Exploratory Learning with Geodromo: Design of Emotional and Cognitive Factors Within an Educational Cross-Media Experience

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Abstract

In this paper we present Geodromo, a prototype of an educational multimedia system, part of the Portuguese Ciência Viva *(Live Science) educational program, which is aimed at young people and designed with innovative characteristics. The project is based on a robotic multimedia simulator and an online puzzle game aimed at the exploratory learning of geology, climate, biology, and archeology associated with a Portuguese National Park. The development of the prototype was challenging, as it involved the interweaving of advanced technology and multimedia content with online resources, based on research that promotes the design of emotional and cognitive factors in educational communications. Independent of the scientific relevance of the topics and the inherent technocultural appeal of the project, the aim was to bring students closer to an "undercover" reality, as authentic as it gets with digital media representations, and allow them to convey emotions naturally. We found these to be major success factors in the establishment of an effective relationship between the technology and the pedagogy required to study those particular topics. (Keywords: Educational multimedia, exploratory learning, simulator platform, educational games)*

In this project, we took on the challenge of involving students (up to K–12) in a holistic sensorial experience beyond the usual point-click-watch activity associated with the computer interface. Instead of just creating a virtual world accessible on a limited screen with a limited interface—always a viable task with the technology available at this time—the idea was to connect the real environment of nature with the virtual environment of a multimedia simulator and an online game. In addition, as technocultures become pervasive and create new challenges for educators, researchers have realized a need for exploring new ways of engaging with the world and with others in an educational context (Gredler, 2004). Previous research has also established that well-designed interactive media tools, such as games, simulations, and virtual environments, provide learners with relevant and engaging paths to content mastery (Squire & Klopfer, 2007). The next step would be to bring the two together. But overcoming the technology gap is just one aspect of the problem. And although the game industry has recognized and embraced such learning fundamentals, weaving them into design to increase value to the learner/player, educational institutions have yet to fully recognize and integrate these models. Of course, one strong reason why these institutions don't do it has to do with financial constraints: In the course of this project, we found that huge costs are involved in the production of high-quality the games and simulations.

In essence, Geodromo deals with science themes relevant to the Natural Park of Aire and Candeeiros Mountain Range located in the center of Portugal. Geodromo is housed in the building of *Ciência Viva* (Live Science) in the Park and has the technology that makes possible a 175-million-year (virtual) journey to the origins of the Alviela spring. Geodromo covers a large part of our planet's history, backed up by computer technology of the last generation, simulating cosmic phenomena, geologic events, and climatic change. This project is an initiative of the City of Alcanena, in partnership with the Natural Park of Aire and Candeeiros Mountain Range, the School of Technology and Management of the Leiria Polytechnic, and the Portuguese Open University (Universidade Aberta), and with the collaboration of the Geology Center and the Museum of Natural History (University of Lisbon). The main goal of Geodromo, as a multimedia experience, is to launch the visitor on a virtual journey to discover historical and scientific knowledge and participate in an educational online game, as well as other activities available on the website (see trailer at http://www.alviela.cienciaviva.pt/exposicoes/modulo.asp?accao=showmodulo&id_exp_modulo=18&id_exposicao=5).

The Geodromo platform is basically a mechanical simulator with 16 seating places controlled by a computer and moving in synch with a video projection. The simulator "carries" the visitor on a trip to the origins of the Alviela spring while showing the formation of the plains where herds of dinosaurs roamed, taking the explorers to the edges of the mountain range and its watercourses, flying high over rims and abysses, and diving in caves with the reassuring company of speleologist-divers.

