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Conceptual framework for design, technological support and evaluation of collaborative learning*

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Computer Supported Collaborative Learning (CSCL) aims at promoting active learning and knowledge construction through the interaction with peers, mediated and supported by software tools, which make it very attractive for engineering courses. Despite this, there are not so many successful CSCL scenarios happening on a regular basis. Several CSCL frameworks try to overcome these limitations by providing guidelines either to educators, or software developers or institutions. However, there is a lack of a global understanding of the whole CSCL lifecycle shared among all stakeholders. Here we propose a framework that tries to point out issues and recommendations for all stakeholders along the whole CSCL lifecycle. It considers the influences between the social and organisational context, the learning process designed by the educator, the technology used to support it, and the evaluation of both the process and the technology. We illustrate the usage of this framework with its application to an engineering course on Computer Architecture conceived for a virtual university.

Keywords: conceptual framework, collaborative learning, learning lifecycle, learning technologies.

INTRODUCTION

INFORMATION AND COMMUNICATION TECHNOLOGIES have been used in education for several years now, from slideshows in traditional classrooms, or email and electronic boards for notifications, to complex virtual campuses that include many different management and educational tools. Technology has been exploited not only by those following traditional teaching styles based on the transmission of content, but also by adopters of new pedagogical styles centred in the students and promoting the interactions between them. In this latter approach, Computer Supported Collaborative Learning (CSCL) [1] has socio-constructivist roots in its claim that technology should mediate not only between the learner and the knowledge, but mostly between learners themselves allowing them to interact fruitfully. Because of the nature of engineering studies, where students are expected to actively discover, discuss and confront proposals with their mates, collaborative learning is often encouraged by educators [2], and there are several examples where this is achieved with computer mediation [3, 4].

CSCL has become a significant research field [5], attracting people with different interests ranging from pedagogy or interaction analysis to distributed systems or human computer interaction, and many new tools and experiences are reported every year. Unfortunately, not so many of these research outcomes are later applied in classrooms on a regular basis [6]. One of the reasons is that educators often find that their desired learning scenarios cannot be supported with existing technology due to the fact that application developers were unaware of the actual educational context [7, 8], concerning the particular topic [9], institution [10] or social environment. In many e-learning programs the context is also ignored by educators who design scenarios that do not suit the needs of learners. In other situations, educators do not consider the available technological opportunities to support their scenarios, and they tend to use general purpose tools instead of more specific ones that better suit their needs and would enable much richer scenarios [10, 11]. Sometimes too, they are unaware of the complexities of student-centred pedagogies, and they fail to play the key role of orchestrator [12], defining the sequence of phases and tasks to be performed, as well as selecting the

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required resources, i.e. documents and tools. Besides, the evaluation of learning and technological designs is often unexploited. Though educators are used to assess the learning process and its results, the implications that particular learning platforms or tools have on them are often overlooked [6]. Moreover, the activity information derived from the use of collaborative learning applications, such as interaction logs, could also be evaluated to achieve a richer insight into the learning process [13].

Such issues provide evidence that there is a lack of a global understanding of the whole CSCL lifecycle shared among all stakeholders [14, 15]. There are some attempts in the literature to tackle this problem with the proposal of different frameworks for CSCL. For instance, [16] presents a preliminary framework grounded in the Activity Theory [17] emphasising the importance of context and mediating artefacts, but lacking concrete design guidelines for stakeholders to enact a CSCL situation. This limitation is partially addressed in [18], that proposes a technological framework for software developers to design CSCL systems. However, the other stakeholders are not considered, thus missing some important aspects in CSCL processes such as the educational context or the need of evaluation. Similarly, [19] provides some guidelines for CSCL developers to consider the implications of the context and the pedagogical strategies, but fails to provide equivalent recommendations for educators, and does not consider evaluation as a relevant issue. In [11], a framework for educational design in collaborative learning studies the relationships between pedagogical objectives, types of tasks and the selection of CSCL tools, though the influence of the social and institutional context is overlooked, as well as the relevance of evaluation. Interestingly, [14] puts forward a theoretical framework founded in four themes: collaborative knowledge building, group and personal perspectives, mediation by artefacts and interaction analysis. These different perspectives reflect the intertwining of pedagogies and social practices with computational support, thus requiring methods for observing and assessing knowledge construction in practice. However, despite the relevance of this work, there are not precise guidelines to apply the framework to real practice.

