IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received 2 February 2023, accepted 27 February 2023, date of publication 9 March 2023, date of current version 15 March 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3254904

RESEARCH ARTICLE

Collaborative Working Spheres for Global Software Development Education During the COVID-19 Pandemic: An International Experience

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ABSTRACT This paper presents our experience implementing Collaborative Working Spheres (CWS) in the context of an international undergraduate course on Global Software Development (GSD) during the COVID-19 pandemic. Many universities around the world increased their efforts in creating educational alternatives for adequately addressing the educational challenges that this pandemic has introduced. A particular case is the training of software skilled graduates to work in globally distributed environments because learning this topic requires a lot of practical work when student motivation could have been negatively affected by the COVID-19 pandemic. However, providing highly practical GSD courses during a pandemic is a challenging task for many of these universities. It is against this backdrop that we have developed an educational tool to provide CWS, enabling undergraduate students to acquire practical experience in GSD and improve their communication and teamworking skills, even during the COVID-19 pandemic. An international empirical evaluation was conducted involving students and teachers from seven universities in different countries around the world. The obtained results showed that our approach can make a significant contribution to the development of practical projects on undergraduate GSD courses with students developing their knowledge and social skills associated with this topic. The data collected on the teachers' perceptions suggested that our approach could also be useful in introducing the GSD approach at undergraduate level when social distancing is in place.

INDEX TERMS Computer science education, global software development, software engineering, collaborative working spheres, COVID-19.

I. INTRODUCTION

Ever increasing technological advances have enabled software companies to hire staff located in different parts of the world to develop software products [1]. Manjavacas et al. [2] state that this way of developing software, called Global Software Development (GSD), is performed by teams from multiple geographical locations, cultures, and languages that can be integrated without the cost of moving to a specific organization's location. While it is true that GSD has a positive impact on the way that software products are developed, there are also the so-called "3C" problems among team members (e.g., challenges regarding communication, coordination, and control) that negatively affect the software development process. Research by Shanyour and Qusef [3] stated that the 3Cs are accentuated by the so-called three distances: geographical, temporal, and socio-cultural. In this context, one of the main strategies that would help in solving

The associate editor coordinating the review of this manuscript and approving it for publication was Francisco J. Garcia-Penalvo.

these problems consists of providing appropriate training for undergraduate students to better support the development of hard and soft skills in order to effectively work in distributed environments. However, most traditional undergraduate courses address the GSD challenges through lectures and practical components that are far removed from a real distributed environment. Moreover, the emergence of the global COVID-19 pandemic has further complicated the educational environment as millions of undergraduate students stopped receiving face-to-face classes [4]. While some efforts have been made at university level during this pandemic to introduce practical activities for software engineering education, the organization of highly practical courses, for example, usually involves various activities ranging from the adaptation of a teaching method to the organization of potential communication infrastructures [5].

In line with the research by Beecham et al. [6], which stated that a traditional computer science curriculum normally prepares undergraduate students to deal with technical challenges related to software development but not for working in globally distributed teams and with the aim of simplifying the teaching of GSD during the COVID-19 pandemic, this study presents our experience of implementing Collaborative Working Spheres (CWS) into an educational tool called "Cadxela", a Zapotec word that means "Discover". This tool promotes the use of effective planning techniques and the development of communication and teamworking skills among undergraduate students, both of which are required in GSD environments.

The rest of the paper is structured as follows: Section II provides the background for GSD, which is the main motivation behind the development of our proposal. Section III provides a detailed description about the incorporation of CWS into a GSD real course, while section IV presents the materials, methods, and strategy used for a case study as well as the collected experiences. Moreover, Section V includes a discussion on the achieved results in comparison with some recent similar works, and Section VI presents the main limitations and shortcomings of our study. Finally, section VII summarizes the main conclusions of the study.

II. RELATED WORK

According to Bosnić et al. [7], it is crucial to provide undergraduate students with real or simulated experiences that develop and strengthen their hard and soft skills to reduce the problems and challenges that they will face when working in real GSD environments. This is even more relevant with the COVID-19 pandemic that has not only affected the practical training of undergraduate students, but also their job opportunities. In fact, despite the COVID-19 pandemic, the demand for distributed software engineers keeps growing, yet most of the educational approaches for teaching GSD at undergraduate level do not provide enough practical experience as they follow a theoretical structure. In this regard, Hjelsvold and Mishra [8] state that any effort to complement undergraduate GSD lecture-based courses must enable students to recognize how the main issues related to the 3Cs (i.e., communication, coordination, and control) and the three distances (i.e., geographical, temporal, and socio-cultural) can negatively impact the performance, budget, and schedule of a GSD project. With this aim in mind, efforts have been made to strengthen undergraduate students' knowledge and understanding of the GSD approach, including educational alternatives for bridging the gap between practical learning and the social isolation requirement imposed by the COVID-19 pandemic.

The COVID-19 pandemic has further compounded this trend with regards to education in this field, specifically in [9], [10], and [11] which have conducted case study research implementing GSD courses. The research by Zhang et al. [9], for example, presented the results of a case study that implemented a joint web course on GSD between two universities from China and Portugal and with the objective of undergraduate students developing a project collaboratively. It is worth mentioning that the participating students were voluntarily enrolled on the course based on their own motivation. The course was supported by different tools that promote communication and distributed work among students, such as version control tools (git, svn, cvs), tools for managing documents online (Google Doc, Microsoft document), tools for storing and sharing documents (github.com, Dropbox), tools for project management (www.assembla.com) as well as communication tools (WeMeet, Zoom, and regular e-mails). Furthermore, the GSD course was a combination of two different existing courses: "Distributed Software Development" at Jilin University, China and "Ubiquitous Computing" at the University of Trás-os-Montes and Alto Douro, Portugal. The study analyzed three dimensions (i.e., inner-team evaluation, inter-team evaluation, and faculty evaluation) to highlight important lessons that can contribute to improving GSD education in similar pandemic situations: (i) the best indicator to assess student learning was their grades, (ii) the appropriate tools to promote collaboration and communication facilitate interaction and distributed teamwork, (iii) it is necessary to consider grammatical errors when participating students speak the same native language, (iv) it is important to work on student empathy, (v) the use of online platforms does not have detrimental effects on student communication, and (vi) the positive results are largely due to the way in which students dealt with the threat of COVID-19 promoting sympathy, help, and cooperation with their peers.

Similarly, Schmiedmayer et al. [10] presented the results obtained from a case study which involved a Global Software Engineering course imparted among three universities in the United Kingdom, Germany, and Russia in order to allow their respective undergraduate students to acquire the skills to undertake a globally distributed project. The students were also enrolled on the course by taking into account their motivation for participating in the study. The course was supported by agile methods and multiple Platform as a Service (PaaS) and Software as a Service (SaaS) solutions such as Slack for creating a workspace for participating students, Zoom as a communication tool, GitHub for sharing knowledge, and Swift and Apodini for creating evolvable web services. Moreover, the topics included in the course addressed the continuous software engineering in combination with IoT smart devices through lectures and the development of a global project which involved students from the Imperial College of London, United Kingdom, the Technical University of Munich, Germany, and the St. Petersburg Electrotechnical University, Russia. In this particular case, the study was not focused on evaluating student performance or any other aspect related to their learning, but rather on collecting lessons for teachers interested in following a similar approach: (i) it is important to ensure that all students have remote access for interacting with their teammates, (ii) it is necessary to have a stable network infrastructure in all locations, (iii) it is advisable to use a central technological platform that facilitates the continuous integration and continuous delivery of the work, (iv) the use of PaaS and SaaS reduces investment in infrastructure for short-term courses, and (v) it is suggested using the distributed pair deployment technique when interaction from multiple sites is involved.

Finally, Titze et al. [11] presented experiences related to the creation of a hybrid course for teaching Global Software Engineering during the COVID-19 pandemic which involved master's degree students from Ritsumeikan University, Japan and the Nuremberg Institute of Technology, Germany. Students from both universities eventually enrolled on the course as an alternative to face-to-face sessions due to the constraints the COVID-19 pandemic placed on education. The course was also supported for diverse agile methods and web tools such as Moodle, Trello, Jira, and Miro. The study used qualitative methods to collect data related to students' experiences during the course highlighting that: (i) the use of asynchronous communication (i.e., written chats) is suggested when there is a lack of experience in communication in different languages, (ii) it is highly recommended incorporating a mixed approach for student attendance which includes an online format and in-person participation, (iii) it is also recommended that the assigned projects have clear specifications for promoting self-organization among students while developing a solution with guidance from project-based learning, and (iv) attention needs to be paid to students having the correct technical infrastructure for online interaction.

In these previous works, some efforts were made to create alternative proposals to support the teaching/learning of GSD during the COVID-19 pandemic. However, the proposal of this paper is configured by embracing the effort of implementing the GSD course in a formal CWS context describing each of its components such as task, characteristics, educational approach, rules, and roles, among others. Moreover, in order to measure the results three dimensions (i.e., pre-post student' GSD knowledge, students' motivation and satisfaction regarding a GSD course, teachers' technology acceptance) were assessed.

III. INCORPORATION OF CWS INTO AN EDUCATIONAL TOOL

The COVID-19 pandemic has reinforced the notion that traditional teaching methods are not suitable for GSD education in any university around the world. Consequently, it was important to implement methods and techniques that allow students to apply the theoretical knowledge on GSD in a highly practical environment, real or simulated, where they could develop a software project in a collaborative manner without risk of contagion. However, the way that students collaborate to work in both real physical spaces and virtual distributed environments is an issue that requires careful consideration. Moreover, the nature of any software development model implies the execution of multiple activities which are inherent in the training of any future software practitioner: supervising software staff, eliciting quality requirements, writing computational programs, performing efficient software testing, participating in different software projects, as well as other activities. This situation increases the complexity of the training process because it is also common for students to have to learn to use a wide variety of software tools to develop distributed projects collaboratively in order to perform more dynamic work. In this regard, González and Mark [12] argued that analysts, programmers, testers, or project managers experience high levels of discontinuity during the execution of their activities in a software project by switching between manual activities (i.e., those which may require pen and paper) and automated activities (i.e., those which require the use of software technology) in the workplace. As with the real industry context, this discontinuity is also experienced by students in academia due to internal interruptions (e.g., when the same student switches between activities when answering a phone call or leaving the classroom) or external (e.g., when a student is interrupted by any situation that he/she cannot control and that forces him/her to switch between activities) while trying to manage multiple activities. While interruptions could be controlled in a real classroom, maintaining this control is difficult when learning through virtual classrooms, and this situation is compounded further by the COVID-19 pandemic negatively affecting students' motivation.

