Immersidata Management and Analysis For Game Development and Assessment For Staying There

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ABSTRACT
New and emerging interactive digital media present many new challenges to human-computer interaction (HCI). With digital media designed to captivate user's attention through stimulating experience and so encourage them in *staying there* engaged in pursuing activities, one of the main challenges is to devise effective and appropriate evaluation and development approaches that don't disrupt the user. While standard evaluation methods can provide insightful information that can be used to inform development, a range of limitations have been identified. In this paper we describe the seamless capture and management of data that represents user's interchanges with interactive digital media. Next we describe two complementary tools that we have developed to help analyze and interpret these interchanges and help us to understand user's experience and behavior to inform development throughout phases of the life cycle. We demonstrate the effectiveness of our approaches through their application to an educational serious game.

Categories & Subject Descriptors
H5.2 [Information Interfaces and Presentation]: User Interfaces - Evaluation/Methodology; H3.3 [Information Storage and Retrieval]: Information Search and Retrieval

General Terms
Human Factors

Keywords
User experience, usability, serious games, game development, clusters, visualization

1. INTRODUCTION
User activities with new and emerging interactive digital media provide experience. We argue that one of the main goals of interactive digital media that is designed to captivate user's attention is to provide stimulating experience. Stimulating experience grabs user's attention and encourages them in *"staying there"* engaged in pursuing activities. Conversely, inappropriate or un-stimulating experience from inadequate or problematic design compromises users in staying there [5, 6, 7].

To operationalize the idea of staying there, the application of appropriate evaluation and development methods are required. While standard evaluation methods provide some insightful information that can be used to inform development of interactive digital media (e.g. virtual and game environment), they have limitations or are problematic because they are too passive, disrupt user's attention and staying there behavior and experience or are collected retrospectively following game play. For example, attempting to interpret behavior and experience by observation alone is problematic because there is little in the way of probes for evaluators to tap into user's opinions, feelings, attitudes or experience. For instance, attempting to understand user's experience through facial expressions is problematic because what is seen externally may not necessarily reflect what is felt internally, or as Levenson and Ruef (1992) in their work on empathy state, there is no one-to-one correspondence between facial expressions and feelings. Likewise, Höök et al. (2000) suggest coding facial expressions (e.g. smiles and frowns) to assess experience from digital media design in use is problematic because smiling may show different things: a user likes something or thinks it's silly. Also, they reason that the presence of a video camera to capture study sessions seems to make some people smile more and some less thereby tainting the data that we are attempting to collect or measure. A similar occurrence was witnessed in our own studies with undergraduate students, as described herein. Likewise, the presence of an observer may interfere with what is being observed, so again potentially tainting the collected study data.

Getting users to concurrently think-aloud (i.e. a kind of running commentary) present evaluators with "an opportunity to trace [user's] cognitive processes" [11], provides information about inadequate or problematic design and provides a way to tap into user's opinions, feelings, attitudes or experience during interaction. However, because users are effectively required to do two things at once, the process of verbalizing can prolong user's response time and interfere with accuracy [11], and may disrupt user's staying there experience [5]. Similarly, providing users with a mechanism or device (e.g. slider [3]) to help identify negative or positive aspects of design or rate their experience divides attention between the operation of the device or evaluation technique and the media experience and so may interfere with a user's assessment of design or the experience that we are trying to measure.

The capture of physiological data (e.g. heart rate) and fMRI brain scans and EEG brain waves overcome some of the aforementioned problems by providing a means to continuously link and assess design and experience. However, this raises the question of whether or not the probes and sensors attached to a user are disruptive, encumbering or obtrusive. Also, while post-study methods such as questionnaires, interviews and debriefing, and retrospectively thinking-aloud allow users to experience interactive digital media without being disrupted or dividing their attention, they are administered following an encounter and hence, it is difficult to link events of scenario and design features/elements with experience and disruption. Furthermore, Russo, Johnson and Stephens (1989) found in studies that retrospective verbal protocols are reliant on users' memory and hence, may produce problems of users forgetting, and even worse, inventing things. Ericsson and Simon (1984) concur with this and warn about the limitations of retrospectively collected verbal protocols.

