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Teaching Communication, Interpersonal and Decision-Making Skills in Engineering Courses Supported by Technology*

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Communication, interpersonal and decision-making skills are essential for engineering work and should be explicitly incorporated in engineering curricula. We have tested a constructivist, technology-supported collaborative strategy in engineering courses that is aimed at supporting the teaching of regular subject matter as well as fostering the development of students' communication and social skills. In this strategy, students communicate face-to-face through a social network while supporting their work with handhelds interconnected through a wireless network. Information transfers from the social network to the handheld network and vice versa, meaning that collaborators maintain face-to-face interaction at all times while also being able to obtain and retrieve information. To implement this strategy, a technology tool named CollPad was created and applied in two computer science courses. The qualitative results of the experience show that students found the tool effective in creating an environment that promotes communication, interpersonal and decision-making skills.

Keywords: face-to-face computer-supported collaborative learning; CSCL; participatory classroom; communication skills; social skills; one-to-one learning; constructivist learning; small group learning

INTRODUCTION

THERE IS AN URGENT AND GROWING NEED for social skills and abilities in leadership, teamwork and multi-disciplinary work in the field of engineering. As Shakhgildian *et al.* [1] notes, 'an engineer's competence can be presented as the aggregate of knowledge, skills and know-how. Knowledge works only through the activity of the person, groups of persons and people'. Complementary techniques based on learning by doing have proved to be most appropriate for computer science teaching [2].

To develop these skills, the traditional class, which is basically centred on the teacher, must be transformed into a participative class centred on the student with work groups that collaborate to meet objectives and develop critical thinking. Li expresses the same idea when he asserts that 'building an education enterprise suited to the new times requires developing new education strategies, designing new teaching and learning modes, and creating learning environments that enhance learners' proficiency in understanding, thinking, reasoning, and problem solving' [3]. We propose a face-to-face computer-supported collaborative learning (CSCL) approach that focuses on the development of communication, interpersonal and decision-making skills inside the classroom in regular course subjects. Our implementation, called CollPad, is based on wirelessly networked PDAs and supports a classroom divided into small groups of students who attempt to solve a problem in a constructivist manner. We analyse the application of CollPad in two computer science courses, one on knowledge management and the other on human-computer interfaces, and present an analysis of the type of activities performed together with the students' evaluation of the experience.

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SUPPORTING COLLABORATIVE WORK IN CLASSROOMS

In the traditional classroom, students are expected to work individually on their assigned tasks without interrupting others. Verbal exchanges between them are usually discouraged and interactions with teachers are generally confined to asking and answering questions. Opportunities to work cooperatively are minimal [4, 5].

Transforming the learning process into an interactive and collaborative experience would result in clear pedagogical benefits [6]. Once students are permitted to work in small groups, they are able to develop a common understanding as well as verbal and social abilities [5]. When working collaboratively they participate more in group discussions, employ a more sophisticated level of discourse, interrupt less when others are speaking and make more intellectually valuable contributions to the discussions [7]. Dialogues in small groups are multidirectional rather than simply bidirectional, as is normally the case in traditional classrooms, or even unidirectional, as often occurs with peer tutoring dyads. The transitive nature of group discussion contributes to productive meta-cognitive decisions by making students think publicly and exposing them to critical scrutiny [8].

The advent of the participatory classroom has been foreseen for some time [9]. Technology supports such strategies through the use of small handhelds or clickers that allow students to respond and interact. It enables instructors to instantaneously collect student responses to a posted question, generally of the multiple-choice variety. Answers are immediately registered and displayed to all students. This approach has been utilized mainly to assess lectures or pre-existing levels of understanding and poll student opinions or attitudes [10].

Social learning, cooperative and collaborative systems all embody a constructive approach in which the computer is used more as a partner than a tutor, that is, as a way of exchanging, controlling, and building knowledge among partners instead of just a device for directed training [11]. With computer-supported collaborative learning (CSCL) [12–13] the focus is not so much on the individual who learns and thinks as on the collaborative group that explores and reasons. The goal of CSCL lies beyond mere technology and its achievement requires an understanding of cognition, communication, culture and the social setting to be successfully implemented.