The aforementioned scenario has led to increased interest in the relevance of the concept of *working sphere* which provides a high-level description of interrelated activities whose realization requires the interaction of a group of people who have the same resources to achieve the same objective and where each person has their own time frame. Examples of working spheres include programmers' efforts to implement a particular software component, the elicitation of requirements using user stories, or the design of test cases to perform software acceptance testing. Working spheres were more precisely defined by [13] as practical activities for developing software through multiple collaborations among individuals. Moreover, a working sphere describes work efforts that people pursue in practical activities in order to fulfill their responsibilities. Such a definition is closely related to the way in which students learn to develop software in a traditional way, since through multiple collaborations they learn to elicit requirements, code the software functionalities, test the software, and deliver a finished product. However, a GSD environment introduces a different scenario as collaborations may demand the simultaneous involvement of people in working spheres that have different purposes, time frames, resources, or even people with different hard and soft skills. Therefore, when considering both the collaborations that must take place to develop the software in a distributed way and the working spheres in which the students must participate, it is important to note that it will not only be crucial to manage and supervise the working spheres, but also the students' collaborations in the working spheres. In this regard, Orre and Middup [14] provided evidence on working spheres and stated that technology can positively influence the interaction between team members when collaboration is crucial for achieving a common goal. Moreover, in order to avoid technology negatively affecting the socialization of team members, these researchers affirmed that it would be necessary to design tools which support the development of collaborative activities by promoting the identification and retention of desirable or potential interactions in teams to obtain more effective results. Taking into account an educational context for GSD, this approach could be useful considering an alternative configuration that would use technology to provide the necessary support for enhancing collaborative work in distributed settings while considering that each participant would have a computer to interact through working spheres pursuing a common goal, otherwise known as CWS. According to Palacio, Morán, González, and Vizcaíno [15], a CWS is a set of working spheres which are represented by resources and people who shared a common goal within a determined lapse of time. Moreover, each working sphere provides information about the activities that each participant is developing to promote the start of informed collaborations.

In this context, Fig. 1 depicts our proposed conceptual configuration for a CWS in which a group of students must collaborate to develop shared activities within the same GSD project. The performance of each working sphere will be influenced by the degree of socialization that each student has achieved with the rest of their teammates regardless of location. It is logical to think then that better performance will correspond to the hard work students had done without having to worry about both internal and external interruptions. Furthermore, each activity should be carried out considering the tasks, events, resources, and actions defined by the GSD project. The main feature of this particular configuration is that it aims to promote favorable collaborations between students located in different geographic locations who, due to the COVID-19 pandemic, may be less motivated to engage in hands-on GSD activities.

Therefore, an important concept represented in Figure 1 is a "potential collaboration", which was also introduced in [15] to integrate the participants' individual perspectives into the CWS for a GSD project by identifying opportune moments for initiating a productive collaboration. Moreover, a potential collaboration would allow students to identify opportunities for interaction that would be monitored to ensure the successful completion of each activity within the project.

According to Palacio, Vizcaíno, Morán, and González [16], the process for characterizing a CWS involves three main tasks which can be tailored for supporting a GSD course as follows:

- Identifying the information of an activity in the GSD project: The educational environment should enable students to visualize, monitor, and follow-up all the activities performed in the CWS throughout the project.
- Identifying a suitable moment to interrupt other teammates during the GSD project: Each student who is a member of a CWS should be able to visualize the progress and status of each activity carried out by each of their teammates to identify interaction opportunities. That is to say, depending on the activity that a teammate is carrying out, another student from the same CWS with the appropriate knowledge can help him/her to finish faster.
- Initiating collaboration: Considering the previous information, students should have the tools for asynchronous and synchronous communication in order to initiate collaborations at appropriate moments throughout the GSD project. The combination of these tools with specific information about the progress of each assigned activity in the CWS would enable students to determine the appropriate moment when a collaboration can initiate. Such collaboration should be monitored by the student assigned the role of project manager and, logically, by the teacher responsible for the GSD course.

Therefore, with the aim of designing an educational tool that would be able to support the development of the activities of a GSD project, the characteristics (i.e., scale, uncertainty, interdependence, and communication) and the design implications identified by [15] were considered as follows:

- Scale: This characteristic is related to four fundamental GSD elements: (1) the size of the product to be developed (e.g., small, medium, large, or very large), (2) the distribution of those who would develop such a product (e.g., among a group of individuals, between groups, within an organization, or between organizations), (3) the geographic distribution of these individuals (e.g., co-located, locally distributed, or globally distributed), and (4) the duration of the project (e.g., days, weeks, months, or years). In the context of this study, it was decided that small projects would be developed by teams of students that were distributed globally to work collaboratively for up to six weeks. It is worth mentioning that since the objective of this study was to instill the hard and soft skills in students that the GSD approach requires, it was decided to create a repository of small projects that students could solve during the duration of a school

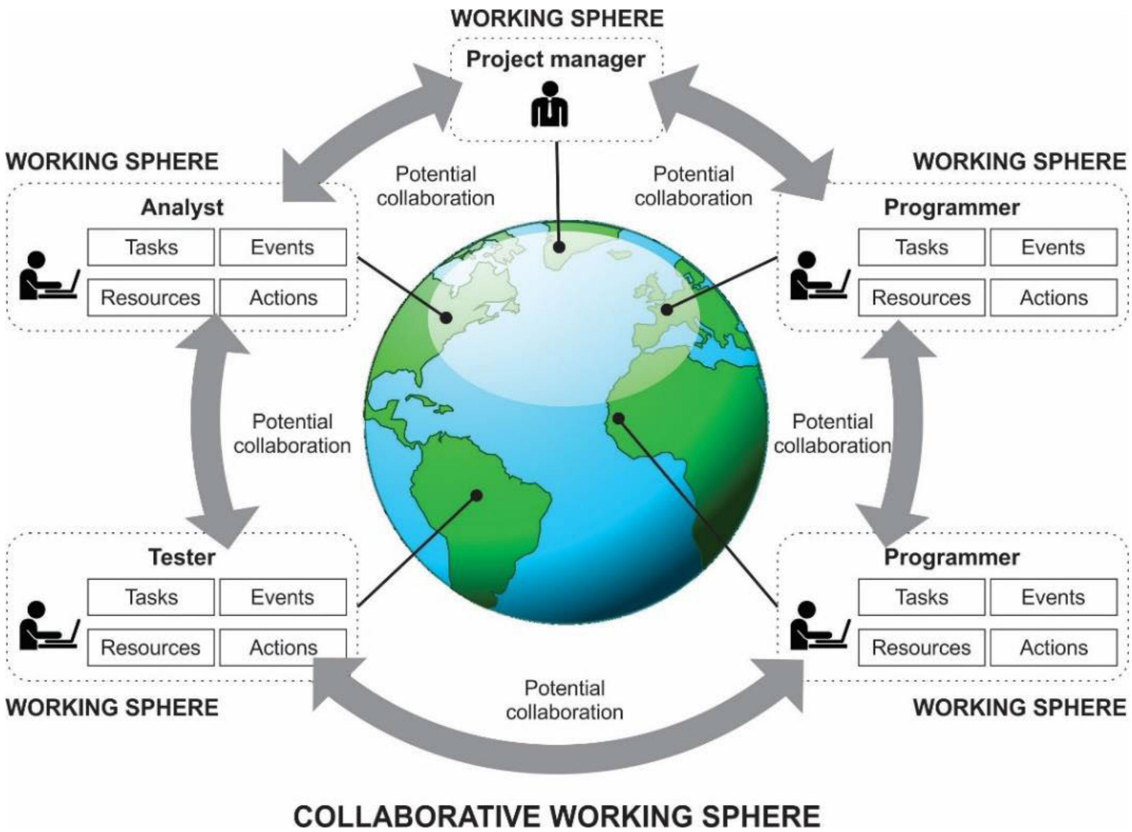

FIGURE 1. A conceptual configuration of collaborative working spheres for GSD education.

semester, instead of proposing complex projects that could not be completed during this timeframe. Moreover, chat and video conferencing modules were created in order to promote interaction among students in the CWS.

- Uncertainty: As with any other software development project, a GSD project introduces a degree of uncertainty since the requirements are constantly changing. However, with this approach a distributed team support each other with the collaborative skills of its members to solve the problems that could arise. Therefore, the members of a GSD team must reduce this uncertainty through continuous interaction, sharing project information, and knowing the progress of the tasks throughout the project. In the context of this study, the design of a hierarchical structure of elements was considered so that students could share, visualize, and filter the information of each project assigned to each CWS. Furthermore, cloud services were implemented to provide information on the GSD project to students.
- Interdependence: This characteristic is directly related to the dependencies that exist between the activities that the members of a GSD team can carry out. Such dependencies may be due to shared resources, activity sequencing, requirement constraints, transference of deliverables among team members (e.g., requirements, code), and dependency relationships among activities. In the context of this study, mechanisms were introduced that allow students to determine the degree of progress of each activity assigned to each teammate in the CWS. Moreover, modules to conduct and record daily face-to-face meetings were implemented as well as a leaderboard in order to provide students with a sense of progression and motivation which could be affected during the COVID-19 pandemic.
- Communication: Finally, this characteristic is related to the way in which information flows between the members of the CWS in order to carry out the project activities, solve problems, communicate the progress of the activities and the achievements of the project, conduct follow-up meetings, among other tasks. In the context of this study, components were designed so that students could carry out formal and informal communication through synchronous and asynchronous communication mechanisms to determine the status of teammates' tasks (i.e., what they did, what they are doing, and what remains to be done) and identifying opportunities for potential collaborations. Moreover, chat and web cam conferences modules were also implemented as synchronous mechanisms for promoting student interaction, a wiki was implemented as asynchronous mechanism for knowledge exchanging,

a Kanban board was implemented for monitoring and controlling the status of the GSD project and the work done by each student in the CWS, and burndown charts were used to improve the visibility of the GSD project progress by analyzing the tasks planned compared to the tasks completed.

