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Adaptive Role Playing Games: An Immersive Approach for Problem Based Learning

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ABSTRACT

In this paper we present a general framework, called NUCLEO, for the application of socio-constructive educational approaches in higher education. The underlying pedagogical approach relies on an adaptation model in order to improve group dynamics, as this has been identified as one of the key features in the success of collaborative learning scenarios. Students' learning strategies are analyzed considering a simplified version of Vermunt's model for learning styles. The resulting profiles provide the basis to group students in teams where each student is assigned a role according to his/her learning strategies. The result is the formation of complementary and semi-autonomous learning teams that collaborate to achieve solutions to the problems provided by the instructor. The framework is instantiated through an online multiplayer role-playing game environment, which sets a stage for the underlying collaborative problem-based learning approach. The framework has been benchmarked in different programming courses at the Complutense University of Madrid during 2007-08 and 2008-09 academic years. This work also presents the results of these experiences.

Keywords

Educational games, Learning Objects model, Learning Objects meta-data, Learning Management System interoperability

Introduction

The Net Generation (Tapscott, 1998) has already arrived at university and college. They differ completely from the people in charge of their education (their teachers and parents) in the role that ubiquitous technologies have played in their everyday lives. Today, students have grown up using devices like computers, mobile phones, and video consoles for almost every activity, from studying and work to entertainment and communication. This has probably altered the way they perceive and interact with the environment, both physically and socially (Prensky, 2001b). To meet the different cognitive requirements of the new generation, the educational community is considering new ways of learning. In particular, there is a wide interest in trying to engage students with the appealing features of videogames and Internet tools (Prensky, 2001a).

Nevertheless, most of these approaches have been developed without taking into consideration the current infrastructure of Learning Management Systems (LMS). LMS are probably the most extended tools for managing the whole educational process in higher educational institutions, from teaching and learning to administration. We think this omission is a mistake: even though learning through games has very positive educational values, it obviously cannot cover the whole range of educational needs. Game-related initiatives are often disconnected from key aspects of an integrated educational process such as storing and managing learning content, performing specific learning management tasks or maintaining historical student records.

NUCLEO is an e-learning framework that comprehends a pedagogical strategy and the technological infrastructure to support it. The learning strategy is deeply grounded in the socio-constructive pedagogical stream (Vygotsky, 1978; Palincsar, 1998): it combines Problem Based Learning (PBL) (Savery & Duffy, 1996) and Computer Supported Collaborative Learning (CSCL) (Koschmann, 1994) in a framework that uses a multiplayer role-playing videogame as the delivery format. In NUCLEO, active collaborative learning takes place in the scenario of a virtual world with game-like mechanics. NUCLEO takes the learners, who are represented by avatars, into a fictional scenario where they have to solve a number of missions. To succeed, they need to collaborate with other students within a team. The missions proposed to the teams respect the style and context of the videogame metaphor and are rendered in the virtual scenario in which the activity takes place. The specific fictional scenario and underlying narrative can be changed to fit different subjects and contexts. In addition, the framework implements a plug-in to work along with a LMS, enhancing both tools with complementary functionalities.

One of the key aspects in collaborative learning is the implicit assumption that the participants learn from each other inside teams. Therefore, the way in which students are grouped has a strong impact on the results of the learning process. A positive learning experience might turn into a negative one depending on the group composition. The coordination for group work is another key aspect for the success of a collaborative learning experience. An effective way to coordinate group work is to assign concrete responsibilities to individuals using functional roles (Strijbos, 2004). NUCLEO addresses these aspects by means of an adaptation model that relies on Vermunt's conception and classification of learning styles (Vermunt, 1992). The "Inventory of Learning Styles" (ILS) proposed by Vermunt is used to try to identify those students who need more intensive guidance through the learning process, and those who are more inclined to drive their own learning experience. By grouping heterogeneous students according to their learning style, we presume that the most autonomous students will provide leadership and guidance to the group. At the same time, the effectiveness of the collaboration process within a team will improve by teaming up students with complementary learning strategies and assigning them concrete interdependent responsibilities linked to a role. Teams are also a way to enrich social interaction among students.

NUCLEO is a complex framework that relies on several hypotheses that need to be experimentally proved. In particular:

- Vermunt's ILS is an effective underlying model for forming teams.
- Using functional roles helps to improve group work coordination.
- The 3D immersive scenario is positive for motivation.
- The role game dynamic is positive for the motivation and induces students to adopt a more active role.
- The competitive atmosphere created by using social recognition strategies is positive for motivation.
- The framework is effective in terms of knowledge acquisition.
- The framework is effective in terms of helping students to acquire soft skills and team work abilities.

In order to prove these hypotheses in a cost-effective way, NUCLEO is being developed according to a fast prototyping development plan. So far, two different prototypes have been developed, *Mundo NUCLEO* and *Mare Monstrum*, each of them conceived to prove different aspects of the underlying assumptions. These two prototypes have already been benchmarked in several cases of study. NUCLEO is a long term research project that, so far, has been running for the last three years. Some results concerning these cases of study have already been published. In particular, (Sancho, Fuentes, Gómez-Martín, & Fernández-Manjón, 2009) discusses the results of the first three cases of study, performed with the Mundo NUCLEO prototype. The main goal of this work was to see if the role game dynamic was effective in terms of increasing motivation; and, also, if students were able to acquire the required technical knowledge included in the course curriculum. In (Sancho-Thomas, Fuentes-Fernández, & Fernández-Manjón, 2009), the results obtained in one case of study with the Mare Monstrum prototype are presented. This case study was conceived to prove if the 3D immersive scenario was positive for motivation and if the framework was effective in terms of helping students to acquire soft skills and team work abilities.

This paper is focused on the new results obtained concerning the effectiveness of using Vermunt's ILS as the underlying model for the adaptation process. In particular, we discuss its effectiveness in terms of team formation and its suitability for role distribution as a way to improve group work coordination. The results have been gathered through the cases of study performed so far with the two prototypes (i.e., Mundo NUCLEO and Mare Monstrum) when applied to university programming courses.