The video and the robotic platform's movements are capable of bringing up emotions and engaging visitors in science themes such as fundamental geologic phenomena, the drift of the continents, the impact of a meteorite, or the rise of the limestone mountain range. These 3D images are computer generated and integrated with real images in a specially designed video narrative. They supply all the clues for tackling online game quests and are complemented by educational materials available on the project website (http://www.alviela.cienciaviva.pt/home). This robotic platform is an immersive environment, if we consider that in a virtual-reality simulation the participant is immersed in a virtual world that fully replicates at least three sensory inputs—vision, hearing, and the kinesthetic system—which allows for a complete physical interaction with the world. Although direct user interaction is not viable with Geodromo's "heavy-duty" robotic platform and multimedia system, it can be later accomplished online with educational resources.

Technology and Pedagogy

The technologies that Geodromo uses are simultaneously "figure and ground," as they embody the virtual environment created but also become instruments to study a historical reality that is long gone. Because technology has an impact on human cognition and therefore on human learning, the emphasis was first put on learner engagement and on the capacity for visualization through the presentation of 3D structures (such as dinosaurs or geologic strata) in ways that maximize learning. As we also recognized that a computer screen–based simulator provides only a limited interface to the human sensory system that is far from physical reality, we decided that the robotic simulator was a smarter choice to establish a bridge with the real world.

Behind all this technological apparatus, there was much work involved. It is essential to point out the role of the different scientific consultants who collaborated in the production of texts, graphics, and images to give scientific credibility to this project. In all, this venture involved a wide variety of human and technical resources, including authors for the multimedia content and a large video production team. We give much credit to the engineers that created the robotic platform and the designers who developed the animated computer graphics, as these were critical factors in the project. The production of all the multimedia components took more than three years of intense labor and involved an iterative and creative process that occupied a great deal of the project time. We used advanced technical resources in the production of the video material to obtain:

- Images of inaccessible spots in the natural park
- Images of caves and speleological activity
- Images of diving in the underground ducts of the Alviela River
- Aerial images over the mountain range
- 3D graphics to illustrate 175 million years of earth history

Pedagogy considerations dictated that the video narrative should not be scientific fiction. We developed the narration with current scientific knowledge in mind. It set out as if the user was part of the computer-generated images, immersed in a theater environment with 3D sound and comfortably riding a moving platform. Digital-image technology showed the alterations in continents' morphology and the global climate changes that converged in the formation of the actual limestone mountain range while the infrastructures of underground water draining were slowly evolving at the same time. Computer animation showed all this clearly and accurately. In certain episodes, ambiguous situations were exposed to provoke curiosity and boost attention. In the Geodromo video, the director and authors' intention was to avoid the traditional didactical approach used in many documentaries and educational programs and to follow a pedagogical approach closer to video games that gives basic information first, provides an always-present timeline to follow, and deliberately motivates emotions.

Two key challenges were (a) supporting the hypothesis-generation-testing cycles that form the basis for exploratory learning and (b) orchestrating all of the events in the unfolding narrative to support appropriate levels of student motivation, engagement, and self-efficacy for effective learning (Mott, McQuiggan, Lee, Lee, & Lester, 2006).

Also, according to Rieber (2004), all exploratory learning approaches should be based on four principles:

1. Learners can and should take control of their own learning.
2. Knowledge is rich and multidimensional.
3. Learners approach the learning task in very diverse ways.
4. It is possible for learning to feel natural; that is, it does not have to be forced or contrived.

On the other hand, while accepting that technology is a key factor in transforming education, we uphold that the most widely established theories and models behind learning are still valid. For instance, the pedagogical framework for implementing new software tools, games, and simulations can be developed by drawing on concepts from constructivism (Bruner, 1966; Piaget, 1973), social constructivism (Vygotsky & Cole, 1978), situated cognition (Barab & Kirschner, 2001; Brown, Collins, & Duguid, 1989), and communities of practice (Wenger, McDermott, & Snyder, 2002). Social constructivism in the Vygostkyan way provides a series of principles that may be accomplished during the development of educational activities. The Piagetian notion of constructivism at the core basically states that students modify their current knowledge schemes to integrate new information and acquire new knowledge when in contact with teachers, peers, and the surrounding environment. In addition, learning activities must be situated in authentic settings and in a context that is meaningful to each student, and their effectiveness may increase when students are part of a community that shares values and contributes to a common objective. Constructivism, situated learning, and the establishment of communities of practice constitute a robust theoretical framework for knowledge acquisition based on the notion that learning occurs in the context of activities that typically involve a problem or task, other persons, and an environment or shared culture.