Taking into account such characteristics and design implications for supporting the distributed development of projects through the integration of CWS, the Cadxela tool was developed as the main technological support for undergraduate courses [17]. During the COVID-19 pandemic, new software requirements were developed to improve its functionalities. Cadxela was designed considering a Representational State Transfer (REST) architecture for providing RESTful web services. This technology provides a working environment that enables teachers and students from different universities which are globally distributed (i.e., with different time zones, working cultures, study habits, hard and soft skills) comprised of different CWS for students to collaborate in the development of GSD projects during the challenging "new reality" created by COVID-19. With this aim in mind, a theoretical undergraduate course was designed which included basic topics on GSD. This was the result of a consensus among ten Software Engineering teachers from Mexico, Spain, Chile, Cuba, Peru, Bolivia, and Ecuador who discussed and defined eight specific topics from the Curriculum Guidelines for Undergraduate Degree Programs in Software Engineering [18] and the Guide to the Software Engineering Body of Knowledge (SWEBOK®) [19]. The content of each topic was designed to provide students with a theoretical basis and practical knowledge on GSD.

On the other hand, different educational approaches have been implemented to strengthen GSD education. Research by Braun et al. [20], for example, used the "learning by doing" approach to improve the education provided in this field, while Gotel et al. [21] and Fagerholm et al. [22] used a Project Based Learning (PBL) approach to reach the same goal. In other studies, Noll et al. [23], Valencia et al. [24] and Ghanbari et al. [25] focused their efforts on creating serious games to support GSD education, while Li et al. [26] and Lappalainen et al. [27] used simulations as a teaching method. In addition, Bosnić et al. [28] implemented the e-learning approach to support a GSD course. In the context of our research, the practical activities of the GSD course were designed considering a PBL approach [29], while the theoretical classes followed a traditional approach based on distance learning due to the social distancing imposed by the COVID-19 pandemic. PBL, which has its origins on the ideas of Jean Piaget and John Dewey, is a teaching method that enables students to gain knowledge by investigating and working for specific periods of time on authentic, engaging, and challenging projects and/or problems [30]. Moreover, research by Anicic and Stapic [31] argues that PBL is widely acknowledged for promoting students' educational experience regarding with the development of soft skills on Software Engineering such as communication, teamworking, planning and leadership. Therefore, PBL was incorporated into Cadxela by defining a set of small projects that were randomly distributed among the different CWS that were formed from a combination of students from seven universities around the world. Students are given "messy" descriptions of each project to apply the agile techniques, strategies, and tools necessary to transform such descriptions into functional requirements, develop a software product that satisfies those requirements, manage the project to completion, and execute the final delivery. This means that students must work together in teams while solving the problems that arise (e.g., technical, cultural, and language issues, for example) thus generating "teachable moments" because the teachers not only supervise the project's progress, but also coach the students to discover their own effective solutions. Moreover, Cadxela integrates an agile software development process combining the role of project manager incorporating traditional methodologies instead of Scrum master, given that the approach of the GSD course is to enable the undergraduate students to assign planning tasks and monitor the project's progress of teammates within the CWS. Table 1 summarizes the proposed theoretical and practical topics to incorporate the Cadxela tool into the GSD course, the relationship of such topics with the aforementioned GSD characteristics, and design implications for achieving an effective implementation of CWS focused on software development projects without risk of contagion from the COVID-19 pandemic. As can be seen, our efforts focused on providing full support to undergraduate students by designing a GSD course and implementing an educational tool incorporating the CWS concept in order to positively influence the interaction among the learners when the distributed development of software is required. Such a tool was created with the aim of students feeling motivated in identifying potential collaborations even when their working culture, schedules, language idioms and expressions, and skills are different. The results obtained from using our proposal on an international course on GSD that was held among seven Spanish-speaking universities around the world during the height of the COVID-19 pandemic are presented in the following sections.

IV. METHODOLOGY

Cadxela was introduced into an undergraduate GSD course with the aim of performing a first empirical evaluation with real students during the 2018-2019 academic year. The course was designed and delivered by teachers from five universities in Chile, Cuba, Mexico, Peru, and Spain, while a total of 20 fourth-year Computer Science students (five students per university) participated in the study [17]. Later, during the first academic semester of 2020 the study was extended using our approach as the main educational support when COVID-19 contagion had considerably impacted education throughout the world. On this occasion the same dimensions were evaluated (i.e., student academic achievements, student motivation and satisfaction, and teacher acceptance), but information

TABLE 1. Components of the GSD course.

Topic	Description	Educational approach	GSD characteristic
1. GSD basic concepts	Students analyze a GSD definition, and an historical perspective and the main characteristics of this approach are explored	Theoretical	--
2. GSD and software industry	Students understand the main benefits of a GSD approach in the modern software industry and discuss real case studies based on software organizations' experiences	Theoretical	--
3. GSD challenges	Students produce a first approximation of the 3Cs (i.e., challenges regarding communication, coordination, and control) that negatively affect a GSD project	Theoretical, practical (PBL)	Scale, uncertainty, interdependence, communication
4. Implications of geographical, temporal, and socio-cultural distances in GSD	Students analyze the negative impacts that such distances introduce to software distributed projects that are developed when teammates from different countries are involved	Theoretical, practical (PBL)	Scale, communication
5. Cultural diversity in GSD	Students are made aware that aspects related to different ways of working, languages, time zones, ethnicity, and even sexual preferences could negatively affect the outcome of a GSD project	Theoretical, practical (PBL)	Interdependence
6. Agile techniques for project management in GSD	Students learn and put into practice some techniques used in Scrum such as user story technique for eliciting software requirements, a poker planning technique for estimating user stories, and the obtention of burndown charts. Moreover, students learn to define and maintain a Kanban board to plan and monitor a GSD project	Theoretical, practical (PBL)	Scale, interdependence, communication
7. Tools and strategies for knowledge management in GSD projects	Students learn to configure and manage an easy-to-use knowledge repository provided by Cadxela, Moreover, students also learn which knowledge to maintain, how to communicate the knowledge, and how much detail should be described	Theoretical, practical (PBL)	Uncertainty, communication
8. Tools and strategies for efficient collaboration in GSD projects	Students learn to identify interaction opportunities as suggested by CWS in order to collaborate with teammates through the Cadxela's synchronous and/or asynchronous communication tools	Theoretical, practical (PBL)	Uncertainty, communication

relating to geographical, temporal, and socio-cultural distances was also collected in order to evaluate if Cadxela could contribute to providing practical knowledge on GSD even when social distancing was in place for a prolonged period.

A. PARTICIPANTS

In this empirical evaluation a total of 70 fourth and fifth-year Computer Science students from universities in Argentina, Bolivia, Chile, Ecuador, Mexico, Spain, and Peru were included in the study.

It is worth mentioning that some of these countries began to feel the effects of the COVID-19 pandemic later than others and were affected in different ways. Table 2 shows the participating universities highlighting the role that they played during the evaluation as well as their time differences compared with the university that coordinated the GSD course. As can be seen, a total of seven universities participated in an undergraduate course on GSD which involved 10 students from each university who took the theoretical lessons locally (where possible) and by video conferencing while carrying out the practical part of the course exclusively with Cadxela. In addition, nine teachers with an average of 14 years' experience designing and teaching undergraduate courses on Software Engineering also participated, teaching the topics of the theoretical course as well as supervising the work of the CWS. Finally, two more researchers participated analyzing the data collected during the evaluation in order to provide support to evaluate the assessed dimensions.

All participating students and teachers included in this empirical evaluation did not participate during the 2018-2019 school year. In addition, three different universities were integrated into the evaluation presented in this study.

TABLE 2. Participating universities.

University and location	Role	Time zone differences
Universidad Tecnológica Nacional (Argentina)	Teaching, supervision	+2 hours
Universidad Mayor de San Simón (Bolivia)	Teaching, supervision	+1 hour
Universidad de Santiago de Chile (Chile)	Teaching, supervision	+1 hour
Escuela Politécnica Nacional (Ecuador)	Teaching, supervision	None
Universidad Tecnológica de la Mixteca (Mexico)	Course coordinator, teaching, supervision	--
Universidad Politécnica de Madrid (Spain)	Teaching, supervision	+7 hours
Universidad Autónoma de Perú (Peru)	Teaching, supervision	None

TABLE 3. Participating students in projects.

Academic year	CWS	Number of members	Small projects	Rounds
March 2020 to October 2020	51	4	8	3

It is important to mention that none of the participating universities has an official GSD course, so it was necessary to analyze the courses that coincided among the institutions to establish a minimum background to start learning on GSD. Therefore, courses such as "Software programming", "Software project management", "Agile development", and "Software Engineering" were considered.

