Using Multiple Choice Questions as a Pedagogic Model for Face-to-Face CSCL

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Received 15 February 2007; accepted 1 September 2007

ABSTRACT: This article describes a collaborative activity based on a pedagogical model which conceptualizes collaboration as a continuous process. Students learn via discussion, negotiation and construction of responses to Collaborative Multiple Choice Questions (CMCQ). Results from the use of CMCQs as an educational instrument in Computer Science are presented and analyzed. Comput Appl Eng Educ 17: 89–99, 2009; Published online in Wiley InterScience (www.interscience.wiley.com); DOI 10.1002/cae.20196

Keywords: computer science education; face to face computer supported collaborative learning; multiple choice questions

INTRODUCTION

The skills required in the training of engineers are changing. The need to develop social skills, as well as those for leadership, teamwork and multi-disciplinary work, is becoming more and more pressing. As Shakhgildian et al. [1] notes: "An engineer's competence can be presented as aggregate of knowledge, skills and know-how. Knowledge works only through activity of the person, groups of persons and people."

The development of these skills requires the modification of a traditional class that is basically centered on the teacher into a participative class, centered on the student, with work groups that collaborate to meet their objectives and develop critical thinking. Li [2] expresses this as: "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'

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proficiency in understanding, thinking, reasoning, and problem solving.''

Collaborative learning is considered an activity that enables the members of a group to articulate their perspectives, negotiate their knowledge or beliefs, and to co-construct new knowledge [3]. Thus, the activity of learning is seen as a process of knowledge construction.

Constructivism conceives individuals as active members in the construction of their own knowledge. They learn through interaction with others, in a common space where conflicts and negotiations are produced [4]. Social-constructivism emphasizes the creation of meaning through the active participation of individuals. A crucial element in active participation is the dialogue that develops from the shared experience of work. Savery and Duffy [5] establish three essential principles in the social-constructivist theory:

1. Understanding comes from the learner's interaction with the environment
2. Cognitive conflict stimulates learning
3. Knowledge evolves through social negotiation and evaluation, for the individual understanding.

In Miao et al.'s [4] model of collaborative learning (Fig. 1), the process of knowledge construction is described through the interaction of individuals in a shared interaction space. The model focuses on the way individuals, as well as the shared knowledge, evolve during the activities of collaborative learning.

At the level of the individual, new knowledge is constructed by integrating new information into his or her own cognitive structure. When new information contradicts existing knowledge in the individual, a conflict is said to occur. The individual must therefore reconcile the conflict by modifying his or her cognitive structure.

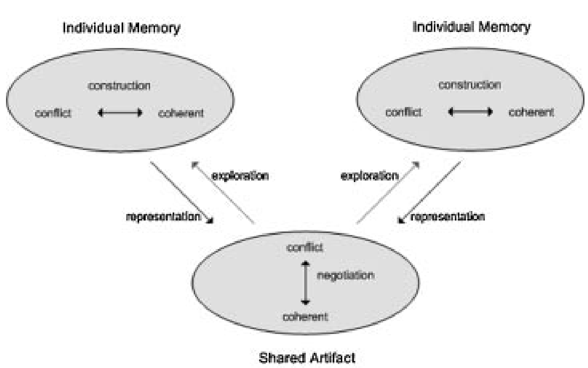

Figure 1 Conceptual model of collaborative learning [4].

The shared space (the concept of ''shared artifact'' used by Miao et al. [4], has been exchanged for the concept of ''shared space'' as the term ''shared artifact'' is used below to refer to the object resulting from collaboration) is a space in which individuals interchange their knowledge and information. When a disagreement occurs in this space, the members of the group need to discuss, identify the points of conflict, and negotiate in order to decide.

The information flows in both directions between the individual memory and the shared space during the process of collaborative learning. In one direction, individuals communicate their knowledge to the rest of the members of the group via the shared space. In the other direction, each individual explores the information that has been contributed by the other members of the group.