In this paper we go one step further, using face-to-face CSCL [14] for the development of communication, interpersonal, and decision-making skills inside the classroom. Face-to-face collaboration involves not only the tasks to be performed but also the human aspects of communication [15]. Face-to-face communication encompasses much more than speech, extending to such elements as gestures, eye contact and other non-verbal cues. The ability to perceive and interpret these forms of information, and their relation to the tasks undertaken by a group, are important for the processes of negotiation, agreement, and acknowledgement of understanding. The different backgrounds of group members require a shared understanding that is facilitated by face-to-face relations [16].

The aim of a constructivist problem-solving strategy is to allow students with different skills and backgrounds to collaborate on a given goal, discussing the task before them in order to arrive at a shared understanding that will lead to a solution. Students accustomed to teacher-directed instruction cannot automatically switch to thoughtful classroom discourse, however, and assistance in initiating and sustaining own and group learning will be necessary [17]. The question, therefore, is how can this assistance be implemented in the classroom.

Mobile technology provides an opportunity to support collaborative work by introducing computing capabilities through a ubiquitous channel. Whereas a PC physically limits a task to a fixed location, mobile technologies allow users to move around while simultaneously accessing information from both the digital and real worlds [18]. With an appropriate conception, mobiles facilitate learning. Designs allowing children to collaborate around a small device can be achieved if close attention is paid to the details of the intended interactions [19].

Wireless handheld devices are the specific mobile tools that allow us to change the nature of students' classroom experience. Interconnected in wireless networks (WiFi), these devices enable face-to-face CSCL to take place [14]. Participating students are each supplied with a handheld, allowing them to work as peers in groups while simultaneously being mediated by the technology. Two networks can be identified, a technological one and a social one. While the users communicate face-to-face through the social network, they support their work with the interconnected handhelds through the wireless network. Information has to transfer effectively from the handheld network to the social network and vice versa, which means that group members must maintain face-to-face interaction at all times while also being able to obtain and retrieve information, thus ensuring mediation by the technological network is adequate [20].

COLLPAD

In the CollPad system [21] a single problem is assigned to a class of students who have been divided randomly into groups of three. The activity begins with individual efforts as each group member inputs an answer reflecting what he/she knows about the problem into his/her personal device. Once all group members have inputted their own answers, they must then collaborate on the determination of a common response. A discussion is initiated in which each of the members makes use of previous knowledge as they attempt to persuade one another, continuing this process until disagreements have been resolved and the group's views have converged on a common solution [11]. The consensus response may be a single member's individual answer or one they have built concurrently.

This group answer construction stage is the key to CollPad's social constructivist approach [22]. The process of arriving as a group at a common understanding is essential, and the system will not allow them to proceed to the final stage until it has been achieved. At this point the teacher's role becomes crucial, as he/she must reconcile the answers of the different groups involved [23]. To

