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Collaborative learning via social computing*

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Abstract: Educational innovation is a field that has been greatly enriched by using technology in its processes, resulting in a learning model where information comes from numerous sources and collaboration takes place among multiple students. One attractive challenge within educational innovation is the design of collaborative learning activities from the social computing point of view, where collaboration is not limited to student-to-student relationships, but includes student-to-machine interactions. At the same time, there is a great lack of tools that give support to the whole learning process and are not restricted to specific aspects of the educational task. In this paper, we present and evaluate context-aware framework for collaborative learning applications (CAFCLA) as a solution to these problems. CAFCLA is a flexible framework that covers the entire process of developing collaborative learning activities, taking advantage of contextual information and social interactions. Its application in the experimental case study of a collaborative WebQuest within a museum has shown that, among other benefits, the use of social computing improves the learning process, fosters collaboration, enhances relationships, and increases engagement.

Key words: Context-awareness; Collaborative learning; Social computing; Virtual organizations; Wireless sensor networks; Real time location system
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1 Introduction

Educational innovation is taking advantage of the amazing technological evolution experienced over recent decades (Zhao and Chan, 2014; Fermoso et al., 2015; Mora et al., 2015; Crawford et al., 2016). The constant advances in electronics have enabled the development of devices in which storage and processing capacity have grown in inverse proportion to their size. In addition to these hardware advances, the evolution of communication protocols has been remarkable and has led to the fast and reliable connectivity between devices that we currently enjoy. Thus, day by day the number of devices around us is growing, including mobile devices that allow us to communicate in real time with anyone anywhere, and non-intrusive devices capable of collecting and storing environmental data all around us (Marin-Perianu et al., 2007). This digital revolution has generated a vast change in the way in which social interactions happen, leveraging economic, political, and social change on a large scale (Mora et al., 2015).

This evolution has facilitated the inclusion of electronic devices in learning contexts, playing an active part in education and changing perspectives in relation to information and communication technologies (ICTs), including new ways for interaction and communication (Lin et al., 2015). In this educational innovation context, a social computing paradigm has emerged as an interesting research field during recent years. At the intersection between computer networks and social networks, it uses information systems as places for social interaction and data ingestion and management (Schroeder et al., 2010; Cox, 2013).

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These places provide capacities for effective collaboration between humans and machines to solve social problems, leading to a natural framework for effective collaborative learning (Shadbolt, 2013; Zhang and Zhang, 2015).

Social computing is considered as the computational gateway for social studies, human social dynamics, and the design and use of ICTs that include a social context (Jin et al., 2010). This social computing paradigm requires the combination of human and ICT resources (Wang et al., 2007): humans bring skills, knowledge and competences, social relationships networks, and understanding of social structures; ICTs allow humans to seek and deliver concrete information. Thus, humans can rely on accurate information in a context to achieve a specific goal. When this goal refers to education, social computing offers an unprecedented environment that can create rich collaborative experiences to build effective learning support (Musser et al., 2003; Chuang, 2016).

Moreover, social computing has great potential in the educational field (Parameswaran and Whinston, 2007). In addition to the great social interaction that currently exists through digital tools, interaction with connected objects grows day by day. These resources allow the delivery of relevant and personalized content to students in a dynamic and efficient way (Jung, 2009), adapting educational processes to any change that may arise immediately.

Collaborative learning is a field where technological advances have enabled improvement and innovation in teaching and learning methods. A collaborative learning environment facilitates sharing and access to learning content (e.g., text or pictures) among users (e.g., students or teachers) (Kirschner et al., 2015). The use of mobile devices and wireless communications (Roschelle, 2003) has become a means to engage students in learning processes and foster collaboration among them (Novak, 2015). There have been many innovative developments in which technology supports collaborative learning such as complex learning platforms like Moodle, Wiki, or LAMS (Cress and Kimmerle, 2008), learning applications that use mobile devices (Sun and Shen, 2014; Melero et al., 2015), context-aware learning tools (Laine and Joy, 2009; Hwang and Wu, 2014), location-based learning platforms (Ryokai et al., 2013; Chou and Chanlin, 2014), augmented reality learning applications (Dascalu et al., 2015), and game-based learning (Barzilai and Blau, 2014). However, while social computing has great potential to cover social interactions and group engagement (Sinha et al., 2015), few studies have addressed the collaborative learning concept from a social computing perspective (Musser et al., 2003; García-Floriano et al., 2017).

The aim of this study is to gain more insights about the use of social computing in collaborative learning processes. Specifically, in this paper we describe and evaluate context-aware framework for collaborative learning applications (CAFCLA) at a technical and social level. This framework has been designed from the perspective of social computing and permits practitioners to design, develop, and deploy collaborative learning applications that make use of social and contextual information. Teachers will be able to design collaborative activities of different types, including problem-based, jigsaw, assessment, coaching, feedback, challenge-based, WebQuest, mobile, or peer-assisted learning activities. Moreover, teachers can define and customize the environment where the learning activity is taking place. They can construct a plot of the place where the student works. In this place, different devices (beacons, sensors, etc.) are placed to provide real-time location information which facilitates the creation and characterization of areas of interest (e.g., paintings in a museum) and collect environmental data. Thus, the information provided to students (learning objects) is customized and personalized for each learner or group of learners (Garrido et al., 2016). The framework also integrates resources to manage social interactions and collaboration among students, and between students and practitioners.

The framework is supported by virtual organizations of agents that provide intelligence to the learning process (Rodríguez et al., 2011; Enembreck and Barthès, 2013; Chen and Chou, 2015). These virtual organizations are responsible for managing the activity, facilitating all the communications between the devices involved, updating contextual information, and monitoring the collaboration between students and teachers. Finally, the integration of technologies within CAFCLA has a main goal: to improve the learning process by fostering collaboration, enhancing relationships, and increasing engagement.

2 Related work

This paper focuses mainly on two technologies that enable the development of adaptable and enriched collaborative learning environments: social computing and context-awareness. In the following, we state the importance of such technologies and present the advances found in the literature in relation to collaborative learning.

2.1 Social computing

Social computing is a new paradigm focused on the study of the interaction that occurs between the scientific study of social behavior and computational systems (Schuler, 1994). Through a new vision, this field aims to resolve computational problems that have become increasingly important since the explosive increase in the use of the Internet. In this vision, problems are solved from a social perspective, with the active participation of humans and computer systems (e.g., CAPTCHA or Amazon recommendations) (Linden et al., 2003; von Ahn et al., 2004). This requires the resolution of new challenges related to human-machine interaction, organizational management and distribution of tasks between humans and machines, which cannot be addressed by existing tools.

In terms of human-machine relations as the basis for social computing, on the one hand, ICTs can provide relevant information to humans which they can use in their contexts to achieve their goals and, eventually, to improve the environment in which they are located. On the other hand, humans can develop their skills, knowledge, and abilities more easily and accurately with the help of socially oriented computer system workflows (Schuler, 1994; Erickson and Kellogg, 2000).