Therefore, in order to operationalize the idea of staying there, we have developed a range of continuous and unobtrusive evaluation approaches. To demonstrate some of our approaches, in this paper we focus on the capture and analysis of user behavior and experience with educational game environments. In short, interacting or playing with educational game environments is referred to as experiential learning or the learning experience, and games exhibiting learning as their primary purpose are increasingly referred to as *serious games*. Interest in serious games has increased significantly, for example in education, the military and for emergency first responders. While a consensus definition of serious games eludes us, they are frequently described as games for non-entertainment purposes, thus distinguishing them from computer or video games developed primarily for entertainment purposes. However, we concur with assertions that learning and entertainment are not necessarily mutually exclusive in serious games and therefore development and evaluation tools and techniques should be able to address both. In general, in games for learning or serious games as they are now commonly known, disruptions or breaks in interaction occur because users pause momentarily to appropriately contemplate the educational content or because of problematic design and programming bugs. While the former is behavior appropriate to the design of the educational game, the latter brings about inappropriate behavior from inadequate or defective design and development and this may unfairly disadvantage game play and/or the learning experience. If recent reports and trends suggesting that games are poised to transform the way we teach our students in schools, colleges and universities are correct, then we must ensure that games are designed and developed according to accepted and recognized methodologies and approaches. This will go some way towards ensuring the effectiveness of games as teaching systems and help to identify and diminish problematic design and bugs. While assessment of user-player experience in serious games provides a means to validate learning and design, there is negligible research literature on the pedagogical value of serious games and moreover, a dearth of available tools and techniques. In short, there is a lack of serious analysis and design methods and approaches for serious games.

This paper addresses some of the issues of digital games and serious games in human-computer interaction (HCI). In doing so, we develop tools for analysis and development that go beyond the process of "bug testing" that has come to epitomize evaluation and assessment, and known as "quality assurance", in the games industry. This paper is arranged as follows. In section two we describe the seamless capture and management of data generated from interchanges between user and digital game. In the next section (2.1) we describe our first approach to analyze the collected data using a tool called ISIS. While ISIS has been shown to be an effective tool for game development [10, 14], in this paper we identify that some users find the presence of a video camera to be intrusive and hence, affects their behavior and experience. To overcome this problem, in the next section (2.2) we introduce a completely unobtrusive technique that is invisible to the user to analyze immersidata using a visualization technique through the use of clusters. In section three we demonstrate the effectiveness of our cluster approach in a study with undergraduates in their natural classroom settings.

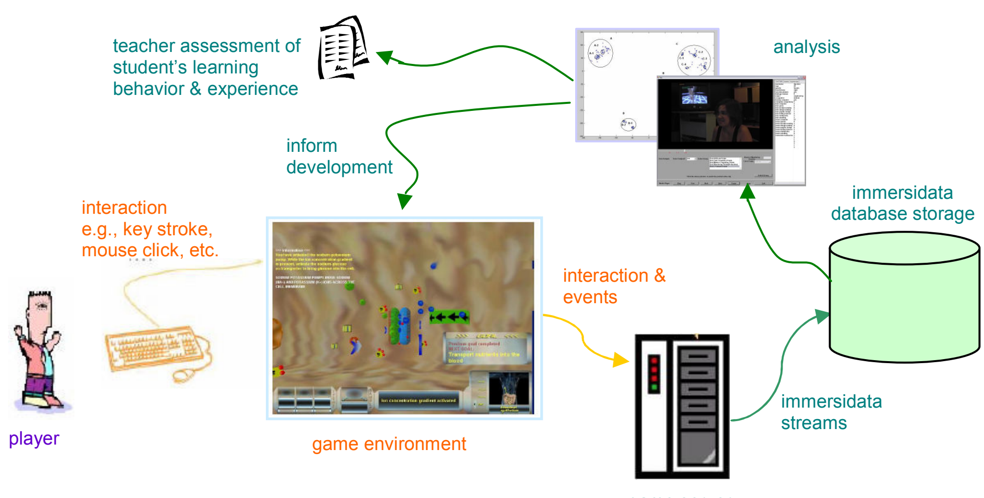

Figure 1. Game Immersidata Collection, Analysis, User Assessment & Informing Development