Within this context, we propose a new conceptual framework that tries to provide a global understanding of the whole CSCL lifecycle shared among all stakeholders with practical guidelines in order to facilitate the enactment of CSCL scenarios. Specifically, the proposed framework considers the influences between the social and organisational context, the learning process designed by the educator, the technology used to support it, and the evaluation of both the process and the technology. The application of the framework is illustrated in a CSCL scenario conceived for an engineering course. The framework is then discussed in order to show its potential benefits for each stakeholder.

A CONCEPTUAL FRAMEWORK FOR CSCL

To address the deficiencies in the design and set up of CSCL scenarios, we propose a conceptual framework detailing what should be taken into account as well as some relevant issues and best practices that we have found in our community of practice and in other works. This framework is pictorially shown in Figure 1, and develops around the learning scenario enactment, which is the result of the learning process design, supported by technology, and the main object of evaluation.

The framework strongly compels consideration of the context before designing the collaborative learning process, selecting the supporting technology or preparing the evaluation. The learning process should be designed to serve the learning objectives, but it is clearly conditioned by the social and human context, as well as by the technological feasibility. In this sense, technology should support the learning process according to the specific needs of the situation conceived by educators. The feedback provided by evaluation should be considered in the design of both the learning process and the technological support. Evaluation will yield recommendations, lessons learned from previous experience that can enrich the framework for future use by all stakeholders. The issues that should be taken into account in each of these parts of the framework are summarised in Table 1 and described in the next subsections.

The learning context

As opposed to many online courses that aim to serve for learning anywhere, anytime, by anyone and in any condition, many CSCL researchers [10, 12, 20, 21] consider that the context should be seriously taken into account both in the pedagogical design and in the technological choices. Both educators and CSCL developers should consider some important contextual issues, as discussed hereafter.

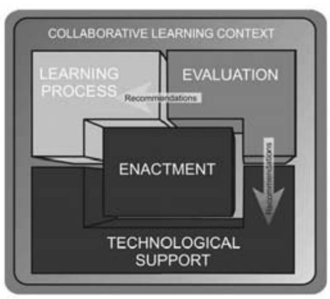

Fig. 1. Proposed conceptual framework for technological support of collaborative learning.

Table 1. Key issues should be taken into account in each part of the framework

Learning Context

- LC1. What are the learning and teaching styles?
- LC2. Is the environment among students competitive or collaborative?
- LC3. What is the adequate group size?
- LC4. Will participants be able to meet in person?
- LC5. Will participants be able to join synchronous activities?
- LC6. What are the technical skills of end users?
- LC7. What is the technological infrastructure available?
- LC8. How much tutoring is needed?

Learning Process

- LC1. What are the learning objectives?
- LC2. What learning activities will be carried out?
- LC3. What resources will be employed in each activity?
- LC4. Should collaboration scripts be employed?
- LC5. If collaboration scripts are employed, what is the appropriate level of prescription?
- LC6. Is there any Collaborative Learning Flow Pattern suitable for the scenario?
- LC7. How groups should be formed?
- LC8. What assessment and evaluation techniques will be employed?

Technological Support

- TS1. Are the tools or platforms suitable for the learning objectives and the educational process?
- TS2. Do they include facilities for user, group and administrative management?
- TS3. Do they explicitly support collaboration?
- TS4. If needed, do they provide participants with guidance according to the collaboration scripts?
- TS5. If needed, are they compatible with authoring tools for collaboration scripts?
- TS6. Do the platforms enable the integration of new tools?
- TS7. Do the tools and platforms provide means to observe the interactions of students?
- TS8. Are there any context-specific technological needs?

Evaluation

- E1. Are all stakeholders involved in the evaluation?
- E2. What are the objectives of evaluation?
- E3. What indicators will be employed for the evaluation of collaboration?
- E4. What data sources and analysis techniques will be employed?
- E5. What features of the technology are being evaluated?
- E6. If technology is experimental, is there a special plan for iterative testing?
- E7. What recommendations stemming from the evaluation can be added to this framework?

First, learning and teaching styles should critically influence the design of both the learning scenario and its computational support [20]. Process and technology should promote participation, initiative and communication, but adapted to the restrictions derived from this issue. For example, students with a reflexive learning style will probably prefer to participate in an asynchronous debate rather than in a synchronous one, while with active students it may well be the opposite case.