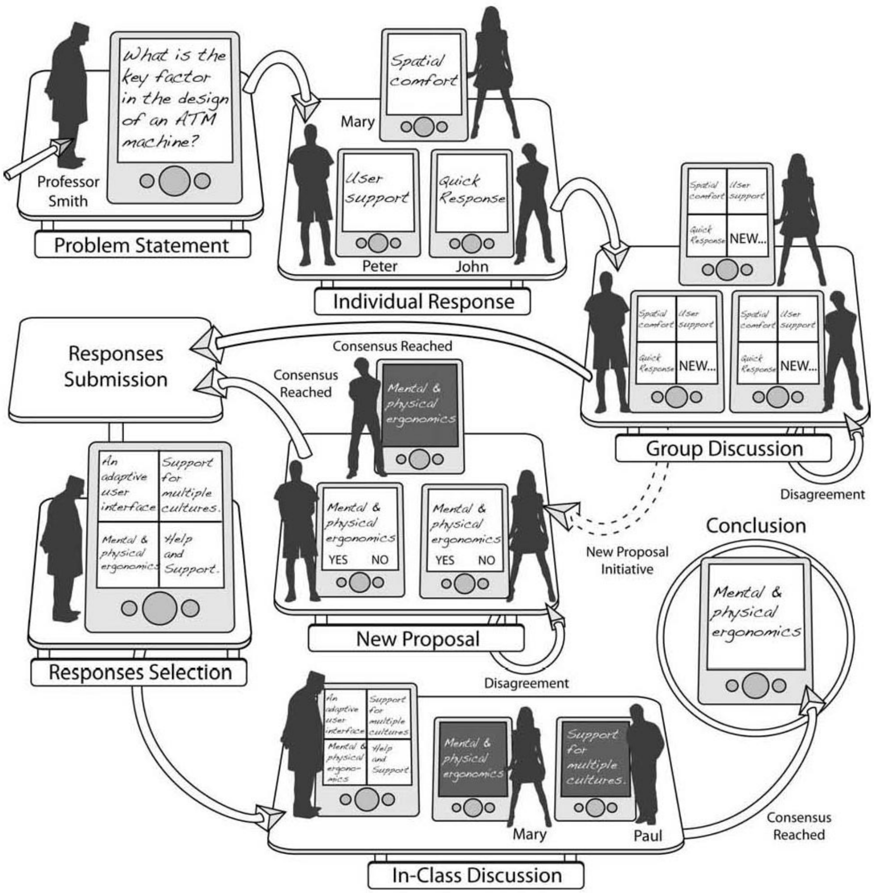

Fig. 1. Example of CollPad strategy.

do this the teacher selects a subset of the answers received. For each group answer so selected the technology randomly picks one of the three members of the corresponding group to be a participant in a classroom discussion. These answers constitute the pieces of knowledge that converge through teacher mediation to a final classroom answer, and thus the whole class arrives at an understanding of the assigned problem.

The diagram in Figure 1 presents an example of a complete cycle of a CollPad activity. Professor Smith begins the activity at the Problem Statement phase by posing an open-ended question: "What is the key factor in the design of an ATM machine?" In the Individual Response phase, all the groups in the class (such as the one in the diagram formed by Peter, John and Mary) receive the professor's question and CollPad then prompts each student to enter his/her own personal response.

Once all their individual answers are entered, the groups proceed to the group discussion phase. As shown in our example, Peter, John, and Mary can see each other's responses in this phase on their screens. They must either agree on one of the responses entered in the individual response phase as their shared, consensual answer, or, if they decide to reject all of these, they must then draft a new one. Whenever the individual group members' choices differ, CollPad prompts each of them to seek agreement with his/her companions and forces the group to continue discussion until all members finally settle on the same choice. If the group agrees on one of the answers from the individual response phase, it is then submitted to Professor Smith and the group waits for the in-class discussion phase. If, on the other hand, the group decides to redact a new joint response, it jumps to the new proposal phase.

In this stage the group must collectively arrive at a new response. In our example, CollPad randomly assigns the role of scribe to John and that of reviewer to both Peter and Mary. John's screen is highlighted, indicating that CollPad has enabled him to record the new answer with the cooperation of his companions. Once John has entered it in his handheld he sends it to Peter and Mary, who can either accept or reject it. If Peter accepts the answer while Mary rejects it (or vice versa), CollPad prompts the two of them to come to an agreement. If they both decide to reject John's answer, CollPad discards it and randomly reassigns the scribe and reviewer roles, thus the entire process is repeated until the reviewers agree to submit the scribe's answer to Professor Smith as the group's final joint response. It is therefore the reviewers' duty to ensure that what the scribe records truly represents the group's shared answer to the problem the professor initially stated.

While the groups are in the individual response, group discussion, and new proposal phases of the activity, Professor Smith continuously monitors their progress. Upon receiving the group responses he/she selects those that show the most potential for generating a whole-class discussion (the in-class discussion phase in Figure 1). In this stage all of the students, mediated by the teacher, work together on exploring these responses to the initial problem as they attempt to reach a final consensual answer. In our example Professor Smith selects four responses (assuming there are at least four groups in the classroom). He/she then chooses one of two modes: discussion or voting. In discussion mode, one member from each group whose response was selected is randomly chosen by CollPad to be a defender. The role of the defenders is to verbally justify their respective groups' answers. In our example, Mary and Paul plus two representatives from the other two groups (not shown in Figure 1) were selected for this task. Their screens are highlighted, showing the responses their respective groups submitted. The other students can see all of the answers selected by Professor Smith and participate in the discussion by contributing their own views and opinions. In voting mode, on the other hand, the responses selected by Professor Smith can by seen as eligible options by all of the students, who must vote for the response they think is best or most appropriate. Professor Smith then picks defenders at random from each group whose answers he/she selected. The voting results are reviewed, the various justifications given by all of the defenders are discussed by Professor Smith and the students, and the entire class works toward a consensual response to the original problem. At this point, the professor brings the In-Class Discussion phase to an end by announcing the correct response (Conclusion).