The idea that technology can provoke radical changes in pedagogical methods and in processes of educational communications reflects a paradigm change that we believe to be decisive. The relationship between technology and pedagogy has changed substantially in the last decade and must be considered in the light of the recent developments in digital technology, as these definitely entail a rupture in the tradition of a rigid curriculum based instruction. For example, simulation-based media such as games challenge both how we teach and what we teach (Squire, 2008). On that note, Starr (1994) argues that simulations—the process of setting up scenarios and exploring under what conditions they might work—are at the core of business, government, and science. For many years researchers have studied the uses of simulations in education and established that well-designed simulations will develop in the student a profound, flexible, spontaneous, kinesthetic understanding of the subject matter (Gibson et al., 2007; Issenberg, 2006; Kezunovic, Abur, Garng Huang Bose, & Tomsovic, 2004; Teodoro, 2004). In fact, studies have found that students who learn by means of simulations can improvise better in real-world contexts. They can handle unexpected situations with easem, and knowledge learnt is not structured around a set of norms or processes but developed from intrinsic personal experience. This is the kind of knowledge students retain for a long time. Unquestionably, today video games are many individuals' primary exposure to this important way of thinking (Squire & Giovanetto, 2008).

Also, given the state of the education today, teaching must become cross-disciplinary and cross-cultural. Through the intersection of multiple perspectives and approaches, new theoretical insights will develop and unexpected practical solutions may emerge. In recent years, the need to reorganize education became a necessity, and finally we perceive that the use of digital media may produce effective and global results. These results are not limited to mere experimental situations, as evidence shows that some progress is under way (Bidarra, Guimarães, & Kommers, 2004)—specifically, that control of learning processes shifted from the teacher to the student, book materials are replaced by multimedia materials (mainly podcasts), and the information is now available online instead of offline.

But, perhaps more important, learners cannot continue to be taken as simple users, as they are also producers of multimedia materials. This was true in the past (Bidarra & Mason, 1998), but today's students not only engage in creative activities such as the production of a video clip or a blog but also spend their days interacting online via multiple media: exchanging messages, sharing images, and playing games. In many cases, students have to work with each other in projects and access the world of subject-matter experts and resources available on the Web. As a rule, freedom of choice, challenge, participation, transparency, integrity, collaboration, fun, speed, and innovation must be a part of their learning experiences.

An Interactive Cross-Media Experience

Along with the pedagogical advantages that the new digital technologies offer, it seems there is often an exaggerated emphasis on the technical characteristics of the multimedia products and little interest in actual educational communications. This superficial attitude means that many see multimedia and games as high-tech entertainment options but not as educational tools. It also means that, in many e-learning cases (Bidarra & Dias, 2003), advanced multimedia materials and websites full of rich content do not support educational objectives and are deficient as instruments for instruction. Graphical animations and videos often have an excess of information that makes it difficult for a student to apprehend the right conceptual framework within the instructional activities and resources. The same is true of many games that fail to deliver the curriculum while involving students in endless (and useless) routines of styling and data manipulation.

On the other hand, research has shown (Roschelle, Pea, Hoadley, Gordin, & Means, 2000) that learning with games also "is most effective when four fundamental characteristics are present: active engagement, participation in groups, frequent interaction and feedback, and connections to real-world contexts" (p. 80). At first glance, this is true of Geodromo, as gaming holds great potential for student learning that extends and builds on tacit knowledge. However, the combination of the mechanical simulator and the online game does not fit easily into a formal game genre.