Social computing is gaining relevance in research and development software system trends. The big challenge to address today lies in the construction of complex social machines that provide efficient solutions to social problems, such as medical care, tourism and leisure, transport, communication, learning, education, and social response to emergencies (Robertson and Giunchiglia, 2013). Research in this area should be conducted based on artificial intelligence mechanisms that build artificial societies, virtual organizations, and other theoretical frameworks and technological infrastructures.

In the literature, we could find only a few references addressing collaborative learning from a social computing point of view. Musser et al. (2003) proposed a social computing and collaboration architecture based on social rules, but they did not present or develop such a framework. Dascalu et al. (2015) presented a recommendation agent for educational materials and tools that considers the learning style, although they did not explicitly refer to the social computing paradigm or include the integration of the context when solving a problem. Berjón et al. (2015) described a tool, SCHOM, which facilitates communication for collaborative learning, but they did not consider aspects related to communication with other elements that may participate in learning, such as sensors that characterize the context in which it develops. Arif et al. (2015) developed a multi-agent architecture to assist students when making evaluation tutorials, but they allowed only asynchronous interactions among participants. García-Floriano et al. (2017) presented a new metadata system to automatically tag distance learning resources, favoring the integration of data with social networks. López-Yáñez et al. (2015) presented their pedagogical experiences when merging collaborative and mobile learning in postgraduate level courses.

In summary, previous studies have not considered the integration of collaborative learning and social computing. In addition, we can see that the most common approach in this area is related to the use of social networks in the process, emphasizing the importance of interpersonal social relationships, while human-machine interactions, which can provide valuable contextual information to improve learning environments, have not been addressed in depth. The development of CAFCLA takes these shortcomings into account, focusing on the integration of different technologies that enhance the relations between humans and between humans and different machines, as a recognized way to improve learning processes.

2.2 Context-awareness

Previous studies have defined social computing in the context of collaborative learning as the use of information systems as “places” for social interaction as well as “spaces” for data collection and manipulation (Musser et al., 2003). Under this umbrella, context-awareness acquires a major role in collaborative learning frameworks.

According to its most widespread definition (Dey, 2001), context-awareness refers to "any information that can be used to characterize the situation of an entity" while "an entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves." Other relevant parameters that affect contextual information are identification, time, and location (Dey, 2001).

The inclusion of context-awareness in the learning process addresses context-aware learning (Laine and Joy, 2009). This inclusion benefits the educational process from different viewpoints. On the one hand, contextual characterization of the educational environment favors the flexibility of the process. Thus, learning can be carried out not only in classrooms, but also in other environments like museums and zoos (Land and Zimmerman, 2015). On the other hand, contextual information improves learning by using different technologies, such as wireless sensor networks (WSNs) or real-time localization systems (RTLSs). These technologies facilitate the acquisition of contextual information as well as the positioning of the elements involved in the educational process (García et al., 2012).

Context-aware learning must consider not only the interactions between people, but also technological elements of the system and their combinations. Few frameworks designed to deploy collaborative learning activities that consider contextual information can be found in the literature. MobiLearn (Castro et al., 2016) is a context-aware mobile learning system that integrates learning monitoring and customized services to students through social networks. It does not give details of the technologies used to obtain contextual information. Masud (2016) described a framework for collaborative learning that includes semantic data interoperability, distributed metadata management, and agent-based query processing, but lacked an integrated architecture that enables the inclusion of context-related data. Luna et al. (2015) presented an approach based on ontologies to represent the interaction process between a user's profile and its context, but it is not enriched with social or human-machine interactions.

Summarizing the frameworks analyzed throughout this section, we conclude that there are certain shortcomings in these works. Most of these approaches do not include a set of technologies that allow indoor localization, outdoor localization, labeling, and sensing through physical sensors simultaneously. Furthermore, none of the frameworks provides management of the environment in which the activity is carried out at different levels, such as the delimitation and characterization of different areas or the identification of objects of interest. In addition, content management, user profiles, and groups to customize learning are insignificant. Finally, none of them addresses the problem of collaborative learning through social computing explicitly, or considers the dual perspectives, pedagogical and technical.

The design of the framework presented in this paper addresses the problem of contextualization from a global point of view. To cover the shortcomings found within the existing solutions, it integrates a large number of technologies that allow as many scenarios as possible to be covered, provides intelligence to the management of learning processes and, above all, isolates teachers and students from technological complexity. Thus, all the potential value can be extracted from the functionalities that CAFCLA offers.

3 Requirement specification

This section describes the precise requirements of the presented framework. The main objective of this section is to help the reader understand what the framework covers and how it functions. Thus, the high-level requirements of the framework are listed followed by the scientific and technical requirements.

There is a lack of transversal frameworks that cover the development of collaborative learning activities through the integration of multiple technologies, especially those related to real-time localization, context awareness, and social computing. According to the shortcomings noted in the previous section and the state of the art performed, the framework designed is aligned with the following requirements:

1. To make easier the process of design and development of learning activities for both teachers and

developers. The implementation and deployment of the supporting infrastructures has to be easy too. Thus, the framework is provided with a set of intuitive design and configuration tools.

2. To enable learning activities to be customized according to a student's or group's profiles. Moreover, teachers are able to monitor and manage the activities dynamically. Thus, the framework generates and stores detailed information about the activity performance that can be further analyzed.

3. To include mechanisms to provide contextual information regardless of the location or the time. The performance scenarios can be distributed and occasionally not connected. It is important to consider the inclusion of mechanisms that permit the selection of the communication protocol to be used, the discovery of potential collaborators, and the discovery of available services.

4. To include within the learning activity a way to describe and characterize an object, person, or area involved. This implies an exhaustive use of ICTs for searching for the best context solution, taking into account all the premises that affect the characterization at a given moment.

5. To consider the different social interactions that can be fostered or generated throughout the educational process proposed. These interactions can be between humans, between humans and machines, or between machines.

6. To provide support to facilitate, encourage, and allow collaboration among students. Thus, the system has to support different communication and collaboration styles. Moreover, the system has to allow interconnection between the participants in the activity without them being aware of the technological complexity.

The scientific and technical requirements that have been established in this work are as follows:

1. To develop a layer-based framework that includes capabilities such as usability simplification, technological transparency for users, development resource efficiency, service ubiquity, human-machine interaction, and social relations incentives.

2. To define an architecture based on distributed virtual organizations, by using flexible and adaptable agents, which allows covering of the management and communication needs demanded by the proposed framework.

3. To integrate indoor and outdoor real-time localization systems, which provide the framework with a high degree of ubiquity in terms of interaction with users.

4. To integrate different wireless communication systems and sensor networks to contextualize environments where learning activities take place, in and out of the classroom.

5. To make the framework interoperable with multiple technologies that provide flexibility and dynamism, so that it can adapt to different application scenarios.

6. To design intuitive interfaces that allow a high level of interaction between users and technology, following the guidelines of the framework, so that the interaction is carried out in a transparent and ubiquitous way.

