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Learning teamwork skills in university programming courses

Pilar Sancho-Thomas, Rubén Fuentes-Fernández *, Baltasar Fernández-Manjón

Dpto. Ingeniería del Software e Inteligencia Artificial, Facultad de Informática, Universidad Complutense, 28040 Madrid, Spain

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ABSTRACT

University courses about computer programming usually seek to provide students not only with technical knowledge, but also with the skills required to work in real-life software projects. Nowadays, the development of software applications requires the coordinated efforts of the members of one or more teams. Therefore, it is important for software professionals to master the sort of skills that assure the success of teamwork, such as communication, leadership, negotiation, or team management. However, these abilities are difficult to teach, one of the reasons being that they require true commitment from the students. However, today students are taking a more and more passive role in their own education, two of the more evident consequences being the increase in dropout rates and the decrease in marks obtained in exams. The NUCLEO e-learning framework has been designed to promote the effective acquisition of teamwork skills and, at the same time, to promote the more active participation of the students in their own learning process. NUCLEO adopts a socio-constructivist pedagogical approach that pursues the development of communities of practice for Problem Based Learning. Our research has rooted the design decisions of NUCLEO in the analysis of its socio-cultural environment with Activity Theory, which considers conflicts within groups as the impetus of their evolution and the forges of their environments. This paper presents the analysis of the main features of NUCLEO according to Activity Theory, as well as the experimental results obtained with the framework in three different case studies in university courses.

1. Introduction

Teams are the basis for the organization of software development today, since the increasing complexity of projects has made them unachievable for individuals. Development teams commonly distribute the work among their members by following well-defined structures of interdependent responsibilities, with typical roles like designers, testers, architects or project managers (Benarek, Zuser, & Grechenig, 2005). In this setting, professionals are not only required to have state-of-the-art knowledge and technical abilities, but also to be able to cooperate successfully inside teams. Effective teamwork requires mastering specific abilities, such as leadership, coordination and conflict management. This implies that if higher education wants to meet the requirements of the students' future professional lives, it has to address the acquisition of such soft skills and has to have the technology to support them (Rugarcia, Felder, Woods, & Stice, 2000).

However, traditional courses do not seem to succeed in helping students to acquire this sort of skills (Wilhelm, Logan, Smith, & Szul, 2002). Most of them are mainly focused on teaching technical contents and they are usually organized according to teacher-centred approaches where the teacher plays the role of information dispenser while the students act as passive receptacles. In this context, students need only to listen, take notes and study for exams. Though this situation is starting to change (Howell, Williams, & Lindsay, 2003) and many teachers are increasingly demanding that their students work in group assignments, this so-called group work is strongly focused on obtaining an outcome. Therefore, how the group has managed its achievement is not significant (Johnston & Miles, 2004), which leads to organizing the teamwork towards minimizing the effort expended in order to obtain the result. Students work individually and they only get together to integrate the outcome, thus reducing the peer-to-peer interaction to the minimum extent (Vik, 2001).

The progressive adoption in higher education of blended learning approaches that manage their distant interactions through Learning Management Systems (LMS) has not been of much help. Without proper guidance, the LMS increases the decoupling of members and tasks even further. This overall virtual organization may improve students' use of time, but it also reduces the social interchange that could require the use of soft skills (Oren, Mioduser, & Nachmias, 2002; Robey, Khoo, & Powers, 2000).

* Corresponding author. Tel.: +34 913947548; fax: +34 913947547.
E-mail addresses: pilar@sip.ucm.es (P. Sancho-Thomas), ruben@fdi.ucm.es (R. Fuentes-Fernández), balta@fdi.ucm.es (B. Fernández-Manjón).

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NUCLEO is an e-learning framework for a blended learning context with two basic objectives: first, to promote the acquisition of teamwork abilities and soft skills and, second, to force the student to adopt a more active role. The framework comprehends a specific pedagogical strategy of collaborative Problem Based Learning and a system that embeds it. The system uses a fantastic immersive multi-user virtual world as 3D skin over an LMS (currently we are using Moodle (Moodle Community, 2008) as a back-end LMS). This virtual world is the user interface where teachers' and students' avatars interact according to an underlying game narrative. Through this 3D interface, most of the learning facilities, data and services (such as communication services, content repositories or student forums) are provided by the back-end LMS application.

In order to overcome the aforementioned limitations in teaching soft skills, this research has analyzed the social environment of NUCLEO using Activity Theory (AT). AT (Vygotsky, 1978) is a philosophical and analytical framework for the study of human praxis as developmental processes where both the individual and social levels are interlinked. It has been widely applied to developing software systems with regard to their human context (Fuentes-Fernández, Gómez-Sanz, & Pavón, 2007; Kuutti, 1996). AT considers that every social setting suffers from tensions among its components (Engeström, 1987). These tensions, called contradictions, explain the evolution and conflicts of groups, the modifications of their environments, or changes in motivation. The study of these contradictions in the NUCLEO project has guided a number of design decisions concerning the framework.

The NUCLEO framework is currently being tested in several higher education contexts for teaching software programming disciplines in university science degrees, to assess its effectiveness in terms of enhancing students' motivation, inducing them to adopt an active role in their learning, and helping them to acquire soft abilities to manage teamwork. Even though we have obtained very promising results (as Section 5 reflects), the implementation of this framework faces important resistance to structural change from both sides of the educational process (i.e. teachers and students), which has also been analyzed following the framework of AT.

The rest of the paper discusses the issues outlined in this introduction. Section 2 makes an overview of the NUCLEO framework and Section 3 briefly presents the sociological framework of AT. Section 4 uses AT contradictions to analyze the sociological context, the group dynamics and the conflicts that arise among participants in the NUCLEO framework. These contradictions are linked to the design described in Section 2. Then, Section 5 discusses the experimental results and conclusions obtained from the case studies performed in the past two academic years. Section 6 contextualizes NUCLEO with other learning approaches. Finally, Section 7 discusses some general conclusions about the NUCLEO framework.

2. An overview of the NUCLEO framework

NUCLEO is an e-learning framework targeted for blended learning contexts that uses Problem Based Learning (PBL) as its underlying pedagogical approach. PBL is "the learning that results from the process of working towards the understanding or resolution of a problem" (Barrows & Tamblyn, 1980). In most cases, problems are solved through collaboration processes inside small groups. In this context, the teacher plays the role of facilitator who shares information and guides the group through the learning process. This organization fosters discussion and collaborative discovery, placing the focus on the process instead of on the result itself. Besides, it has shown its effectiveness in developing the sort of abilities we are pursuing in both face-to-face and virtual environments (Duch, Grosh, & Allen, 2001). Nevertheless, it is not easy to implement PBL solutions in blended environments where face-to-face interactions are necessarily more restricted (Oren et al., 2002; Robey et al., 2000). According to several research works, in order to achieve effective collaboration it is essential to build social and affective links among participants. These links are less likely to emerge in a virtual setting mainly because of the difficulties in achieving the right group dynamics (Garrison, 1993). NUCLEO addresses these difficulties by using two of the system components: a user interface that stages the learning in the virtual world of a role game, and an adaptation module aimed at forming effective and semi-autonomous teams.

2.1. The user interface: a multi-user virtual world and role game dynamics

The use of games as educational tools has drawn significant attention (Gee, 2003). Games engage users with challenges that take place inside immersive narratives using realistic artificial scenarios. In this context, users regard solving problems as challenging tasks to test their knowledge and skills. Besides these motivational issues, the game scenario in NUCLEO pursues a twofold objective:

- The shift in context puzzles students, prompting them to abandon their passive listening role. In this sense, there is an increasing use of games and virtual worlds in education to engage students in active learning processes (Corti, 2006).
- This kind of scenario is more likely to create a propitious atmosphere that stimulates the emergence of social and affective bonds among players, which leads to the formation of communities of practice (Baron, 1999).

The NUCLEO game takes the students to a fantasy world, Dragon Island, inhabited by the survivors of an ancient civilization, the Picts. They are menaced by a terrible enemy, the Dark Lords, who want to destroy all forms of knowledge and plunge their world into darkness. The Sea Dragons, the last guardians of wisdom, take on the responsibility to train the Picts in the weapons of knowledge. The game simulates a school of warriors competing to get the grade of Dragon Warriors. Students' avatars play the role of these candidate champions, while tutors play the role of the Sea Dragons. This approach affects not only the presentation of the contents but also the social dynamics of the course.

