | | | Identify pancreas, liver and muscle | |
| | | | Identify hepatocyte and muscle fibers | |
| | | Increase blood glucose levels | | |
| | | | Collect glucagon | |
| | | | | Collect adenyl cyclase |
| | | | | Collect glycogen phosphorylase |
| | | | | Release glucose monomers from glycogen polymer |
| | | Reduce blood glucose levels | | |
| | | | Collect insulin | |
| | | | | Mobilize GLUT-4 transporters to membrane |
| | | | | Collect glycogen synthase |
| | | | | Polymerize glucose monomers into glycogen |
| Digestive processes and adsorption | | | | |
| | Provide energy source and reactivate digestion and adsorption processes | | | |
| | | Unlock wormholes | | |
| | | | Identify stomach and small intestines | |
| | | | Identify gastric glands and intestinal epithelial cells | |
| | | Breakdown food present in stomach | | |
| | | | Restore blocked gland secretion | |
| | | | | Identify parietal, chief, and mucus cells |
| | | | | Collect pepsin and pepsinogen |
| | | Complete digestion to release nutrients | | |
| | | | Collect bile | |
| | | | Transport nutrients into blood | |
| | | | | Establish sodium gradient |
| | | | | Harness stored energy from gradient |

## 4 Empirical Studies

Following the development of a beta version (in-house design and testing) of Metalloman, numerous studies were carried out with general users to evaluate both usability and user experience. At earlier stages in the development life-cycle this was carried out with a user population as close as possible in age (18-22) and educational level (undergraduate) to that of the typical end users. Using HABS and underlying concepts provides a framework to trace user's progression/interactions through missions, as shown in table 1. Any disruption from input interactive devices or design features can be identified through shifts between levels from operations to actions, as shown in figure 3. Various methods were employed to identify positive as well as problematic aspects of design using observation, getting users to think-aloud, questionnaires and debriefing sessions. Following each study, analysis of data was used to inform redesign. The screenshot of the *"digestive process and adsorption"* mission in figure 4 shows many design solutions that were implemented as a result of user studies. For example, after users repeatedly verbalized their frustrations about losing track of where they were inside Dr. Metal's body and becoming disoriented, a map of the human body indicating the user's location was implemented and displayed at all times in the bottom right-hand side of the screen. To aid users in fulfilling their goals after making a number of errors, navigating in the wrong direction or taking excessive time to complete a task, a sliding instruction box appears at the bottom right-hand side of the screen for a short duration as a gentle reminder to users of their goals. As identified through observation and questioning, users had no idea that they could pass through an opaque membrane wall. As shown in figure 4, the inclusion of a revolving green cylinder with black arrows in the membrane wall was found to overcome this problem. A preliminary study was carried out at a later stage in the life-cycle with four users with biology backgrounds to assess the learning outcomes, as described next.