4 Framework description

This section is intended to overcome all the shortcomings noted in the previous sections regarding social computing and context-awareness in collaborative learning. In the following, we first give a general description of the developed framework and then detail the underlying technical layers that constitute its core.

4.1 Conceptual approach

CAFCLA is a framework whose main objective is to provide teachers with an easy way to design collaborative learning activities using contextual awareness via social computing whether in or out of the classroom. One of the most important aims of CAFCLA is to simplify the use of social interactions and contextual information, enabling teachers to block out tedious processes that are not related to education. Similarly, it aims to provide developers with a set of tools to design, develop, and deploy the applications that will implement the designed learning activities. CAFCLA is intended to improve not only the individual learning processes of students, but also interpersonal relationships, teamwork, and solidarity among them.

The process of design and development of a collaborative learning activity through CAFCLA takes into consideration the objectives that the student should achieve, the learning content, the teaching resources available, the physical or virtual spaces that have been selected, the evaluation and monitoring of the activity, and pre-established social rules. To illustrate the main components of the framework, Fig. 1 presents a hypothetical activity deployed in the Museo Del Prado. The different roles that are handled, the necessary communication infrastructure, and the contextualization of the environment in which the activity occurs can be identified. This infographic will serve as a basis for providing examples of all the concepts depicted in the following sections.

4.1.1 Social actors

One of the ambitions of CAFCLA is to cover the entire process of developing a collaborative learning activity. We can identify three different actors that take an active part in the process of design, and launch the activities considered here, depending on the role they play:

1. Teacher: he/she oversees the design of the activity that will be developed and deployed using CAFCLA. Teachers have an educational profile that allows them to contextualize the environment in which the activity is displayed. The tasks that teachers must carry out are: establishment of the objectives of the activity, definition of the kind of activity to develop, specification of the students who are to participate in the activity, definition of collaborations between students, definition and description of the areas and objects of interest, provision of the data that the system will store to be delivered during the activity, and establishment of the social rules.

2. Student: he/she is the participant who conducts the activity. Students have a final-user profile whose valuable feedback may be obtained indirectly. The tasks performed by the students are: accessing the resources offered by the application through different mobile devices, collaboration with others to solve the social problem, achievement of the goals of the activity, and assessment of the application.

3. Developer: he/she is responsible for developing the application and the necessary infrastructure for the tools that CAFCLA offers to analyze, design,

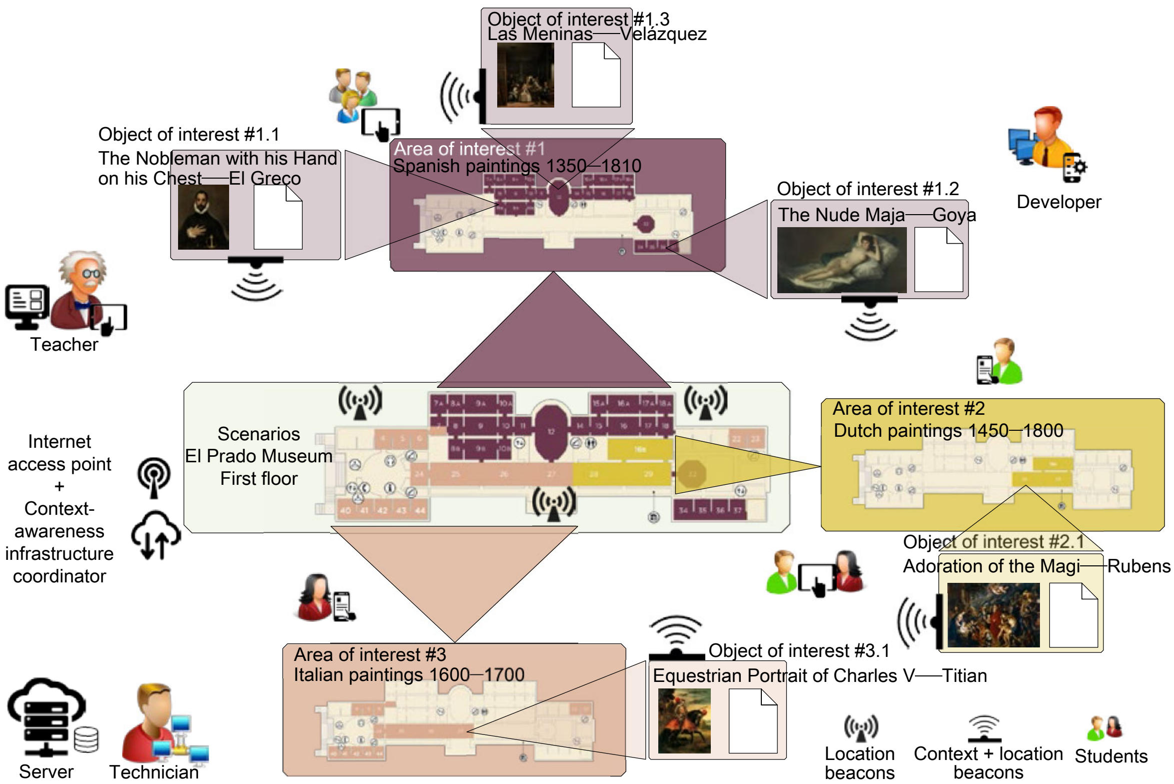

Fig. 1 An infographic showing an example of a CAFCLA deployment in the El Prado Museum with three different roles (teacher, student, and developer), the structure followed to contextualize the learning environment (scenario, areas, and objects of interest), and the hardware infrastructure to be deployed

program, etc., according to the activity designed by teachers. Developers have a technical profile and are software oriented (applications). The tasks that the developers fulfil are: design of the application, definition of infrastructure, programming the application, and tuning the designs and developments based on the feedback received from teachers and students.

4.1.2 Context conceptualization

The environment where the collaborative learning activity takes place must create a rich social experience for students. Thus, the contextual information becomes fundamental for building an effective learning support system and engaging students in the learning process (Musser et al., 2003). Any place or item in the learning environment will be able to provide relevant information to be used in the learning process. Thereby, CAFCLA allows teachers to describe any place or item capable of being studied in the activity regardless of its size and location. This description can be used for elements of various kinds, such as a place, a piece of art in a museum, or the data obtained by measurements collected from a sensor.

It is important to structure contextual information to provide it in an efficient form to students. For that reason, CAFCLA defines three description levels that provide enough granularity in the information required by the activity:

1. Scenario: covers the entire environment in which the activity occurs. Following Fig. 1 the scenario is the first floor of the museum.

2. Areas of interest: dimensional spaces into which the scenario may be divided and where one or more study elements for the activity are placed. Three areas of interest are defined in the museum (Fig. 1).

3. Object of interest: includes information about an item of study that is part of the activity. According to Fig. 1, there are five objects of interest.