In NUCLEO, social interaction takes place according to two different schemas (competition and collaboration) and two different levels (individually and in groups), in which students interact through their avatars. Competition and collaboration are two of the team-making mechanics that have proven to boost motivation and to improve group dynamics in different learning contexts (Johnson & Johnson, 1975). NUCLEO supports these mechanics with two main resources. First, it promotes social recognition through rankings and rewarding students' avatars with distinctive physical characteristics linked to their intellectual achievements. Second, it addresses the different levels and schemas of social interaction by dividing the virtual world of NUCLEO into three different zones, with specific tools to facilitate interaction (see Fig. 1):

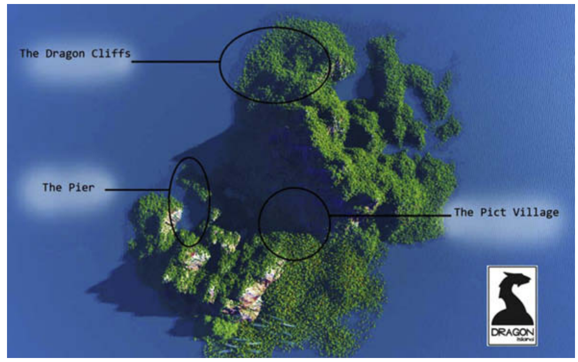

Fig. 1. Different areas on Dragon Island.

- *The Pict village for global interaction:* It contains information panels, such as mission announcements, individual and group rankings, and the public forum. These panels are directly connected to the LMS (i.e. Moodle). All the students in all the courses have access to this zone, even though they only see the information related to the course they are registered in. The rankings are public to all members of the same course in order to foster motivation by social recognition (see Fig. 2).
- *The boats at the Pier for group interaction:* A boat at sea is the group's restricted interaction zone. It is equipped with social tools useful to managing group collaboration, such as private forums, blogs or group-restricted file sharing facilities (see Fig. 2).
- *The Dragon Cliffs for student–tutor interaction:* There are two types of facilities in this zone: a zone to send messages to the dragon (see Fig. 2), which is restricted to some avatars (see role assignment in Section 2.2) and a zone in which the tutor can leave files that the students may copy into their private inventories.

2.2. The adaptation module: team formation and role assignment

The adaptation module of NUCLEO has a twofold purpose: to form heterogeneous teams and to assign functional roles to individuals within the teams. These activities pursue a common objective: to form effective and semi-autonomous teams. The adaptation is performed based on Vermunt's Inventory of Learning Styles (ILS) (Vermunt, 1992) as follows:

- *Formation of heterogeneous teams:* Heterogeneity in team formation has been defended in several research works (Oakley, Felder, Brent, & Elhajj, 2004). An underlying assumption in collaborative learning is that students teach and learn from one another. This means that all members of a heterogeneous team can benefit from observing capabilities that are different to the ones they have. We are using

Fig. 2. From left to right, top to bottom: Information panels at the Pict village, the Dragon at the Dragon Cliffs, boat at the pier and detail of the boat.

Vermunt's "Inventory of Learning Styles" (Vermunt, 1992) in order to classify students according to the strategies they usually employ to approach learning. The inventory distinguishes four learning styles: meaning-directed (MD), application-directed (AD), reproduction-directed (RD) and undirected (U). MD and AD patterns are students that show strong independence and can self-regulate their own learning process, so they would benefit from a looser teacher strategy. Meanwhile, RD students need stronger teacher control and guidance, but are more systematic and follow linear patterns in learning. RD students are strongly motivated by getting good marks and recognition is very important to them. U students combine characteristics of both MD and RD patterns, and they also need strong guidance and control during the learning process. The arrangement of teams is performed around the MD and AD students to provide a figure that can exert inner guidance in the problem-solving process.
- *Management of the internal dynamics of teams through the assignment of functional roles:* Roles are common means of organizing group work (Strijbos, 2004). This kind of organization is the backbone of software engineering projects today, so its use in NUCLEO is a way of training future engineers in their required professional skills (Rugarcia et al., 2000). NUCLEO considers three different roles: team organizer, knowledge integrator and head of communications. The role assigned to a student influences some of his/her duties and responsibilities inside the system, and they are assigned using Vermunt's classification. We consider *a priori* that MD and AD students will better perform the role of leaders; RD students will act as integrators, a duty that requires systematic capabilities; U students will exert the role of communicators. Also, specific distinctive visual features of the students' avatars are reflected in the virtual world (leaders take a sword, communicators an ancient rune, and integrators an aura). These features pursue the student's immersion in his/her role, and enforce a true division of responsibilities and tasks among team members.

The adaptation module provides for the dynamic reconfiguration of teams and the rotation of roles. Steady teams for the whole course offer limited opportunities to practice teamwork skills, as students soon become used to their mates and roles, and they only experience a given setting. To avoid this situation, NUCLEO changes the teams' composition and this may lead to changes in the team role that students play during the course. These changes promote the acquisition of different abilities (Barak, Maymon, & Harel, 1999). This strategy also has the additional advantage of promoting the ability to think and anticipate the individual needs and expectations of the other roles in the team, since students can compare their fulfilment of a role with their previous expectations (Aquino & Serva, 2005). Finally, these changes also confront students with the paradox of having to collaborate sometimes and to compete other times with the same people.

3. Activity Theory

Activity Theory (AT) (Leontiev, 1978; Vygotsky, 1978) is a framework for the study of different forms of human practices and their evolution. It focuses on the interactions and the conflicts between individuals and their societies. According to AT, people belong to a sociocultural context and their behaviour must be understood in that context. Individuals interact with the environment by changing and being changed by it. These complex interactions among individuals and their surrounding context are the *activities* and they constitute the minimal meaningful unit of analysis in AT.

An *activity system* is the context that encompasses the activities and the interactions among them (see Fig. 3). This system considers the individual and social dimensions of human activities. At the individual level, the *activity* is a process carried out by a *subject*, which can be a single person or a group. The subject has some specific needs represented by *objectives*. The objective is satisfied by the *outcome* produced in the transformation of an *object*. In order to carry out that transformation, the subject uses *tools*. *Tools* always mediate the processes performed by the subjects on the objects, enabling and limiting the activity at the same time (Leontiev, 1978). At the social level, the *community* represents those subjects that act directly or indirectly on the same object (Kuutti, 1996). *Rules* mediate between the subject and the community (Engeström, 1987). They specify how subjects fit into communities and cover norms, conventions, and social relationships within communities. The *division of labour* mediates between the object and the community (Luria, 1976). It refers to the explicit and implicit organization of the community as related to the transformation process of the object into the outcome. An *artefact* can represent any of the previous elements, and it is used as a comprehensive term for the other concepts or when differences between types of elements are not relevant. Most of the artefacts described here can be both concrete (e.g. a program, a computer or a classroom) and/or abstract (e.g. a plan, the language or experiences). Thus, the activities are not only physical tasks but also mental processes.

AT represents complex social systems as networks of activity systems interconnected through shared artefacts. For instance, any activity system can produce an outcome that becomes an input artefact in other activity systems (e.g. subject, tool, activity or rules). In this case, the activity producing artefacts for others is called a *neighbour activity* and the activity that uses those artefacts is the *central activity*. The possibility of analyzing the role of an artefact from different perspectives is one of the key features of AT, as it allows for the consideration of mutual and non-trivial influences among systems.

In AT analysis, the dynamics of social systems are also considered. The systems' internal contradictions trigger and drive their evolution. These contradictions are tensions between the elements of activity systems. AT classifies these contradictions in four groups, depending on what elements of the activity system they affect (Engeström, 1987):

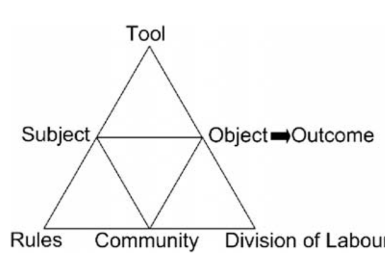

Fig. 3. Diagram of the activity system.

- *Primary contradictions:* They are internal contradictions occurring inside elements of an activity system or between elements playing the same role in the activity system. For instance, this is the case of conflicts inside objects trying to satisfy different needs or among contradictory rules.
- *Secondary contradictions:* These contradictions are due to inadequacies between different elements of an activity system that play different roles. They have their origin in the environment and usually appear when new elements enter the activity system and originate conflicts with the capabilities expected of existing elements.
- *Tertiary contradictions:* These contradictions are concerned with the evolution of a dynamic system. They appear between the current forms of an activity system and other forms that are culturally more advanced.
- *Quaternary contradictions:* They appear in the interactions between an activity system and its interconnected *neighbours*.

4. A social analysis of the NUCLEO framework based on the Activity Theory

The design of the NUCLEO framework briefly outlined in Section 2 tries to overcome the common limitations to implementing collaborative PBL in blended-learning contexts. Besides, the introduction of NUCLEO in university courses leads to the emergence of a number of tensions caused by the substitution of the traditional learning approach for the new method. The analysis described in this section has been used to study these problems and determine the mechanisms to overcome them. The study considers the four levels of contradictions in AT regarding different aspects of the learning process.