TWO EXPERIENCES IN COMPUTER SCIENCE TEACHING

We begin with some basic information on the objectives of the courses and the students registered in them, and then present two different analyses of the experiences. The first evaluates the quality of the activities in terms of the objectives of CollPad while the second is based on the points of view of the students who participated in the activities.

Context and sample

The CollPad system was applied in two computer science courses given in 2007 as part of the engineering program at the Pontificia Universidad Católica de Chile. The courses were taught in consecutive semesters by the same professor, who is also one of the authors of this paper. Each course consisted of about 16 three-hour lectures.

In the first semester, CollPad was used in a course on knowledge management. Its objectives are to increase students' awareness of the significance of human beings amid the dizzying pace of technological development, and the importance of understanding and modeling their role with a view to better comprehending this process and how to intervene in it. In the second semester, CollPad was used in a course on human-computer interfaces whose goal is to study how humans carry out a task with an artifact. The analysis undertaken addresses their cognitive aspects in addition to other factors peculiar to the process arising from the artifact's use.

The two courses are aimed at graduate students as well as upper-year undergraduates in the engineering program who are specializing in computer science. There were 27 enrolled students in the first course and 28 in the second. Since eight students were taking both, the total number of different enrollees was 47.

CollPad activities were carried out in the courses in almost every class, always using the same methodology. Groups of three students were formed randomly from among those present, who would then have to respond to a question set by the professor on a subject related to the material being covered in that class. Once all of the groups had submitted their answers, the professor selected the four that appeared to be the most interesting and the system randomly named a student from each group whose response was so chosen to defend it. The entire class then voted on the answer they believed was the correct one. As an incentive the professor awarded extra marks to the members of the four groups whose responses were selected, the highest award being given to the group whose answer received the most votes.

Evaluation of the activities

To measure the quality of the CollPad activities performed in the two courses, a series of variables were defined as set out in Table 1. For the purposes of this study, quality means the ability of each activity to support the achievement of our objectives, which are to develop communication, interpersonal and decision-making skills. A secondary factor for determining quality is an activity's ability to support learning by the students. Thus, the variables denoted Amplitude and Discussion-Oriented measure the support for the above-mentioned social skills while the Coverage and Scope variables gauge the activities' support for learning.

A total of 21 activities were evaluated, of which 12 were carried out in the Knowledge Management course and 9 in the Human-Computer Interface course. Since the outcomes for the two courses were quite homogeneous, it was decided for evaluation purposes to treat them together rather than separately. The results of the evaluation are graphed in Figure 2, showing the frequency of the scores obtained for each variable. As can be

Table 1. Evaluation format for scoring CollPad activities

Variable	Definition	Possible scores
Amplitude	Indicates the number of different viewpoints that may be present in the analysis of the activity.	– High – Medium – Low
Discussion-Oriented	Defines whether the activity allows for discussion of the solution among the students in which they can develop their answers, or whether the solution is exact and therefore not open to discussion.	– High – Medium – Low
Coverage	Indicates how much of the course material intended for reinforcement is covered by the activity.	– High – Medium – Low
Scope	Indicates whether the scope of the question is merely conceptual or encourages the students to apply the material in other contexts.	– High – Medium – Low

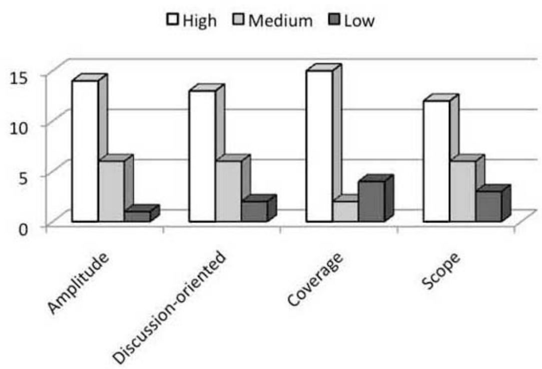

Fig. 2. Distribution of scores for each evaluation variable.

observed, for all of the variables a score of High predominates. If to this is added the fact that more than 60% of the activities scored a High on at least three of the four variables, we may safely conclude that the quality of the activities conducted was sufficient to support this study's objectives in terms of developing the skills indicated above.