4.2 Technical description

CAFCLA has been designed following a layered scheme for the integration of the different technologies that meet the functional requirements of the framework (Table 1). In the following, we provide a description of each layer and a brief justification of the selection of each technology to better understand the functionalities of CAFCLA that each technology covers.

Table 1 CAFCLA layers diagram

Layer	Technologies
Physical	Tablet, smartphone, sensors
Communication	3G/GPRS, Wi-Fi, ZigBee
Context-awareness	WSNs, real-time localization
Management	Social computing, virtual organization of agents
Application	API, learning activities

4.2.1 Physical layer

This layer includes all the devices that can be used in CAFCLA. For running applications, there are mobile devices, such as tablets, laptops, or smartphones. For contextual information acquisition, there are sensors, localization beacons, or identification tags. For communication, there are Internet access points (Wi-Fi, 3G, Ethernet, etc.), data collectors to send data from WSN or RTLS via Internet or beacons to transmit data. Finally, to complete the services, there is a data storage and application server. CAFCLA permits a seamless integration of the above-mentioned technologies, selecting those appropriate for each scenario in a fashion transparent to teachers and students.

4.2.2 Communication layer

The communication layer in CAFCLA integrates all the communication protocols that allow the sending and receiving of information between physical devices. They are responsible for transporting the contextual information dynamically generated during the development of the learning activity, collected whether by sensors or by any of the tracking systems. Currently, CAFCLA integrates 3G/GPRS, Wi-Fi, and ZigBee. Wi-Fi and ZigBee enable the contextualization and carrying of sensor data. Finally, the characteristics of the wireless signal transmitted are used to calculate the position of the devices in the indoor RTLS.

In addition, the framework is open to integrate any other protocol in future.

4.2.3 Context-awareness layer

Three context-aware technologies that facilitate the identification, characterization, and localization of any object or place in the learning activity have been integrated:

1. WSN platform: the framework integrates the *n*-Core platform (Nebusens, 2018). This platform allows the aggregation of a large number of sensors (e.g., pressure, temperature, or humidity). Sensors form a mesh network using the ZigBee protocol, where the data collected is sent to a data collector that transmits the information to the CAFCLA data server through the Internet.

2. Outdoor localization system: the integrated technology is a GPS positioning system, which is fully integrated into most of the mobile devices currently on the market, facilitating its integration into learning activities. This functionality also integrates the Google Maps platform.

3. Indoor localization system: the integrated RTLS is based on *n*-Core Polaris (Nebusens, 2018), which works in those places where a GPS signal is not available. To calculate the location, the area is equipped with a set of *n*-Core Sirius RadIOn beacons. Each student has to wear a ZigBee device called an *n*-Core Sirius Quantum. This device communicates with its closest beacons that collect different measures of signals sent by the Sirius Quantum devices, and a localization engine in the data server calculates the position of the student. Other indoor localization protocols were discarded because they do not meet the requirements in terms of accuracy (Prieto et al., 2012, 2015), obstacle penetration (de Marziani et al., 2009), or drift error mitigation (Zampella et al., 2013; Prieto et al., 2016).

When designing an activity, teachers delimit a space on the indoor or outdoor map and include all the contextual information related to this space that could be defined as an area or an object of interest. As soon as the student crosses into an area of interest or approaches an object of interest, the contextual information is delivered through a mobile device.

4.2.4 Management layer

The management layer integrates the social machine and is responsible for the effective, predictable, and distributed operation of the context-awareness layer and the communication layer. For the development of the social machine, we propose a virtual organization (VO) of agents where heterogeneous entities are grouped and collaborate with each other, and among which there is a separation of form and function that requires definition of the behavior of each entity (von Ahn et al., 2004; Rodríguez et al., 2011; Villarrubia et al., 2014). The use of VO of agents allows the control of the behavior of an agent, the dynamic composition of groups of agents, and the dynamic creation of components (Villarrubia et al., 2014).

The aim of the management layer is to implement the social machine based on a VO of agents that supports context-aware collaborative learning. Fig. 2 shows the different organizations that integrate the proposed architecture:

1. Data gathering organization: this manages the data sources that supply the system. It receives data from sensor networks, localization systems, or the teachers when creating content or public information.

2. Data management organization: this maintains the integrity of data during the learning process and decides what data should be stored and developed. It classifies the information to be delivered depending on the context and social information surrounding the student during the activity.

3. Context organization: this controls the information gathered by the sensor network. It must be coordinated with the data management organization to keep updated the information from any physical service.

4. Activity organization: this coordinates and manages the whole activity and receives all the information from the social machine (profiles, contextual data, collaborations, etc.). It decides which information is provided to each student depending on the learning model and the state of the activity.

5. Social machine organization: this performs several analyses for the extraction of socially relevant information from the interaction among the agents:

(1) Student agents: grouped in organizations, they store the students' profiles and all the information related to the activity process. This organization allows the student-student and student-machine interactions.

(2) Teacher agent: this agent establishes the social rules underlying the social machine organization and creates, modifies, and monitors the development of an activity.

(3) Collaborative agent: grouped in organizations, this agent monitors the entire process of communication with the Activity and the Context organizations.