4.1. Organization of work

The traditional organization of the programming courses in which the NUCLEO framework is to be applied usually includes teamwork assignments, though they are mainly focused on the individual acquisition of technical skills. These group assignments are a tool to give students a perspective on working in projects. Teachers commonly make the groupings for these courses according to two different modalities. In the first one, students are free to organize themselves in small teams, which results in friends tending to cluster together. In the second one, teachers arbitrarily form the teams, at most including considerations about the compatibility among the members' schedules. Both of these modalities present important limitations when considering the acquisition and practice of team skills (Deibel, 2005): the first organization relies on previously existing bonds, which decreases exposure to different ideas and personalities, and the second one can isolate individuals and lead to the emergence of improper behaviours like cheating or passive attitudes. Moreover, in most of this teamwork (Johnston & Miles, 2004; Oakley et al., 2004), the process itself is not as important as the final result, which leads students to work individually and to reduce social interaction as much as possible. This overall organization of work produces the secondary contradiction reflected in Fig. 4.

Fig. 4 shows the structure of an activity system (see Section 3) whose centre is students' *Learning*. In the NUCLEO context, learning promotes the acquisition of teamwork skills along with technical skills. To do so, students work in teams using a PBL approach. Following are the elements in this activity system:

- *Activity:* The activity under scrutiny is the students' *Learning* of technical and teamwork skills.
- *Subjects:* The main active subjects that carry out the activity *Learning* are the *Students*. Other active elements like teachers are not the focus of this activity, although they can participate in it through the communities or neighbour activities.
- *Objects:* Multiple students' objects are affected by the activity, such as their technical knowledge, their problem-solving skills, or even their marks. However, this analysis focuses on *Teamwork skills*.
- *Communities:* The communities represent the groups of people involved in the activity, and provide its social context. The minimum groups involved in this activity are the student teams. According to the previous discussion, these are usually of two types, *Teams of friends* or *isolated individuals* who work within arbitrarily formed teams. Note that though student teams are the minimum community affecting the system, a complete analysis must also consider communities at other levels, such as the students' course, the universities and the education system of the country, or even their society and culture. Nevertheless, given the focus of Fig. 4 on the contradiction between the *Teamwork skills* object and the student teams with their current organization, these other communities are not included.
- *Rules:* Rules govern the behaviour of the community in the activity system, but they come from outside the system, from the surrounding society and encompassing activity systems. The rules in Fig. 4 are *Split tasks and integrate results*. They correspond to common knowledge about working in teams: it implies planning the achievement of certain goals through several interconnected tasks carried out by different people, and whose combined results will satisfy the goals.

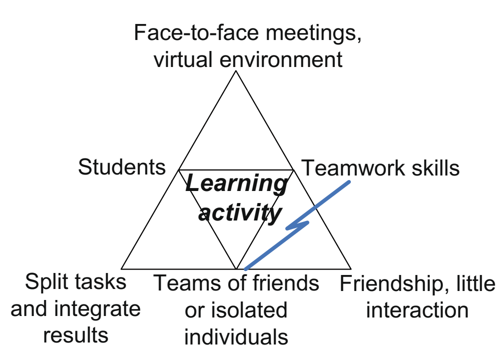

Fig. 4. Secondary contradiction between the traditional organization of teamwork in courses and the acquisition of teamwork skills.

- *Division of labour:* It governs and organizes the community specifically for the activity under study. In the learning activity (Deibel, 2005), teams of friends work based on the bonds of friendship, which are previous to the collaborative assignment, and arbitrary teams commonly cause people to work individually and only collaborate to integrate results. In Fig. 4 this organization appears as *Friendship, little interaction*.
- *Tools:* The tools used to work in teams are the *face-to-face meetings, virtual environment*.

Fig. 4 also represents a secondary contradiction of the *learning* activity by using a lightning bolt between the object and the community of the activity system. This contradiction points out the inadequacy of the current communities for the acquisition of teamwork skills. The type of communities (i.e. *Teams of friends or isolated individuals*) that characterizes the traditional learning activity system biases the required soft skills to interactions that are not those common to real-life projects (Deibel, 2005). This means that in order to promote the acquisition of these abilities, NUCLEO needs to establish different social interactions between students than those provided by the current teams. These interactions must lead them to discover and practice the teamwork skills targeted, and must consider the possibilities and limitations of a blended-learning context that comprehends both a virtual and a face-to-face setting.

NUCLEO addresses this problem through the management of team formation, looking to promote the outgrowth of the social interactions required in learning soft skills through three complementary strategies. These strategies regard the grouping itself, the internal structure of groups, and the setting up of a motivating context.

The NUCLEO environment seeks to form groups whose members are heterogeneous in ability in order to increase team synergies and to promote a wide range of interactions. Following existing research on learning profiles (Vermunt, 1992), NUCLEO considers that students have heterogeneous learning habits, some of them being more successful than others. The rationale behind this heterogeneous organization is supported by several research works (Hilborn, 1994; Oakley et al., 2004). In a heterogeneous group, students with poor learning habits can benefit from the example of students with more effective learning strategies. This implies that a greater effort is required of skilled students. Nonetheless, all of them get the benefit of experiencing teamwork in a heterogeneous context, as they similarly will find in their professional lives, thus enriching their soft knowledge. Also, students with poorer learning strategies may be more skilful than their more efficient mates in communicating with others or in managing conflict, which means they can enrich their more organized and efficient mates with good modelling in this sense. NUCLEO uses a simplified version of Vermunt's ILS and its questionnaire to classify students (Vermunt, 1992) (see Section 2 for more details on Vermunt's model).

The composition of teams based on learning profiles is not enough to guarantee that their members establish the proper interactions. Thus, NUCLEO also considers the internal team organization while assigning functional roles to its members. NUCLEO contemplates three roles: team organizer, knowledge integrator and head of communications. The organizer is in charge of project planning and monitoring. The knowledge integrator has the responsibility that all team members receive the knowledge gathered in the project. The head of communications manages the communication between team members and tutors, as well as conflicts among members, and also documents the products of the project team. This assignment of concrete responsibilities to individuals is one of the ways to make them interdependent as a means to encourage collaboration, thus fostering group cohesion and responsibility (Johnson, Johnson, & Smith, 1991). Besides, it makes all members of a team feel that they are relevant to the success in the project, which increases their own self-commitment (Biddle, 1979). The division of work and its structuring through roles seems to be more relevant and easily accepted when the problems proposed are complex enough to make them unapproachable by even skilled individuals (Benarek et al., 2005). An additional advantage of the *division of labour* with roles is that it is a common practice in real software development projects, where responsibilities and tasks are assigned to roles such as projects managers, systems analysts or designers (Benarek et al., 2005). Since the NUCLEO framework makes students experience this kind of organization with well-defined roles, it provides a way of training future professionals in the social skills required in their work.

The previous changes in the usual organization of teams are likely to produce conflicts with students. In some cases, they lose their freedom to choose their teammates, and in any case, their internal team organization is constrained. NUCLEO tries to pare down this reluctance by moving the learning context to a scenario where students can see this organization as motivated by the nature of the environment. This new learning scenario is a multiplayer team role game embedded in a virtual fantasy world. Multiplayer games and virtual worlds are used in education for their power to create immersive and engaging experiences for students (Gee, 2003). Different researchers claim that they are an effective seed for communities of practice where students create powerful affective bonds among themselves that lead to the improvement in the effectiveness of their collaboration (Baron, 1999).

4.2. Evolving assignments and dynamics

Traditionally for the subjects targeted in our case studies, the teams into which the students were grouped remained constant for the whole course and their members' marks were those of their team. Nevertheless, this organization has a negative impact on a framework aimed at the acquisition of soft skills, since it impairs group dynamics in several ways:

- The social bonds developed among teammates do not correspond to the usual setting of a real project team, where these bonds are formed with the objective of achieving common goals. On the contrary, students usually become friends, which may lead to a distortion of the social bonds created and falling into negative dynamics (Deibel, 2005).
- It generates social dynamics that easily fall into promoting the "hitchhiker" figure (Oakley et al., 2004). These are team members who refuse to do their share of the work but try to get the same grades as their more responsible teammates, assuming their individual work cannot be discerned from the common group work.
- There is no motivation to interact between teams. Essentially, teams are isolated groups that need to work on fulfilling teachers' requirements to pass the exercise. Again, this is not a situation in real life. A team commonly depends on and interacts with other teams; for instance, it has to negotiate deadlines and products, ask for support, look for advice or compete to obtain a project. Besides, inter-team interaction allows teams to compare their results and it motivates them through a feeling of competition (Michaelsen & Black, 1994).