Table 2 shows several examples of CollPad activities conducted during the two courses that received good or bad evaluations. Generally speaking, those that were evaluated negatively were conceptual in nature and covered little course material. It should also be noted that the topics treated in both courses lent themselves well to the application of CollPad.

The definition of the variables in Table 1 and the process of evaluating the activities both postdate the application of CollPad in the Knowledge Management and Human-Computer Interface courses. The professor involved was therefore not aware of either at the time the courses were given. The high scores registered by the activities (Figure 2) indicate that an expert in a given field would be able intuitively to develop activities that meet the defined objectives (Table 1) without requiring explicit, formal guidelines for specifying them.

Evaluation of CollPad by students

To evaluate the students' views on the usability of CollPad, an open questionnaire was distributed containing four questions (see Table 3). This was done some time after the second of the two course experiences with the system to ensure there would be no relationship between the students' course performance and their opinions on the collaborative activities. Although all 47 students involved in the CollPad experiences were invited to return a questionnaire, only 29 did so. Of these, 17 had taken the Knowledge Management course and 19 the Human-Computer Interface course, with seven enrolled in both.

Table 2. Examples of good and bad questions used in the two courses

Course	Evaluation	Question	Explanation
Knowledge Management	Good	Give examples of the Vygotsky model based on situations in your daily life.	A broad question whose scope is applied; can be developed from the point of view of each student's experiences.
Knowledge Management	Bad	What is the objective of an interview and how do you know you have achieved it?	Direct question on the material, no room for different responses.
Human-Computer Interface	Good	Which of the defined criteria for evaluating usability were not used in http://www.big.dk/big.html?	All of the criteria must be analyzed and a certain number chosen. The students thus have various alternatives for choosing and then analyzing and discussing.
Human-Computer Interface	Bad	Apply the sentence "A relationship with an artifact is human if it responds to a human need and takes human weaknesses into account" to the image in the figure.	The quoted phrase is the answer, leaving little room for the students to add anything through their own responses.

Table 3. Questionnaire on CollPad experience distributed to students

No.	Question	Question type/options
1	What is CollPad?	Open
2	Name up to 4 attributes of CollPad.	Analysis, Learning, Collaboration, Conversation, Study, Evaluation, Explanation, Mediation, Testing, Reinforcement, Tasks, Group Work
3	Indicate your positive and negative experiences with the CollPad activities carried out in the classes.	Open
4	Under what circumstances would you recommend the use of this experience in these courses?	Open

As regards the first question, three types of answers were given:

- Those that perceived the technical aspect of CollPad, clearly identifying the model in Figure 1.
- Those that emphasized the collaborative aspect of the activity.
- Those that combined the technical and the collaborative aspects.

During the first stage of the experiences, the students acquired a purely technical knowledge of the workings of CollPad. Later, as they came to appropriate the system, they discovered its true potential and thus gained a more conceptual knowledge of it. This is reflected in the questionnaire responses, in which 38% mentioned only the technical characteristics, 38% referred to its collaborative aspects and 24% cited both.

In considering the responses to the second question, it should be recalled that the ultimate purpose of CollPad is to learn while simultaneously developing social and communication skills. As a means of learning, the system promotes collaboration, discussion and group work. The answers to this question, in which students were asked to name the attributes of CollPad, indicated that those students most frequently associated with the system were collaboration, group work, conversation, and analysis (see Figure 3). These match perfectly the methods used by CollPad to achieve its objectives. Also evident in the students' replies was that the attributes linked to evaluation were infrequently mentioned as evaluation, or not cited at all, as study, testing and tasks. Although the lack of a control group in this study rules out any pronouncements on CollPad's ability to improve student learning, the answers to this question do permit the conclusion that the students found the system to be a useful tool for creating an environment that promotes learning. Indeed, the characteristics of CollPad they most recognized were those that supported the development of the social skills mentioned earlier as part of the study's objectives.

As for Question 3, which asked students to indicate the positive and negative characteristics of CollPad (see Figure 4), the majority stressed as positive those that related to the system's purpose (*e.g.*, collaboration, group work, learning). Most of the negative characteristics they cited had to do with technical difficulties (e.g, network problems, complicated interface, small screen). This implies that the students validated the model behind the system but that the technological platform was not optimal. As for the negative conceptual aspects, most of them involved the particular methodology used in the courses, and especially the method of evaluation, rather than the main concepts underlying the CollPad model.