B. RESEARCH STRATEGY

Our approach was incorporated into the "Software project management" course which was a common course in the Computer Science programs of all the participating universities, while the topics on GSD defined in Table 1 were also added. In order to carry out a controlled evaluation, the students who were really interested in participating in this complementary course were invited to join and, consequently, 10 students per university were enrolled. All of the students were enrolled in Computer Science undergraduate programs. Moreover, 63% of students were male and 37% were female. An important fact is that 78% of the participants are students whose average in their respective degree programmes is 85, and 100% of students had previously taken the "Software programming", "Software Engineering", and "Software project management" courses. The age of the students ranges between 21 and 22 years old. As previously stated, the coordination of the course was provided by the Universidad Tecnológica de la Mixteca (Mexico) and the same materials (e.g., PPT slides, lessons content, practical exercises) were used by all the participating universities. The aim of the course was to randomly distribute the work related to the development of a software project to 51 CWS comprised of four students from different countries, thereby exposing them to the effects of geographical, temporal, and socio-cultural distances in order to find solutions and collaborate on the projects, creating their own knowledge on GSD (see Table 3).

In addition to the topics that address the theoretical part of the course, a repository of eight small projects was created to incorporate the hands-on activities on the course.

The complexity of these projects is such that they can all be completed by students within one school semester (i.e., approximately 24 weeks). Each project requires each CWS to create a software solution from a general textual description to develop an academic grading management system, a sales point for a retail store, a management system for book loans, a soccer tournament management system, a package delivery management system, an informative website for a small fictitious company, a movie loan management system, or a restaurant appointment management system. Therefore, 51 different CWS (i.e., 17 CWS for each round of projects) were created throughout the course incorporating students from the participating universities to solve the eight projects in three rounds of six weeks per project. More than one CWS received the same project assignment. Fig. 2 depicts the process that was carried out in this empirical evaluation. The dotted box highlights the activities that were carried out through Cadxela, while the other activities were carried out through video conferencing, online questionnaires, and analysis of the data generated with the interaction of students during the evaluation process. As can be seen, Fig. 2 establishes that the data would be collected through observation and the development of projects by the students, for which a case study was established as the main method for carrying out the empirical evaluation. It is important to mention that the process represented by the dotted box was repeated for each project developed by each CWS, while the pre and post evaluations were carried out only once at the beginning and at the end of the case study, respectively.

On the other hand, during the development of the distributed projects, the students must apply all the techniques and tools that were implemented in Cadxela to avoid the use of multiple software tools that could distract them during learning (e.g., a software module to obtain user stories as requirements elicitation technique, a software module to estimate the effort of each story through the planning poker technique, a software module for the analysis of burndown charts, a software module to apply the earned value management technique). The techniques and tools correspond to the description of GSD features and related design implications that were described in section III.

C. INSTRUMENTS

According to Bosnić et al. [32] and [7], assessing students in a GSD environment can be a challenging task as supervision of students' remote work as well as group and individual performance evaluation is often difficult.

In this regard, Clear et al. [33] suggested several recommendations as a result of a systematic literature review on the design and delivery of global software engineering courses in order to correctly address the assessment during GSD courses. With the aim of incorporating such recommendations into our case study, we have designed three instruments for collecting information as follows:

- In order to identify the students' starting skills by assessing the theoretical knowledge on GSD and interaction skills, a 20-item questionnaire (with 3 open-ended questions and 17 multiple choices closed-ended questions) was designed by all the participating teachers to include topics such as communication, collaboration, as well as agile techniques for GSD. Moreover, the same instrument was used to perform a final summative evaluation to assess student learning.
- In order to determine the students' perceptions on motivation and satisfaction during the case study, a 24-item

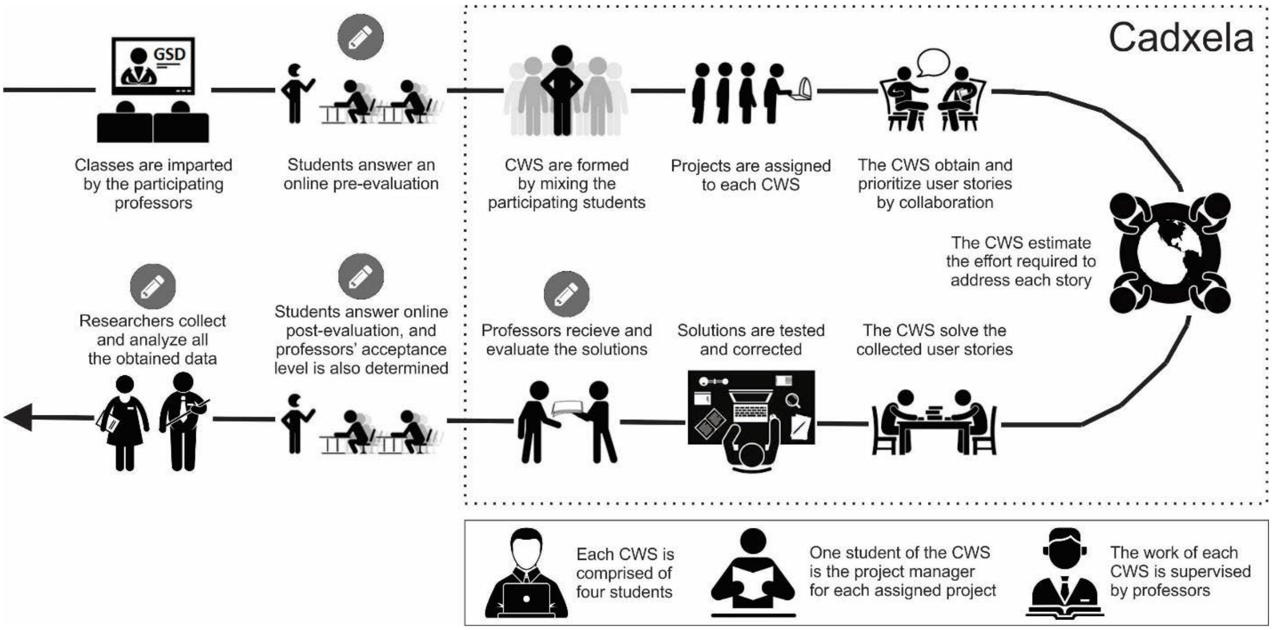

FIGURE 2. Representation of the empirical evaluation process.

questionnaire was designed to incorporate a qualitative approach by combining two instruments used in our previous research [34], [35]. The questionnaire is based on a 4-point Likert scale. As it is not our main goal, we did not include questions about the effects of the COVID-19 pandemic on their motivation for learning.

- In order to evaluate the teaching quality and the teachers' technology acceptance, a 13-item questionnaire was designed by following the recommendations of the Technology Acceptance Model [36] and the Unified Theory of Acceptance and Use of Technology model [37].

The Chi-square test [38] was also conducted to determine whether there is a significant difference between the expected frequencies and the observed frequencies when using Cadxela to support the GSD course in order to achieve acceptable levels of student motivation, student satisfaction as well as an acceptable teacher acceptance level.

All the instruments used in the case study are available in (https://docs.google.com/spreadsheets/d/1lXoyXHQXPCf-Js7KtPFnQhot78tVB2sA/edit?usp=sharing&ouid=103939208919543218647&rtpof=true&sd=true).

Furthermore, considering Clear et al.'s [33] recommendation on designing an assessment process tailored to the GSD practice, Cadxela provided teachers with the automatic generation of statistics which facilitated the analysis of interactions among students as well as evaluating their group and individual participations in the CWS (e.g., student participation in daily meetings using synchronous and/or asynchronous communication, student collaboration in the projects within the CWS, number of user stories elicited by the CWS, individual student contributions during effort estimation, students participation in solving problems within the CWS). In addition, in order to promote the relevance of software quality in the real industry among students, teachers tested the resulting software products at the end of each round in terms of functionality and errors. Therefore, the evaluation was influenced by the software quality, as higher quality led to better grades for students in the CWS. It is worth mentioning that, as Clear et al. [33] also recommended, the application of these questionnaires and testing the software products took no longer than 5 minutes for each CWS.

Finally, a leaderboard was integrated into Cadxela to provide the learners with a sense of progression. A recognition was awarded to the students who gave their best effort during the course while following our approach, thereby helping with motivation which was negatively affected during the COVID-19 pandemic.

D. RESULTS

The aforementioned instruments were used to obtain qualitative and quantitative data throughout the GSD course with the aim of collecting positive and negative aspects of the proposed approach during the worst of the COVID-19 pandemic. The pencil icon in the process represented by Fig. 2 indicates four fundamental points for data collection: a pre-evaluation, the delivery of students' solutions at the end of each round of projects, a post-evaluation as well as the application of the questionnaire to the participating teachers, and the collection of students' perceptions on their motivation and satisfaction during the course. Data was also obtained from Cadxela throughout the course with the aim of complementing the information related to the student academic achievements, and the issues faced with geographical, temporal, and socio-cultural distances while they collaborated within the CWS.

1) STUDENT ACADEMIC ACHIEVEMENTS

Once the theoretical lessons ended, a pre-evaluation was conducted through the application of the designed assessment instrument. As previously mentioned, the topics included in the theoretical part of the course were proposed, reviewed, and accepted by the nine participating teachers, meaning that the same curricula was taught at all universities. Students' previous skills on programming, requirements elicitation, software testing, or even Scrum was considered as Software Engineering background that was a requirement for students before participating in the GSD course. However, no hard skills assessment was conducted to select the participating students. With the aim of students collaborating on the development of projects within a CWS, it was therefore decided to create a GSD course that was not taught in any of the participating universities before the preparation of this case study. Moreover, at the end of each theoretical lesson, the teachers held work sessions with students to discuss the presented topic prior to the pre-evaluation which consisted of formulating open-ended questions and discussing the answers among students. Students were not aware of the grades obtained in the pre-evaluation. Table 4 shows the results obtained by each participating university in pre and post-evaluation. In this regard, students from the Universidad Autónoma de Perú (Peru) only answered 23% of the questions correctly during the pre-evaluation, a low number considering the results of the Universidad Politécnica de Madrid (Spain) which obtained the highest number of correct answers in the pre-evaluation with 44%. It is worth mentioning that the pre-evaluation was carried out to determine the effectiveness of a traditional approach in teaching a GSD course during the COVID-19 pandemic, which, as is well known, forced universities to significantly reduce the physical interaction among students when carrying out teamworking practices. It is evident that despite this scenario, the GSD projects could have been carried out locally through student collaboration using various software tools. However, very few universities were prepared to undergo radical change in the way that highly practical courses were delivered. With the intention of exposing students to geographical, temporal, and socio-cultural distances, participating teachers gave the lessons and advised students from other universities to develop the hands-on activities by using Cadxela. Therefore, all the CWS were comprised of four students from different countries, one of whom assumed the role of project manager to directly interact with the teacher in order to solve problems during the three rounds of projects and monitor progress. Once each round of projects was completed, the CWS were reorganized with different students and the role of project manager was assigned to the student who had performed the most impressively in their respective team in the previous round. With this aim in mind, the 8 projects were randomly assigned among the 51 CWS to put into practice the theoretical concepts learned from the lessons over a six-month period which coincided with the worst period of the COVID-19 pandemic.