These tensions correspond to secondary contradictions, in this case between the communities of practice that aim at emulating real software projects and the real dynamics that the fixed grouping provokes. The contradiction could be represented in a diagram similar to the one for the learning activity in Fig. 4. In this case, the element that focuses the analysis is the new *community of practice*, which is intended to allow meaningful collaborative learning. This *community of practice* should become the basic *community* in the learning activity system. The undesired dynamics of steady groups are a conflicting *division of labour* within teams. NUCLEO resolves this conflict through a dynamic re-assignation of roles and teams at the end of every learning cycle (i.e. assignment of work) and by implementing an evaluation procedure with a public reward system sustained by social recognition.

The dynamic re-assignation of teams and roles promotes the development of a rich set of interaction patterns. Students have the opportunity to work with different people and assume several perspectives in the fulfilment of a project. Moreover, they have to deal with different personality types, some being more capable and easy to work with than others. Research in group dynamics (Oakley et al., 2004) has identified several conflictive personality types that can appear in teams: the previously mentioned "hitchhikers"; domineering members, who try to coerce the others into doing everything their way; resistant members or "couch potatoes" who resent having to work in a team and refuse to participate. Even if team students are collaborative, it is still probable to find members with widely divergent goals (e.g. some wanting an A grade no matter what it takes and others wanting to do just enough to get a C grade).

Although a variety of experiences is desirable, NUCLEO also needs to evaluate the students' performance, channel interactions to productive dynamics and give teachers the means to detect potentially conflictive situations. For this purpose, NUCLEO tries to ascertain the individual commitment of team members to the common goal. The system includes a peer-to-peer evaluation in which students get an individual mark according to how their own teammates have perceived the fulfilment of their responsibilities within the group. A member of the team that receives an optimal evaluation from his/her teammates obtains the same mark as the group (i.e. 100%), but one that receives a negative evaluation only gets a fraction of the group mark (from 0% to 85%). This kind of system is in quite widespread use to assess individual performance in groups (Johnston & Miles, 2004). Of course, there exists a risk that students could frustrate this scoring strategy by reaching previous agreements among co-members of teams, in order to give to each other the highest possible mark. Nevertheless, as NUCLEO includes the dynamic reassignment of teams this effect is minimized by the dilemma of getting an individual high fraction of a low group score caused by a non-effective group, or giving the right evaluation and having the chance to be moved to a more successful group. This mechanism allows us to deal with the presence of "hitchhikers" and "couch potatoes" on teams, and minimizes the temptation to become one of them (Johnston & Miles, 2004).

To enrich intra and inter-group interactions, NUCLEO simultaneously promotes both collaboration and competition at different levels: individually within a group and among different groups. These dynamics have proved to be an effective means to providing students with ongoing feedback about their learning and motivating their work (Johnson & Johnson, 1975). Concerning inter-group interactions, the atmosphere of competition is enhanced by the group evaluation procedure. At the end of every assignment, teams deliver their solutions to teachers, who choose the one they consider the best. This best solution determines the highest mark and the rest of the solutions are graded on a curve compared to it. The learning cycle ends by publishing the team ranking for the assignment in a public forum. NUCLEO also rewards collaboration among teams. At the beginning of the course, teams receive credits-of-help to exchange with other teams for advice or knowledge. The final group mark takes these helping credits into account. These same patterns of collaboration and competition are also used to increase individual students' motivation and to enrich their interactions. The game structure is conceived of as an individual competition whose final aim is to get the highest individual mark. Nevertheless, the structure is organized in a way that this can only be achieved if students learn how to collaborate and fulfil their role responsibilities in an effective way. Individual rankings are also exhibited because social recognition (Baron, 1999) has proved to be a powerful propelling force within a community of peers. It implies the sense of "glory" derived from particular achievements in competition, the recognition emerging from mastering knowledge or skills, or the "shame" of poor performance. This recognition (Baron, 1999) promotes the appearance of the affective bonds that foster the emergence of communities of practice, improving collaboration and social interaction among students. NUCLEO implements social recognition not only by making the rankings public, but also by distinguishing the students' avatars in the virtual world with physical elements linked to their intellectual achievements. This gives students and everybody else clear feedback about personal status inside the NUCLEO society that represents the whole course.

4.3. The pedagogical shift to Problem Based Learning

NUCLEO can be regarded as a PBL (Barrows & Tamblyn, 1980) framework that includes specific techniques to manage interactions in a course in order to address one of the classical PBL problems: obtaining communities of practice where significant learning happens. PBL structures learning around open-ended problems that represent real-world situations that students solve by collaborating in small teams. Students are used to traditional courses where they play a passive role, working only a few weeks before the final exam (Astin, 1999). On the contrary, the NUCLEO approach requires that they actively explore problems, resolve technical aspects, and address conflicts emerging from personal interactions with other students and groups on a regular basis. This shift causes conflicts with the traditional structures and procedures, which correspond to several AT contradictions. These conflicts emerge at the frontier of two interlinked activity systems: the central one that focuses the analysis corresponds to the learning activity; its neighbour corresponds to the *design activity* that produces the organization and contents of the course. Fig. 5 represents this vicinity.

The central activity comprehends the different elements in the traditional and the new learning activity. Traditional courses are focused on making their students obtain *technical knowledge*, while the needs of the current real work environments also demand *teamwork competencies*. NUCLEO addresses these new needs by means of a pedagogical strategy based on PBL. Nevertheless, the migration between strategies implies opposing different perspectives of the elements that participate in learning. These elements appear in the activity system:

- *Activity:* The learning activity carried out by students.

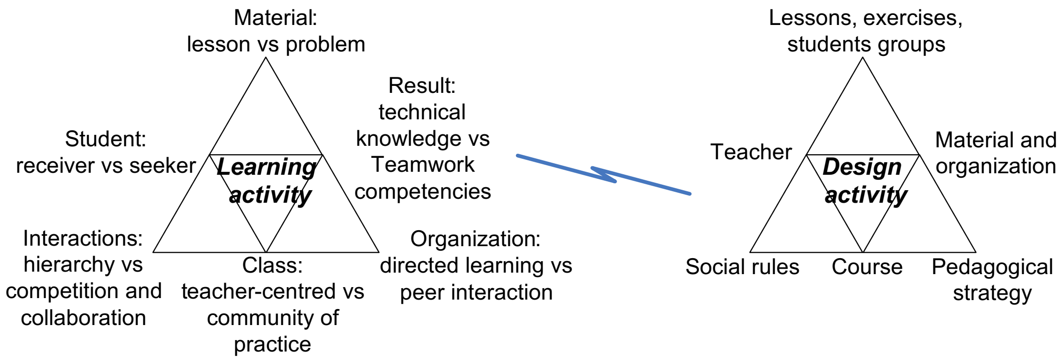

Fig. 5. Contradictions emerging in the pedagogical shift to PBL. The primary contradiction between traditional and PBL pedagogical approaches appears as "vs" pairs in the *learning activity*. A quaternary contradiction with the neighbour *design activity* is represented with the lightning bolt.

- *Subject:* The subjects in both conceptions are the students who do the learning, but while the traditional teacher-centred perspective see them as the passive *receivers* of lessons (Astin, 1999), PBL tries to make them the active *seekers* of knowledge and the effective subjects of the activity (Barrows & Tamblyn, 1980).
- *Objects:* Although the intended object of both approaches to learning can be seen as including both *technical knowledge* and *teamwork competencies*, the focus is clearly different. Traditional learning mainly pays attention to individual technical skills, but this leads to a conception of engineering work as if made by individuals and not by teams, as it is in real practice. On the contrary, NUCLEO highlights the relevance of the acquisition of teamwork skills in courses.
- *Communities:* In both approaches, the community is the class that comprehends both students and their teachers. However, the traditional perspective organizes the class around the teacher and PBL does it as communities of practice around students. This opposition appears in Fig. 5 as the conflicting communities *Class: Teacher-centred vs community of practice*. The opposition between classes as hierarchical or peer communities affects other social constructions of the activity system (i.e. rules and division of labour) (Bonk & Kim, 1998).
- *Division of labour:* The division of labour that governs a *teacher-centred* community is one of *directed learning*. On the contrary, the division of labour for *communities of practice* relies on *peer interaction* between students with the teacher playing the role of facilitator.
- *Rules:* The previous divisions of labour have their origin in more general social constructions. *Directed learning* emerges socially from the rules of hierarchical organizations, where a leader commands or guides his/her followers. For communities of peers, common patterns of behaviour are collaboration and competition.
- *Tools:* The different needs when organizing work in these communities are reflected in the pedagogical tools used to structure the contents of the course: the *lesson* delivered by the teacher versus the *problem* that students must work out to gain new knowledge.