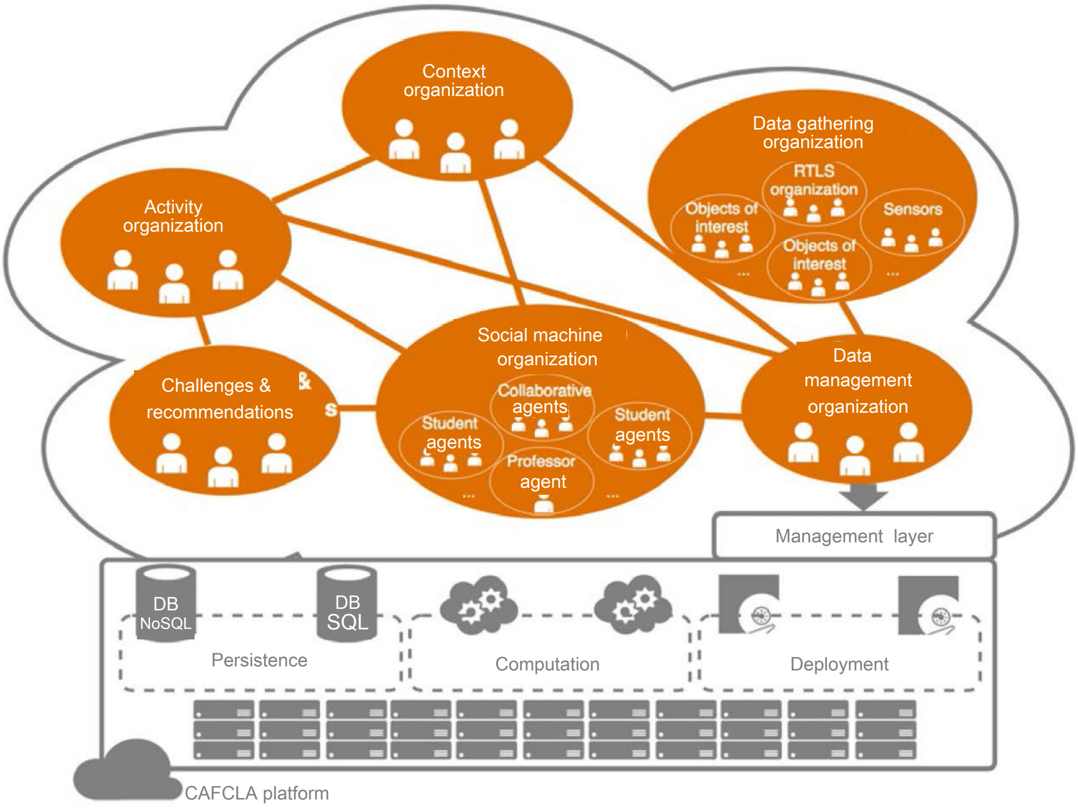

Fig. 2 The abstraction of the social problem of collaborative learning as a virtual organization of agents enables an adaptive and effective way to implement the CAFCLA framework

6. Challenges & recommendations organization: this organization produces engaging personalized actions for the students to meet the established goals in the Activity organization.

The implementation of the virtual organization of agents has been developed using the Java Agent DEvelopment framework (JADE) (Bellifemine et al., 2001), a framework implemented in Java to facilitate the design and development of autonomous reactive and deliberative agents. The framework provides multiple tools to create, organize, manage, and control virtual organizations of agents. Moreover, it supports the creation of sub-organizations, and the management of roles, services, rules, security, communication, and reliability (Bellifemine et al., 2007).

The organizations and agents developed in this work require the inclusion of social features such as collaboration, interaction, negotiation, or decision-making. Within JADE each agent has its own behaviors which are held by the container of the host to which it belongs. Their concurrent execution allows the interaction among them, regardless of their container or host (Al Maghayreh et al., 2012).

4.2.5 Application layer

The application layer in CAFCLA supports the collaborative learning activities to be developed and, therefore, provides interfaces between the users with an educational role (teachers and students) and the other components of the framework. Within the process of building an activity, the first limitation encountered is the type of device that will be used (laptops, tablets, smartphones, etc.) and the communication protocols available (Wi-Fi, GPRS/3G, Ethernet, etc.). After this choice, it is important to know the type of contextualization that is going to be carried out and to define if it will be done through the use of sensors, an indoor/outdoor location, or both. Then, participants and context information has to be included: students' data, as well as sensors and/or locations, objects, and areas of interest.

Once the general and common information for all activities has been included, the configuration of the activity will require more specific actions depending on the type of activity that will be implemented. Currently, eight types of collaborative and social learning activities that can be easily designed and developed using CAFCLA have been defined. Below, a summary of the operation and objectives of each kind of activity is presented:

1. Challenge-based learning: in this learning practice, students work individually or in small groups to solve a challenge generated by the social machine based on the rules established by the teacher. Students are responsible for their own organization while the activity is taking place, but they are always supported by the teacher, who acts as a facilitator of resources. This practice fosters communication and social interaction between students, as well as the development of problem-solving and collaborative skills. In CAFCLA the teacher defines the goal, learning material, and how students can collaborate (the relations allowed between individuals or groups).

2. Treasure hunt: this method is a collaborative guided learning activity in which the teacher determines multiple physical paths that students must follow. Throughout this tour, students receive clues after solving questions that help them, first, to continue the proposed activity and, second, to obtain relevant information to achieve the ultimate goal of the activity. The main objective of this learning activity is to reach a collaborative goal by following different clues that the social machine generates based on the interactions of students working in groups. Therefore, social skills and problem resolution are enhanced in this practice. CAFCLA permits the teacher to define different routes along which students collect clues and information offered by multiple objects of interest. Routes to be followed do not have to be composed of a single path, but may include branches that allow the division of tasks between the different students who are part of the group. The teacher is also able to assign one or more routes to a particular group, and establish the key clues in the process that students are required to complete to be able to continue receiving information. Finally, the teacher defines a challenge, work, or final question that the social machine will require the students to complete or answer from the information received on each clue (e.g., complete a questionnaire, produce a written document, or make an oral presentation).

3. Peer-assisted learning: this technique aims to improve the learning process of students through their conscious involvement in assisting others to learn. The key components of this method are the pairs of students or student groups. Thus, throughout the activity, reviews, tips, and recommendations are conveyed from one side to the other, so that the acquired knowledge is reinforced through the promotion of social ties among participants. As in the previous technique, CAFCLA integrates tools that facilitate the design of content and peer management by the teacher.

4. Assessment: this is a kind of participatory activity in which an iterative process is followed. In this case, the material that facilitates the work of teacher is available at certain stages of the process. Thus, the achievement of objectives produces evidence about the learning outcome. This learning practice fosters social interactions with the contextual information and among students. In this case, CAFCLA allows the teacher to define the learning process by deciding when a particular material is delivered depending on the stage of the process.

5. Jigsaw: in this type of practice the teacher divides the activity into different subjects to study individually at first and then collaboratively. First, the teacher assigns each student a specific topic in which he/she will become an “expert.” Then a number of groups are formed consisting of students to whom different topics have been assigned. For the correct operation of the activity, the teacher indicates the documents that have to be generated at each stage as a response of the activity. The phases are single-phase, expert (collaboration between all students working with a theme), and group stage (collaboration between members of groups with different themes). The final result of the activity (e.g., a presentation) should be presented by the group leader, a role that has been assigned by the teacher. Similarly, the teacher determines which areas of interest that have been created belong to each of the topics assigned.

6. Collaborative WebQuest: this is built around an attractive environment that triggers reasoning about the steps that are taking place. It gives meaning to the search for information. The main task is to develop a solution to the problem by reasoning from the answers to specific questions that have been raised. These activities allow the development of information management skills, such as receipt, processing, and production, and foster social skills. In CAFCLA, the teacher is able to design a battery of questions to be

answered in the areas or objects of interest. Questions can be formulated generically, expecting a redacted response, or as a test, in which different response options are offered. These questionnaires can be adapted to each user level and several can be defined for the same area or object. In addition, the teacher can create a final questionnaire that is completed in a particular place (e.g., the classroom) in which questions related to all questionnaires that have been made in the activity are collected. Moreover, the teacher matches each questionnaire with its corresponding student or group.

7. Feedback: in this practice students receive information about the accuracy or quality of the responses to questions raised by the activity in order to reach a goal. In CAFCLA, this feedback is provided either by the teacher, by interacting with the activity in real time, or by the system, providing feedback responses that have previously been established by the teacher. This practice promotes social skills and group discussion of questions when it is raised as a collaborative activity.

8. Coaching: the fundamental aim of this technique is to observe the collaborative learning process and, after its analysis, provide advice to improve and correct its deficiencies. This method improves the performance of activities through observation and guidance, facilitates the establishment of objectives, and improves the collaborative groups on the fly.