After three rounds of projects, the assessment instrument was reapplied to carry out the post-evaluation that led to an improvement of 60% regarding the global average for the evaluations, considering the results obtained during the pre-evaluation six months previously. In contrast, it was observed that the University of Santiago de Chile (Chile) obtained a score of 98% in the post-evaluation, while the Universidad Tecnológica Nacional (Argentina) showed the lowest percentage of correct answers with 89%. Although this last value is lower than that obtained by the Argentine students, a significant improvement was observed in general terms between the initial and final scores of all the participating students when using the assessment instrument.

Therefore, we believe that GSD teaching should not be based solely on theoretical lessons that harm student learning when in isolated environments such as the one imposed by the COVID-19 pandemic. On the contrary, better results were observed when combining this traditional approach with technology for promoting active and timely collaboration through CWS which were comprised of students from different countries in order to achieve a more complete understanding of the complexities and challenges of the GSD.

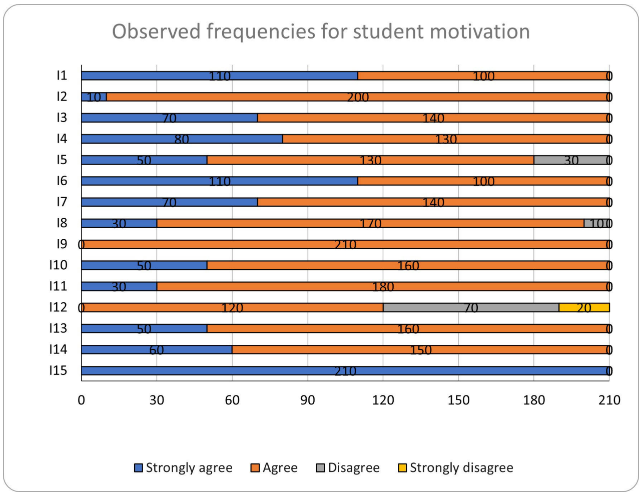

FIGURE 3. Students' perceptions on motivation using Cadxela as an educational support.

2) STUDENT MOTIVATION AND SATISFACTION

The application of the assessment instrument showed relatively positive results on the students' general perceptions after having participated in the development of three rounds of projects. Initially, the information collected with the Likert scale was converted into a numerical value in order to obtain a quantitative measure, and the mean (M) and standard deviation (SD) were also calculated considering all the students' responses. Subsequently, a statistical analysis was performed with the Chi-square test.

TABLE 4. Pre and post-evaluations scores by university.

Topic	UTN – Argentina		UMSS – Bolivia		USC – Chile		EPN – Ecuador		UTM – Mexico		UPM – Spain		UAP – Peru	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1. GSD basic concepts	20%	90%	30%	90%	40%	100%	20%	80%	30%	100%	40%	90%	30%	90%
2. GSD and software industry	10%	80%	30%	100%	20%	90%	30%	90%	40%	90%	50%	100%	10%	80%
3. GSD challenges	30%	80%	10%	90%	30%	100%	40%	100%	20%	90%	30%	100%	20%	100%
4. Implications of geographical, temporal, and socio-cultural distances in GSD	20%	90%	20%	80%	20%	90%	20%	100%	40%	100%	30%	90%	20%	90%
5. Cultural diversity in GSD	40%	80%	30%	100%	50%	100%	40%	90%	40%	90%	50%	80%	10%	100%
6. Agile techniques for project management in GSD	60%	100%	40%	100%	40%	100%	50%	90%	50%	100%	60%	100%	40%	90%
7. Tools and strategies for knowledge management in GSD projects	30%	100%	20%	100%	40%	100%	30%	100%	30%	100%	50%	90%	30%	90%
8. Tools and strategies for efficient collaboration in GSD projects	50%	90%	40%	90%	50%	100%	30%	90%	40%	100%	40%	90%	20%	90%
Improvement average by university	56%		66%		61%		60%		60%		49%		69%	

Fig. 3 shows that 100% of the students stated that they felt comfortable with the approach that was applied on the GSD course (*I15. I liked the approach adopted by the course*, M = 4.0, SD = 0.0). Moreover, considering the negative effects of the COVID-19 pandemic on students, the vast majority stated that they were motivated to put into practice the theoretical concepts learned on the GSD course (*I2. I felt motivated to apply the learned theoretical concepts in a practical environment*, M = 3.0, SD = 0.2) and they enjoyed collaborating in the CWS with their teammates to develop the assigned projects by using the technology created to support the course (*I9. I enjoyed collaborating during the development of projects with Cadxela*, M = 3.0, SD = 0.0).

In addition, positive responses were also obtained from the students who stated that doing the practical part of the course represented a challenge in their training (*I1. I realized that the practice represented a stimulating challenge for me*, M = 3.5, SD = 0.5) because they were able to understand the relevance of GSD in the current industry in a more real way (*I6. I understood the relevance of GSD training when working in a project*, M = 3.5, SD = 0.5).

Similarly, positive perceptions, although with a more marked difference between the responses ''Agree'' and ''Strongly agree'' were collected when students stated feeling motivated to work with foreign students (*I4. I felt motivated to learn about other ways of working while developing a project with my foreign teammates*, M = 3.4, SD = 0.5) as well as satisfied when collaborating in the CWS despite not knowing their teammates (*I5. I felt motivated to collaborate with people from different places with whom I had not worked before*, M = 3.1, SD = 0.6), which caused a feeling of having been efficient as members of each CWS in which they participated (*I14. I am satisfied that I collaborated efficiently in the development of all the projects that were assigned to all the teams in which I participated*, M = 3.3, SD = 0.5). Furthermore, students argued that they were willing to finish each project within the established schedule (*I3. I felt motivated to complete each project in a timely manner*, M = 3.3, SD = 0.5) at the same time that they better assimilated the theoretical concepts learned on the course (*I10. The approach used to cover the practical part of the course enabled me to strengthen the theoretical concepts learned*, M = 3.2, SD = 0.4) while also strengthening their communication and teamwork skills (*I7. I realized the importance of teamworking and communication when I used Cadxela to develop the projects*, M = 3.3, SD = 0.5) as well as resolving as a team all the inconveniences that arose in each project (*I11. I was able to fulfill all the assigned tasks despite the inconveniences that arose during the development of a project,* M = 3.1, SD = 0.3).

While most perceptions were quite positive, there was a higher difference in student perceptions when asked about their performance as project managers. For example, 4.8% of students argued that they did not feel comfortable when they had to manage and control a project (*I8. I felt motivated when I had to manage and control an assigned project*, M = 3.1, SD = 0.4), while 43% stated that they were not satisfied with performing such a role (*I12. I am satisfied with my performance as a project manager*, M = 2.5, SD = 0.7). In contrast to these perceptions, students stated that they felt more comfortable as members of a CWS when they played the role of programmers (*I13. I am satisfied with my performance as a programmer and member of a GSD team*, M = 3.2, SD = 0.4). When discussing these perceptions, the participating teachers determined that the training of undergraduate students is regularly more focused on providing technical knowledge that promotes the hard skills among students focusing on software development (e.g., programming, software testing, interface

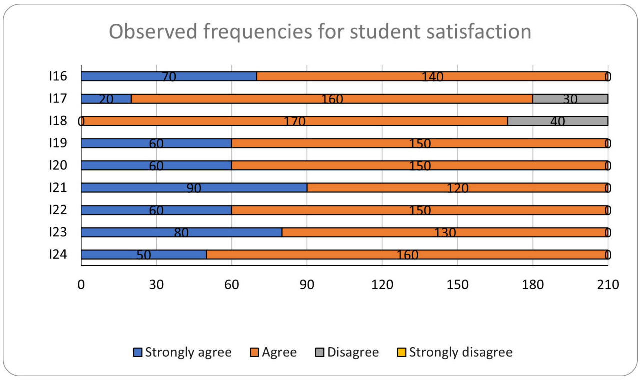

FIGURE 4. **Students' perceptions on satisfaction using Cadxela as an educational support.**

design), while paying less attention to the development of managerial and/or decision-making skills. Therefore, it was found that the approach presented in this study can contribute to improving the undergraduate training of students in this regard.

The information collected with the assessment instrument on student satisfaction also provided quite positive results but also showed drawbacks that, although they did not significantly affect student satisfaction, it is important to mention since they are directly related to the temporal distance that existed among students. For example, Fig. 4 shows that students expressed feeling comfortable putting into practice the techniques learned during the theoretical course (*I16. I felt comfortable applying the agile techniques when I participated on the development of a project with Cadxela*, M = 3.3, SD = 0.5), since the knowledge acquired allowed them to carry out the hands-on activities for each project (*I21. I believe that the theoretical classes were useful in helping me to perform the tasks assigned during a project's development*, M = 3.4, SD = 0.5) in collaboration with their colleagues (*I22. I collaborated efficiently with my teammates*, M = 3.3, SD = 0.5) to develop and evaluate their GSD skills (*I23. I was able to evaluate my GSD skills and I would like to enhance them in order to be better prepared for working in real GSD environments*, M = 3.4, SD = 0.5). This achievement coincides with the research by Clear [39] which claimed that agility can be taught in a such way that the motivation levels can help to develop the students' 'judgement' and 'professionalism' as their mindsets not only change but evolve. However, negative perceptions related to effective communication were also collected as 14% of the students claimed to have had difficulties establishing good communication (*I17. I was able to establish effective communication with all my teammates when using Cadxela*, M = 3.0, SD = 0.5) and 19% experienced problems related to teamworking (*I18. I was able to work efficiently with my teammates when developing projects*, M = 2.8, SD = 0.4).