The *design activity* depicts what *teachers* have to do when preparing a course, especially concerning its organization and material. Its simplified activity system in Fig. 5 is as follows:

- *Activity:* As stated before, it is the development of the elements required to teach the course.
- *Subject:* The subject is the *teacher,* who designs the course.
- *Objects:* In the NUCLEO approach, they comprehend the syllabus of the course, the problems around which knowledge is structured, and the related information to guide the students. They also include the following procedures to organize the course: group formation, role assignation, and the resolution of conflicts between students.
- *Tools:* To generate the contents, teachers frequently resort to artefacts from previous courses such as *lessons* in the form of class notes or presentations, *exercises* used for individual homework, and literature of the area. To organize the course work, the basic tool is *student groups*, though depending on the pedagogical approach, the procedures to manage them change.
- *Community:* The main community that contextualizes this activity is its target *course*, although others, like the degree of the course and its university, also have a clear impact on it.
- *Division of labour:* The teacher producing these artefacts must consider the norms emerging from the division of labour corresponding to the *pedagogical strategy* selected. Examples of these norms are the potential arrangements of contents and organizations of groups.
- *Rules:* The implementation of these norms can consider the *social rules* applicable to the strategy.

The neighbourhood in Fig. 5 presents a primary contradiction that permeates all the elements of the learning activity system and which arises from the opposition between the traditional and the PBL pedagogical strategies. To overcome it, both students and teachers need to completely change their attitudes and working procedures (Smith, 1995). Students, as the subject of the new PBL learning activity, have to discover and exercise their soft skills. Teachers have to abandon their classical "sage on the stage" role and exert loose control over teams, simply playing the role of facilitators. If teachers exert too strict guidance, they impoverish student interactions, thus precluding the meaningful acquisition of the soft skills.

The new pedagogical strategy also affects the course structure and the development of contents. A key factor in the success of PBL strategies is the careful design of the educational experience (McCracken & Waters, 1999). Embedding traditional educational content in problems would make students feel deceived because they have to learn the concepts at the same time that they are doing the practical work (i.e. programming assignments). Hence, teachers must adapt the design of the complete course to the PBL context. The need for these changes points to a quaternary contradiction between the central activity of learning and the neighbour activity that designs the course.

The teacher, who is the subject of this neighbour activity, pursues the objective of providing students with the means for a fruitful learning experience, and this requires having means adapted to the new context of collaborative PBL.

To resolve these contradictions, NUCLEO completely redesigns the course. Following the strategy of PBL (Savery & Duffy, 1996), it presents problems as projects that students have to work out collaboratively. These projects are real-world, open-ended problems, as in a classical PBL scenario, only in this case the "real world" is the virtual world of NUCLEO. The solution to these projects often requires providing the teams with information and hints that guide them to the solution. For this purpose, the teachers give them preliminary dossiers and follow their evolution with support tools, offering help and additional information when the situation requires it. In any case, the delivery of information depends on the students since their search for the solution to the projects determines when and what information is meaningful. The issues pertaining to the organization of the interactions between students and with teachers in PBL are the ones already considered in the previous sections.

4.4. Dismantling the mindset

NUCLEO implies a structural change in the way most university courses are taught. This means the need to overcome inertia and dismantle the existing "mindset". Both teachers and students feel reluctant to change their usual routines, even if they do not seem very successful (Rugarcia et al., 2000). From the teacher's point of view, a common prejudice towards new pedagogical approaches, especially if they imply student initiative and teamwork, is that they mean a far greater workload and probably worse results. From the students' point of view, NUCLEO means a profound change in their work habits that relies on a basis of continuous work instead of the traditional just-study-for-the-exam routine. In terms of AT, these are tertiary contradictions between the classical courses and the emergent new approach. To resolve these contradictions, NUCLEO uses the immersive features of games.

The NUCLEO virtual learning scenario is a game that places the student in a medieval universe inhabited by the Pict tribes. These tribes have lived in peace in their homeland for centuries. The coming of the Dark Lords vanquishes their civilization, throwing the Picts to an obscure new era. Only some of them get to run away to the remote Dragon Island, where the Sea Dragons will instruct them in the weapons of knowledge to fight against the Dark Lords. In this metaphor, teachers play the role of the Sea Dragons (i.e. advisors) and students are candidates to Dragon Warriors. The training of candidates in the school simulates the situation of real attacks by the Dark Lords in the form of missions, in which the aspirants must fight back. Only those students with the best scores will become Dragon Warriors and fight the real war against the menace. The metaphor of the game integrates the aforementioned elements of NUCLEO. The school organizes candidates in crews (i.e. groups) according to the students' learning profiles. Functional roles determine different posts for the crew. Crews have assigned ships for their internal work. Each crew writes a logbook about their progress that they share with the Sea Dragons to receive advice. Besides, students can also use some of the communication tools to ask for and receive additional help from the teachers (see the *Dragon Cliffs* in Section 2.1). Every project in the course is a mission of the school. Finally, the students' scores determine the features and garments of their avatars, and their access to specific resources (e.g. files, tools or databases) in the world.

This shift in the learning scenario captivates students and detaches them from their common assumptions, even though they rationally know that they are following a university course; it creates a positive atmosphere that forces the students to change their attitude towards learning (Gee, 2003). The new scenario sets them in a situation in which they are no longer the passive receivers of the knowledge delivered by the teacher, but the active solvers of a game related to certain course topics. Their teacher is no longer an opponent, but a Sea Dragon who is their collaborator and advisor. Finally, although the game includes learning material and exercises as a traditional course does, advancing through that material requires and gives clear and immediate feedback, which also improves the sense of continuity in the course.

5. Case studies

The NUCLEO framework has been tested in several real educational contexts in order to verify the hypotheses that arise from the analysis performed in Section 4. The case studies presented in this paper were conducted for university courses in the context of Spanish higher education: the course Programming Fundamentals (PF) participated in the academic years 2007–2008 and 2008–2009, and the course Laboratory of Programming 2 (LP2) only in 2007–2008. In all cases, the NUCLEO framework was applied to teach programming courses. In year 2007–2008, the participation in the NUCLEO experiment was voluntary for both courses (i.e. PF and LP2) and the group was divided into a control and an experimental group. In 2008–2009 the participation in NUCLEO was compulsory for all the students in the PF course.

The experimentation considered the following metrics about the effectiveness of the framework (see Section 4):

- The initial support of students for the implantation of the NUCLEO framework, and the percentage of students in the experimental and control groups, measure the power of the game metaphor to generate the shift in students' attitude to a potentially more active role and the acceptance of the new pedagogical strategy.
- The comparison of dropout rates between the experimental and the control groups measures the effect of the framework on students' motivation.
- The percentage of students passing the course allows us to measure the improvement in efficiency brought about by the NUCLEO system in terms of knowledge and skills.
- The suitability of forming heterogeneous groups and the accuracy of Vermunt's framework for role assignment was measured using two different metrics. The first one was applied to the two case studies in 2007–2008, and it consisted of a peer evaluation questionnaire within teams, extracted from Oakley et al. (2004). In the 2008–2009 case study, we used a satisfaction questionnaire that included questions to elicit the students' opinion about the team formation and role assignation procedures.
- To assess efficiency in terms of improving soft and social skills, as well as the development of teamwork abilities, the students were asked to complete a final questionnaire at the end of the course.

The rest of the section includes two parts. The first one introduces the courses that were the object of the experiment. The second one discusses the statistics of these courses.

5.1. The courses

The case studies refer to two courses of computer programming at the Complutense University of Madrid, Spain. PF is taught as an optional semestral subject at the Electrical Engineering School, in the second cycle of a five-year degree. This course is aimed at teaching programming basics, such as algorithms, program design and coding. The second course is LP2, which is taught as an annual subject in the second year of the three-year Computer Science Technical Engineering degree. This course is focused on teaching advanced programming on the object-oriented paradigm and data structures.

Over the previous few years, lecturers had observed some worrying situations that were becoming increasingly noticeable. In the first place, dropout rates had grown alarmingly and the marks were getting lower. On the other hand, teachers observed that grouping students with a close friend did not result in the acquisition of teamwork skills expected (e.g. division of tasks, use of well-defined communication procedures, or independent coding).

The analysis of the case studies began in the period 2005–2007 (i.e. during two academic years), when the lecturers of the two courses followed a traditional teacher-centred approach that included lectures in the classroom, practical sessions in the laboratories and a compulsory final exam. For calculating the students' final grades, the lecturers took into account the marks obtained in the practical sessions and the final exam.