The rest of the paper further discusses the elements outlined in this introduction with the following structure. First, we describe the pedagogical foundations underlying NUCLEO. Then, we present the overall structure of the framework and describe two NUCLEO-specific instances, with different narratives and game metaphors, already applied in the prototypes of the cases of study. After that, we describe the cases of study undertaken so far, presenting and discussing the results obtained. Finally, we summarize our conclusions and outline future lines of work.

Related Work

The NUCLEO framework combines several existing learning approaches. NUCLEO considers dPBL (distributed Problem Based Learning), CSCL (Computer Supported Collaborative Learning), student centered models using adaptation according to learning styles, and learning in virtual worlds or MUVE (Multi-User Virtual Environments).

These approaches offer a wide range of alternatives for team formation and organization. Our choices have been determined by our specific goals and contexts. There are different works belonging to these three approaches that share some features with the NUCLEO framework. This section presents some of the most similar to NUCLEO in terms of the adaptation model.

Team formation and organization have drawn important attention for both educative and work environments. Literature describes different alternatives according to the goals intended for the team activity (Morgeson, Reider, & Campion, 2005). Since one of the NUCLEO objectives is the acquisition of teamwork skills by students, it considers heterogeneous teams of students. This choice is in the line of some authors (Oakley, Felder, Brent, & Elhajj, 2004) that consider this heterogeneity can enrich the discussion in the group with different perspectives and knowledge, offering students the opportunity to deal with different personalities, and gathering ineffective students with stronger learners, who can provide inspiration and guidance. Nevertheless, this kind of team organization also presents some risks in an educational context (McCracken & Waters, 1999). First, there are personalities that are inherently difficult to work with them. Composing groups with such people can lead to form ineffective team works. Nevertheless, it can be argued that real teams may include that kind of personalities and, of course, no students should be put aside because of their personalities. Second, programming problems with a true need of teamwork require a long time, since they are closer to real projects in the range of months than to toy practices of a few weeks. However, programming courses commonly pose several problems in the course with reduced development times. A heterogeneous team of non-related students can find it difficult to set up the required bonds and routines in such short periods. The problem in both risky situations is that failing to achieve a proper workflow can affect the motivation of the entire team, and prevent the students from acquiring the intended skills. A different interesting approach for CSCL can be found in (Bravo, Redondo, Verdejo & Ortega, 2008).

The other relevant feature of NUCLEO discussed in this paper is the organization of work through functional roles. Industrial software development commonly uses this organization to set up team organization (Brooks, 1975). Thus, NUCLEO considers adopting it as a way to train students in real team work practices, but also to develop suitable soft skills. However, roles are only one of the ways of making students interdependent and therefore setting up their social bonds (Johnson, Johnson, & Smith, 1991). Besides, imposing teams an internal organization that they do not agree can prove to be a futile effort (Oakley et al., 2004). Students forced to work following an imposed organization of work, can externally accept it but internally work in a self-organized way. This misleads the learning goals of the intended approach with roles. NUCLEO tries to avoid this situation through two mechanisms: an imposed composition for the teams and the assignment of different roles; making individuals accountable for the work related with their role.

Finally, there are also implementation aspects of the adaptation model in MUVE and LMS. The integration between them has also been explored through initiatives such as SLOODLE (Kemp & Lingstone, 2006; Gonzalez & Blanco, 2008). However, NUCLEO's distinguishing feature is that the integration is driven by the underlying pedagogical model described in the following section.

Pedagogical Model

The NUCLEO framework proposes an educational model deeply rooted in socio-constructive pedagogical theories (Palincsar, 1998). As previously mentioned, it combines several existing approaches to socio-constructive education, such as CSCL, PBL, student-centered models using adaptation according to learning styles, and MUVE. In fact, NUCLEO's underlying learning strategy is actually an enhanced PBL approach that makes use of the following strategies in order to reach the pursued educational objectives:

- A role game and a 3D immersive scenario in which students are represented by avatars. This strategy is conceived to address the following educational objectives:
    - To promote active roles between the students, who are incited to abandon their usual passive attitudes (Corti, 2006).
    - To create a propitious atmosphere for the emergence of social and affective bonds among players, leading to the formation of communities of practice (Baron, 1999).
    - To promote competition by social recognition through a game narrative in a 3D scenario. This "good competition" between students can provide an additional push to the enhancement of motivation (Johnson & Johnson, 1994).

- An adaptation model based on a simplified model of Vermunt's ILS (Vermunt, 1992) (see section Adaptation to Learning Styles) with a twofold objective:
    - Forming effective semi-autonomous teams in which students are grouped considering their compatibility in terms of their learning strategies using Vermunt's ILS (Vermunt, 1992).
    - Improving group coordination by distributing the work according to functional roles that are also assigned to the students by means of their classification in the ILS. A learning strategy structured by collaboration scripts in order to guarantee students' participation in educationally meaningful activities.

The rest of this section further describes these pedagogical foundations of our framework.

Collaboration and Problem-Based Learning

According to Barrows and Tamblyn (1980), Problem-Based Learning (PBL) can be explained as "the learning that results from the process of working towards the understanding or resolution of a problem." In most cases, PBL is performed in small groups, fostering discussion and collaborative discovery, as the groups need to work together towards the solution for a specific problem or set of problems. A group has a tutorial leader or facilitator who shares information and guides the group through the learning process. In sum, PBL is a process of building new problem solving skills on prior knowledge by using critical thinking approaches and reflection (Maudsley, 1999). This self-directed and collective approach constitutes a very different way to teach compared to traditional lecture-based approaches.

Educational literature has shown the benefits of using PBL and other approaches that promote active collaborative learning to improve students' thinking skills (Kreijns, Kirschner, & Jochems, 2003). It has been demonstrated that it leads to deeper levels of learning, critical thinking, shared understanding, and long-term retention of the learning material. Furthermore, collaborative learning also provides opportunities for developing social and communication skills, acquiring positive attitudes towards co-members and learning material, and building social relationships and group cohesion (Johnson & Johnson, 1994).

However, the collaborative nature of PBL is frequently an issue. It is often difficult to arrange the schedules of all the members of a team to participate in work sessions. The possibility of meeting remotely can allow more effective PBL initiatives. New technologies have made possible to delocalize this approach, the so called dPBL (distributed Problem Based Learning) and sometimes CSCL techniques are used as virtual implementations of this pedagogical approach (Resta & Laferrière, 2007).