2. IMMERSIDATA MANAGEMENT AND ANALYSIS

In virtual and games environments users are immersed in activities with characters and objects within places depicted virtually. Shahabi (1999) coined the term *immersidata* to refer to the data generated from user interchanges in these environments. Immersidata can be considered as being either non-continuous or continuous data streams typically depending on the virtual or game environment of interest and generated from interactions, events and sensors (e.g. mouse movements, keyboard presses, virtual glove movement, object selection, weapon firing, etc.). The amount of immersidata that is required to be captured to represent user behavior and experience in virtual and game environments is considerably large. Hence, this creates the difficulty of how to efficiently store and retrieve the immersidata. In an effort to address this challenge, Shahabi (2003) proposed An Immersidata Management System (AIMS). AIMS consists of four components: acquisition, storage, offline query and analysis, and online query and analysis. In order to have seamless interaction between game engine and the query engine, we built customized database schema and storage subsystems. We implemented the database sub-component for the game engine in C++ using Oracle, Odbc and DB2-CLI Template Library (Sourceforge©). Refer to Figure 1 for schematic of game immersidata collection. To the best of our knowledge, this is the first serious game with a full-blown database backend. In the following sub-sections we describe two complementary tools to aid in analysis of immersidata and to help us understand user's experience and behavior to inform development of an educational computer game throughout phases of the development cycle. The first called ISIS is for use from early to late phases of game development and the second a completely unobtrusive visualization technique is appropriate from early phases through to finished product.

2.1. ISIS (Immersidata analySIS)

In reference to Figure 2, ISIS (Immersidata analySIS) is a graphical user interface (GUI) that allows us to query immersidata to identify data of interest and index this to video recordings of user-player's gaming sessions. Identified data and indexed events within video clips can then be analysed to help understand user-player's behaviour and experience and this provides an insight into which game elements and features work and those that don't. This information is then used to iteratively inform game development for user-players staying there. In the next sections we describe four of the main queries implemented in ISIS for analyzing user-player behavior and experience to assess learning and for informing design to make improvements to the game. Refer to [10] for a description of additional queries implemented in ISIS to identify users undertaking the most difficult or *critical tasks* and problematic design/navigation difficulties identified through *collisions* with walls and objects. Although our research has focused on ISIS applied to an educational game, it is anticipated that these queries can generalize to other serious games and across different game genres that are primarily for entertainment purposes.

While the user-player attempts to fulfil the game's tasks, we capture two types of immersidata generated from interchanges between user-player and the game: the user-player's position immersidata in the game and the events immersidata generated from the user-players' interaction within the game (e.g. object selection and placement). The position immersidata stream is continuously generated and stored in the database. While the sampling rate can be increased according to the requirements of the application under evaluation, we found that a sampling rate of three times a second was more than adequate for our analyses. In reference to Table 1, each position immersidata typically contains a timestamp in milliseconds, the 3D positional information (X, Y and Z) of the user-player within the game, the direction that the user-player is facing (RX, RY and RZ) and the direction in which the user-player is looking in the game (EYEX, EYEY and EYEZ). The event immersidata is, on the other hand, typically not generated continuously but when the user-player explicitly interacts with the immersive environment. In reference to Table 2, the event immersidata contains a timestamp in milliseconds, the position and angular coordinates (as described above), and the description of the event that occurred. In addition to the immersidata, we collected and display demographic data (e.g., gender, age, etc.) and pre-study subject content questionnaire results shown in the right-hand panel in Figure 2.