In 2007–2008, teachers decided to adopt the NUCLEO approach for the courses. The PF course was followed by 60 students (all in the same class). The LP2 course was distributed in two classes: group A, with 101 students that attended class during the morning session, and group B, with 75 students during the afternoon session. Traditionally, group B is the one preferred by students that are already working or that failed the course in previous years. Therefore, group B usually presents worse performance indicators than group A. In both courses (PF and LP2), the NUCLEO approach was presented as an optional choice, and the students were divided into an experimental group (i.e. NUCLEO approach) and a control group (i.e. traditional approach). For both courses, more students preferred following the traditional approach, but the experimental groups were big enough to get relevant data. In 2008–2009, only the PF course applied NUCLEO, and participation was compulsory for its 54 students enrolled.

In all the courses and years, lecturers organized the students who chose the NUCLEO approach into teams following the rules explained in Section 4. In the traditional approach, PF students did the class work individually, and LP2 students worked individually the first semester and organized themselves into groups of one to three members for the second semester.

The social interaction among NUCLEO students in the different case studies was supported by the NUCLEO system described in Section 2. Both traditional and NUCLEO students had the additional support of the LMS provided by the University for all students and courses.

The new approach also brought some changes in the organization of classes for the NUCLEO students. These students were excused from attending the theoretical lectures. In the PF courses, they had a two-hour on-site session every two weeks aimed at having a shared discussion about the requisites for the missions proposed. In the LP2 course, they had a weekly briefing with their lecturers to discuss their progress with the problems.

The courses ended with the final exam for all the students. The calculation of the final marks followed the same formulas of previous courses, which considered the exam and the practical assignments.

5.2. Results of the case studies

The overall goal of the case studies was to verify if the application of the NUCLEO framework improved the metrics considered in the introduction of this section when compared to the traditional approach. This section summarizes and discusses these measures throughout the period 2005–2009.

A first concern was whether the role game environment was appealing enough to break students' initial reluctance to change from the traditional approach to the NUCLEO one. Table 1 compares the number of students that chose each one of the available approaches for the year 2007–2008. Although the figures show a clear preference for the traditional approach, the percentages indicate that the metaphor and presentation of NUCLEO were appealing enough to attract a relevant percentage of students. In fact, 36.67% of PF students, 26.73% of LP2 A and 25.68% of LP2 B chose it, providing a relevant partition of the groups between control and experimental students.

Although the initial impact of the presentation of NUCLEO was positive, the question of whether or not the NUCLEO framework would reduce the very high dropout rates was still open. The dropout rate is here defined as the number of students that attend the exam compared with the total number of students enrolled in the course. Table 1 also summarizes these figures for the different academic years, courses and approaches. It shows dropout rates over 62% and rising during the academic years 2005–2006 and 2006–2007. Although this data corresponds to just two academic years, they make patent a tendency qualitatively observed by teachers in the previous years. The introduction of the NUCLEO approach in the academic year 2007–2008 improved these statistics, lowering global dropout rates to 45% for PF, 60.4% for LP2 in group A, and 71.62% for LP2 in group B. The highest dropout rate for the NUCLEO groups appeared in group A of LP2 with 14.81% while their classmates in the traditional approach dropped out of the course in 77.03% of the cases.

Nevertheless, it was very difficult to evaluate whether the success in terms of dropout rates was due to the NUCLEO framework itself or to several other reasons. In fact, evaluating the effectiveness of game-based learning approaches still constitutes an open issue in this domain (Hays, 2005). For instance, in our case, participation in the NUCLEO framework was voluntary in 2007–2008. In these circumstances, it was hard to ascertain if the *a priori* more motivated students enrolled for the NUCLEO experiment, thus making its dropout rates very low. As shown in Table 1, in 2007–2008 the dropout rates were: 9.09% (experimental) versus 65.80% (traditional) in PF; 14.81% (experimental) versus 77.03% (traditional) in LP2 group A, and 10.53% (experimental) versus 92.73% (traditional) in LP2 group B. To decide this issue, in 2008–2009 participation in NUCLEO was compulsory for the whole class in PF. Even though dropout rates were a little higher than the previous year (16%), they still show a great improvement over the rates from 2005 to 2007 (in 2006–2007 it reached 70%). Based on these results, we think that our first claim is supported and that the contradictions presented in Section 4.4 about motivational issues were correctly managed in the design of the NUCLEO framework.

Table 1
Students per approach and dropout rates in the case studies for the academic years 2005–2009.

Academic year	Course	Group	Pedagogical approach	Students enrolled	Students attending the exam	Dropout rate (%)
2005–2006	PF		Traditional	115	43	62.61
	LP2	A	Traditional	93	22	76.34
		B	Traditional	57	13	77.2
2006–2007	PF		Traditional	110	33	70
	LP2	A	Traditional	106	24	77.36
		B	Traditional	65	14	78.46
2007–2008	PF		Traditional	38	13	65.8
			NUCLEO	22	20	9.09
	LP2	A	Traditional	74	17	77.03
			NUCLEO	27	23	14.81
		B	Traditional	55	4	92.73
			NUCLEO	19	17	10.53
2008–2009	PF		NUCLEO	54	45	16

Although students' motivation is a relevant indicator, we were also worried about how effective our system was in terms of helping students to acquire technical knowledge. We have taken the rate of students passing the course examination as the metric for this result. Whether exams are a valid metric for knowledge acquisition or not is out of the scope of this paper. The fact is that, nowadays, exams are the most common indicator used in higher education. Hence, an improvement in the students that passed a course implies that more students were able to acquire more efficiently the technical skills that are part of the goals of these courses. Fig. 6 shows the percentages of students that passed the courses in comparison with those enrolled. Again, the statistics show an improvement in the years 2007–2008 and 2008–2009, considering both the experimental and the control group together. The lowest rate in the year 2007–2008 corresponds to group B of LP2 with 17.57% (13 over 74 enrolled). The percentage of students that passed the course in the same group the year 2006–2007 was 10.77% (7 over 65 enrolled). Although the global figures are significant, the statistics per approach make the efficiency of NUCLEO even clearer. In the worst case for NUCLEO, which was group B of LP2, the students in the NUCLEO approach passed the course at a rate of 47.37% (9 over 19 enrolled) while only 7.27% (4 over 55 enrolled) of those following the traditional course passed. In the PF course 2008–2009 when all the students followed the NUCLEO approach, 72.22% of the students were able to pass the exam. These figures lead us to conclude that NUCLEO has a positive effect on the number of students that pass the course. Nevertheless, statistics also show that the highest marks in the courses did not rise significantly. For instance, in PF it was 5.0 in the year 2006–2007 and 5.2 in the year 2007–2008. That is, NUCLEO seems to be effective for students with lower marks, since more of them passed the exam, but not in improving the technical knowledge of the better students, since the marks remain at the same levels.

The rate of students passing the final exam can also be considered as an indirect measure of the effectiveness of NUCLEO in addressing two of the contradictions outlined in Section 4: first, the secondary contradictions about the organization of work in Sections 4.1 and 4.2, which NUCLEO manages with a new system of work based on heterogeneous teams organized according to learning profiles; second, the new learning strategy and its material, which constitute the way to address the quaternary contradiction in Section 4.3. In both cases, the NUCLEO decisions seem to have a positive effect in terms of knowledge acquisition, since more students passed the course faced with the same exam requirements that in previous years. Of course, these statements are still hypotheses based on the available non-conclusive results for these aspects, and thus more experimentation is required regarding these decisions.

In order to evaluate the effectiveness of the underlying model for forming the groups, this experimentation considered two different metrics: In 2007–2008 we considered peer evaluation (i.e. the evaluation that students made for the rest of their teammates at the end of every mission), because this indicates how well everyone fulfilled their assignments according to their teammates' opinions. And in 2008–2009 we used a satisfaction questionnaire. The results obtained in both cases are described in the next two paragraphs.