Unfortunately, it is not easy to implement a PBL approach effectively when we factor out the direct personal contact. This is due to different reasons, and one of the most important ones is that PBL relies very heavily on group dynamics for its success. If group cooperation and cohesiveness are key factors in PBL, we must take into account that the lack of face-to-face interaction affects them negatively. Simply providing students with some remote communication tools does not guarantee the emergence of the social interactions that lead to effective collaboration (Lurey & Raisinghani, 2001).

As it has already been stated, NUCLEO applies two different strategies to address these problems and enhance group dynamics:

- An adaptation model aimed at forming heterogeneous, effective and semi-autonomous teams by means of an adaptation of the classification model of Vermunt's learning styles.
- A role game and an immersive virtual world in order to promote the affective links that may lead to the formation of communities of practice among players.

Adaptation to Learning Styles

User adaptation in e-learning can be characterized as the ability of a system to personalize the learning experience to different individual conditions over time. In general, the adaptation process includes three stages (Brusilovsky & Maybury, 2002): gathering information about the user; processing this information to initialize and update a user model; and using that model to provide the adaptive behavior. One of the students' features that can be considered in these models is their learning styles.

Learning styles have generated a lot of debate over the past few years mainly because, in spite of long empirical efforts to pin them down, their identification remains elusive. Nevertheless, some approaches that describe learning styles as flexible strategies to tackle learning have got positive evaluations in relevant independent studies (Coffield, Moseley, Hall, & Ecclestone, 2004). In particular, Vermunt's model (Vermunt, 1992) was specially conceived for university students. It is really more a classification of students according to the strategies they usually employ to approach learning than a categorization of learning styles, as they are commonly understood. This view fits with our idea of reaching auto-regulated teams, as it can provide criteria for the organization of teams.

Vermunt classifies students into four types depending on the attitudes they adopt in five different areas of learning by means of its ILS. These four learning styles are: meaning-directed (MD), application-directed (AD), reproduction-directed (RD), and undirected (U). This approach helps to distinguish the students who need more intensive guidance through the learning process from those who are more capable of guiding their own learning experience. Those students who are able to self-regulate their learning processes usually present MD and AD patterns, and they would benefit from a more open teaching strategy. Students who would need stronger teacher control and guidance commonly correspond to the RD and U patterns (see *Table 1*).

Our team formation strategy is based on grouping three or four students, among which there is at least one MD or one AD student. In every team, students are assigned different roles, embedded in the game metaphor, according to their ILS profiles (see Table 1). The Captain of the crew (assigned to MD or AD profiles) is in charge of project planning and progress monitoring. The Knowledge Integrator –KI- (assigned to RD profiles) is in charge of controlling and supervising that all team members acquire the required knowledge. The member Responsible for Communication –RC- (assigned to U profiles) is in charge of managing communication between team and tutor. All of them have concrete tasks, interdependent responsibilities and specific tools assigned.

Table 1. Main characteristics of the four profiles according to Vermunt's ILS and correspondence with NUCLEO functional roles

Role	**CAPTAIN**		**KNOWLEDGE INTEGRATOR**	**COMUNICATOR**
Learning style	**Meaning-directed (MD)**	**Application-directed (AD)**	**Reproduction-directed (RD)**	**Undirected (U)**
Cognitive processing	Look for relationships between key concepts/theories: build an overview	Relate topics to everyday experience: look for concrete examples and uses	Select main points to retain	Find study difficult: read and re-read
Learning orientation	Self-improvement and enrichment	Vocational or "real world" outcomes	Prove competency by getting good marks	Ambivalent; insecure
Mental model of learning	Dialogue with experts stimulates thinking and engagement with subject through exchange of views	Learn in order to use knowledge	Look for structure in teaching and texts to help take in knowledge and pass examinations. Do not value critical processing or peer discussion.	Want teachers to do more. Seek peer support
Regulation of learning	Self-guided by interest and their own questions; diagnose and correct poor understanding	Think of problems and examples to test understanding, especially of abstract concepts	Use objectives to check understanding; self-test; rehearse	Not adaptive

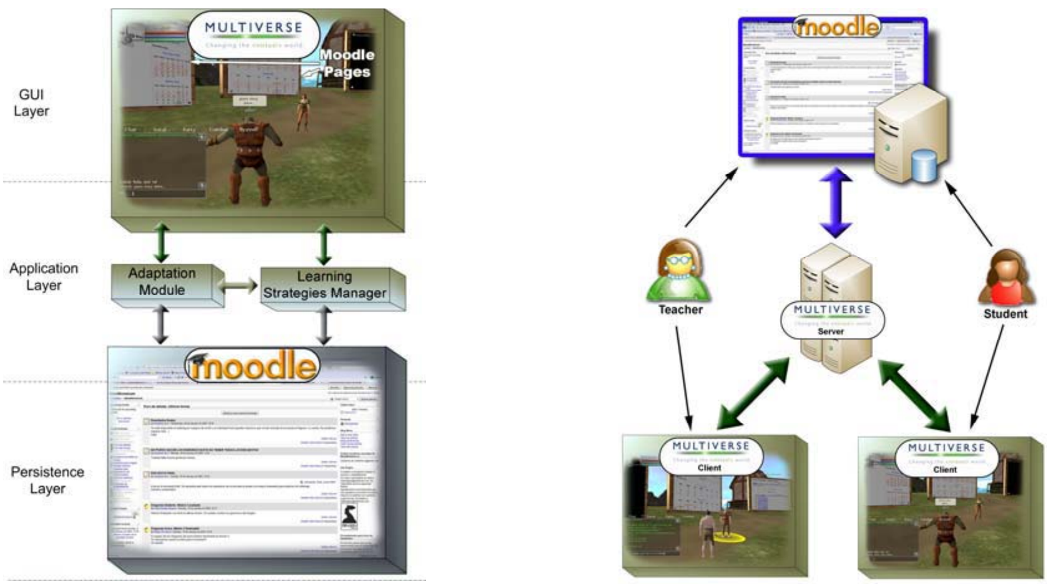
Motivation, Narrative, and Role-Playing Games

As stated in the introduction, authors such as Prensky (2001b) or Tapscott (1998) consider that the Net Generation belongs to a new digital media culture that behaves very differently than their teachers and parents do in profound and fundamental ways. For instance, these students are used to multimedia content connected with hyperlinks, and find the traditional teacher-centered courses quite unattractive, preferring a collaborative learning with peers. Although there have been important advances to make teaching strategies more interactive and appealing to them (Prensky, 2001b), this evolution does not seem to completely fulfill the needs of knowledge disclosure for these students.