Note that CAFCLA provides a set of common tools for all the activities presented above regardless of their kind. These tools (1) foster social interaction among students using different tools of communication, both asynchronous (email) and synchronous (instant messaging via chat), and (2) provide context-awareness by defining scenarios, areas, or objects of interest, using the offered RTLS or different wireless sensors. Moreover, the teacher has resources to manage groups and social interactions. The practitioner has the ability to define different working groups formed by the number of students he/she deems appropriate, assigning devices that each group or student uses, and to define the allowed interactions between students or groups.

The next section presents a practical case study that demonstrates the performance of the different components of the CAFCLA framework presented above.

5 Case study: Higher Schools Museum

In the following, we illustrate the experimental activity carried out to assess the proposed techniques and detail the performance results obtained during the experiments.

5.1 Experimental setup

The main educational objective was to perform a collaborative learning activity among primary school children (8–10 years old) that promoted teamwork and social interaction to achieve a common goal. The location chosen to carry out the experiment was the Higher Schools Museum of the University of Salamanca that consists of two floors (Fig. 3). The lower cloister is located on the ground floor which hosts several old classrooms dedicated to a historical personality of relevance to the University of Salamanca. The upper cloister is located on the first floor which hosts the historical old library, the new library, an historical panelled staircase, and an exhibition of documents and historical materials used for study and research over the centuries.

In this environment, we designed a Collaborative WebQuest in which groups of students had to discover and identify objects in different parts of the building and later to locate them chronologically throughout the history of the University. The activity was divided into the following three phases:

1. In the first phase, each group of four students had to identify and locate four objects of interest through specific clues in the form of questions provided by the teacher (Table 2). Each student had the responsibility to identify only one of the four objects of their group. The students were not allowed to talk to each other until they reached a consensus and approved the object identified by a team member, but they could send messages to the group to ask questions and send photos of objects that they considered relevant, based on the given clues. Once the student identified the object of interest assigned, he/she requested a vote by his/her peers. If the majority agreed that it was the object sought, the location of the object was transmitted to the rest of the group who then gathered there to discuss the validity of the answer. At the end of this phase, each group should have identified and located the four objects of interest assigned. This phase strengthened collaboration and social ties

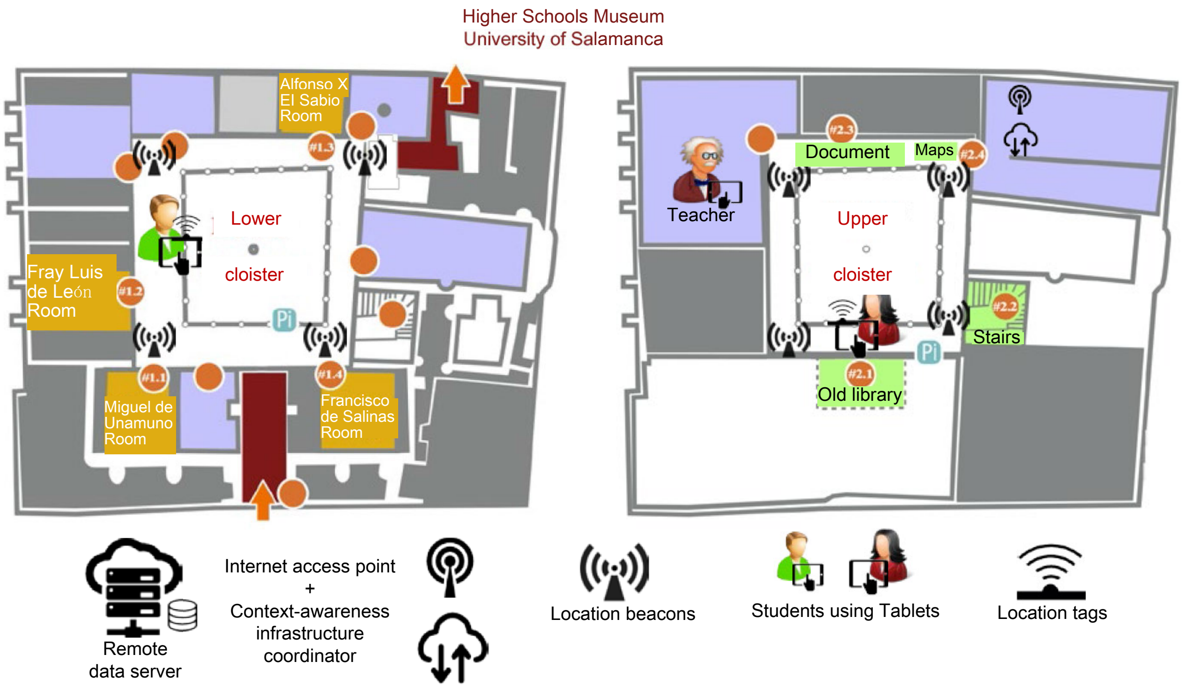

Fig. 3 The social computing framework assessed in a real scenario within the Higher Schools Museum of the University of Salamanca
The flexibility of the CAFCLA framework allowed the inclusion of heterogeneous technical infrastructure for the experimental setup and the storage of the placement of each device

Table 2 Correspondence of the zones defined to provide clues while performing the activity, and the object of interest associated

Zone	Clue	Object of interest
Z-1.1	Balustered seat	Fray Luis de León room
Z-1.2	Prison	Fray Luis de León room
Z-1.3	Queens	Francisco de Salinas room
Z-1.4	Music	Francisco de Salinas room
Z-1.5	Win but not convince	Miguel de Unamuno room
Z-1.6	Two times rector	Miguel de Unamuno room
Z-1.7	Wisdom	Alfonso X El Sabio room
Z-1.8	King	Alfonso X El Sabio room
Z-2.1	Do not mistreat books	Old library
Z-2.2	Artistic panelling	Old library
Z-2.3	Five riders	Stairs
Z-2.4	Learn–Get knowledge	Stairs
Z-2.5	Globe	Historical maps
Z-2.6	Exotic animals	Historical maps
Z-2.7	Fernando III	Historical documents
Z-2.8	Alexander IV	Historical documents

between the group members, facilitating teamwork and promoting discussions to achieve consensus in solving the proposed social problem.

2. In the second phase, students had to assign a date to each object of interest. This time the objects of interest were exchanged between groups. Each student had to identify a specific object within the four assigned to each group. In this case, the student was allowed to check the validity of the approach only with the student responsible for identifying that object

in the previous phase. Once each student had identified the object of interest, he/she joined another member of the team that had not identified the object yet to collaborate with them. When all objects were identified, the group visited all of them to agree on the validity of their answers. This phase promoted and enhanced social interactions and solidarity among groups, by helping peers and through the discussions held to reach a consensus group response.

3. In the third phase, the members of both groups worked together in the classroom. Students shared the information that each group had obtained to locate on a map all the objects of interest searched and the dates associated with them. This phase enhanced social skills through face-to-face teamwork.