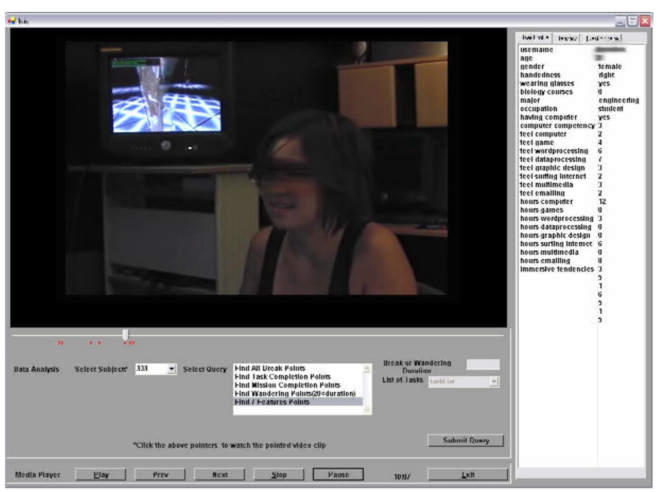

Figure 2. ISIS graphical user interface for analysis and assessment of user behavior and experience. The display shows a student interacting with an educational serious game. Red markers under the display show indexed immersidata.

Table 1. Snapshot of the position immersidata stream

X	Y	Z	RX	RY	RZ	ANGLE	EYEX	EYEY	EYEZ	TIMESTAMP
305.154	293.45	225.431	0	0	1	3.06333	.0760947	-.970336	.229472	1821446
305.154	293.45	225.431	0	0	1	2.52883	.553923	-.787906	.269022	1821779
305.154	293.45	225.431	0	0	1	2.46949	.615973	-.774143	.145877	1822112
305.154	293.45	225.431	0	0	1	2.62135	.492279	-.859306	.13876	1822445
305.154	293.45	225.431	0	0	1	2.40612	.670534	-.741063	-.0347949	1822778
305.154	293.45	225.431	0	0	1	2.4134	.665196	-.74619	-.0311537	1823111
306.393	292.06	225.432	0	0	1	2.4134	.665196	-.74619	-.0311537	1823444
308.481	289.719	225.432	0	0	1	2.4134	.665196	-.74619	-.0311537	1823777
310.379	287.59	225.432	0	0	1	2.4134	.665116	-.745929	-.0347949	1824110
311.581	286.242	225.432	0	0	1	2.4134	.665116	-.745929	-.0347949	1824443
49.6673	108.873	258.649	0	0	1	1.73761	.985522	-.16594	-.0347949	1824776

Table 2. Snapshot of the event immersidata stream

EVENTTYPE	OBJECTNAME	X	Y	Z	RX	RY	RZ	ANGLE	TIMESTAMP
pick	liver	302.826	293.232	225.45	0	0	1	.487397	1794750
place	liver	302.826	293.232	225.45	0	0	1	1.41507	1797406
pick	intestines	305.154	293.45	225.431	0	0	-1	1.0532	1807417
place	muscles	305.154	293.45	225.431	0	0	1	2.59662	1809241
pick	lungs	305.154	293.45	225.431	0	0	-1	1.06403	1812053
place	muscles	305.154	293.45	225.431	0	0	1	2.59106	1813977
pick	muscles	305.154	293.45	225.431	0	0	-1	.698755	1816303
mouse_click		305.154	293.45	225.431	0	0	1	2.661143	1818359
place	muscles	305.154	293.45	225.431	0	0	1	2.60985	1818780
task_completed	organ_identified	305.154	293.45	225.431	0	0	1	2.60985	1818730
mouse_click		305.154	293.45	225.431	0	0	1	2.47313	1822141
teleport	body_room_bi_muscles	310.750	287.64	225.432	0	0	1	2.4134	1824191
enter_room	muscles	49.6673	108.873	258.649	0	0	1	1.73761	1824541

2.1.1. Queries

2.1.1.1 Activity Completion Points

The activity is made up of many tasks as described below. This query identifies the moment when a user-player completes the final tasks associated with a particular activity. As well as providing the overall completion time of activities, it provides a frame for the tasks and sub-tasks associated with an activity.