Considering these observations, the potential use of videogames as a tool for education has drawn significant attention, especially for PBL approaches. Games present several relevant features that could benefit the students' learning experience (Gee, 2003). They offer immersive and realistic scenarios with engaging narratives that challenge the user to solve problems embedded in the game. At the same time, they are designed to continually offer problems that are just beyond the limit of expertise of the player. They also deliver the required information on demand and in context, when the player can make a meaningful acquisition of it. Finally, games are often the seed of communities of practice where players spontaneously collaborate to build knowledge to solve the game quizzes. Moreover, in the case of multiplayer games, this collaboration is closer as it happens in the same place and time (Lave & Wenger, 1991).

Despite these positive features, videogames are still a resource of difficult use for education. First, their successful use is not just a matter of changing the presentation style of the traditional contents (Laurel, 2001). This destroys the fun and immersion of the game, and therefore its usefulness as educational resource. It is important to perform a reworking of the teaching material to get its proper integration in the dynamics of the game. Second, videogames are not a universal solution. They need adaptation for a wide range of students' learning styles and subjects. Third, playing does not produce "per se" a valuable learning experience. This depends on the effort invested in the development of the underlying pedagogical approach. Besides, the results of these environments must be compared against traditional ones to consider if they really bring some kind of improvement in a given educational context.

Considering these potential drawbacks, our proposal adopts a different perspective from the one most frequently adopted in videogames. Instead of trying to disguise the educational content inside a game, we have turned the whole learning scenario into a game, based on the idea that gaming is essentially about solving problems that are immersed in the game narrative.



General architecture of the NUCLEO framework showing the different modules and the integration with Moodle. | The architecture allows teachers and students interact with Moodle or with the NUCLEO MUVE.

Figure 1. Two different perspectives of the NUCLEO framework architecture.

Description of the framework: NUCLEO reference architecture

As we have previously mentioned, NUCLEO is a general framework for collaborative PBL that includes a reference architecture to instantiate different applications following its underlying pedagogical principles.

The NUCLEO reference architecture has been designed in a modular way in order to:

- Apply a set of strategies to reach the educational objectives described in the “Pedagogical Model” previously described.
- Be used as a plug-in application over a LMS. This allows the reuse of managing services and tools at the same time that deals with data in a centralized way, which simplifies its integration in the educational infrastructure.

Figure 1 depicts the main components of the NUCLEO reference architecture. The LMS acts as a *Persistency Layer* and, at the same time, offers an alternative way of accessing the contents without high technological requirements. The *Application Layer* is in charge of two main duties: to handle the adaptation process (by means of the *Adaptation Module*) and to coordinate the activity of the students based on the collaboration scripts (by means of the *Learning Strategies Manager*). The following subsections describe in deeper detail the main components outlined here.

Learning Strategies Manager

Research studies show that when learners are left to their own devices in collaborative learning contexts, they rarely engage in educationally relevant activities (Dillengbourg, 2002). A common practice in CSCL environments is to use collaboration scripts that aim at structuring collaborative learning processes in order to trigger group interactions that rarely take place in free collaboration.

Nowadays, in most CSCL systems, the logic underneath scripts is embedded within the system code. However, there are alternatives to model CSCL scripts in computer interpretable ways that separate the logic from its rendering. In particular, a number of pedagogical modeling languages have been developed for this purpose, such as IMS Learning Design (IMS Global Consortium, 2005), which is considered the *de facto* standard for pedagogical modeling.

Within our system architecture, the Learning Strategies Manager module is in charge of the creation, storage, and management of the personalized learning strategies and all their components. Currently, these components include phases, roles, activities, environments, tools, and learning objects.

Adaptation Module

This module is in charge of providing adaptive behavior. The adaptation logic of a personalized learning system can be defined in the following terms (Karagiannidis & Sampson, 2004): the constituents (what is being adapted?), the determinants (what is the adaptation based on?) and the rules (the logics that define which constituents are affected by the determinants and how).

The constituents are aspects of the learning experience that are subject to adaptation. In NUCLEO there are two constituents: team formation and individual role assignation. In an indirect way, the learning experience is also personalized as it depends on the individual role. The determinants are the aspects of the learning experience that drive the adaptation. This information is stored in the student model (SM). In NUCLEO the SM is initialized with the results obtained by the students in the Vermunt’s ILS questionnaire. More specifically:

- Team formation. The goal of the first constituent (i.e., teams) is to try to form effective and semi-autonomous teams. The system groups heterogeneous students according to their learning style searching to: a) foster collaboration, as the students interact with peers with compatible learning strategies, and b) to increase group work effectiveness. As previously described this team formation is based on the students answer to the Vermunt’s ILS questionnaire.
- Role assignment. Group performance strongly depends on the handling of increased coordination. As described in the pedagogical model, we use functional roles to afford the work organization and communication between members. Roles appear to be most relevant when a group pursues a shared goal requiring a certain level of task division, coordination and integration of individual activities (Strijbos, 2004).

Figure 2 shows the adaptation cycle for the NUCLEO system. In the first step of the process, the SM is initialized by means of the result obtained in the ILS questionnaire. Then, the groups are formed and the roles are assigned. This automatically leads to a personalization of the learning strategy, as roles imply specific duties and use certain tools of the system in order to fulfill them. The learning cycle is adjusted to the resolution of a mission. After every mission, the SM is updated collecting information from three different sources: the mark obtained by the group in the mission, the individual mark obtained by the student in the peer-to-peer evaluation (every student evaluates his/her teammates) and the frequency of use of the specific role tools. According to this information, students' roles and teams can be reassigned, for instance, in order to reduce intra-team conflicts or to give students the possibility of experiencing new social contexts.