Finally, Question 4 asked the students to indicate the circumstances in which they would recommend CollPad. From their answers we extracted the variables they felt should be considered in deciding whether to use CollPad as part of a given learning process. As can be seen in Figure

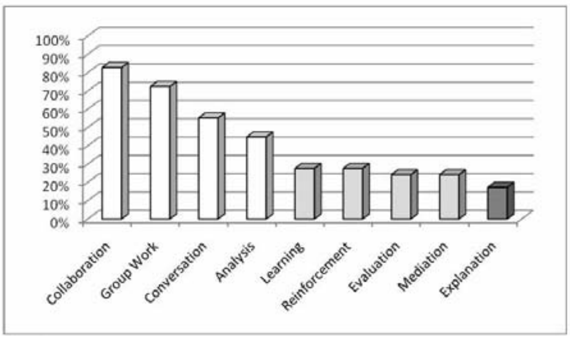

Fig. 3. Frequency of citation of CollPad attributes by students (attributes not cited by any student are omitted).

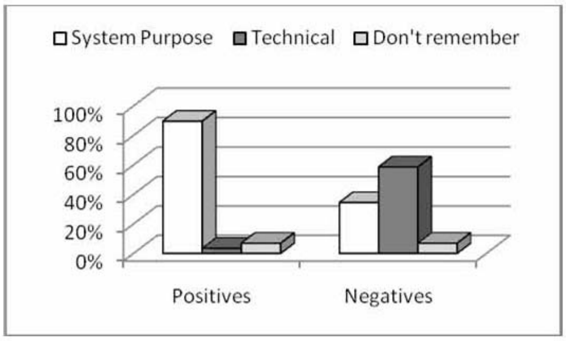

Fig. 4. Distribution of the students' positive and negative opinions by type.

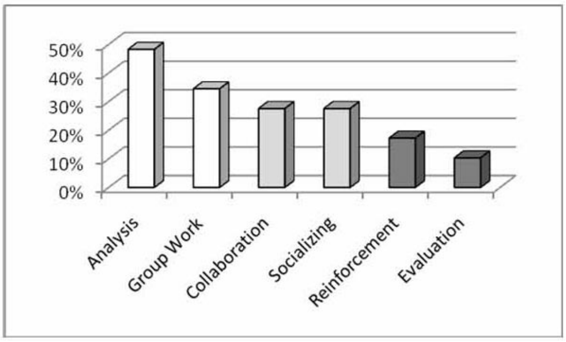

Fig. 5. Distribution of variables that students felt should determine whether or not to use CollPad.

5, the attributes they most frequently named were: development of ability to analyze, group work learning, and development of social and collaborative skills. Comparing these open answers with those given for Question 2 as the main attributes of CollPad, we find a clear relationship that validates the system attributes most frequently mentioned by the students. This shows that the students perceived CollPad to be a tool for creating an environment that promotes development of communication, interpersonal and decision-making skills, which as noted in the Introduction are a necessary element of engineering curricula.

DISCUSSION

Organizing a classroom into small groups fosters the verbalization of ideas [24] and thus the development of communication skills. When defining small group composition [25,26] a choice must be made between:

1) best group performance, where high achievers are the most productive;
2) improving individual performances through group collaboration where high achievers are somehow affected by the mix and low achievers benefit from a mixed group, provided there is positive interdependence between group members.

In this study we chose the second alternative, randomly assigning group members from among students with a range of different skill levels and perspectives. Such an approach satisfies the Vygotskian condition of providing information within students' zones of proximal development and also creates the socio-cognitive conflict necessary from a Piagetian perspective [27]. In this way, random assignment of group members supports the development of social abilities. As we have seen, in different social settings [28, 29] peers accept the defined group allocation when the groups are assigned by the system and so will collaborate with classmates they otherwise would never work with.

Effective collaboration must be learned and requires guidance, instruction, and training [30]. Well-defined criteria are therefore needed for determining how students should interact and solve problems [31]. Actually achieving these collaborative elements is difficult without resorting to some type of digital scaffolding [21].