Although, as previously mentioned, these numbers are not alarming, it is important to explain the causes that might have led to this situation. Firstly, it has been said that three rounds of projects were carried out with different CWS, therefore problems arose during the first round related to student schedules and agendas when using the synchronous and asynchronous communication mechanisms. Furthermore, the student's work culture initially presented some obstacles in reaching an agreement on common schedules to work on the projects assigned, particularly for the phase of requirements elicitation, which required work sessions to generate user stories that were subsequently prioritized through the collaboration of all the members of the CWS. That is to say, some students used to work at night, while others preferred to work in the afternoon. Consequently, the lack of communication during the first round of assignments caused students to display a negative attitude about communication with their teammates. This situation was improved during the second and third rounds since the participating teachers established rules for regulating student participation. Therefore, most of the negative perceptions came from data collected on the first round of projects. Secondly, it is important to mention that this was not an official course, but rather a complement to another course called "Project Management" where student enrollment was strictly voluntary, which may have initially affected the commitment of the participating students.

In this regard, the COVID-19 pandemic has brought these issues to the fore as remote working and distance learning have had to become necessary and ingrained patterns in many students' lives around the world. While it is true that the collected evidence in this study demonstrated good interaction and collaboration levels among students when working as CWS in Cadxela, it cannot be ensured that this achievement will be permanent among students. Therefore, we agree with Clear [40] when stating that the reality of relationships in virtual teams depend not on surface contacts, but upon a deep set of underlying connections built up progressively through joint experiences. We strongly believe then that Cadxela can be an educational tool that helps to make students aware of the importance of communication and collaboration in virtual teams in a GSD context. Moreover, the obtained results evidenced the need to improve the content of topics 3, 4, and 8 of Table 1 and even be more emphatic when explaining and putting into practice communication, collaboration, and commitment skills in the development of GSD projects.

On the other hand, although the students did not feel comfortable playing the role of project manager, a good percentage of them stated that they were able to plan and monitor a project while organizing the activities of each CWS (*I19. I felt comfortable planning a project in Cadxela*, M = 3.3, SD = 0.5 and *I20. I felt comfortable managing a project in Cadxela*, M = 3.3, SD = 0.5). In conclusion, although students are not used to performing activities of project managers on traditional courses, Cadxela can represent an alternative educational resource to instill hard and soft skills required in project management in general.

Finally, a last positive perception was observed from the students who declared that they would be willing to continue using Cadxela in their courses even after the COVID-19

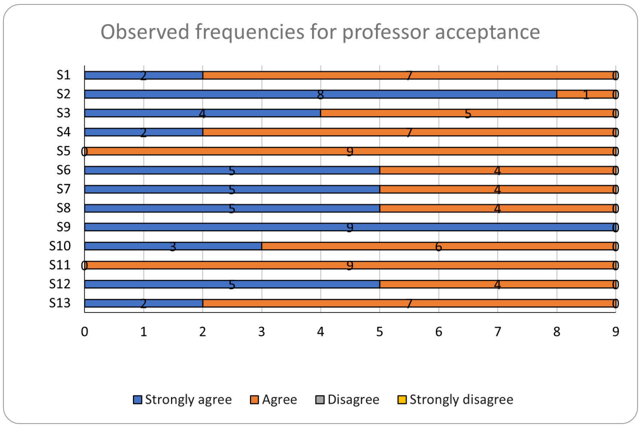

FIGURE 5. Teachers' perceptions on the use of Cadxela as an educational support.

pandemic (*I24. I would definitely like to participate in more Cadxela projects even if the COVID-19 pandemic ends*, M = 3.2, SD = 0.4).

In addition, the Chi-square test for analyzing the questionnaire Likert scale data was applied because it enabled us to determine whether there was a significant difference between the expected frequencies and the observed ones, after Cadxela influenced the three dimensions empirically evaluated (i.e., student motivation, student satisfaction, and teacher acceptance). The Chi-square evaluates the statistical significance of a given hypothesis; the higher the level of deviation between the observed and expected responses, the higher the Chi-square statistic will be, meaning that the results will conform less to the hypothesis. The expected frequencies were determined based on PBL's theoretical considerations and data collected from our previous applications, as cited in [38], which involved undergraduate students working with similar tools. The statistical detailed analysis of the data, resulting charts, and obtained values are available in (https://docs.google.com/spreadsheets/d/1lXoyXHQXPCf-Js7KtPFnQhot78tVB2sA/edit?usp=sharing&ouid=103939208919543218647&rtpof=true&sd=true). In summary, the test for the goodness-of-fit revealed no significant differences between the expected and the observed data for student motivation (x^2 = 0.0; degree of freedom = 3) and student satisfaction (x^2 = 0.0; degree of freedom = 3).

3) TEACHERS' ACCEPTANCE

The assessment instrument designed to determine the teachers' acceptance of the technology used as main support for the GSD course collected important information that confirmed a general acceptance of the approach followed during the worst of the COVID-19 pandemic.

Figure 5 shows that 100% of the teachers agreed that using Cadxela as the main support for the course was an easy task (*S9. It was easy to use Cadxela*, M = 4.0, SD = 0.0) since specific instructions were received when finding inconveniences during the project development (*S11. I received proper instructions from Cadxela when I needed help solving a problem*, M = 3.0, SD = 0.0) or even when receiving appropriate guidance when Cadxela did not provide proper assistance (*S12. When Cadxela's help was not useful, there was always a person ready to help me*, M = 3.6, SD = 0.5).

Furthermore, the teachers also agreed with the results obtained when evaluating the student motivation since they stated that this tool helped the students to improve their practical knowledge on GSD (*S5. Cadxela enhanced student motivation with regard to learning and strengthening their knowledge on GSD*, M = 3.0, SD = 0.0).

Similarly, teachers stated that Cadxela could be a useful tool for promoting GSD practical learning (*S1. Cadxela was able to support the learning process for practical education in GSD*, M = 3.2, SD = 0.4) because it allowed students to develop specific skills by putting theoretical concepts into practice (*S3. Cadxela helped my students to improve their knowledge and skills related to GSD*, M = 3.4, SD = 0.5), while facilitating the assignment of activities and monitoring student progress (*S6. Cadxela facilitated the organization of student teams and the assignment of projects*, M = 3.6, SD = 0.5).

In this regard, the teachers argued that the mechanisms implemented in Cadxela to monitor the project status (*S7. Cadxela provided me with proper tools for project and team monitoring*, M = 3.6, SD = 0.5) and establish effective communication with students (*S8. Cadxela allowed me to establish effective communication with the students*, M = 3.6, SD = 0.5) did not require extra effort when using the tool and they were even able to provide better guidance to the students (*S10. No extra effort was required on my part when learning to use Cadxela*, M = 3.3, SD = 0.5).

It is worth mentioning that, based on the results obtained in the first empirical evaluation carried out during the 2018-2019 academic year, Cadxela was improved by incorporating a mechanism so that each participating teacher could share additional readings, suggestions, or even lessons learned with the CWS. In this way, the teachers' acceptance increased (*S2. Cadxela helped me to better prepare for my practical exercises related to GSD*, M = 3.9, SD = 0.3) in relation to such an evaluation.

Finally, the teachers stated that the implemented technology made it easier for him/her to teach, from a more practical point of view, all the activities related to GSD (*S13. It is more interesting to teach the GSD concepts following the proposed approach*, M = 3.2, SD = 0.4) and that they would undoubtedly use it in future courses (*S4. I strongly believe that Cadxela can be a useful tool for other courses on GSD*, M = 3.2, SD = 0.4).

On the other hand, a small difference was also obtained for teacher acceptance (x^2 = 0.7; degree of freedom = 3). After conducting interviews with the nine participating teachers, it was determined that this difference was due to the fact that the teachers considered that Cadxela could be a useful resource for supporting GSD courses during the height of the COVID-19 pandemic. Therefore, our historical expected values did not contemplate learning situations when social distancing is in place.

4) EXPERIENCES RELATED TO GEOGRAPHICAL, TEMPORAL, AND SOCIO-CULTURAL DISTANCES

In addition to the aforementioned results, the empirical evaluation enabled us to identify some issues that students experienced in relation to the geographical, temporal, and socio-cultural distances which are present in all GSD projects. Therefore, information was collected through project online monitoring with Cadxela, as well as through the data analysis that the same tool provided teachers on the student interaction and their participation in each CWS during the COVID-19 pandemic. The aim of presenting this set of experiences is to contribute similar research that intends to incorporate the CWS concept into other Software Engineering courses under conditions of strict social isolation.