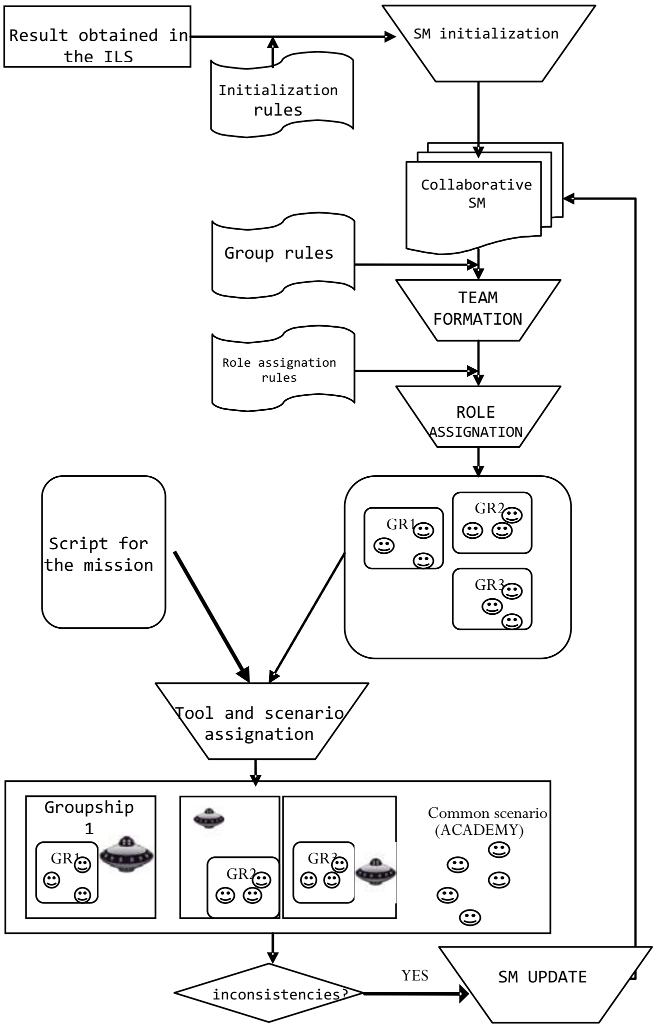


Figure 2. Adaptation cycle for the NUCLEO system

NUCLEO Graphical User Interface

NUCLEO uses as Graphical User Interface (GUI) a MUVE that stages the game scenario in a fantastic immersive world in which students are represented by avatars. Digital games are an ideal channel to promote relevant educational aspects such as problem-solving skills or analysis and reflection. Among the educational benefits that videogames can bring to instructional methods, we are very interested in the social bonds formed among players, especially in multiplayer games. These bonds may foster the creation of communities of practice (Lave & Wenger, 1991). The virtual world serves as a setting for an engaging narrative that adds meaning and contextualization to the different missions.

In the current stage of development of the NUCLEO project, two different instances, that use different ambiences and metaphors, have been developed: Mundo NUCLEO and Mare Monstrum. The first instance sets the pedagogical background described above in a fantastic futurist scenario and the second in a medieval one, but both share the same narrative essence. The students belong to a civilization menaced by a terrible enemy and they have to be trained in the weapons of knowledge to confront it. The scenario and the game reproduce a school of warriors in which aspirants have to compete solving different missions that simulate a real attack from the enemy. With this purpose they are integrated in small combat units (usually of 3 or 4 members). Only those who pass the training will graduate as Paladins.

Persistence Layer: LMS

As has already been mentioned, the use of digital games and MUVE as educational tools can provide a number of advantages over traditional education. However, there are some drawbacks that have not been totally addressed yet. For instance, digital games and MUVE are rarely fully integrated in the educational infrastructure and usually behave as "black boxes". It is therefore impossible to get any instructionally relevant information about the course of the game-based learning experience from them, such as students' performance for assessments or keep a persistent student historical record.

These issues could be addressed by taking advantage of the already deployed e-learning infrastructure. Many educational organizations are using modern Virtual Learning Environments (also called Learning Management Systems or LMS) not only for distance learning, but also as a complement for traditional lectures within an educational trend usually known as blended learning or b-learning. Those LMS (e.g., Moodle, Blackboard-WebCT or Sakai) (Wainwright, Osterman, Finnerman, & Hill, 2007) are not only content repositories, but rich web-based systems that provide instructors with tools to track and evaluate the performance of the students, keep a record of each student or to promote communication and collaboration between students. Thus, synergies between educational gaming and e-learning could bring together the benefits of both worlds, an approach that the NUCLEO framework actively explores. In fact, NUCLEO is currently integrated with Moodle LMS (see **Error! Reference source not found.**) that provides the persistence layer and some functionality (e.g. forums and shared repositories). Teachers and students can access both systems.

Application of the framework: cases of study

Up to now, four cases of study have been conducted in two different courses during two academic years, three of them performed in 2007-08 and another one in 2008-09, with the two instances of the NUCLEO framework (i.e., Mundo NUCLEO and Mare Monstrum). The courses chosen for the experiments shared common characteristics such as a decrease in students' motivation in recent years, resulting in high drop-out rates, low involvement in classes, and low grades.

Our first concern, therefore, was to determine what the effects of the NUCLEO framework were on students' motivation. Given the difficulties in assessing student attitudes, we adopted the drop-out rate as an objective measure. This drop-out rate is defined as the number of students who do not attend the final exam, as compared to the number of students enrolled in the course.

Even when motivation is a key factor of a successful learning experience, it is not enough to improve the student acquisition of knowledge and skills. In fact, one of the identified common pitfalls in the use of PBL, CSCL, and games in learning is that students focus on the joy of the experience and fail to get the related knowledge (Royle, 2008). In order to determine the contribution of NUCLEO in knowledge acquisition, we considered the results in the final individual exam, which was mandatory for all the students. An improvement in exam grades may imply that more students had been able to achieve the learning goals. The main conclusions drawn from the experiments concerning motivation and knowledge acquisition can be found in (Sancho et al., 2009).

It was also important for our objectives to determine how the students perceived the key aspects of our learning framework (i.e. acquisition of soft-skills (Sancho-Thomas et al., 2009b) and efficiency of the adaptation model). For this paper, we focused on the performance of the adaptation model in order to constitute the teams and the usefulness of functional roles to coordinate the group work. In order to include some abstract notions such as leadership or commitment in our performance measures (which may be cloaked by a low performance in a specific exam), we also included a peer evaluation mechanism in which the students in each group rated each other's performance.