Also, we should find out whether the environment among students is competitive or collaborative [22]. In the former case, collaboration should be strongly promoted and supervised, while students with better attitude towards collaboration may benefit from more freedom to self-organise. For instance, technologies such as Wiki may fail in a competitive environment, even if the educator wants it collaborative, since bad intentioned participants may edit the text of other students to spoil their work.

With respect to organisational issues, the number of persons in each group is also an important contextual issue [20] since collaboration may be barely fruitful or even unfeasible when the size of groups is not adequate for the activity to be performed or the tool to be employed. For example, a brainstorming session supported with a chat tool may be unfeasible if groups are very large.

Further, whether participants will be able to meet in person or not will determine the feasibility of face-to-face and blended learning which, under many circumstances, may be preferred to pure distance learning [23]. Similarly, whether participants will be able to join a synchronous activity or not will help to determine the suitability of a given collaborative strategy [20]. For example, it is not a good idea to schedule many mandatory synchronous debate activities for an adult training course given that participants may not have coincident free time due to their work responsibilities.

In addition, the technical competence of both educators and learners is usually assumed, but this is not always the case [12]. In fact, many tools and systems conceived for the support of learning have failed because of this assumption [24]. Therefore, it is very important to take into account how good are the technical skills of end users at the time of choosing or designing the technological support of a collaborative learning situation. Another issue that is often overlooked refers to how good is the technological infrastructure available. In many cases, the technological requirements imposed by some tools or systems cannot be met by the infrastructure, thus making their use unfeasible. For instance, a 3D Virtual Learning Environment may require expensive servers and a high bandwidth, which are not available in many primary schools.

Finally, tutoring should be planned to be very intense in collaborative learning settings [25], to address not only conceptual problems, but also the lack of technical or collaboration skills. In this sense, a learning situation including new tools or complex collaboration strategies may fail if students do not receive an adequate support to overcome their difficulties.

The learning process

When preparing a course, educators first decide the learning objectives [26]. These include not only concepts that students should learn, but also procedures (e.g. how to plan a significant experiment, or write a report) and attitudes (e.g. believing that sharing information is positive). Then, a set of learning activities is planned that help to meet these objectives, as well as required resources [26]. Specifically, educators decide which documents should be read or written, tools to support their design, group activities with fixed or variable members and roles, etc.

During this design process, educators should consider the convenience of formalising their collaborative learning scenarios in collaboration scripts. A collaboration script is a set of instructions specifying, among other issues, the sequence of activities to be performed by participants, their timing, the groups to be formed in each activity, and the way participants should collaborate. Following [27], it can be employed as a didactic contract between educators and students in order to structure collaboration with the aim of enhancing the effectiveness of learning by introducing a certain degree of prescription. Educators should take into account their learning context when choosing the appropriate level of prescription [27], since too prescriptive scripts may decrease the motivation of students, but the contrary may lessen the effectiveness of learning.

Educators should also consider the possibility of using a Collaborative Learning Flow Pattern (CLFP). CLFPs are widely accepted techniques (e.g. jigsaw, pyramid) that can be easily adapted to several situations in order to promote the achievement of different educational goals [28]. Thus, they can be seen as template collaboration scripts that avoid creating collaborative learning scenarios from scratch. Clearly, contextual issues, such as the feasibility of synchronous interactions or the size of groups, will affect the convenience of each CLFP.

In addition, group formation policies should be defined considering contextual information [29], such as the background of students. For example, to promote integration of students with different cultures, heterogeneous groups are the choice; while to achieve very specialised learning goals, students could group homogeneously according to their interests. Finally, educators should acknowledge the accomplishment of specified learning objectives and give feedback to learners, introducing assessment and evaluation techniques in the learning process [12, 21] (e.g. using reports, questionnaires, interviews, presentations, tutoring, exams).

The technological support

Only after we have learnt about the educational and organisational context, we can move onto the design of the computational support since, as mentioned above, the context will greatly affect the choice of technology both in the case of educators that want to use already existing tools and platforms and of developers that want to create new ones. These stakeholders should take into account the following issues in order to select the appropriate technology to support the learning scenarios.

First of all, special attention should be paid to the suitability of the tools and platforms to the learning objectives and the educational process designed by the educator [9, 11]. In this sense, [12] provides some useful hints to map learning tasks into generic types of tools that can be used to support them.

One of the common restrictions stemming from this context is to have facilities for user, group and administrative information management. Because of this, often educators tend to select generic e-learning platforms (sometimes called Virtual Learning Environments), such as Blackboard (http://www.blackboard.com) or Moodle (http://moodle.org), which are convenient for institutional information management. However, they are thought for traditional knowledge transmission pedagogies, and collaboration can mostly happen through document exchange, being unsuitable for CSCL [11]. Instead, tools or platforms that include explicit support for collaboration should be employed [11].