Geographical distance would commonly be related to the measure of the effort required by students to travel between different countries to work on the software projects while establishing relationships and creating a team spirit within the CWS where they participate. In the context of the GSD course, this distance introduced issues that complicated collaboration as well as CWS awareness and trust among students. The main issue was the lack of formal meetings that limited opportunities for students to exchange knowledge in the first round of projects, and it also negatively affected the generation of interpersonal relationships among them. In this regard, since most of the students are used to communicating through social networks, the holding of informal meetings from the start of the practical component of the GSD course was carried out without problem in terms of problem solving, collaborative discussions, brainstorming for identifying the user stories, tutorial sessions, among other tasks. On the other hand, students were more reluctant at the beginning to hold formal meetings since these require a more formal structure. These meetings were held to discuss the project progress and began with an introductory talk by the teacher in charge of each CWS for approximately 10 minutes to present the project's pending activities, followed by a 3-minute participation by each student depending on their role in the project. These meetings were supported by the Kanban board implemented by Cadxela and the compulsory participation of all the CWS members was established at the beginning. However, the geographical distance initially affected the participation of students in these meetings, therefore it was decided to improve the mechanisms implemented in Cadxela to mitigate its effects. Therefore, considering the recommendations of Al-Zaidi and Qureshi [41] and Ka e nat et al. [42], the synchronous and asynchronous communication mechanisms were improved from the integration of the CWS concept as follows:

- Cadxela was able to detect collaboration opportunities and generate an automatic alert for the CWS members in order to start a real-time communication. Such an alert was sent through the e-mail registered in the tool, and sending text messages by cellular phone was also added. In this regard, the chat module presented the topics to be discussed depending on the activities managed through the Kanban board with the aim of generating more productive communication over a shorter period. Of course, in addition to this improvement, students could communicate at any time in a "same time, different place" mode through chat in a traditional way to deal with other issues related to solving problems, discussing activities, or simply chatting.
- In addition, the video conferencing module was improved to carry out follow-up meetings, leaving a simple interface to use so that the network infrastructure of each university would affect the quality of communication to a lesser extent.
- On the other hand, considering the communications in "different time, different place" mode, the wiki initially implemented in Cadxela was preserved as an asynchronous communication mechanism as well as the sending of e-mails and the use of video tutorials. However, it was also decided to store and share all the conversations carried out through chat as long as they had been derived from a collaboration opportunity suggested by Cadxela. Similarly, in the activities where the exchange of ideas was carried out through text inputs (e.g., requirements elicitation, effort estimation, story user prioritization) the conversations were stored so that they could be consulted by the students, mainly when their schedules did not coincide or when communication was not clear due to the use of Spanish language idioms, as will be explained later.
- Finally, a discussion board was incorporated into Cadxela as a synchronous or asynchronous communication mechanism so that students could exchange their ideas on the project. In this way, the students were able to talk as well as reflect upon issues that arose throughout the course.

In addition, *temporal distance* would be defined as the measure of the change or alteration in time, derived from geographical distance, which is generally experienced by two students within a CWS who want to interact to perform a particular activity. In the context of the GSD course, this distance results in few hours when students can participate in asynchronous meetings. Moreover, it caused delays in knowledge transfer among the CWS members and decreased their coordination quality, caused mainly by the time zone differences. With the aim of addressing this shortcoming, research by Alotaibi and Qureshi [43] was taken into account in order to mitigate the negative effects of temporal distance as follows:

- It is unfeasible that students located in different places around the world can always coincide to carry out remote face-to-face meetings due to geographic distance and the different time zones. Therefore, the original design of Cadxela was changed to hold weekly meetings instead of daily meetings using for the most part the videoconference and chat modules implemented into the tool.

- Furthermore, although it was intended to prevent students from wasting time by using multiple software tools to develop and manage each assigned project, the creation of WhatsApp groups was introduced into the GSD course as an additional tool for facilitating synchronous communication and the coordination of the project activities.
- Similarly, a work policy was established that was not used during the empirical evaluation carried out in the 2018-2019 academic year, which consisted of students responding to e-mails or messages sent within 8 hours at the most in order to avoid delays in a project's delivery. In this regard, this new policy was related to the Cadxela functionality of sending messages to the students' cellular phones to constantly update them on the status of their CWS.

Finally, *socio-cultural distance* would be defined as the measure of a student's understanding of a teammate's culture, ethnicity, social values, and even sexual preferences. Such a distance would hinder not only the communication among students, but also the proper choice of communication mechanisms. Furthermore, culture may influence the students' interpretation of a conversation, mainly due to the different interpretations that a certain action can have in different cultures derived from the diverse cultural norms, ethnic and religious beliefs, and the understanding of gender equity. The Spanish language, for example, has a significant number of idioms in Latin America, which can often cause confusion and misunderstanding among speakers. This situation not only hinders conversation but can also affect the understanding of technical terms. Therefore, the following actions were required:

- Based on the results obtained from the empirical evaluation of the 2018-2019 academic year, a glossary of Spanish words was prepared to address the language differences among students during this new empirical evaluation. Such a glossary was updated and expanded during the first round of projects to include as many Spanish idioms as possible with the intention of improving communication between students from different countries.
- On the other hand, the minimal confusion or misunderstanding during the interaction of the CWS members negatively affected their productivity and the adherence of the teams in general at the beginning of the collaborations. Therefore, it was established that the students should organize meetings through the Cadxela videoconferencing module to clarify technical doubts and the meaning of the colloquial idioms that were often used. Therefore, the interaction with the synchronous communication mechanisms provided by Cadxela was weighted to use facial expressions in favor of the students when a teammate tried to explain the meaning of a term used in providing a response within the CWS.
- Finally, the students' assumptions about the work culture and work habits of their counterparts in other countries also negatively affected the productivity of the CWS during the completion of the first round of projects. Therefore, it was necessary to improve the theoretical material related to the topic "5. Cultural diversity in GSD" so that teachers provide a better cultural orientation to students leading to a better understanding of relevant aspects of the development of GSD projects such as work habits and time availability. In addition, taking into account the suggestions by Imtiaz and Ikram [44], a software component was incorporated into Cadxela to manage the workload experienced by the CWS in each project with the aim of monitoring the performance of each member and providing them with specific corrections that increased the coupling of the CWS and the feeling of belonging among the students. Such a strategy improved student performance in comparison with the initial round of projects because the number of meetings, participating students, number of interactions, number of inquiries to clarify Spanish words, and feedback among students were measured.

In conclusion, the collection of these experiences shows that the objective of our study was to provide students with training which was as close as possible to reality on obtaining maximum productivity in short periods of time when software is developed in a distributed manner, a main objective in real GSD contexts.

V. DISCUSSION

Although there are a number of research studies that have focused on improving education in GSD at undergraduate level, there were few efforts aimed at strengthening students' skills in this flied during the COVID-19 pandemic. Moreover, the number of studies is further reduced if the participation of different countries, universities and students is involved. Table 5 presents a comparison with three similar studies [9], [10], and [11] all of which were conducted by case study research. For this comparison, the number of countries and universities, number of students, number of developed projects, educational and technological approach, dimensions and number of items measured were taken into account.

Most of the studies were implemented in undergraduate programs, except for the study by Titze et al. [11] that was implemented on a master's degree program. The resulting proposals from the research by Zhang et al. [9], Schmiedmayer et al. [10], and Titze et al. [11] were implemented among universities located in countries in Asia (China, Japan) and Europe (Germany, Portugal), while Cadxela was implemented in universities located in countries in Latin America (Argentina, Bolivia, Chile, Ecuador, Mexico, and Peru) and Europe (Spain).

TABLE 5. Comparison with previous studies.

Study	Number of participating countries and /universities	Number of participating students	Number of developed projects	Educational approach	Technological approach	Dimensions measured or lessons learned	Number of items
Zhang et al. [9]	2/2	37	1 (12 weeks)	PBL	Multiple web tools	Inner-team evaluation Inter-team evaluation Faculty evaluation	6 3 5
Schmiedmayer et al. [10]	3/3	21	1 (1 week and 3 days)	Mixed (theoretical lessons and PBL)	Multiple web tools	Recommendations and Lessons learned by teachers	5
Titze et al. [11]	2/2	11 Japanese students, the number of German students is not specified	Not specified, only the development of "multiple" software prototypes is mentioned	Mixed (theoretical lessons and PBL)	Multiple web tools	Students' experiences during the course	Not spec ified
Our study	7/7	70	8 (26 weeks)	Mixed (theoretical lessons and PBL)	Cadxela and WhatsApp	Student' GSD knowledge Student's motivation Student's satisfaction Teacher's Cadxela Technology acceptance	20 15 9 13

The educational approach is one of the important aspects to considerer when a CWS is implemented, which is why combination of the PBL and theoretical lessons is recommended. It is important that the students are introduced to both approaches, either previously or during the implementation, so as to avoid situations like the ones described in the study [11] where the German students were not familiar with PBL or study [9] that only applied the PBL approach. For this study all the universities had worked with both educational approaches before starting the GSD course, which proved advantageous for both teachers and students.

In this regard, although in this case study all the students spoke the Spanish language, the cultural implications of each country were reflected in the use of multiple Spanish idioms for the same word. This situation initially represented an obstacle for effective communication among students during the first round of projects since the meaning and interpretation of many words were different. In addition, difficulties were experienced due to the students' work habits, since, for example, participants from Argentina, Chile, and Spain took less time to reply to e-mails, provide an asynchronous comment, or complete an assigned task, while students from Bolivia, Peru, and Ecuador took more time due to their communication culture that values discussion and consensus before giving a response. Mexican students, on the other hand, preferred direct interaction. In this regard, lessons learned from research by Hodar et al. [45] and Bosnić et al. [7] were taken into account to create a glossary that was uploaded to Cadxela. This mean that any student and/or teacher could consult it at any time so that each CWS could clarify any doubts relating to certain phrases or words that could generate confusion and, as a consequence, negatively affect communication during the development of a project. Table 6 shows an example of a few words that were included in the glossary solely with the intention of demonstrating that language differences were one of the main challenges that socio-cultural distance introduced among students. Considering that all the work conversations carried out by each CWS with the Cadxela's asynchronous communication mechanisms were stored for possible later revision, the students could use such a glossary to clarify their doubts when it was not possible to use a synchronous communication mechanism. Similarly, the recommendation of asynchronous communication was found in study [11].

Furthermore, Argentine and Mexican students did not usually respond to emails to confirm, for example, their approval of an important project decision that had been taken during an asynchronous interaction. The students assumed that this decision already reflected the opinion of the majority and concluded that they should not respond. However, students from Chile, Spain, and Bolivia interpreted this silence as a lack of interest in the project. Therefore, the teachers paid great attention to always carrying out an equitable distribution of the workloads with the intention of leveling the effort and time that all the students dedicated to the project's development.