The constructivist problem-solving strategy presented here is structured in a sequence that permits information sharing and knowledge construction, moving from individual participation to (small) group collaboration and finally to construction of a teacher-mediated whole classroom solution. This sequence can be understood in terms of the three critical moments in classroom learning [32]:

1) Moments that create confusion, when a new topic is presented or a problem assigned and the student recognizes that his/her knowledge or experience is insufficient. In this state, the student must confront his/her understanding, creating his/her own knowledge representation or constructing his/her own answer. He/she must be able to learn to work with his/her own ideas and what he/she is able to figure out by him/herself. The strategy presented here supports this moment by focusing the student's work in such a way that he/she can only proceed by coming up with his/her own answer, that is, by realizing his/her own knowledge.
2) Moments responsive to student learning, when the teacher creates opportunities for students to interact with one other and they become involved. After they perform individual work, a discussion is held in which students are confronted as a group with their answers and must either agree on one of them or use their peers' knowledge to create a new one.
3) Moments that steer the discourse, in which responses from all pupils have to be considered and the interaction must be controlled without (necessarily) queuing the students to a predetermined answer or the teacher's agenda. In the in-class discussion, the last phase of the activity, the teacher sees the different groups' answers on his/her machine and ascertains how they approached the assigned problem. He/she then selects the answers that will steer the group discussion towards the activity's learning objective.

Our analysis of the questionnaire results suggests that in general, the students understood the purpose of CollPad and the techniques used by the model to achieve its objectives. In their comments on using the system, most of them made reference to collaboration, discussion, and analysis. On this basis we may assert that CollPad creates an environment favorable to the development of communication, interpersonal and decision-making skills, all of which should be an integral part of engineering curricula. In addition, the students' qualitative observations revealed a deeper understanding of the different topics covered during the discussions held over the course of the semester. More importantly, CollPad gave a voice to those students who in other contexts never participated in class, and it was they who most appreciated the process. This phenomenon has also been noted in K-12 classrooms [21]. Since the groups were randomly formed, all of them agreed that they got to know classmates they had never previously spoken to. The students also indicated that the system forced them to verbalize ideas in the classroom, something they otherwise would not have done.

As regards the negative aspects cited by the students, the great majority focused on the computer platform that was utilized and made no mention either of the model behind CollPad or the techniques used for achieving its learning objectives. This leads us to infer that using some other technology such as Tablet PC or Netbook would improve the user experience by providing a significantly larger space for student responses without sacrificing the mobility afforded by a mobile device. With this in mind, CollPad has now been ported to Windows XP.

Students were also critical of the CollPad voting mechanism, which encouraged participants to seek out innovative and imaginative solutions that led to greater discussion but were not necessarily correct. Some noted that the groups eventually adapted their behavior to the evaluation model, deliberately attempting to generate answers that were different from the others even if incorrect so that the professor would choose their response, thus winning them extra marks. This tended to shift the groups' focus away from the central theme of the discussions, which was the search for the best answer.

The two courses in which CollPad was applied were qualitative in nature, and it was in this aspect that the system clearly demonstrated its utility. CollPad could also be used in quantitatively oriented courses where problems can be posed that allow for various solution methodologies or leave certain assumptions undefined. Students can then be assigned the task of finding these assumptions, defining them as they think best and arriving at a result. The discussion in such cases would centre around finding the correct methodology or the most important elements involved in solving the problem as well as finding the correct values for these elements given the problem's context.

The CollPad technology was made available to all faculty members at the Universidad Católica's School of Engineering for an entire year. However, although four other professors made an initial effort to apply it, after a time they abandoned the experience due mainly to the lack of personal incentives. The initiation of an inclusion process for a technology such as CollPad requires that instructors devote additional hours to learning the process, preparing materials, etc., and with no extra incentives for participating in the project nor any compensating reduction of teaching loads, as was the case with the experiences reported here, the chances for its success are limited [33].

The design of CollPad is simple, making the system easy to appropriate by both students and instructors. While the technology assists the instructor in monitoring the activity progress and scaffolds the students' work, the instructor's role remains vital in defining appropriate tasks and mediating the in-class discussion phase. As regards the operationalization of Collpad, instructors found setting up the software to be simple. Reliability issues with the WiFi network sometimes required that groups log in to the activity a second time, consequently, this produced some disruption in the classroom.

Possibilities for future work include a study that incorporates a control group to quantitatively validate CollPad's ability to promote the development of communication, interpersonal, and decision-making skills and improvements in student learning.

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