The experiments involved four groups: two control groups (control groups 1 and 2) of eight students each that carried out the activity previously (without using any or the full range of resources), and two groups (groups 1 and 2) of four students each that completed the whole process of the activity using all the technical resources designed and deployed.

1. Control group 1 developed the activity with "pen and paper," without using the technology. During the first phase, they had to identify the objects and discuss among the members if these were well identified. During the second phase, they did not check the validity with the results of phase 1.

2. Control group 2 made use of the technological resources, but without the social computing-related resources. During the first phase, they did not carry out any voting to validate the objects of interest. During the second phase, they did not carry out the validation of the object of interest between members of different groups.

The teacher determined the scenario, areas, and objects of interest. In this case, the scenario was the whole museum while areas and objects of interest are shown in Fig. 3. The deployment of the activity required a specific technological infrastructure. Students used Android 5.0 Tablet devices with Wi-Fi connection to obtain the data necessary to develop the activity. The contextual information was collected using the indoor RTLS offered by CAFCLA, formed by eight localization ZigBee beacons (Sirius RadIOn) deployed across the scenario, four in the lower cloister and four in the upper cloister (Fig. 3). Each student also carried a ZigBee tag (Sirius Quantum) that transmitted its position to the location beacons continuously. Contextual information related to the clues was determined by the position of the student. Moreover, a context-aware coordinator in the upper cloister gathered the location information of the ZigBee beacons and sent it to the data server using Wi-Fi infrastructure. Finally, a remote data server stored all the information needed for the performance of the activity, and integrated all the logic and intelligence offered by CAFCLA.

After completing the definition of the scenario and technical infrastructure, CAFCLA guided the teacher in the activity design process. The practitioner followed a set of concrete steps where he/she determined users and groups, the type of activity and its phases, social relationships among participants, and available resources including contextual information. Furthermore, the teacher can monitor each student's movements and evaluate the activity at any time by accessing the state of the learning process (Fig. 4).

The following section reproduces the teacher's work when using the framework and delves into the results obtained by the development of the activity.

5.2 Experimental results

The first two phases were developed during one morning, including the deployment of the infrastructure and its implementation. The control groups performed their specific activities one week before their schoolfellows. It was planned that students should have taken 30 min for each phase. All tasks were completed correctly by the students. To analyze and evaluate the performance of the activity, a Student's t-test and a Levene's test were performed to assess differences in means and variances in time taken, respectively, between groups (Tables 3 and 4) and phases (Table 5). The hypothesis that the means were equal was rejected with a 95% confidence level (P-value<0.05).

Based on these results, we conclude that:

1. None of the control groups completed the first phase of the activity correctly as they were not able to achieve a group consensus in form and time. Moreover, the times they took to complete the activity were significantly longer than the times taken by groups 1 and 2, especially in the second phase (Table 5). Table 4 shows that this time difference was significant, since the P-value was under 0.05 in all cases after performing the Student's t-test comparing the mean

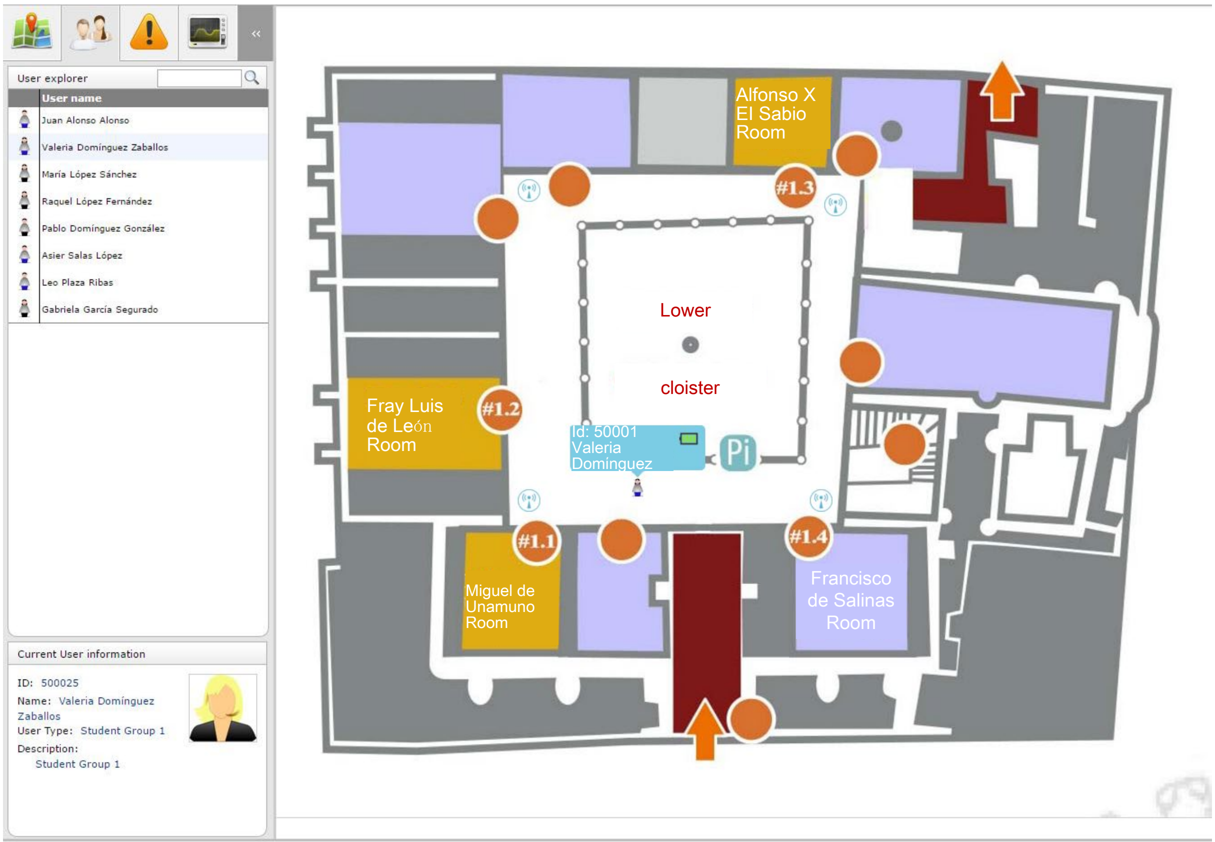

Fig. 4 The interface activity monitoring allowing the location of students to be tracked

Table 3 Results of the Student's *t*-test and a Levene's test performed to assess differences in means and variances between groups 1 and 2*

Variable	Group 1		Group 2		Group 1 vs. Group 2			
	Mean	Std dev	Mean	Std dev	t	P-value (2-tailed)	F	P-value
Phase 1								
Identification (t_i)	23:56	02:19	14:58	01:59	5.846	0.001	0.323	0.590
Consensus (t_c)	15:15	01:29	12:59	00:29	2.883	0.028	3.554	0.108
Discussion (t_d)	12:28	00:46	14:29	01:03	−3.084	0.022	0.285	0.612
Phase 2								
Identification (t_i)	10:29	00:27	08:49	00:57	3.125	0.020	0.575	0.477
Consensus (t_c)	13:06	00:49	11:13	00:35	3.697	0.010	0.477	3.697

* Time in min:sec format

time taken in each phase between groups 1 and 2 and the control groups.