THE USE OF MCQ IN COLLABORATIVE ENVIRONMENTS

The use of multiple choice questions (MCQ) has been widely studied. Amongst the advantages of using MCQ [6] are that these provide rapid feedback, can be automatically evaluated, and stocked in databases of questions for re-use as required. Amongst the disadvantages, it has been argued that their construction requires considerable effort, that they can only evaluate knowledge and recall, and do not consider aspects of analysis and creativity, resulting in students adopting a superficial attitude to learning.

Woodford and Bancroft [7] show that many of these criticisms can be evaded, and give examples of ways that MCQ can be used in Information Technology to evaluate comprehension, application and analysis, according to Bloom's scale of six levels of cognition [8]. This scale goes from simply recording facts (knowledge) to a level that considers skills for evaluating information.

In our proposed collaboration the use of MCQ fulfils a fundamental role. The questions must be of an adequate extent and content to provoke discussion within each group, generate processes associated with collaboration, and meet the class objectives.

Roschelle et al. [9] indicate that an important characteristic of a class supported by wireless technology is the accelerated cycle of interaction between the teacher and the students. In a traditional class, this cycle starts when the teacher assigns an activity to the student and continues when the student returns the assigned work to the teacher. This cycle may only be completed days later when the teacher evaluates the student's work. In a class supported by technology this cycle can be completed within the class using short tasks such as MCQ. Its use in classes supported by technology allows the teacher to quickly gain information about the level of comprehension and progress of the students, and thus to intervene during the class.

One of the first systems to use MCQ in technology-supported classes was Classtalk [10], a system where students answer MCQ using mobile devices. This enables the possibility of discussion after the task with the whole class (normally using histograms), taking into account the distribution of the answers. This dynamic is a variation of the dynamic of the active class known as peer instruction [11]. In the latter, it is suggested that, ‘‘the real heart of the learning occurs when the students engage with each other conversationally on the basis of the dissonances revealed by the shared display’’ [7]. In this context, the shared display constitutes the shared space of collaborative work where the dissonances and reconciliations described by Miao et al. [4] are produced.

The studies carried out into the use of these systems, known generically as classroom response system [21] or Classroom Communication Systems (CCS) [12], have shown that the role of technology is valuable within the classroom [21]. Technology provides anonymity, quick collection of answers, and the ability to produce a shared visualization which improves the recognition of common positions. Technology thus acts as a catalyst, producing a change in the climate of the class, the pedagogy and the resultant learning [10].

Unlike the dynamics described above, in which the discussion space is shared at a whole-class level, our proposition is based on the collaborative work of students in small groups, in which the shared space involves a smaller number of individuals, thus allowing greater possibilities for participation for each member of the group. According to MacKnight [13], ‘‘the active exchange of ideas within small groups not only increases interest among the participants but also promotes critical thinking.’’

COLLABORATION AS A PROCESS

A model which conceptualizes collaboration on a continuum of processes that move from social presence to production of a shared artifact is proposed by Murphy [14] (Fig. 2).