2.1.1.2. Task Completion Points

This indicates the points when a user-player finishes each task and the duration of each task. Evaluators and developers can choose which task completion points they want to retrieve from the database and from analysis of video clips, learn which behaviors and strategies a user-player employed to fulfill a particular task and reason about the kinds of experience they have been through.

2.1.1.3. Break Points

A break is defined to be the moment when the user-player does not make any movement and no events occur with and within the game for a specific period of time. Building on earlier work contained in [8] that hypothesized that zero or near-zero immersidata (position and events) generated from virtual or game environments could be used to identify the cause of breaks in users' experience. By identifying breaks in immersidata and then analyzing the point, during or circumstances surrounding the occurrence of breaks in video recordings of study sessions, we were able to validate our hypothesis. Break is a very important concept in game assessment and development for staying there because it provides clues to causes of what interrupts the user-players while they are playing the game. In serious games for learning, the cause of breaks can be either that the user-player is appropriately *contemplating* the educational content of the game or there is a *design problem*. The implementation of a break query in ISIS provides evaluators and game developers with an efficient way to select break points and analyze video clips associated with break points to determine the cause of break. For example, Figure 3(a) illustrates the point at which a user-player in a study session stopped playing the game because she was not sure what to do next after successful completion of a task. This suggests a lack of instruction after finishing the first task and further analysis confirmed this to be the case. Figure 3(b) shows the moment when a user-player is frustrated by problematic design and so stopped playing. Figures 3(c) identifies when a user stopped play to offer advice about how improvements to the game could be made 3(d) identified when a user stopped play to appropriately contemplate the educational subject content of the game.

2.1.1.4. Wandering Points

Wandering points are similar to breaks queries but identify when the user-player is moving but no events immersidata occurs for a specific period of time. Evaluators can use this query to analyze user-player behavior to identify any difficulty user-players may have encountered with problematic learning or design and inform developers. For example, in study sessions conducted in laboratory settings, one user-player was identified as wandering around for quite some time and said that she was "not sure what to do next". Following further analysis and comparison with the behavior of other user-players using ISIS, we were able to reason that the problem was not with design as we had first suspected but a lack of game playing experience on behalf of the user.