The peer evaluation questionnaire within teams was adapted from (Oakley et al., 2004). It included seven questions rated from 0 (i.e. never) to 10 (i.e. always). These questions were related to issues such as how every student had perceived the commitment of each of his/

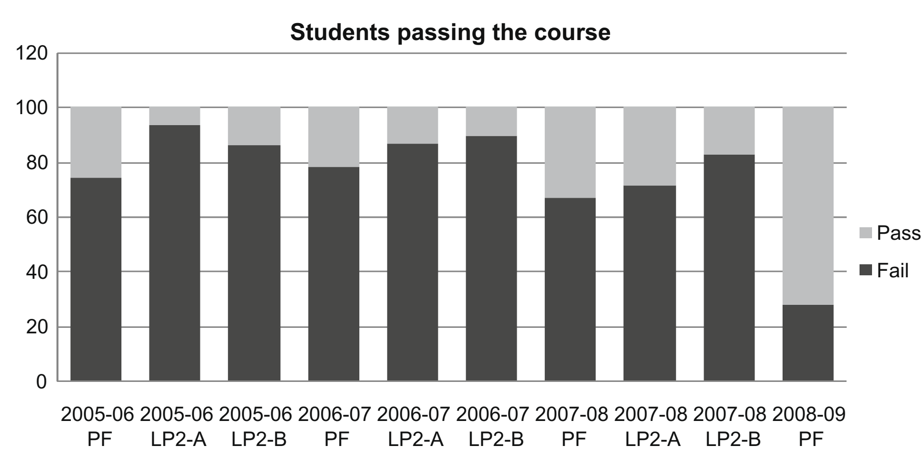

Fig. 6. Percentage of students passing the courses. Academic years 2005–2006 and 2006–2007 used a traditional approach, the 2007–2008 used both the traditional and NUCLEO approaches, and the 2008–2009 used only the NUCLEO approach.

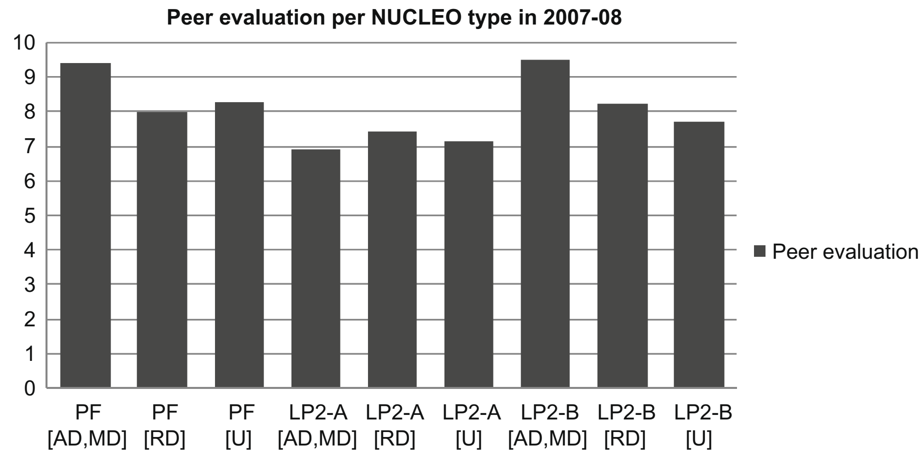

Fig. 7. Average peer evaluation of students within the teams per group of learning profiles. Vermunt's learning profiles are: application-directed (AD), meaning-directed (MD), reproduction-directed (MD) and undirected (U).

her teammates, his/her contribution in teamwork, or his/her respect for the opinions of other members. The average results in Fig. 7 are the marks obtained through the different assignments categorized by profile (i.e. AD–MD, RD and U). It is important to highlight that in the intra-group evaluation, two opposing considerations worked. On one hand, students pursued a high mark, which could only be achieved if the team was effective and got high marks, and if peers evaluated the student as a good teammate. On the other hand, students could only change their mates or group by justifying their discontent in the peer evaluation. Therefore, if they belonged to a team in which group work was inefficient because one or more team-mates did not fulfil their responsibilities properly, they had to reflect it in the peer evaluation. Otherwise, the tutor would not accept their request for a change. This fact was discussed in the contradictions about group organization in Section 4.2.

44 students answered the satisfaction questionnaire used for the 2008–2009 case study. It included two explicit questions to evaluate these issues about group management. The first one was "Do you think roles are useful for teamwork coordination?" and 61.63% of the students thought they were. The second one was: "Do you think that the model used for forming the teams is satisfactory?" and 65.91% of the students agreed with this question. In our opinion, even though Vermunt's model works fairly well, the rate of discontent students (up to 38.37% in the worst case, that is, the use of roles for team coordination) leads to the conclusion that the model has to be improved. In fact, 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 the undesirable mate types outlined as a contradiction in Section 4.2. These circumstances can probably be avoided by extending the adaptation model to include personality traits focused on social bonds. This kind of studies has already been considered in research for team formation (Morgeson, Reider, & Campion, 2005). In any case, NUCLEO has to incorporate mechanisms that articulate conflict resolution to tackle these situations when they emerge in teams.

The last issue to consider is assessing the potential improvement in social skills produced by NUCLEO. Measuring these features has proved to be quite an elusive task (Morgeson et al., 2005). In the case of the NUCLEO framework, measurement is particularly difficult because of the limited capability of tracking students outside the NUCLEO system. For instance, researchers cannot know how students perform if they agree to a face-to-face meeting or if they use collaborative facilities like common e-mail or instant messaging. Given these facts, researchers chose to perform a qualitative evaluation of these skills according to students' subjective insights in the PF course 2008–2009. Fig. 8 shows the results obtained. Among the 44 students, 90.91% considered that the course helped them to develop their

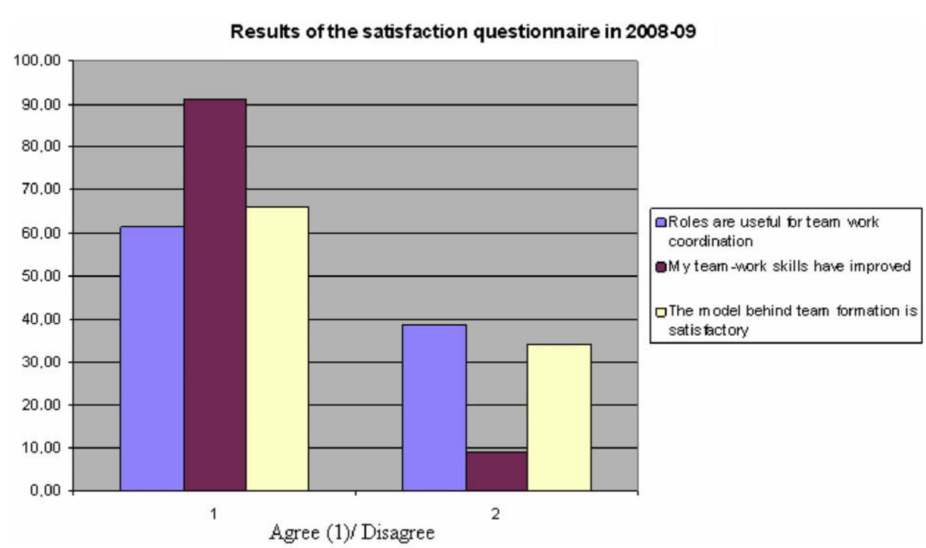

Fig. 8. Results obtained in the questions about social skills, assignation of roles and team formation, posed to students in an open questionnaire in 2008–2009.

teamwork skills. This result indicates that from the students' point of view, NUCLEO has been successful in addressing the secondary contradiction about the acquisition of teamwork skills in Section 4.3.

6. Related work

The framework proposed combines several different existing approaches, specifically dPBL (distributed Problem Based Learning), CSCL (Computer Supported Collaborative Learning), and learning in virtual worlds or MUVEs (Multi-User Virtual Environments). There are a number of applications belonging to these three approaches that share some features with the NUCLEO framework. This section presents some of those most similar to NUCLEO, although as far as we know, NUCLEO is a unique combination of all these approaches.

Team formation and organization have drawn a lot of attention in learning settings. Among the different approaches available (Morgeson et al., 2005; Robey et al., 2000), NUCLEO advocates for heterogeneous but complementary teams of students. Some authors (Deibel 2005; Oakley et al., 2004) consider that this heterogeneity enriches group discussion with different perspectives and knowledge, it offers students the opportunity to deal with different personalities, and allows strong students to lead and give ineffective students familiar models. Nevertheless, there is also literature (McCracken & Waters, 1999; Robey et al., 2000) that considers these groups to have certain risks. First, the search for heterogeneity can lead to forming ineffective teams, as not all the personalities are equally desirable or compatible for teamwork. Second, programming problems with a true need for teamwork require a significant time investment. However, programming courses commonly pose several problems with reduced development times throughout the course. A heterogeneous team of non-related students can find it difficult to establish the required bonds and routines in such short periods. In both situations, failure to achieve the goals can lead the whole group to a lack of motivation and to not acquiring the intended skills.

Another subject of discussion is the organization of work through functional roles. Although this is a common practice in software development (Benarek et al., 2005), it is only one of the ways to make students interdependent and therefore to establish social bonds (Johnson et al., 1991). Besides, some authors (Oakley et al., 2004) warn about the difficulties in making students adopt a role organization that does not emerge from them. When students are forced to work following an imposed organization of work, they can just ignore it, and work in a self-organized way. NUCLEO tries to avoid this situation through two mechanisms: controlling team formation and role assignment; and making individuals accountable for the work related to their role.