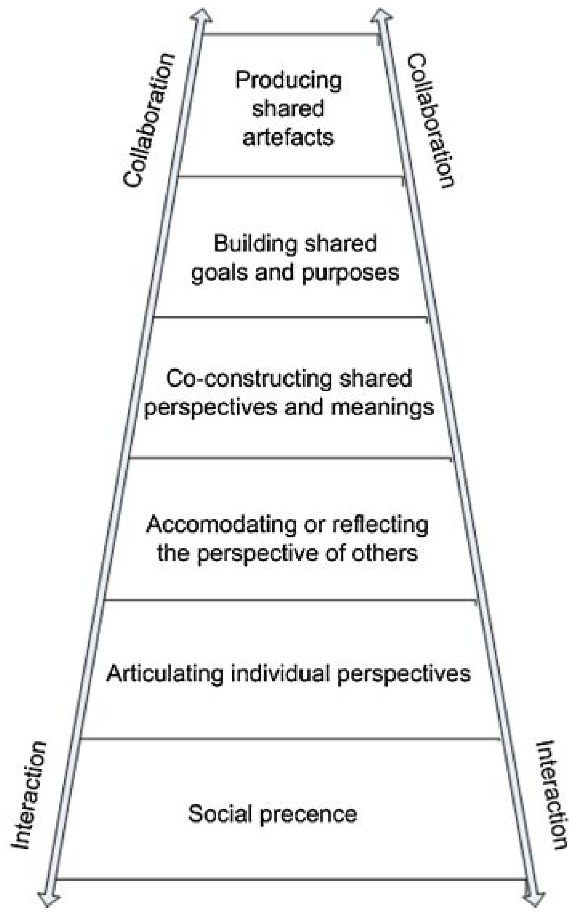

Figure 2 Murphy's model of collaboration [14].

Describing the process from which this perspective is implied assumes that the earlier processes are pre-requisites for the later processes [14]. Thus, in order to generate collaboration it is necessary that the members first interact at a primary level, and consecutively produce those events that characterize a collaborative situation.

Murphy characterizes six processes that describe this continuum:

Social Presence

The first step in collaboration comes about when the individuals recognize each other as members of a group. Garrison et al. [15] refer to this first contact as ‘‘social presence,’’ describing it as, ‘‘the ability of participants in a community of inquiry to project themselves socially and emotionally, as ‘real’ people (i.e., their full personality), through the medium of communication being used.’’

Social presence is of particular importance for the group's cohesion which enriches its interaction [16].

Short et al. [17] note that, "when social presence is low, group members feel disconnected and group dynamics suffer. Conversely, when social presence is high, members should feel more engaged and involved in group processes."

Articulating Individual Perspectives

At this level, the participants expose their different points of view without asking for others' opinions or referring to the others. As the participants externalize their opinions, possible areas of conflict are made explicit.

Accommodating or Reflecting the Perspectives of Others

From this moment, the individuals express their agreement and disagreement with respect to the distinct opinions given in the group, as well as introducing new points of view. This process of questioning, evaluating and criticizing perspectives, beliefs and assumptions allows participants to restructure their thinking [14].

Co-Constructing Shared Perspectives and Meanings

Once the perspectives of the individuals have changed, the members of the group ought to work together, generating and responding to questions, seeking feedback and clarifying opinions in such a way that they can construct meanings.

Building Shared Goals and Purposes

When the individuals reach a state in which they share opinions and points of view, a common feeling of purpose arises. It is at this moment that the individuals work together and start to move in a common direction [14].

Dillenbourg [18] points out that a significant criterion for characterizing a collaborative situation is that in which a common objective is established. This common objective can only be partially fixed prior to the collaboration, since it must be negotiated, and possibly revised, as part of the collaborative process. Additionally, this ensures that the members of the group are mutually conscious of the common objective.

Producing Shared Artifacts

The collaboration is finally complete when a shared artifact is constructed. This shared artifact may manifest itself in different forms. As Leigh and MacGregor [19] describes it, collaborative work is for understanding, solutions, or meanings, or creating a product. Given that collaboration is given in terms of producing something, its results ought to be measurable.

A MOBILE COMPUTER SUPPORTED COLLABORATIVE LEARNING MCQ ACTIVITY

Wireless mobile learning devices open new opportunities for introducing collaboration and thereby changing classroom pedagogical practices [20]. In addition, they have the attractive advantages of portability, low cost, and interconnective characteristics [21]. Cortez et al. [22] state that "wirelessly interconnected handhelds are a unique opportunity to create a learning environment where technology is a transparent, non-invasive support to group learning."

According to Roschelle et al. [23], the use of technology fulfills three mediating roles:

1. To represent information in a way that support group cognition.
2. To coordinate the flow of information in ways that reinforce group rules and roles that actively support collaborative learning.
3. To relate private and public spaces.