Further, if collaboration scripts are going to be used, it is convenient to select a tool or platform that helps participants to follow the sequence of activities defined in collaboration scripts according to the prescription degree chosen by educators [27]. In this sense, some existing collaborative distance learning platforms such as Universanté (http://www.universante.org) force students to follow a sequence of activities predefined by developers, probably different from the sequences desired by educators. On the contrary, other platforms like Synergeia (http://bscl.fit.fraunhofer.de) do not enforce any particular sequence of activities, thus introducing a low prescription degree, which is not suitable for many learning scenarios. Others, such as as .LRN (http://dotlrn.org), allow educators to specify the sequence of activities through a collaboration script, which is interpreted by the platform. However, this last type of platforms employed machine-understandable scripts that educators may find difficult to create unless the platforms include or are compatible with authoring tools that help educators to design and code scripts [30]. For example, LAMS (http://www.lamsinternational.com) includes its own graphical editor for the sequence of activities and phases, while .LRN includes an IMS-LD [31] engine for scripts that may be coded with external editors, e.g. Reload (http://www.reload.ac.uk) or Collage (http://ulises.tel.uva.es/collage).

Moreover, tools included in platforms such as Synergeia, .LRN are often too generic, and educators tend to complement the support provided by these platforms with different tools, relevant to their scenario (e.g. simulators). To facilitate this, learning platforms should enable educators to easily integrate other tools required by their design. This is a significant trend in the industry, which has already detected a 'growing demand for a reusable mechanism for integrating third-party tools with core Learning Management System platforms' [32]. As an example, LAMS publishes APIs to allow the programming of functional extensions by thus making it possible to integrate new tools.

Tutoring and evaluation are critical in collaborative learning [33], and to support them the technology should provide means to observe the interactions of students both with the system and with other participants, as well as to support tutoring and regulation among students [21]. This way it can be possible, for example, for students to get group awareness information that encourages participation, or for the educator to suggest organisational tips [34].

The effect of other technological features may not be relevant for CSCL in general, but quite context-specific. For example, with large groups of participants it is important to pay special attention on the scalability of applications. For institutions with limited availability of computational resources, it may be a good choice to adopt a technology that enables resource sharing among different institutions.

EVALUATION OF THE LEARNING PROCESS AND ITS TECHNOLOGICAL SUPPORT

Evaluation of CSCL scenarios is generally made by each stakeholder separately, since apparently their interests differ. Most of the existing CSCL evaluation approaches are along with this idea, which means that it is normally not expected to achieve mutual understanding within and across all the groups of stakeholders. In this way, developers typically test correctness and usability with beta tests [35], educators are concerned with the learning outcomes and the way learning is achieved [12], while institutions often care for efficiency and productivity. However, the complexity of the field, and the dependencies between context, process and technology discussed above, call for the active participation of all stakeholders in the evaluation as part of the development cycle [6].

The first and obvious decision is what are the objectives of the evaluation. Different approaches have focused on the learning achievements (interesting for educators and also institutions), the tool capabilities (developers), the course development (educators), the educational programme (institutions), the teaching strategy (educators) and the suitability of the tool for it (both educators and developers), but other objects of attention could be defined.

Concerning the interests of educators, they should define indicators and milestones for the evaluation of procedures and attitudes related to collaboration [34], such as leadership, fluency of discussion or significance to the group, in addition to product related indicators (e.g. if a group submits a report without having exchanged a single message, collaboration failed). Note, however, that these issues can be closely related to the technology used, and the results of this evaluation also interest application developers.

Moreover, the observability of the interaction also depends on what technology is used, and how it is used. Thus, evaluation data sources can be diverse: some data used in traditional scenarios, such as questionnaires or interviews, can still be useful; new sources, such as interaction logs, transcription of chats or notes posted in document repositories, can provide further information, and can be processed automatically to perform a Social Network Analysis (SNA) [36], to calculate indicators of interactivity, etc. The high responsiveness of this type of indicators can provide quick feedback to the learning process. Thus, it is important to determine which combination of data sources and processing techniques are going to be used. In this sense, if the focus is on quantitative data, the evaluation is more efficient but less informative [37]. On the other hand, qualitative analysis can require a considerable research effort but may provide a richer insight [38]. Finally, a mixed method could use both types of sources and techniques [37].