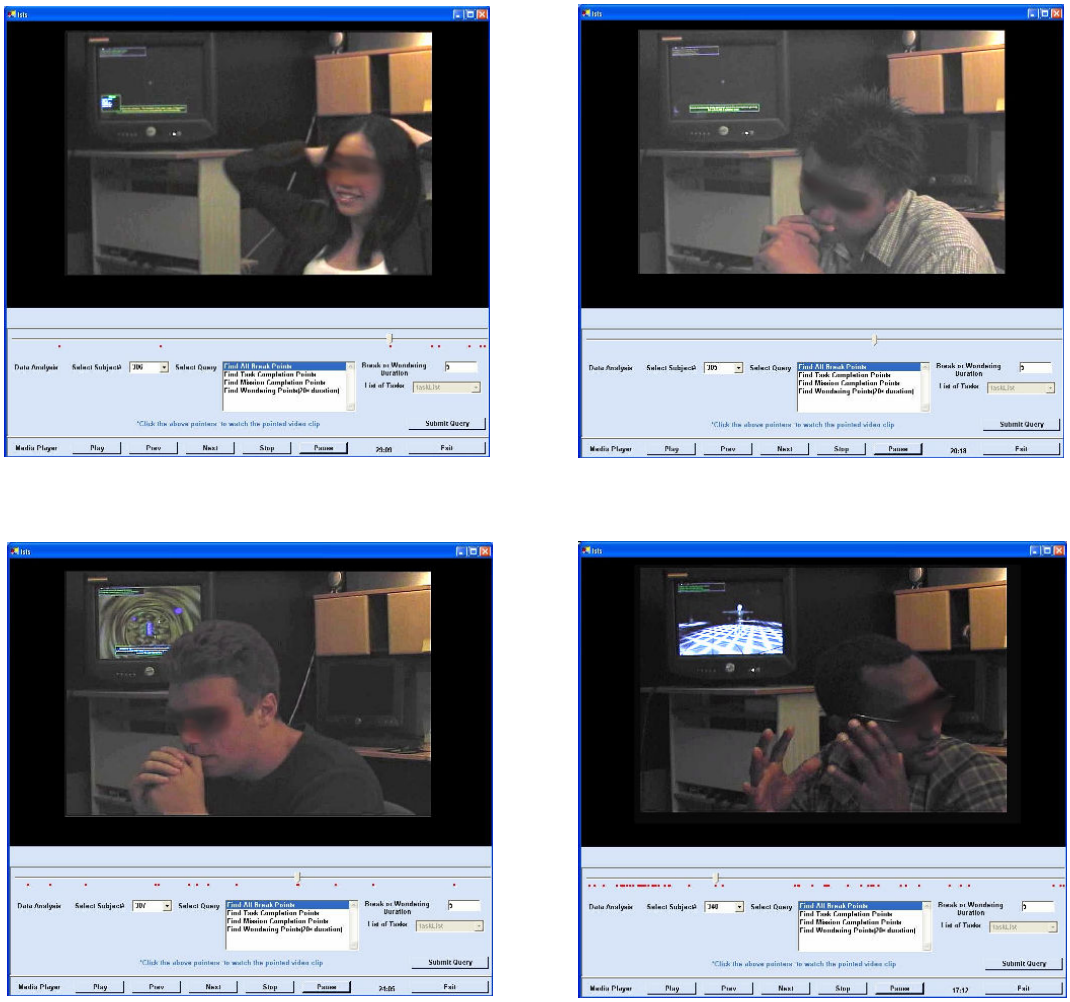

Figure 3. Breaks identified using ISIS. From top left clockwise: (a) user unsure what to do next (b) frustration caused by problematic design (c) user suggests how improvements to the game could be made (d) user appropriately contemplates the educational content of the game. Demographic and questionnaire data panel from the right-hand side has been removed for clarity.

2.2. Visualization Using Clusters

While ISIS aims to be both continuous and unobtrusive, some user-players find the use of video to capture events to be intrusive and potentially affect their game play. Therefore, we devised a way to further extend our analysis techniques without the use of a video camera. This technique allows analysts to visualize clusters of immersidata representing user-player behavior and experience. To demonstrate this approach we focus on visualizing clusters of interruptions or breaks. As well as being suitable for use in most stages in the game development cycle, this approach is particularly suitable for the assessment of games in the later stages of development through to the finished product because it is completely unobtrusive or invisible to the user.

The first process in order that we can plot clusters of breaks is to identify the location or scenario point in the game during which breaks occurred. Next we use principal component analysis to visualize multivariate data in 2 dimensions. Next, two principal variables are plotted (x, y). In the next section we describe our technique when applied to a serious game with undergraduate students in their natural classroom environment.

3. FINAL STUDY DESIGN

Twenty-six subjects were divided into two groups of thirteen. We focus on one of the study groups (7F and 6M) undertaking one of the games missions. The study was carried out in the students' natural classroom settings.

3.1. Serious Game Test Environment

In the Integrated Media Systems Center (IMSC) at the University of Southern California (USC), a serious game has been developed. Refer to Marsh et al. (2005) for an overview of our experiences in the development of this serious game. The games' objective is to help students learn the physiology and biological processes of human organs. It consists of three activities or missions. One training mission and two main educational missions: Nature Pumps and Control Systems. The Training mission familiarizes users with the fundamentals of the game, instructing them on how to move within the game and how to interact with the environment. The Nature Pumps mission helps students learn the processes of digestion and absorption of nutrients, and the Control Systems mission teaches students the roles of glucagon and insulin in maintaining blood glucose levels.