In this regard, students from Mexico and Peru were characterized by giving their maximum effort during the final phase of the projects, while the students from Argentina, Bolivia, and Spain worked at the same pace throughout the project. On the other hand, important time zone differences affected the agenda when their schedule did not coincide.

A set of experiences related to geographic, temporal and socio-cultural distances that affect all GSD projects that can

TABLE 6. An example of the cadxela glossary to standardize the different interpretations for spanish words and phrases during the GSD course.

Word/phrase	Spanish idioms
Friend	*Boludo* (Argentina), *Tío* (Spain), *Pana* (Ecuador), *Cuate* (Mexico), *Weon* (Chile), *Causa* (Peru)
Do something at an indefinite time	*Ahoritinga* (Bolivia), *Ahorita* (Mexico), *Rajado* (Chile),
Work (assigned tasks)	*Curro* (Spain), *Chamba* (Mexico, Perú, Ecuador), *Laburo* (Bolivia), *Pega* (Chile)
Cool (we like a person or situation)	*Guay* (Spain), *Chido* (Mexico), *Chévere* (Ecuador), *Piola* (Peru), *Bacán* (Chile, Peru), *Copado* (Argentina)
I agree	*No veeeee* (Bolivia), *Vale* (Spain), *Sobres* (Mexico), *Bacán* (Peru)
I'm tired	*Ya no jalo* (Ecuador), *Estoy zombi* (Chile), *Estoy hecho percha* (Argentina), *Estoy molido* (Mexico)
It is very easy (task, work)	*Chupado* (Spain), *Papayita* (Peru, Chile), *Pan* (Mexico), *Boludez* (Argentina)
Get upset about something	*Cabreado* (Spain), *Le dio el indio* (Chile), *Se le saltó la térmica* (Argentina), *Asado* (Peru), *Encabronado* (Mexico)

be useful even outside of the COVID-19 pandemic was compiled. One important difference with the approach proposed in this paper is that, as previously mentioned, except for the use of WhatsApp, all of the tools that the students used are implemented into Cadxela, thus reducing the level of distraction from students when collaborating in project activities.

Finally, it is important to remember that our research implemented the CWS concept with the aim of helping students to identify opportune moments of collaboration during the development of different projects under conditions of total social isolation.

In summary, the COVID-19 pandemic introduced educational challenges that affected the education of undergraduate students in different areas of Software Engineering, but also provided opportunities to create hybrid work proposals that would maintain appropriate student motivation and commitment to generate meaningful learning. Therefore, we strongly believe that no research is better or worse as all investigations were carried out with the intention of training well-skilled students in GSD and generating a set of learned lessons that can be useful after the COVID-19 pandemic.

VI. LIMITATIONS

One of the main limitations of our study is related to the number of universities and students that participated in the empirical evaluation. In this regard, our research focused on evaluating an educational approach that only involved highly engaged students motivated to collaborate with their peers from other countries at the height of the COVID-19 pandemic. In this regard, since it was extensively documented that student motivation and performance were negatively affected as a result of social isolation, it was decided that each participating teacher would launch the call to enroll ten of their most motivated students to participate in the GSD course. Consequently, it was decided not to determine the exact sample number since the situation that the students were going through during the COVID-19 pandemic was not the most conducive in encouraging them to take a course not deemed compulsory. Therefore, in no way should it be interpreted that the results presented in this article can be generalized since this requires more evaluations with a larger number of participants. Moreover, the results reported in this study cannot be extrapolated to represent students from each participating country in general terms.

Furthermore, the Spanish language is another shortcoming of our study since it limits its applicability in universities where the native language is different. This was mainly due to the ease of initially working with collaborators from universities where collaboration and/or friendship relationships were previously established thereby facilitating the definition and coordination of a one-semester course. However, a third case study is planned for the middle of 2023 involving four public universities from Ireland, the United States of America, and China which will require that participating students use the English language.

Similarly, the fact that an unofficial GSD course was designed and delivered among the participating universities reduced the possibility of having more student participation. However, the study considered it more important to have students who were really motivated to learn and put into practice techniques and tools used in the industry for the distributed development of software projects during the COVID-19 pandemic. Despite the fact that it is practically impossible to standardize a GSD course in the curricula of all participating universities once the pandemic was over, in the upcoming case study participating students will be incentivized by obtaining credit, potentially helping their grades in courses related to Software Engineering.

Finally, the experimentation strategy in our case study did not define experimental and control groups since the course was designed for a pandemic scenario for which there was no educational GSD material that combined practical activities with a theoretical approach. Therefore, we consider that the replicability of our proposal is limited to the definition of strategies that use only an experimental group of students. Despite the fact that we consider that this does not detract from the results achieved with this case study, the undertaking of new empirical evaluation will be contemplated using a different approach where students from an experimental group use Cadxela to carry out the practical part of the GSD course, while a control group uses a traditional approach making use of tools such as Zoom, GitHub, and Jira to evaluate student productivity during the course.

VII. CONCLUSION

Globalization, economic growth, and technological advances have changed the way that software is developed around the world. Currently, this task can be carried out by people who perform their job in different locations, which are not necessarily within the same country, and who are younger, better skilled, and enjoy collaborating with other people from other countries with different work habits, national cultures, sexual preferences, and who even speak different languages. It is true that this work paradigm, called GSD, has revolutionized the software industry since it has increased organizations' profits while reducing development costs. However, it is also true that it has introduced an imperative need for teaching methods that contribute to the training of highly skilled software graduates who should be able to work efficiently in this distributed scenario. Unfortunately, the COVID-19 pandemic that began worldwide in April 2020 introduced many more difficult challenges to solve, mainly for the universities that were not ready to adapt to the drastic changes in the teaching paradigm. Therefore, the aforementioned pandemic forced many academic institutions to transition to fully online or hybrid model courses, affecting the students' acquisition of hard and soft skills in highly practical and technical areas such as GSD.

Considering this educational scenario, the study presented in this paper aimed to address the problem of training undergraduate students during the COVID-19 pandemic and whose professional careers were related to Software Engineering. Particular attention was paid to software development considering the global context of the students' geographic locations. Therefore, the review and implementation of the CWS concept was considered to instill in undergraduate students from seven different countries the detection of potential interactions that generate productive collaborations so that they would be able to understand the importance of respecting cultural differences, work habits, and time availability of their partners when GSD is implemented in a real context. In this regard, the main focus of our research was to make students experience first-hand the challenges generated by the so-called three distances: geographical, temporal, and socio-cultural, present in this way of developing software. It could be argued that our proposal makes no sense since given the nature of GSD, where it is not necessary for students to be located in the same classroom to learn principles, techniques, or processes related to this work approach, because it is a fairly similar scenario to that established by social distancing caused by the COVID-19 pandemic. Nevertheless, many universities around the world rely on the traditional teaching paradigm to cover Software Engineering related courses, which are commonly supported by the PBL approach for students to develop GSD projects by co-located or locally distributed teams. Therefore, our research aimed to provide educational support for such universities, as otherwise, students would not be able to receive specialized training during the almost three years that the COVID-19 pandemic has lasted.

With this aim in mind, an educational tool called "Cadxela" (a Zapotec word than means "discover") was introduced to achieve this goal. Cadxela is an open-source tool which represented the most cost-effective and practical approach for teaching GSD, as suggested by Beecham et al. [46], during the COVID-19 pandemic. Moreover, students were introduced to GSD challenges and collaborated in GSD projects by using Cadxela in order to apply specific techniques and processes that students had to master. It is worth mentioning that our proposal implemented the CWS concept in Cadxela for academic purposes only and it is not an objective of this study to create a tool that competes with Microsoft Teams, Trello, Slack, git, Jira, or even Moodle, Classroom, or Zoom, all of which have been widely used to support undergraduate courses during the COVID-19 pandemic. As previously mentioned, the aim of our study was to make learning GSD easier without the need to use multiple tools in order to hold students' attention for as long as possible.

The results derived from an empirical evaluation conducted during the March 2020 - October 2020 academic semester with teachers and students from seven universities in different countries showed positive effects on the participants who improved their academic achievements, and obtained acceptable levels of motivation and satisfaction, despite being immersed in the COVID-19 pandemic. In addition, the study carried out allowed the collection of a set of experiences that may be useful for other teachers and/or researchers who may be interested in carrying out similar projects. Therefore, the evaluation instruments used to determine the academic achievements, motivation and satisfaction of the students, as well as the questionnaire designed to determine the acceptance level of teachers and the instrument for the analysis of the collected data are being shared in this contribution with the aim of promoting the reinforcement of teaching topics related to Software Engineering at undergraduate level such as GSD. As a final consideration, it is worth mentioning that the organization and delivery of distributed courses represent a challenge for the universities and teachers involved in their design and delivery. Without efficient communication and the real commitment shown by all of the participants, it would have been impossible to establish a common schedule to carry out an additional course which required a greater effort. That is to say, the course presented in this empirical evaluation was carried out in parallel to the official curricula, meaning that there was an increased workload for both students and teachers. In addition, this situation was further complicated by the COVID-19 pandemic. Thus, it is important to mention that the positive results that were presented in this study largely correspond to the climate of collaboration that was established between the teachers after more than 10 years of friendship, respect, and hard work. Furthermore, we consider it important to mention that any effort that is intended to start an improvement in the teaching/learning process of different Software Engineering topics, be it based on the friendly relationships among researchers and their positive experiences of working together in such a way that be possible to carry out productive efforts that lead to obtain useful experiences which allow improving the training of undergraduate students while the COVID-19 pandemic continues.

Finally, we believe that our research has contributed to Software Engineering education by presenting detailed technical aspects on how to implement the CWS concept when highly technical knowledge is comprised, a collaborative course on GSD that will be constantly improved by the addition of more universities, a technological platform that supports teacher activities, and a set of lessons learned that might be useful for other teachers in motivating their students even when the COVID-19 pandemic is under control.

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