Besides, both educators and developers should commit to evaluating the suitability and limitations of the software tools used. This can help to produce better tools for future iterations of the learning scenario. Some relevant issues to look at are:

- usability [39], which becomes particularly critical if practitioners do not have advanced technological skills;
- scalability, relevant for intensive use or a large number of students, which specially concerns institutions;
- robustness, stability and support, which clearly affect the adoption of technology;
- reusability, which reduces the technological learning needed by users and increases the developer benefit;
- standardisation and compliance with institutional policies.

Other application specific aspects can also be of interest, such as the response time of a videoconference tool.

All the above issues are important even with mature technology, since they will affect their suitability for the learning situation. In the case of very innovative technologies, though, an iterative evaluation plan should be carried out before implanting them in real scenarios. More specifically, [35] recommends a series of evaluations beginning with beta tests and feature validations, through controlled case studies with end users.

As a final guideline, consider that evaluation results can help to add new recommendations to this framewor*k*, so that the next iteration in designing a learning scenario and selecting its technological support includes a broader experience. As an example, our suggestion to use CLFPs comes from the fact that they are best practices obtained from collaborative designs applied by different educators to different environments with or without technology [28]. They have shown

Table 2. Answers to framework issues in Computer Architecture course

E1.	Educators and developers are involved, and also the institution may be interested
E2.	Achievement of learning objectives defined in LP1, adequacy of scripting and selected CLFPs, suitability of selected tools and platform
E3.	Participation (number and relevance of interactions) and SNA indices will be used
E4.	Evaluation data will come from application logs, reports, questionnaires and interviews; they will be analysed with quantitative and qualitative techniques
E5.	Robustness, usability, scalability and reusability should be assessed

educational benefits and can thus be reused by other practitioners in designing their learning scenarios.

Illustration of framework in engineering course

To illustrate the framework, we will take an engineering course that we have conceived for a virtual university interested in introducing into one of its programs a collaborative learning design. It is based on an on-site course that has long been part of our traditional campus university, as described in [40]. A summary of the application of the framework to the course is shown in Table 2.

Context of the course

Our example course will be on computer architecture, in the second semester of a Master Degree in Telecommunications Engineering. We expect students to have technical skills and a basic background on computer architecture topics (elements of a computer, programming, compilers) as well as some other related issues (computer networks, technology market). However, individualised attention should be paid to students coming from an undergraduate course in which these topics are not covered.

Around 60 students were expected, most of whom have never met before. Many of them have studied at the same virtual university, and thus we expect some experience in remote collaboration and a good collaborative spirit. Nevertheless, advising on collaboration strategies and the use of collaborative technology could be convenient. In this sense, educators have a strong motivation for collaborative and participative learning. In fact, they had previous experience of applying CSCL, but mostly using document repositories and discussion forums, relying heavily on social protocols, so they would need more formal ways to guide and observe collaboration.

Since the course is entirely remote, the infrastructure should be able to support distance collaboration; synchronous meetings will be required. Concerning resource availability, all participants have broadband Internet access and common desktop applications. However, the virtual university does not have a set of computers with different architectures that could be used for experimentation during this course, but machines available at our campus university could be shared remotely.

All this contextual information influenced the learning design, the technology choice and the way evaluation is performed.

The learning process

The main conceptual objectives in this course are computer organisation, cost-performance analysis, processor architectures, parallel machines, memory hierarchies and input/output schemes (basically, units AR3 through AR9 from the IEEE/ACM Computing Curricula 2001 [41]). In addition, we want students to develop competences for planning and doing experiments, reading technical documentation, writing reports, discussing and meeting agreements. Finally, we would like students to be more collaborative, and to develop critical thinking regarding commercial information.

To achieve these goals, the course is planned as a design and evaluation project. A fictitious customer (played by educators) hires consultants (played by students) to design a computer system. Customers are inspired in real cases, such as an institute interested in the assembly of genome sequences or an Internet-based music distribution service provider. In fact, five different customers are proposed, but each pair of students deals only with one; they have to compare their solution to those proposed by other students with the same and different customers.