While the game has two missions the dissemination of the course curriculum using a variety of teaching methods (e.g. lecture, handouts) meant our end user student population undertook just one mission with the game, either:

i) Nature Pumps: provide energy source and reactivate digestion and adsorption processes
ii) Control Systems: regulate available blood sugar and restore systems that maintain blood glucose

So while subjects in empirical studies that were carried out from early to the later phases of the development life cycle in laboratory settings undertook either one or both missions (depending on the study design), in the final study with the end student group in their natural classroom settings, they were divided into two groups with one group performing one mission and the second group the other. We present the results from a study with a group undertaking the Natures Pumps mission.

3.2. Results

In reference to Figure 4, analysis of thirteen students' immersidata collected in studies of undergraduates in their natural classroom settings revealed four clusters of interruptions, labeled 'A', 'B', 'C' and 'D' with each corresponding to a scene in the game. Within each cluster there are sub-clusters where the concentration of interruptions is high. These high-density sub-clusters point to areas within the game where most subjects experienced interruptions. For example, the sub-cluster labeled A-2 in Figure 4 indicates an area where subjects stopped and stared at the details on the inside wall of the intestinal epithelial cell. Cross-referencing with Table 3, we identified that 11 out of 13 students experienced this particular break a total of 75 times. With games that are early in the development cycle this would typically identify design problems. In our study with our educational game environment late in its development cycle, we found that rather than identifying design problems, interruptions or breaks more often than not identified points where subjects paused for a while after entering or exiting a scene, to read a text message or to appropriately contemplate the educational content of the game. Thus, confirming that many of the design features of the educational game environment have reached a level of sophistication so as not to be the cause of unintentional or unnecessary interruptions to subjects' game play. Hence, in this study our visualization technique using clusters and corresponding table presents the results of students' learning behavior and experience.

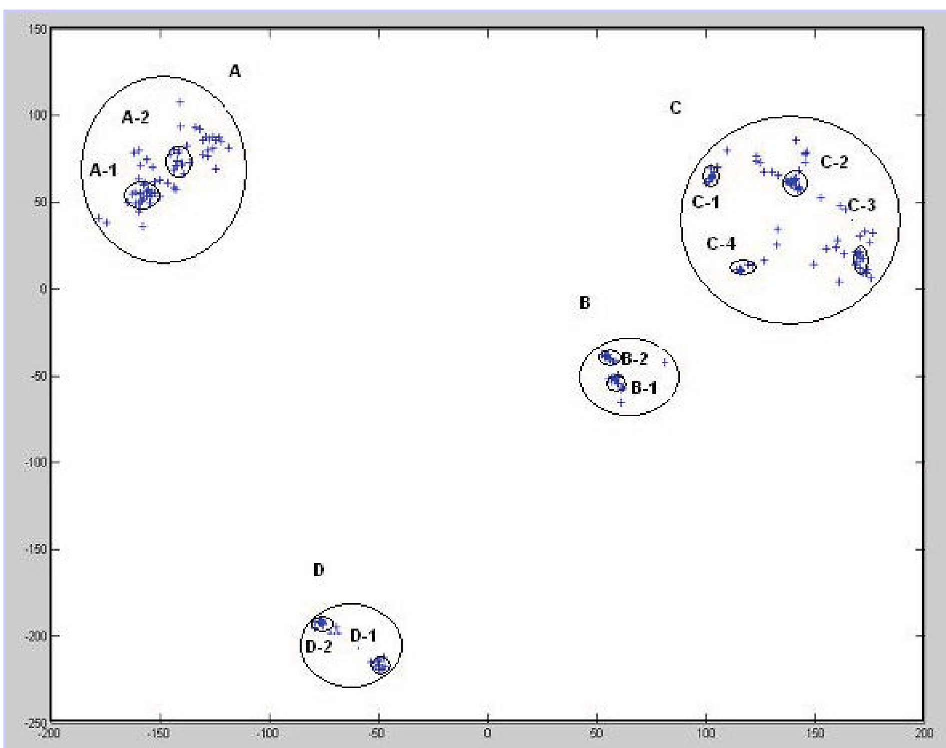

Figure 4. Plots of subjects' positional immersidata in the game where breaks occurred. 'A', 'B', 'C' and 'D' are the main rooms or scenes within organs of the human body as cross-referenced in Table 3. X and Y-axes represent two principle components.