Zurita and Nussbaum [24] state that the problems detected in collaborative classrooms, such as weaknesses in coordination, communication, organization of materials, negotiation, interactivity and lack of mobility, can be solved with a mobile Computer Supported Collaborative Learning (mCSCL) environment with handhelds interconnected by a wireless network.

According to Zurita and Nussbaum [24], in a mCSCL activity, the use of handhelds creates a natural environment for collaboration. Whilst students communicate face-to-face interacting in a social network, their work is supported by using a wireless network of handhelds. Since the devices are small and mobile, according to the user's needs, the technology is effectively transparent, which favors collaboration.

In our proposal to create a mCSCL MCQ activity, the teacher's first task is to design a set of questions that motivate students to work on the subject matter, apply their knowledge, reinforce what they have learned or analyze how they are applying it. Each question will have a multiple-choice answer set that is stored in the teacher's mobile device before the class [25].

Taking as a reference the collaboration process established by Murphy, the proposed activity follows a continuum of processes (Fig. 3), in a sequence that is not necessarily lineal. Within the continuum, each element must be present to give rise to a collaborative learning activity.

The sequence of the steps shown in Figure 3 is the following:

Social Presence — Group Conformation

At the beginning of each class, students should randomly form groups of three members [26]. In order for this to succeed, each student is informed as to which group they will belong to by their PDA at the start of the activity. The students then find the other members of their group. The distribution of the groups is random so that the students learn to work with different type of people, as in the work place or daily life [26]. During the course, each student will work with different group conformations that include peers with stronger or weaker abilities for the subject, and with better or worse team work skills [25].

Articulating Individual Perspectives—Working With Questions

Once the groups have been formed, each mobile device shows the students a MCQ, (as in Fig. 4), to be resolved individually. In this step, each student elaborates a response based on his or her knowledge and beliefs.

For the MCQ of Figure 4, each student must decide on the possible correct option. This reasoning, based on the individual experience and knowledge of each member of the group, should then be expressed in an opinion to the rest of the group members as to the possible correct option.