In a high-level view, the course is organised in three subprojects: in the first, students characterise the workload of the system and perform a requirements analysis for their assigned customers. Afterwards, they benchmark machines with different features and make a recommendation to the customer. In the second subproject, a new processor is designed and simulated. In the final subproject, students design the memory hierarchy and the input/output subsystem. In several milestones all participants meet to debate the achievements made so far. Furthermore, students produce reports after each subproject. Educators will also be available for synchronous communications at appointed times, and asynchronous tutoring will be permanently accessible. Reports and questionnaires are also planned throughout the process to assess the achievement of the learning objectives and take corrective actions if necessary, as well as to enquire about the suitability of the selected learning design and technology. Figure 2 (bottom) shows more details of the whole design.

With the aim of facilitating the realisation of this learning process, we decided to use collaboration scripts. Indeed, prescribing the flow of activities was considered very adequate by educators in order to enforce learners to accomplish them in a timely manner. Thus, each week of the course a different scenario was enacted as described in a collaboration script. Here we will focus on the scenario corresponding to the second week in

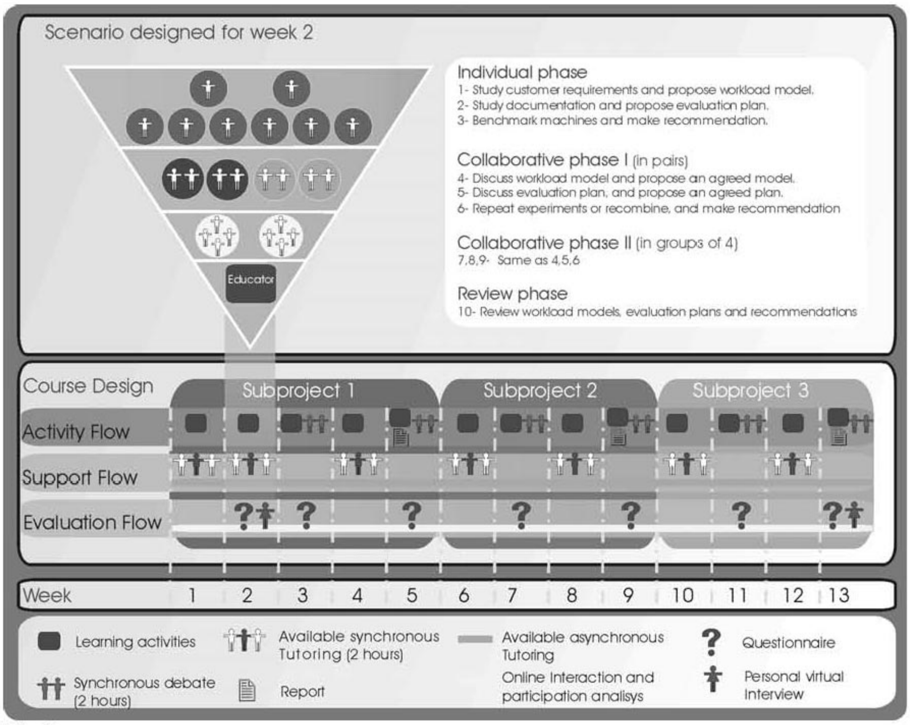

Fig. 2. General design for learning process (bottom), and detailed design for scenario week 2 (top).

which students must plan a benchmark to be applied to machines existing in a virtual laboratory, and make a preliminary recommendation to their customer. The activities planned to achieve this were formalised using the pyramid CLFP [42], as shown in Figure 2 (top). Initially, each student had to benchmark all machines, and then join his/her partner to discuss the results obtained and prepare a short report. This stage was repeated with progressively larger groups, until all students with the same customer had a global discussion. The pyramid pattern was chosen because of its advantages concerning our context and objectives [42]: it serves to reach agreements in large groups, promotes collaborative skills such as discussing or accepting critics and helps homogenise groups of people with different expertise.

In summary, the above design is aimed at achieving learning objectives by describing activities and resources in the big (course-wide) and the small (for each session). The details provided and the degree of prescription imposed in each session may vary depending on its specific goals.

Technological support

As discussed previously, there are already a number of Virtual Learning Environments such as Blackboard or Moodle that, in principle, may be suitable for the support of a virtual course such as the one considered here. However, a closer look at these platforms reveals several important drawbacks. First, the support for collaboration is limited to the inclusion of a few generic tools such as forums and chats. Besides, they do not enable the possibility of interpreting the collaboration scripts that educators prepared for this course (Moodle could with experimental extensions). Moreover, they do not allow educators to integrate new tools, e.g. CPU simulators, which are required to support the many different activities that are planned for the course.