A recent trend has been so-called "augmented reality games," which are location-based and have a context-sensitive dimension related to a precise physical space (Squire & Klopfer, 2007). Also known as "enhanced reality," this usually refers to virtual experiences that are played out in real-world spaces. In general, players can discover contextualized clues only via the digital interface when he or she arrives at the right location with a mobile device. In contrast, the (first) physical part of Geodrome is on location in the form of a video projection synchronized with a robotic platform engineered to create the right "virtual context" for the game to take place. Geodromo comes closer to the concept of an alternate reality game—an interactive cross-media narrative that evolves based on knowledge associated with a real-world setting. In this case, the high emotional impact of the physical experience (people seated on a robotic platform that moves and jumps in synch with a video projection) is an important feature to engage the players in further gaming/learning activities. This experience takes place in a physical space, but it is also a "virtual journey" in the sense that the content presented compresses 175 million years into a 10-minute 3D digital video reconstruction of ancient times featuring extinct dinosaurs, prehistoric landscapes, and the first men hunting for food.

The game works like a kind of online scientific detective story. For example, a player has to find a clue in the 3D representation of the Alviela Spring, which triggers a further investigation process. The player follows up on the clue, locates particular information online, has to answer specific questions, and inputs the information within the game environment. Players may also negotiate meaning through the social context of game play, which promotes collaboration. They do this through the co-construction of knowledge as each player uses specific information, bridging physical and digital game space with support on messaging. Usually most K–12 students can do this on their own, whereas the younger ones need assistance and guidance (usually from teachers or parents).

Sometime after we finished the prototype of Geodromo, to eliminate likely obstacles and refine the setup, we decided to collect some preliminary data by means of direct observation and serial one-on-one interviews with a panel of five teachers and 10 students (K–12) considered representative of the main target public. We conducted the interviews immediately after panel members experienced the multimedia platform and used the online resources. We followed an empirical approach that relied on open-ended questions to explore user attitudes, feelings, and expectations, but also included a number of questions designed to assess comprehension of multimedia content. In essence, we tried to get reactions to these main questions: Were users satisfied with Geodromo? Which aspects were less satisfying? What made activities interesting or fun? How could we maximize enjoyment without sacrificing instructional quality? (The last question was addressed to teachers only.)

After we carried out the interviews to the panel of five teachers and 10 students and had them transcribed, we highlighted distinct issues and stated opinions, which we subsequently classified into three categories: technical issues (e.g., sound, image, pace), content issues (e.g., intelligibility, style, expressions), and pedagogical issues (e.g., cognitive overload, dispersion, disorientation). This was a recursive process: As we were collecting the data, we were noticing new things that were important, so we collected new information covering those things, and all this time we were already mentally thinking about those issues we uncovered. We also checked the answers we received against our direct-observation data about the users' emotional and affective actions. This thinking process enabled us to make some kind of sense out of the information received, to look for patterns and relationships, and to make general assumptions that showed the way to actual improvements in the system.

Although the diagnostic study is beyond the scope of this article, we consider it useful to mention here that both the analysis of observational data and interviews with teachers and students provided us with valuable information to understand implementation. For instance, teachers were pleased with the diversity and scientific quality of the digital material but were less confident about the recreational narrative style that Geodromo used. Students were content in general with the robotic platform and multimedia presentation but found the online resources less appealing and indicated that interactivity was poor. The data collected also allowed us to uncover unexpected technical problems that were not previously identified in project evaluations (e.g., lack of clarity in the video audio/narration and insufficient detail in some images). We are conscious that, because of the small sample size, we must interpret the results with caution. Even if some operational issues were resolved and users seemed to be generally satisfied with the project, evidence that such factors lead to better student outcomes does not yet exist.