The presentation of these results is organized in three subsections. The first one makes a brief introduction of the settings. In the second one, the statistics obtained as result of three cases of study are presented. The third section briefly discusses the global results of the experiments.

Description of the cases of study

In this paper we consider the results obtained in three of the four cases of study performed so far, because they all refer to similar programming courses in the Spanish university context. The remaining one was analyzed in a previous study (Sancho et al., 2009) and was applied to a completely different setting (vocational training).

At the University Complutense of Madrid (UCM), in Spain, several schools teach programming courses. The Electrical Engineering School offers the "Programming Fundamentals" (PF) elective course. PF belongs to a five-year degree and it is studied as part of the second cycle (the fourth or fifth year of the degree). It focuses on some programming basics, such as algorithms, program design and coding. The Computer Science School at the UCM also teaches "Laboratory of Programming II" (LP2) in the second year of the three-year Computer Science Technical Engineering degree. This course focuses on object-oriented programming and data structures.

During the 2005-07 period (i.e., over two academic years), the teachers of these courses followed a traditional teacher-centered approach that included lectures in classroom, practical sessions in the laboratories and compulsory final exams. To calculate the students' final grades, the teachers took into account the marks obtained in the practical sessions (20% of the final mark in LP2 and 40% in PF), and the final exam (the rest of the mark).

During the 2007-08 academic year, both courses implemented the NUCLEO approach (using the Mundo NUCLEO instance) as an optional choice. Sixty PF students and 175 LP2 students participated in this experiment. Given the differences in the scheduling of the courses, the experiment was held in the PF course during the entire semester, while LP2 followed a traditional approach in the first semester and the experiment was performed in the second one. In both courses, students were divided into Experimental (EG) and Control (CG) groups. EG followed the NUCLEO approach, while CG attended traditional lectures. Lecturers organized the NUCLEO students in teams according to their learning profiles, as previously explained. All the teams had a leader who was a self-directed, autonomous student. In the traditional approach, PF students did the class work individually, and LP2 students organized themselves into groups from one to three members.

NUCLEO team formation relies primarily on the assumption that there is a student with good learning practices who plays the role of the captain of the crew. Therefore, in order to evaluate the effectiveness of the ILS as the underlying model behind team formation, we measure whether Vermunt's ILS really identifies strong students accurately by verifying if MD and AD students get better marks than the other profiles. To verify the accuracy of Vermunt's model for assigning the functional roles, we measure students' satisfaction with their peers, in terms of how their teammates perceive the fulfillment of their responsibilities.

During the 2008-09 academic year, a new experiment has been performed in PF, with some differences from the previous ones:

- All 54 students in the course followed the NUCLEO approach. This time, participation was compulsory.
- We used the Mare Monstrum instance of the framework, instead of Mundo NUCLEO.
- In addition to the information gathered in previous experiments, we also distributed a satisfaction survey aimed at collecting the subjective impression of students about how successful team formation and role assignation were.

Summary of the statistical results obtained in the three cases of study

Table 2 contains a summary of the most important results about the adaptation model for each of the courses studied. Students were categorized and assigned to a different role depending on the results they obtained from the initial learning style questionnaire: MD and AD students were captains, RD students were knowledge integrators and U students were communicators. Every member had to perform different duties inside the team depending on the role he/she was assigned to. At the end of each mission, students were asked to evaluate their teammates, taking into account several issues concerning the fulfillment of their assigned duties. *Table 2* reflects the grades obtained in the final exam by the NUCLEO participants according to their role and the average punctuation obtained by each role according to the perception of their teammates.

Table 2. Main experimental results from the 2007-08 and 2008-09 courses for grades obtained in the exam and for peer evaluation results by different profiles

	Programming Fundamentals (2007-08)	**Programming Lab II (2007-08)**	**Programming Fundamentals (2008-09)**
Instance	Mundo NUCLEO	Mundo NUCLEO	Mare Monstrum
Students in CG	38	102	0
Students in EG	22	73	54
Average grade of MD and AD students	6.66	5.87	6.92
Average grade of RD students	5.36	4.9	5.1
Average grade of U students	5.53	5.7	5.4
Average peer-evaluation grade of MD/AD	9.375	9.5	9.65
Average peer-evaluation grade of RD	7.954	8.2	8.01
Average peer-evaluation grade of U	8.24	7.68	8.32

Table 3. Students' Questionnaire and responses

Question	**% in strong disagreement or disagreement**	**% in strong agreement or agreement**
1. I think the use of roles facilitates handling coordination and group work.	39.53%	60.47%
2. In my opinion, the team assignment process is suitable for the course and works well.	32.56%	67.44%
3. I think that the virtual tool is useful to coordinate the activities and enhances collaboration.	4.65%	95.35%

At the end of the course, the students completed a survey composed of nine questions, three of which were aimed at figuring out how the adaptation model was perceived by students. These questions and the results obtained are reflected in *Figure 3* and *Table 3*. The answers ranked from 1 (strongly disagree) to 4 (strongly agree).

Discussion of the results

The results in *Table 2* show that, for the three cases of study performed during the 2007-09 period with the two instances of the NUCLEO framework, students with MD and AD profiles obtain significantly better grades than the other two profiles (RD and U). This suits our initial hypothesis that MD and AD students have more effective learning strategies than the other two profiles. Nevertheless, no significant difference among the other two profiles can be observed.

In terms of the peer-to-peer evaluation results, MD and AD profiles (who performed the role of captain) also received significantly better marks from their peers than the RD or U profiles. In addition to this, it can be observed for all the cases of study that RD profiles (who performed the role of knowledge integrator) received the poorest evaluation from their teammates. According to these data, two possible conclusions of the accuracy of the model can be extracted: the role of captain is suitable for MD students, while even though the other two obtain fairly good marks, RD and U students do not perform their assigned duties so well. Knowledge integrator (RD students), in particular, is the less suitable profile for its assigned duties.