Within this context, we decided to develop a new virtual learning environment called Gridcole [12] that we designed to overcome such drawbacks. Significantly, Gridcole can interpret IMS-LD compliant collaboration scripts created by educators using authoring tools such as Collage [30]. Furthermore, Gridcole allows educators to easily integrate tools following the ‘tailoring by soft integration’ approach defined in [43]. Gridcole also includes facilities for user, group and administrative management, common to the majority of virtual learning environments.

One key feature of Gridcole is that it allows the integration of tools that may be developed using two different technologies. First, web-based tools can be integrated, enabling the possibility of using a wide range of already available applications such as BSCW (http://public.bscw.de/) for the sharing of documents among participants of the course. Second, tools shared by third parties offered as presentation-orientated grid services can also be incorporated. This approach has a number of advantages [44], such as enabling the possibility of using tools that employ resources not owned by the institution where Gridcole is used. This is especially relevant for our virtual course since the benchmarking activity planned requires a set of computers with different architectures provided by the campus university. Furthermore, grid service technology can also be employed to develop either generic collaborative tools, such as a chat, or tools with specific support for collaboration such as a collaborative network simulator [45]. Finally, in grid-service-based tools functionality can be easily decoupled from communication, so that interceptor or listener services can be developed in order to know what invocations are made in the tools. This way, user interactions can be observed, even if tools do not provide specific functionalities for that. As mentioned above, this information is very useful for evaluating collaboration.

Concerning the achievement of the learning objectives, in the case of conceptual topics or reading and writing documentation, Gridcole offers the benefit of selecting and integrating the most suitable tools for such goals. For instance, the benchmarking tool will help learners to understand how to compare different computer architectures (conceptual learning objective). Moreover, related to skills in experiment planning, a scripted system that allows the educator to control the level of prescription (possibly to decrease it along the course) will help to promote students in taking responsibilities and organising their own plan [12].

Evaluation plan for course

For evaluating this course, both educators and developers will participate. The virtual university organisation may also be interested to see what pedagogical or technological choices can be generalised to other courses. The evaluation objectives will mostly concern the achievements of the learning goals (note that some refer to contents, while others refer to skills that must be assessed using the subjective opinions of students and teachers), as well as the convenience of the pedagogical process and the technology to achieve them (e.g. has the pyramid CLFP and its interpretation from a script to provide guidance by the application helped in learning and collaborating more, in the activity of the second week?). Since it is a new technology, it is also convenient to assess its robustness and usability by both teachers and students, and to carry out pilot experiences in controlled environments. The virtual university may also want to address its scalability and the level of software reuse in order to adopt it institution-wide. Also all will be interested in judging reusability of tools in the Gridcole platform.

To study these evaluation objectives, some relevant data sources used in face-to-face settings are not possible (e.g. direct observations). However, we plan to benefit from new data sources, such as logs of chats (in the activity for the second week) and discussion forums, or annotations in document repositories (in other activities). These data can be processed online to compute participation indices (number and relevance of interactions) or to apply social network analysis that pictorially shows social bounds in the virtual classroom. After the process is completed, these data can be combined with qualitative data coming from web questionnaires or interviews, so that practitioners and developers gain a deeper insight into the process and the usage of technology that may help to improve both.

The data sources and timeline of evaluation for the whole course are summarised in Figure 2 (bottom) above. Quantitative data can be obtained from interactions all along the course. Besides, the actual chat and discussion contents can be processed offline. Subjective opinions of participants should be surveyed through web questionnaires after each synchronous debate, with quantitative and qualitative questions. They will address the suitability of the learning process (e.g. number of hours devoted to each activity, convenience of a sequence of activities), collaboration (e.g. subjective perception of their level of interaction), and the computational support (e.g. user-friendliness or efficiency, usage of alternative means of communication). Finally, focus groups should be set up with volunteers after the course is completed, either in person if possible or by videoconference, in order to validate some of the conclusions found from other data sources. All these data sources will be combined according to the mixed method described in [13].

Pilot experience

Since the technology involved in this CSCL experience is new, following [35], we have decided to carry out a pilot experience in rather reduced and controlled conditions to assess the feasibility of the whole design. This experience will realise only the design for the second week of the course, illustrated in the upper part of Figure 2. Feedback from this experience will help to improve the technology and maybe even modify the learning design before putting it into practice in the real situation. The two educators teaching this course in our campus university and eight volunteer students taking it participated in an experience in which we reproduced the conditions of a distance learning setting.