The expectation that Geodromo will improve achievement scores bears further investigation, as it is likely that, to expect achievement gains, this project would need to be part of a larger, more comprehensive effort to improve instruction. Imagine for a second that you are a teacher or instructional designer, charged with developing an advanced science course covering a few hundred new terms, facts, and concepts. How would you go about designing materials that cover these concepts? What kinds of experiences would you want learners to have? How would you pace them, and how would you know if they truly mastered what you needed them to learn? There is great complexity in this process. We found that, for some teachers, much of the enthusiasm about the potential of providing students with multimedia and games is tempered by an appreciation for the complexities and difficulties in the implementation of educational technologies. Often new technological innovations have proven unusable to a wide range of teachers, either because schools lack the capacity to put them into practice or the culture of the school is not supportive of technology adoption.

Emotion and Cognition Issues

The current model of pedagogy in schools (and universities) is essentially teacher focused and features only one-way communication. It tends to isolate the student in the learning process. Evidence shows that students learn more by collaborating with their teacher and with each other in the context of educational narratives (Pachler & Daly, 2009). Also, there is evidence that a new model of education is emerging that is student-centered, networked, customized, and collaborative, leading to the creation of mechanisms through which infusion experiences and other rich learning contexts may support activity in novel situations (Shaffer, 2004). In addition, it is now recognized that student emotional expressions are a part of the learning process and an essential component of basic education, but so far this continues to be a minor concern in schools and higher education. There is a growing body of evidence from the neurosciences and the cognitive sciences that stresses the importance of emotions in cognitive processes and memory operations (Caine, Caine, McClintic, & Klimek, 2008). They are telling us what we as educators have intuitively known for a long time: Factors related to biology, experience, and culture indicate that students actually learn from everything that touches their lives. If we take this research seriously, then we understand that, with this extended view of learning, education is never just about memorizing facts and passing tests. The Portuguese-born neuroscientist António Damásio developed a theory of emotion that has evolved from his first book, *Descartes' Error: Emotion, Reason, and the Human Brain*

(Damásio, 1994), which explains how feelings are entangled in the cogitations of the brain and the circumstances of the body. In his second book, *The Feeling of What Happens: Body and Emotion in the Making of Consciousness* (Damásio, 1999), he explores the role of emotion connecting the neurology of emotion to the neurology of consciousness and extends this to the existence of a sense of self. Essentially Damásio states that mind and body are inseparable and integrated via mutually interactive biochemical and neural components, such as the endocrine, immune, and autonomic neural constituents, which produce chemical and electrical transmitters.

Let's imagine a young student riding the Geodromo platform in full motion. He is emotionally satisfied and fully engaged in the experience. Suddenly there is a strong thump, and a dinosaur appears in close-up. The sensory input sends the brain the image of the dinosaur. The brain sends signals using neurotransmitters telling the body to react: The heart speeds up, the muscles tighten, blood rushes to certain parts of the body. Simultaneously, the image of the dinosaur is sent to other parts of the brain for analysis. This analysis accesses stored knowledge and memories. These working regions of the brain continue to process further information to the brain hub, which then sends another message to tell the body to relax. The heart slows, the muscles relax, the blood flow returns to normal. Why? The robotic platform has slowed down, and the images suggest that the dinosaur is walking away (sign of relief). Later on, while playing online, that situation has left a mark, and the student definitely remembers the dinosaur and its specific features.

We argue that any project developing a game or multimedia environment must acknowledge the value of emotions as a tool to be used in the cognitive dimension, particularly when the education and training of young students is involved. There is also a need to shift curriculum focus from knowledge about things to knowledge significant to each learner, and this must include emotional play. Changing the focus of education in this way is not an easy task, as the current school environment and its operation are very distant from the world of today's digital natives. In this context, Geodromo tried to break away from mainstream curriculum and instruction but also tried to shift the educator's view on emotions by giving it new status as a dimension that co-exists with the intellect, taking students to do something new: ride on a robotic simulator platform and later interact online with a game-like environment.