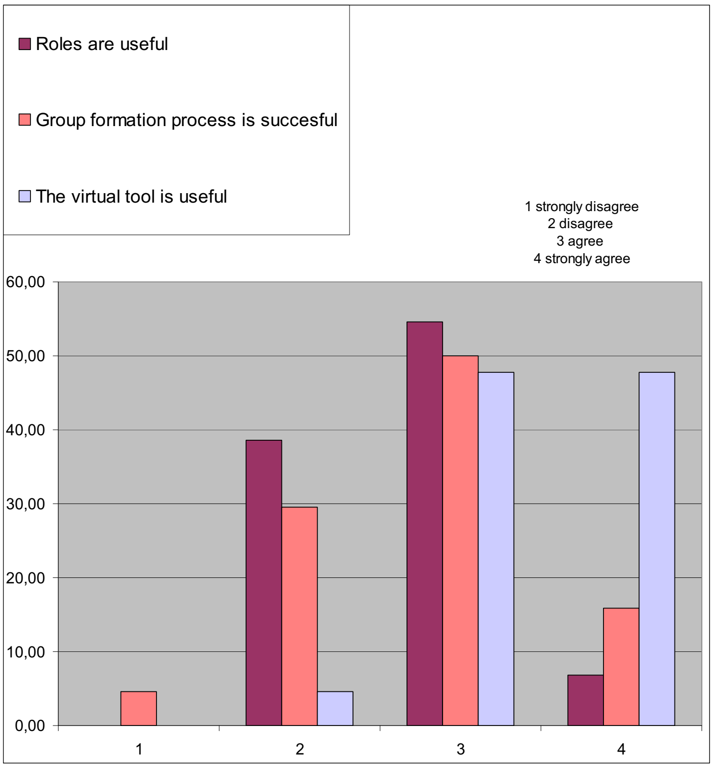


Figure 3. Answers to the questionnaire at the end of the 2008-09 course

For the two cases of study performed during the 2007-08 academic course, participation was voluntary, while in 2008-09 all the students followed the NUCLEO approach. Even though we thought that the volunteer enrollment could have skewed the results of the experiment (with the most enthusiastic students participating in NUCLEO), no significant differences can be observed between both sets of results.

During the 2008-09 case study, we have added an additional source of information to evaluate the system. A satisfaction questionnaire was filled at the end of the course by all the students, asking them to contrast the approach with their previous experience with traditional approaches. Here, it must be noted that PF is only available for students in the fourth and fifth courses. There were three questions related to how the students have perceived the efficiency of the adaptation model.

An overwhelming majority (95.35%) of the students thought that the Mare Monstrum virtual learning environment was satisfactory, with half of them considering it “very” satisfactory. This shows a very high degree of satisfaction with the 3D game environment and its general dynamics.

The percentage is lowered to 67.44% when evaluating the results of the team formation process, with fewer than 10% of students considering it as “very” satisfactory and being the only aspect of NUCLEO that some of them considered “very” unsatisfactory. Two specific reasons were among the most frequently cited for student dissatisfaction. Firstly, although most teams established correct social interactions, some of them seemed to include personalities with a high degree of incompatibility. This incompatibility was related to conflictive mates. These circumstances can probably be avoided by extending the adaptation model to include personality traits focused on social bonds. This kind of study has already been considered in research for team formation (Morgeson et al., 2005). In any case, NUCLEO has to incorporate mechanisms that articulate conflict resolution to tackle these situations when they emerge in teams. Secondly, a considerable number of students felt uncomfortable working with unknown mates. They adduced that the team formation process was unsatisfactory because they would have preferred to work with friends. However, given the objectives of the NUCLEO framework (one of which is to help to improve team work abilities and social skills), being able to work with different kinds of people is a key point.

When analyzing role assignment as a way to improve group work coordination, the percentage of satisfied students is 60.47%. In this case, most of the discontented students thought that the only important role within the organization was the captain and that the other two were secondary with marginal tasks. Specifically, students who held the role integrator role were the most discontent with their attributions, as they found them boring and repetitive.

Conclusions and future work

In this paper, we have described the NUCLEO framework to develop adaptive PBL approaches. The framework encompasses a general conceptual model and a reference architecture. Its learning is staged in a 3D immersive world following the mechanics of classical multi-player role based games. This framework has been used to build two different applications (Mundo NUCLEO and Mare Monstrum) that have been benchmarked in the Spanish higher educational context during 2007-08 and 2008-09 academic years.

Even though the results obtained have been globally satisfactory in terms of rising student motivation and final grades (Sancho et al., 2009), we must point out that these conclusions have to be supported with data collected over next few years to get a wider temporal perspective. Only in this way we will be able to know if the approach itself increases the students' motivation and learning results, or if it is just a side-effect of enthusiasm for the novelty.

Even though the framework is massively perceived by the students to be useful for learning soft and group work skills, and to develop technical knowledge, our results show that some aspects of the system have to be improved. First, the adaptation model to form the teams needs to be enhanced. Vermunt's model for learning styles has to be complemented with other sorts of information, as personality traits. We are also studying other possibilities for the conceptual model behind the team formation like Kirton's Adaptation-Innovation theory (Kirton, 2006). In the second place, while the role of captain seems to be satisfactory according to all the measurements of success used (e.g., perception, assigned tasks or linked learning profile), the other two roles have to be reconsidered. The role of knowledge integrator seems to be especially inadequate for RD types.

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References

Baron, J. (1999). Glory and shame: powerful psychology in multiplayer games. *Proceedings of the Game Developers Conference*, San Francisco, CA, retrieved May 1, 2009, from http://www.gamasutra.com/view/feature/3395/glory_and_shame_powerful_.php.

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education*, New York: Springer.

Bravo, C., Redondo, M. A., Verdejo, F., & Ortega, M. (2008). A framework for process-solution analysis in collaborative learning environments. *International Journal of Human-Computer Studies, 66* (11), 812-832.

Brooks, F.P. (1975). *The mythical man-month: essays on software engineering*, Reading, MA: Addison-Wesley.

Brusilovsky, P., & Maybury, M. T. (2002). From adaptive hypermedia to the adaptive web. *Communications of the ACM*, *45* (5), 30-33.

Coffield, F., Moseley, D., Hall, E., & Ecclestone, K. (2004). *Learning styles and pedagogy in post-16 learning: a systematic and critical review*, report No. 041543, London: Learning & Skills Research Centre.