A potential problem in the shift to collaborative PBL is breaking course inertia, both about its organization and its pedagogical strategy. For this purpose, the introduction of virtual worlds has been a common resource. PBL has been implemented in virtual settings for different domains, including subjects related to software programming. To briefly discuss a few that share some features with the NUCLEO system, this section compares it to CROCODILE (Miao, Holst, Haake, & Steinmetz, 2000), STEP (Steinkuehler, Derry, Woods, & Hmelo-Silver, 2002), and Alien Rescue (Liu, Williams, & Pedersen, 2002). CROCODILE (Miao et al., 2000) is a multi-interface PBL system in which groups interact through shared virtual rooms. The interaction among the NUCLEO community also takes place in a virtual world where the members of the same team interact within the limits of their ship and whole class interaction occurs in a common virtual space. This organization may be comparable to CROCODILE virtual rooms, with the difference that our framework has two different scenarios for the two levels of social interaction our system requires. STEP (Steinkuehler et al., 2002) is a dPBL environment that uses specialized tools to facilitate the execution of a set of individual and group tasks in which the resolution process for the problems proposed is divided. In NUCLEO, there are different tools assigned to different roles and the resolution of the problem is the underlying objective of different activities. Alien Rescue (Liu et al., 2002), like NUCLEO, stages a PBL strategy in a fantasy world within the context of a game, but it does not include any procedure about team formation, and nor does it consider how to manage group dynamics or how to evaluate students.

Several CSCL applications have studied the impact of team composition on the efficiency of collaborative learning. I-Help (Hansen & McCalla, 2003) identifies four standard patterns of behaviour in collaborative learning (i.e. tutor, student, expert and fellow learner) using taxonomies. GRACILE (Ayala & Yano, 1998) links students to the execution of specific learning activities based on the intentions of the group and its common knowledge. In the work of Muehlenbrock (2006), the complementary knowledge of individuals is taken into account when forming groups. Alfonseca, Carro, Martín, Ortigosa, & Paredes, (2006) and Deibel (2005) take into account students' learning styles in group formation by using Felder–Silverman's learning style model (Felder & Silverman, 1998). Finally, in (Sánchez-Hórreo & Carro, 2007) a model based on the student's personality and intelligence is proposed to make up the groups. As Section 4.1 describes, NUCLEO develops specific processes for group organization (i.e. with Vermunt's learning styles) and to manage their interactions (i.e. missions in the school and their marks). These other approaches could provide complementary information to improve group formation, which some students see as conflictive in the current state of NUCLEO (see Section 5.2). This should lead to a tailored version of the Vermunt's questionnaire to elicit personality traits helpful in managing teams.

The application of AT to dBLP and CSCL is also closely related to the NUCLEO framework. It has two main dimensions: the study of existing systems and the development of new ones. Several research efforts (Barr, 2008; de Freitas & Oliver, 2006; Steinkuehler, 2006) have considered AT for the study of games as tools for CSCL. These works consider existing games and analyze the kind of relevant features that they present to support certain types of learning (mainly based on problems or cases) or users' interactions. The research that uses AT for system development covers a wide range of approaches. Some works simply apply AT to elicit requirements, trying to grasp the implications of the human context for the system envisioned (Kaptelinin & Cole, 2002). There are also proposals where AT articulates the analysis and design of system interactions (Beetham, 2001; Collis & Margaryan, 2004; Zurita & Nussbaum, 2007). Currently, in (Zurita & Nussbaum, 2007) AT is used in a similar way as the one described in this work. Nevertheless, our work differs from this one in that we have emphasized the contradiction analyses to identify the limitations of integrating our proposal in its social context. Finally, participatory design considers AT in order to manage the *design activity* itself through its inner contradictions between customers and the development team (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005). Nevertheless, in all these cases, this kind of studies is applied to the first stages of development, i.e. requirements elicitation and analysis. Then designers must interpret this highly abstract information and convert it to design decisions for the computer-supported cooperative system by applying their own knowledge (Kuutti, 1992). The NUCLEO project adopts AT for the analysis of the setting and the proposal of solutions for its contradictions. It also presents explicit solutions to the contradictions found that correspond to functional requirements, like how to classify students or manage their ranks. In this sense, NUCLEO extends the presence of AT principles and solutions to the analysis and design of the CSCL game.

Finally, the interest in immersive virtual worlds or MUVEs to stage learning is rapidly increasing. Some examples are: the River City project (Harvard University, 2008), the Revolution project (Massachussetts Institute of Technology, 2004), Quest Atlantis (Barab et al., 2005) or AquaMoose 3D (Georgia Institute of Technology, 2008). There is also now emerging a whole branch of applications based on the use of the Second Life environment (Linden Research Inc., 2008) for educational purposes. Over 400 universities and 4500 educators participate in the Second Life Educators List (SLED) (SLED, 2008). Another related project is Sloodle (Sloodle Project Team, 2008), which uses Moodle services (Moodle Community, 2008) and databases through the 3D interface of Second Life. In this line, the NUCLEO system adds an underlying LMS that provides tools, data and services, and a virtual world interface.

7. Conclusions and future work

NUCLEO is a socio-constructivist environment based on PBL to teach computing courses in university science degrees. It adopts the aesthetics and rules of a role-based game to embed the educational content in an appealing fantasy scenario where students collaborate and compete to fulfil their missions. These interactions lead to the development of effective social bonds, which promotes the emergence of communities of practice among the participants. These communities of practice have several positive effects on the learning experience: their social recognition complements the traditional motivation for students to pass the course; they constitute an effective tool for the exchange of information and feedback between students; they provide an experience of teamwork that is closer to the industrial practice than more traditional formats.

The design and implementation of the NUCLEO framework face several problems that have been analyzed and addressed through an AT analysis based on contradictions. In order to validate the previous mechanisms, we have carried out case studies during the academic years 2007–2008 and 2008–2009 with two programming courses that sum up 289 students. The data gathered from these groups draws some relevant conclusions. NUCLEO had a very positive influence in decreasing the dropout rate. Figures fell from around 70% in previous years to a maximum of 16% in the NUCLEO groups (corresponding to the 2008–2009 PF course). This positive influence also extends to the percentage of students that passed the exam. For instance, group B of LP2 had the lowest pass rate among the NUCLEO groups with 47.37% (9 over 19 enrolled), but only 7.27% (4 over 55 enrolled) passed the exam in the corresponding traditional group of the course. This corresponds to a global rate of 17.57% (13 over 74 enrolled) compared with 10.77% (7 over 65 enrolled) of the same course the year 2006–2007. These figures mean that more students were able to sit at the final exam and pass it. However, the marks for the year 2007–2008 showed only a slight improvement in the knowledge acquisition of the better students. This seems to indicate that students with less effective learning strategies are the most benefited by the NUCLEO approach, although it is clear that the new approach does not harm the better students. Although evaluating the acquisition of soft skills was more difficult than for the previous metrics, students' questionnaires in the year 2008–2009 point out a positive experience of these abilities and improved skills to work on real projects. 90.91% of the students answered that the course had helped them to develop their teamwork skills. Finally, students also positively evaluate the composition of teams, since the data about peer evaluation shows overall marks above 6.9 on a scale to 10 in the year 2007–2008, and 65.91% of students positively evaluate the model for team forming in the year 2008–2009.

Several concerns arise from this experience. The first one is that the NUCLEO framework needs to make the learning experience even more customized and with richer social interactions. A probable reason for the similar marks of the traditional and the NUCLEO approaches is that the exercises have not offered a true challenge to the best students. Thus, a careful assessment needs to be made of the learning goals for new exercises customized for these students. Nevertheless, we have to consider that these courses belong to degree programs and the effort required from the students must match their limited time for each course. A second issue is the adequacy of the Vermunt questionnaire in classifying students. Given the use of profiles to constitute the teams, NUCLEO should probably focus on those features of Vermunt's styles related to teamwork. Third, we have found a small percentage of highly incompatible groups. Although these situations are difficult to anticipate, NUCLEO should incorporate mechanisms for conflict resolution within teams that try to minimize the impact of such problems. Finally, we do not have available a comparison of the effort required for the two approaches. Students filled out a questionnaire at the end of the course about the approach they have followed and their level of satisfaction, but it just indicated a positive perception of NUCLEO. The final support system for NUCLEO should incorporate resources to measure students' efforts more accurately.

Next steps in the project include a new version of the NUCLEO framework with a more tailored learning experience for students. In addition, we have identified a conflict regarding the new tasks imposed by the approach on teachers, such as group formation and group redistribution, which the NUCLEO system must support. Besides, to reduce the teacher workload we are designing new tools that simplify the administrative tasks in the course.

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