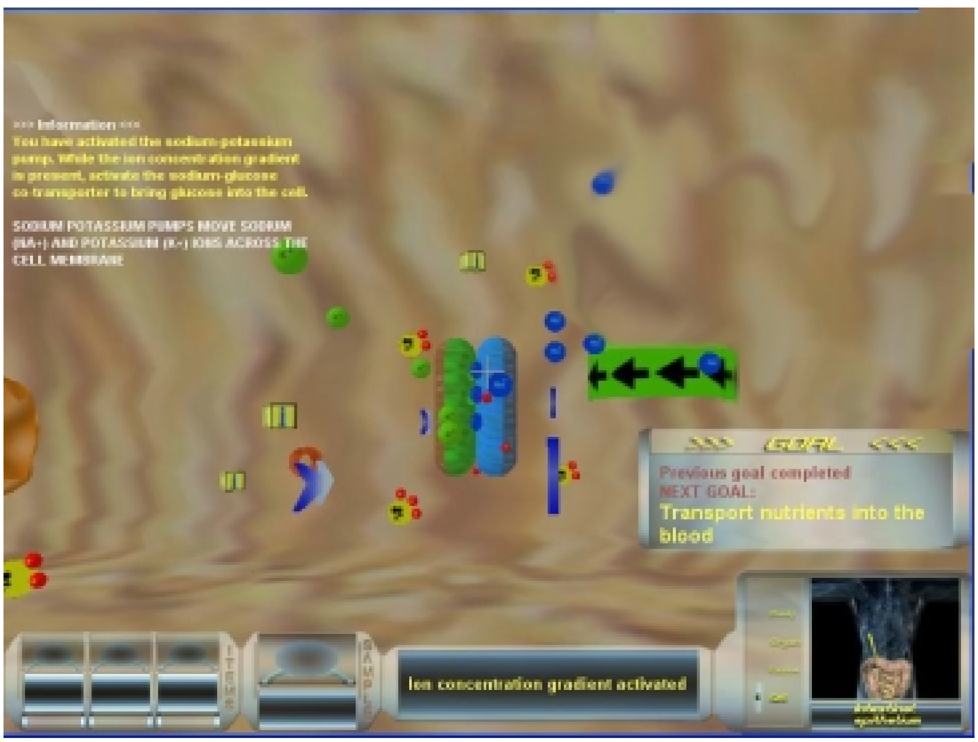


**Figure 4:** Example screenshot from the *Digestive Process and Adsorption* mission.

## 4.1 Preliminary Study to Assess Learning Outcomes

To assess learning outcomes and to provide feedback on how well Metalloman represents biology processes, a study was carried out with four subjects (2 M, 2F) with biology backgrounds. Their ages fell within the following ranges: 15-18, 23-26, 27-30, 31-34. They used computers from 20 to 80 hour per week and played digital games from 0 to 10 hours per week. Before undertaking missions subjects filled-out a short questionnaire to provide baseline measures of their biology knowledge. Subjects then undertook a training mission to familiarize themselves with navigation, function/item selection and the many design features that they will confront during their missions. Next subjects undertook the remaining missions. Following completion of missions, subjects filled-out a short questionnaire to provide post study biology learning outcome measures.

### 4.1.1 Results

All subjects completed missions with minimal guidance successfully with the exception of subject "1" with no computer games experience and had to be guided through one of the missions. By using HABS user's progression/interactions were traced through missions, and usability and design concerns were captured through observation, users' verbalizations and in debriefing sessions, and used to inform redesign. As shown in figure 5, over the two missions, all four subjects' learning outcomes increased by varying amounts. Tables were drawn up to show all questions with a positive learning outcome (subjects learnt from game play), a static learning outcome (pre and post remain the same) or a negative learning outcome (subjects got a question wrong following game play). Static and negative learning outcomes potentially point to problems with the design of the questions or the design of the content/tasks to provide a learning outcome. Some questions identified as being problematic were changed and design relating to content/tasks will be investigated further in later studies.

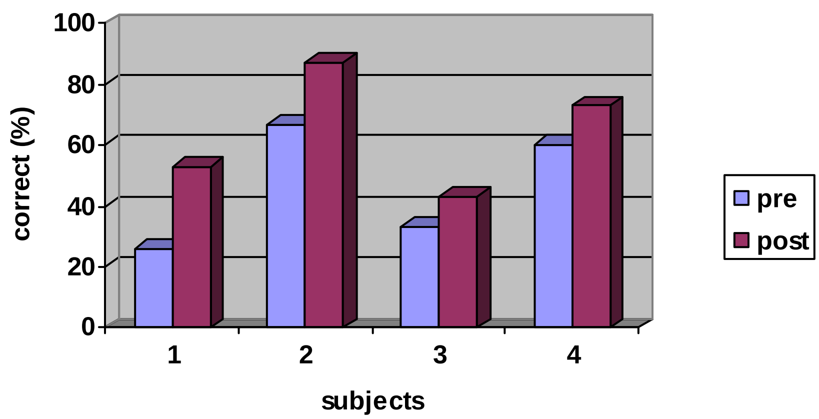


**Figure 5:** Graph showing subjects' learning outcomes

## 5 Discussion

This paper has described our experiences in the on-going development of a three-dimensional immersive learning environment called *Metalloman* to teach bioscience concepts to engineering undergraduate students. It has focused on work towards the development of a methodology to inform design and evaluation for enjoyable, engaging and motivating, as well as usable immersive learning environments. In particular, we have outlined the development lifecycle for 2020Classroom project, described a user-centered design approach for the development of the Metalloman backstory, adopted the hierarchical activity-based scenario approach to frame and refine the narrative of backstory and educational activities/objectives and actions/goals, and informed from HABS concepts, studies have been described to evaluate usability and user experience to inform redesign. Preliminary studies to assess learning outcomes were outlined and it was shown that all subjects' learning outcomes increased following the completion of the games' missions. Results were used to identify and amend problematic questions and future work should be used to identify limitations in design of content and tasks to provide learning outcomes. Using the concepts from HABS of objective outcome coinciding with motive provides an approach to reason about the success of an encounter with three-dimensional learning and digital games environments. At this stage in our research it would be a little premature to reasonably conclude that Metalloman provides appropriate learning outcomes or experience to be judged as successful. But preliminary results of users' learning outcomes/experience are promising and suggest that we are on track. Future studies are planned with our typical end users (engineering undergraduate students studying bioscience) in their natural classroom environments. Finally, while the focus of this paper is on design, evaluation and to inform redesign of an educational game, the methodology described herein is not only appropriate to education per se, but to a range of digital games genres.

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