2. Regarding the time taken by control groups 1 and 2, the mean time to complete the identification part of the first and second phases of the activity was significantly longer than that taken by groups 1 and 2. This assertion is supported by the Student's *t*-test presented in Table 4, which shows *P*-values of 0.04 and 0.018 for this part of the activity in phases 1 and 2, respectively, when analyzing the mean time taken by control group 1 and groups 1 and 2, and a *P*-value of 0.001 when analyzing the same situation between control group 2 and groups 1 and 2.

3. Further, the analysis of different tests showed that the use of social computing substantially enhanced the collaborative learning process within this activity. This is supported by the comparison made between the times taken in the performance of the activity by the control groups and groups 1 and 2 (Table 4), in which the *P*-values between 0.018 and

Table 4 Results of the Student's *t*-test and a Levene's test performed to assess differences in means and variances of times between control groups and groups 1 and 2*

Variable	Group 1 + Group 2		Control group 1 vs. Group 1 + Group 2			
	Mean	Std dev	t	P-value (2-tailed)	F	P-value
Phase 1						
Identification (t_i)	19:27	05:11	−2.885	0.004	6.414	0.030
Discussion (t_d)	13:29	01:22	−10.375	0.001	0.047	0.833
Phase 2						
Identification (t_i)	09:39	01:08	−2.145	0.018	8.334	0.016
Consensus (t_c)	12:09	01:12	−7.710	0.001	2.391	0.153
Variable	Group 1 + Group 2		Control group 2 vs. Group 1 + Group 2			
	Mean	Std dev	t	P-value (2-tailed)	F	P-value
Phase 1						
Identification (t_i)	19:27	05:11	−8.362	0.001	5.862	0.036
Discussion (t_d)	13:29	01:22	−5.574	0.001	1.434	0.259
Phase 2						
Identification (t_i)	09:39	01:08	−5.029	0.001	0.727	0.414
Consensus (t_c)	12:09	01:12	−5.016	0.001	1.109	0.317

* Time in min:sec format

Table 5 Results of the Student's *t*-test and a Levene's test performed to assess differences in means and variances of time between phases*

Variable	Phase 1		Phase 2		Phase 1 vs. Phase 2			
	Mean	Std dev	Mean	Std dev	t	P-value (2-tailed)	F	P-value
Group 1								
Identification (t_i)	23:56	02:19	10:29	00:27	11.310	0.001	14.671	0.009
Discussion/consensus (t_d/t_c)	12:28	00:46	13:06	00:49	2.510	0.046	1.282	0.301
Group 2								
Identification (t_i)	14:58	01:59	08:49	00:57	5.553	0.001	3.610	0.106
Discussion/consensus (t_d/t_c)	14:29	01:03	11:13	00:35	4.552	0.004	0.080	0.787
Control group 1								
Identification (t_i)	27:27	02:16	19:29	03:02	4.186	0.007	0.429	0.537
Discussion/consensus (t_d/t_c)	22:47	01:38	15:23	01:58	5.570	0.001	0.004	0.951
Control group 2								
Identification (t_i)	25:10	01:53	13:34	01:31	9.670	0.001	0.033	0.861
Discussion/consensus (t_d/t_c)	19:18	00:47	14:06	00:52	6.322	0.002	0.038	0.851

* Time in min:sec format

0.001 indicate that these time differences were significant.

4. The process of adaptation of students to technology was fast and the learning curve was short: for example, the mean time taken for identification in phase 1 was significantly longer than the mean time taken in phase 2, with a P-value of 0.001 for all the groups using it (Table 3).

5. The work load between different groups was not balanced, as can be seen from the time it took to carry out the activities: for example, the mean time taken for identification by group 1 was significantly longer than that taken by group 2, with P-values of 0.001 for phase 1 and 0.020 for phase 2 (Table 3).

6. Finally, Table 5 shows the difficulty of finding the different objects of interest within groups 1 and 2

was similar: no significant differences between the standard deviations were found. However, this process was more difficult for the control groups, especially for control group 1, as shown by the mean time taken to complete these parts in both phases, especially phase 2. The highest significant differences in variance found were between phase 1 and phase 2 for identification (groups 1 and 2; Table 3), which strengthens our thesis of rapid adaptation to technology.

5.3 Applicability to other contexts

The flexibility of the framework to integrate technologies makes it applicable to other contexts easily and quickly, covering a wide range of cases of use and learning activities that can be developed.

Thus, the framework can be used, for example, in outdoor activities with geo-referenced information and data collection from sensors (e.g., by studying the conditions in which different plants grow in a botanical garden), in collaborative games (e.g., by developing activities such as treasure hunts that use localization and contextual information to look for objects, places, or hidden clues), in environmental awareness campaigns (e.g., by empowering public workers to acquire good energy-efficient habits through engaging challenges), in guided tours (e.g., by developing a collaborative visit to a zoo), or in work spaces (e.g., by allowing a project owner to manage workers, assign shared tasks according to their location, and follow up the state of the process). Moreover, CAFCLA is suited to industrial or military team collaboration activities, in which time and location play a key role.

6 Conclusions

In this paper we have presented a collaborative learning framework based on the social computing paradigm that integrates advanced technologies to solve educational social problems, considering human-machine interactions and context-awareness. In comparison to existing solutions, this framework shows several advantages that benefit the learning process: (1) CAFCLA lets teachers define multiple types of activities through different learning processes and techniques; (2) All these activities are designed to favor the social relationships of the participants, both among themselves or with the machines integrated in the process (e.g., sensors); (3) CAFCLA allows a detailed and high granularity description of contextual information by means of real-time localization systems; (4) From the social point of view, the framework allows teachers to manage all the interactions that take place while the activity is being performed, so that the cooperation and participation of all the stakeholders involved in the activity is encouraged; (5) The flexibility of the framework brings added value compared to other solutions thanks to the integration of multiple technologies and communication systems, enabling the implementation of activities in any formal or informal environment; (6) Students reduce their learning time through the use of these kinds of activities, receiving a more effective and self-reported learning.

The proposed CAFCLA framework was evaluated in the Higher Schools Museum of the University of Salamanca. Although limited in terms of participants and the duration of the activities, this case study showed that providing contextual information via social computing in collaborative learning activities improves the acquisition of knowledge, fosters collaboration among students, strengthens social bonds, and increases the satisfaction of participants.

Future work will include the recasting of the system into computer-supported cooperative works (CSCW), and the design and deployment of more demanding applications including larger teams, larger distances, different locations, and other scopes, such as energy savings, emergency management, or the simulation of rescue missions.

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