Corti, K. (2006). *Games-based learning; a serious business application*, retrieved April 1, 2009, from http://www.pixelearning.com/docs/seriousgamesbusinessapplications.pdf.

Dillengbourg, P. (2002). Over-scripting CSCL: The risks of blending collaborative learning with instructional design. In Kirschner, P. A. (Ed.), *Three worlds of CSCL. Can we support CSCL*, Heerlen, The Netherlands: OUN, 61-91.

Gee, J. P. (2003). What video games have to teach us about learning and literacy. *ACM Computers in Entertainment, 1* (1), 1-4.

Gonzalez, C. S., & Blanco, F. (2008). Integrating an educational 3D game in Moodle. *Simulation & Gaming*, *39* (3), 399-413.

IMS Global Consortium (2005). *IMS Learning Design Specification*, Retrieved May 30, 2009, from http://www.imsproject.org/learningdesign/index.html.

Johnson, D. W., & Johnson, R. T. (1994). *Learning together and alone: cooperative, competitive and individualistic learning* (5th Ed.), Boston, MA: Allyn & Bacon.

Johnson, D. W., Johnson, R. T., & Smith, K. A. (1991). *Cooperative learning: Increasing college faculty instructional productivity*, ASHE-ERIC Higher Education Report No. 4, Washington DC, USA: The George Washington University.

Karagiannidis, C., & Sampson, D. (2004). Adaptation Rules Relating Learning Styles Research and Learning Objects Meta-data. *Paper presented at the 3rd International Conference on Adaptive Hypermedia and Adaptive Web-based Systems*, August 23–26, Eindhoven, The Netherlands.

Kemp, J., & Livingstone, D. (2006). *Putting a Second Life "Metaverse" Skin on Learning Management Systems*, retrieved May 1, 2009, from http://www.sloodle.com/whitepaper.pdf.

Kirton, M. J. (2006). *Adaptation-Innovation in the context of diversity and change*, New York: Routledge.

Koschmann, T. D. (1994). Toward a theory of computer support for collaborative learning. *Journal of the Learning Sciences*, *3*, 219-225.

Kreijns, K., Kirschner, P. A., & Jochems, W. (2003). Identifying the pitfalls for social interaction in computer-supported collaborative learning environments: a review of the research. *Computers in Human Behavior*, *19* (3), 335-353.

Laurel, B. (2001). *Utopian Entrepreneur*, Cambridge, MA: MIT Press.

Lave, J., & Wenger, E. (1991). *Situated learning: legitimate peripheral participation*, Cambridge: Cambridge University Press.

Lurey, J. S., & Raisinghani, M. S. (2001). An empirical study of best practices in virtual teams. *Information & Management*, *38* (8), 523-544.

Maudsley, G. (1999). Do we all mean the same thing by "problem-based learning"? A review of the concepts and a formulation of the ground rules. *Academic Medicine*, *74* (2), 178-185.

McCracken, M., & Waters, R. (1999). Why? When an otherwise successful intervention fails. *ACM SIGCSE Bulletin, 31* (3), 9-12.

Morgeson, F. P., Reider, M. H., & Campion, M. A. (2005). Selecting individuals in team settings: the importance of social skills, personality, characteristics, and teamwork knowledge. *Personnel Psychology, 58* (3), 583-611.

Oakley, B., Felder, R.M., Brent, R., & Elhajj, I. (2004). Turning student groups into effective teams. *Journal of Student Centered Learning, 2* (1), 9-34.

Palincsar, A. S. (1998). Social Constructivist Perspectives on Teaching and Learning. *Annual Reviews in Psychology*, *49* (1), 345-375.

Prensky, M. (2001a). Digital natives Digital immigrants. *On the Horizon*, *9* (5), retrieved May 1, 2009, from http://www.marcprensky.com/writing/Prensky%20-%20Digital%20Natives,%20Digital%20Immigrants%20-%20Part1.pdf.

Prensky, M. (2001b). Do they really think differently? *On the Horizon*, *9* (6), retrieved May 1, 2009, from http://www.marcprensky.com/writing/Prensky%20-%20Digital%20Natives,%20Digital%20Immigrants%20-%20Part2.pdf.

Resta, P., & Laferrière, T. (2007). Technology in support of collaborative learning. *Educational Psychology Review*, *19* (1), 65-83.

Royle, K. (2008). Games-Based learning: A different perspective. *Innovate Journal of Online Education, 4* (4), retrieved January 30, 2009, from http://innovateonline.info/index.php?view=article&id=433&action=article.

Sancho, P., Fuentes, R., Gómez-Martín, P. P., & Fernández-Manjón, B. (2009). Applying multiplayer role based learning in engineering education: Three case studies to analyze the impact on students' performance. *International Journal of Engineering Education, 25* (4), 665-679.

Sancho-Thomas, P., Fuentes-Fernández, R., & Fernández-Manjón, B. (2009). Learning teamwork skills in university programming courses. *Computers & Education, 53* (2), 517-531.

Savery, J., & Duffy, T. (1996). Problem based learning: An instructional model and its constructivist framework. In B. Wilson (Ed.), *Constructivist learning environments: Case studies in instructional design*, Englewood Cliffs, NJ: Educational Technology Publications, 135-148.

Strijbos, J.-W. (2004). *The effect of roles on computer-supported collaborative learning*, Heerlen, The Netherlands: OUN, retrieved May 30, 2009, from http://www.ou.nl/Docs/Expertise/OTEC/Publicaties/jan-willem%20strijbos/Dissertation_Strijbos__Online_rev_1-11-04.pdf.

Tapscott, D. (1998). *Growing up digital: The rise of the net generation*, New York: McGraw Hill.

Vermunt, J. D. (1992). *Learning styles and directed learning processes in higher education: towards a process-oriented instruction independent thinking*, Amsterdam/Lisse: Swets and Zeitlinger.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological process*, New York: Harvard University Press.

Wainwright, K., Osterman, M., Finnerman, C., & Hill, B. (2007). Traversing the LMS terrain. *Proceedings of the 35th annual ACM SIGUCCS conference on User services*, New York: ACM, 355-359.