Table 3. List of behaviors within rooms or scenes ('A', 'B', 'C', 'D') of organs in the human body (cross referenced with Figure 4) where interruptions or breaks occurred by subject, the total number of subjects experiencing an interruption and the total number of times an interruption occurred.

cluster	scene	sub-cluster	subjects' behavior	subjects													subjects perform behavior	sum total behavior occurred
				1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*		
A	intestinal epithelial cell	A1	reflecting/staring at lumenside	0	2	2	0	3	2	1	0	8	2	0	0	2	8	22
		A2	reflecting/ staring inside	2	3	5	2	3	7	9	0	28	11	3	0	2	11	75
B	body-room	B1	reflecting/ staring at body	0	0	6	0	0	4	2	5	0	1	1	6	5	8	30
		B2	looking around inside	0	0	3	0	0	3	1	5	1	4	0	6	0	7	23
C	intestine	C1	looking around inside	0	2	11	0	0	3	1	0	4	5	0	0	0	6	26
		C2	reading text	0	0	1	0	0	5	2	0	0	3	0	2	1	6	14
		C3	observing digested food	0	4	1	0	0	2	3	0	1	0	1	4	1	8	17
		C4	reflecting/ staring inside	0	3	2	0	5	3	2	2	1	2	13	1	0	10	34
D	gastric gland	D1	stationary on entry	0	2	2	0	3	2	1	0	1	1	1	1	1	10	15
		D2	reading text	0	2	1	0	2	2	1	2	0	3	0	1	0	8	14

4. DISCUSSION AND CONCLUSION

In this paper we have describe the capture and management of data that represents user's interchanges with an educational serious game. Then we described two complementary tools that we have developed to help analyze and interpret these interchanges and help us to understand user's *staying there* behavior and experience to inform development of an educational serious game throughout phases of its life cycle. The second of these, that is introduced herein, is a completely unobtrusive approach to analyze immersidata using a visualization technique through the use of clusters. We demonstrated the effectiveness of this approach in a study with undergraduate students in their natural classroom environment. The visualization technique overcomes problems associated with using a video camera to capture study sessions as used with ISIS that some users find obtrusive. While sharing similarities with standard techniques in HCI that collect keystrokes in an attempt to trace users' interactions, our approaches are more powerful because, firstly, we can seamlessly collect any amount of immersidata from any source or sensor that we choose. Using ISIS then provides a way to query and index immersidata to virtual or video replays for analysis in a non-sequential manner, and using our visualization technique provides a completely unobtrusive way to query and then plot immersidata of interest for analysis and identify through clusters potentially problematic design features or elements.

While the focus of this paper has been predominately on the analysis and interpretation of user's behavior and experience to inform game development, we have shown throughout how our approaches can be used to assess and reason about user's learning experience. Indeed, in final studies in students' natural classroom settings using our visualization/cluster technique with the educational serious game late in the development cycle, we found that rather than identifying design problems, interruptions or breaks, we captured students' learning behaviors and experience. For example, where subjects paused to read educational text messages or to appropriately contemplate the educational content of the game. Examples of how ISIS was used to analyse and reason about students' learning behaviors and experience have also been presented. Thus, demonstrating that both ISIS and our visualization technique using clusters can be used as tools not only to inform game development per se, but also as tools for teachers, researchers, academics, educationalists, therapists, etc. to qualitatively and quantitatively analyse and reason about user's learning behavior and experience.

While the effectiveness of our approaches were demonstrated through their application to an education serious game, many of the issues addressed in this paper are equally applicable to a range of serious, computer and video games genres irrespective of whether they are predominately for entertainment or non-entertainment purposes. In addition, it is anticipated that many of the issues addressed in this paper can be applied to new and emerging interactive digital media that are designed to provide stimulating experience and so engage the user in pursuing activities and encourage them in *staying there.*

5. ACKNOWLEDGMENTS

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