Ideally the Geodromo game should have been more complex and based on simulation, with several levels of varying degrees of difficulty through which the players could move and learn new skills. However, because of financial constraints, the first instance of the game became more like a puzzle falling within the detective genre. Nevertheless, the success of the project is evident, and it has been reassuring to see many thousands of students (and general public) use the simulator platform. Furthermore, teachers have been using both the platform and the online materials to engage students and deliver part of the curriculum.

The Geodromo project also gave us the perception that it is pedagogically more effective for teachers and young students to be able to graphically "see" abstract concepts before discussing them, for example, in areas such as geology, climate, biology, and archeology. We feel that instructional design and scientific representation today converge in the creation of digital 3D models that can show a "hidden" reality (long gone or difficult to apprehend). No matter if some scientific representations are just educated guesses based on the limited data available (e.g., dinosaur bones), we think it is worthwhile to promote students' engagement and facilitate access to some curriculum subjects by means of digital technology.

In a project of this kind, it's also important to emphasize the imagination factor, often described as the capacity to create mental "images," as a key element of educational communications. When we try to describe imagination, most of the time we mention the capacity to develop images in our mind, frequently images of things that not even exist in the real world. The nature of these images is sometimes difficult to describe; they can be almost pictorial, exact images, or even vague impressions. For Egan (1986), imagination is the support of the so called oral cultures. In these cultures, the knowledge of the social group has to be preserved and kept alive for future memory. This implies the use of techniques of representation and narration with a recognized social value, such as words and rhymes or music and rhythm, that are important for the spread of a culture and the prospect of future memorization. Today this is achieved through digital technology, social networking, and games in exciting new ways (Web 2.0, podcasts, massively multiplayer online games, etc.). The only difference is that knowledge is not stored in people's memories, but rather widely distributed across a network of electronic devices. However, this is another interesting issue for future discussion.

Conclusions

Geodromo was designed to be an innovative prototype of an educational multimedia infrastructure. The primary goal was to provide young students and general public with knowledge of important concepts in several domains—including geology, climate, biology, and archeology—related to the specific context of a National Park. To achieve its goals, Geodromo employed a number of techniques and methodologies for improving learning quality, including the explicit consideration of emotional and cognitive issues in educational practice. Geodromo was a pioneer effort to bring about new ways of involving students in a holistic sensorial experience while exploring learning content beyond the usual keyboard, mouse, and screen practice. At the same time, this project dealt with aspects of the instructional design process that are sometimes neglected. We found that to design an instructional game or multimedia environment well, we had to be simultaneously systematic and intuitive, analytic and artistic. In mastering the design process, we've learned to handle the cognitive side of instruction (which, almost by definition, is the most important), but we've also learned to deal with the affective side of instruction. It was a difficult and fascinating challenge for the technologists and instructional designers involved. Eventually, everyone agreed that the implications for understanding the relationship between multimedia/games and learning are that these features don't have to be defined as essential instruments or content, but as contemporary human creations whose forms and meanings are strategic.

So far, the thousands of young people (at this time 35,000 people have visited Geodromo) the simulator has attracted are a promising indicator. In addition, many teachers have been using both the platform and the online materials to engage students and integrate with formal curriculum and instruction. However, we sense that a lot of work still has to be done on the online game. A future major concern is improving the integration of the "virtual reality" presented by means of the robotic simulator with the digital environment accessed online in such a way that the narrative carries on from one to the other in a more fluid and seamless manner.

The questions that will dominate future research are essentially:

- How do we represent reality in a simulation?
- How do we balance simplicity, efficiency, and playability against realism, richness, and complexity?
- How do we make sure students effectively learn subject matter with multimedia and games?

Investigating issues of effectiveness entails using measures as simple as recall and as challenging as near and far transfer. Efficiency is an important concern, as exploratory learning is known to suffer from efficiency issues: Exploratory learning, even when guided, is often more time consuming than more didactic approaches. One expects to find a trade-off between effectiveness (especially motivational effectiveness) and efficiency, and it will be interesting to see how the trade-off plays out in practice.

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