During the experience, Gridcole prototype was used to support the pyramid scenario depicted in Figure 2 (top) above, which was formalised in an IMS-LD script. A chat tool was developed as a presentation-orientated grid service, to be used not only for communication between students, but also with the educators to get assistance on concepts, the platform or the collaborative strategy. Besides, a benchmarking tool, also offered as a presentation-oriented grid service, allowed students to run benchmarks on a set of machines with different computer architectures. As evaluation data sources we used transcriptions of the chats, questionnaires passed before and after the experience, and a focus group held about a week later. Educators were also interviewed. Some of the main conclusions of the evaluation process are outlined, while more details can be found in [46].

Table 3. Results of analysis of quantitative data obtained from the questionnaires answered by eight students who participated in the pilot

	Completely agree	Agree	Somewhat agree	Somewhat disagree	Disagree	Completely disagree
System helped to realise the situation in collaboration with the partner	2 (25%)	4 (50%)	2 (25%)	0 (0%)	0 (0%)	0 (0%)
Benchmarking tool was useful to realise the situation	5 (62.5%)	3 (37.5%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Chat tool was useful to realise the situation	1 (12.5%)	3 (37.5%)	4 (50%)	0 (0%)	0 (0%)	0 (0%)

Regarding the learning design, we found that most students appreciated the degree of prescription achieved by scripting, as shown in Table 3; they explained 'it helped us to apply the methodology, but we still have to make our own decisions on what benchmarks to apply and how many times'. Further, they liked the pyramid pattern to achieve the appointed goal of a common machine recommendation. Educators also valued the possibility of adapting their learning design easily by just changing the IMS-LD script. Further, monitoring the completion of each activity helped them to follow the progress of the scenario.

Concerning the technological support, educators found convenient that they could easily integrate the desired tools in Gridcole. Students, on the other hand, highlighted the utility and usability of the benchmarking tool that allowed them to easily apply different tests on several remote machines through a simple graphical interface. According to questionnaires reported in Table 3, all students 'agreed' or 'completely agreed' that it was useful, and in the focus group they provided some hints to improve it, such as enabling the possibility of running sets of benchmarks in batch mode. They also mentioned that the chat was useful, but pointed out several limitations, like the lack of support for cut-and-paste. This type of comments can help developers to design better tools or educators to choose them.

Though the reusability of tools and platform can only be assessed in the long term, Gridcole has already been successfully applied to support a few more collaborative learning scenarios. This can be attributed to its flexibility for interpreting any IMS-LD script conceived by educators as well as the possibility of integrating new tools. For the same reason, we believe that tools that can be integrated in Gridcole will also be reusable in different learning scenarios.

CONCLUSIONS

Computer Supported Collaborative Learning has been around for several years with the promise of offering new learning experiences, centred in the students and the interactions among them. The underlying socio-constructivist pedagogy claims that students build deeper and more significant knowledge by being active in learning and interacting with peers. Although some frameworks can be found in the literature to help educators in designing successful CSCL scenarios, there is a lack of a unifying view that concerns all stakeholders and deals with the whole CSCL lifecycle.

In this paper, we have proposed a new conceptual framework derived from the study of literature and from our own experience in designing CSCL scenarios, using and developing technology for them, and also evaluating them intensely. We believe our framework provides benefits for all stakeholders by setting a common grounding where developers and educators can gain understanding of each other's needs and restrictions. Significantly, the framework explicitly relates context, learning process, technological support and evaluation. To illustrate it, we have adapted an on-site engineering course, in which CSCL can be considered suitable to promote the desired collaborative skills. The results from evaluating the pilot experience indicate that the proposed approach is feasible and provides relevant feedback for all stakeholders. Not only knowledge of the context influenced the learning design, but also both aspects were jointly considered when making technological choices. In fact, many existing e-learning platforms would not suit this course. For example, Blackboard or Synergeia would not allow scripting, and though .LRN would, it does not permit the integration of new tools. Remarkably, such integration of new tools is critical in the scenario under consideration since it requires specialised tools such as a benchmarking tool. As for the technological platform used in our example, Gridcole can be tailored by integrating both web and grid service-based tools.

As a means of spreading and encouraging use of the framework, and thus enriching it by additional experience, we plan to implement a web-based tool that can be used as a wizard for stakeholders participating in any stage of the CSCL tool. The documentation gathered this way (e.g. description of learning designs, tools, evaluation designs and results, etc. in response to the framework issues) could be shared to form virtual communities of practice, where all stakeholders can benefit from the knowledge of other experiences.

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