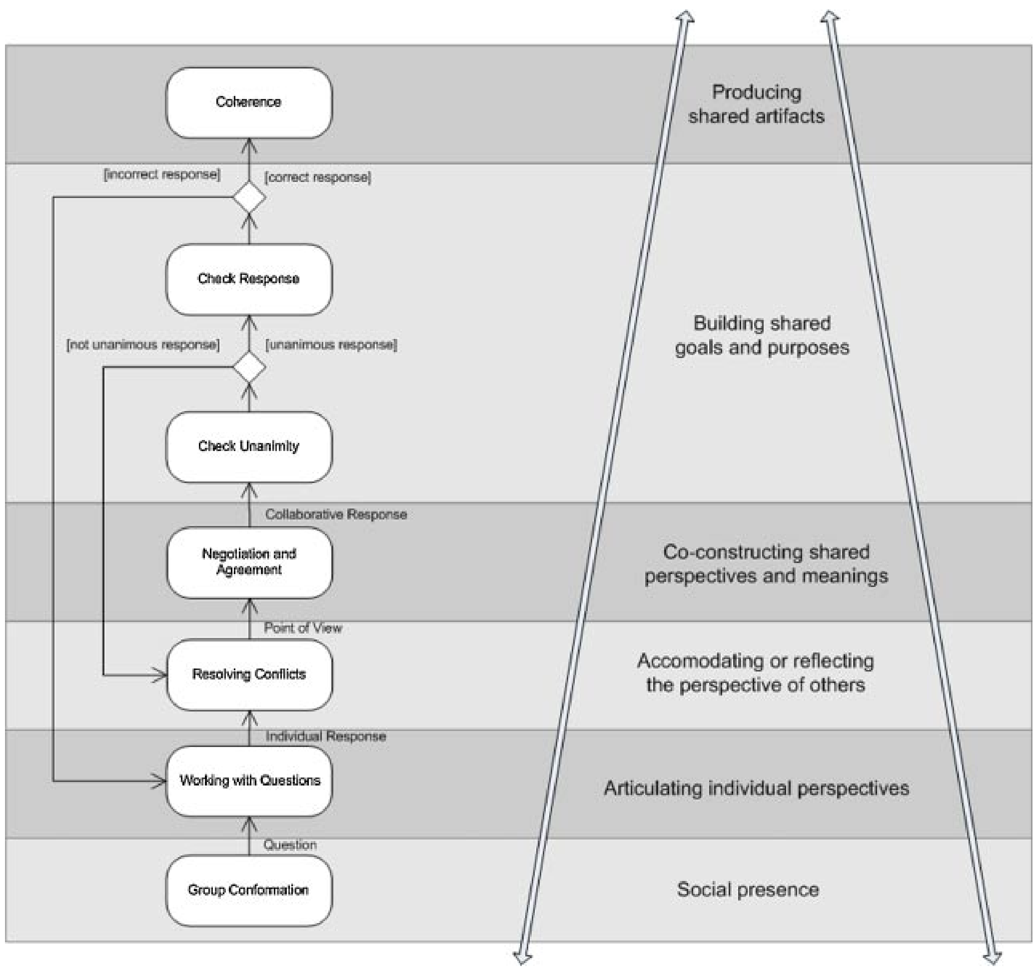

Figure 3 mCSCL and MCQ as a collaborative process.

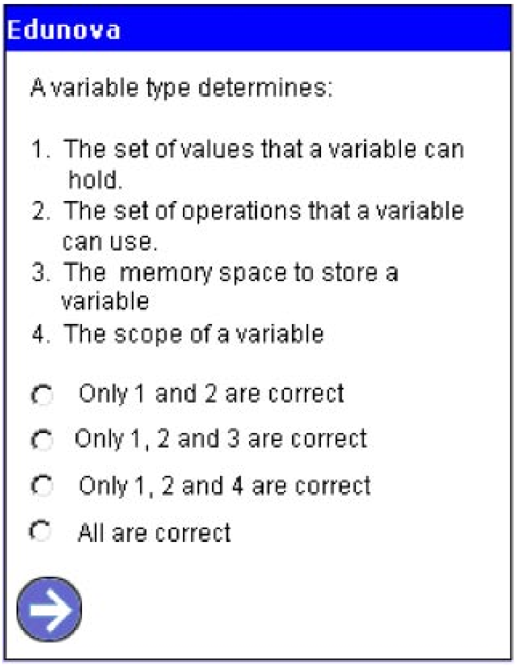

Figure 4 A multiple choice question.

Figure 5 Students working on a mCSCL activity.

Accommodating or Reflecting the Perspective of Others—Resolving Conflicts

On the previous foundation, a discussion process should start. The students ought to manifest their agreement or disagreement with the points of view of the other members of the group. This can open new propositions or strategies for searching for the correct answer.

If we consider a question as shown in Figure 4, students will agree, for example that the first statement is correct; and disagree, for example with respect to the validity of the third statement. The students will therefore begin a discussion in a social space shared by the three group members (Fig. 5), in which they will discuss knowledge, cases and examples that confirm or refute the third statement.

Co-Constructing Shared Perspectives and Meanings—Negotiation and Agreement

Each phase of the discussion should conclude in a process of negotiation and agreement in which the group members ought to reach the same opinion as to which is the correct answer; this requires them to agree meanings via a common process of knowledge construction.

In our example of Figure 4, the students can, after a process of discussion, conclude that the second option is correct, affirming the first three statements and discarding the fourth one. This agreement should, therefore, entail a consensual and common response for all the members of the group.

Building Shared Goals and Purposes—Choosing a Response

The system requires the students to choose a sole response (the common objective). If they choose different responses (showing disagreement), the system will prevent them from advancing to the following question. In this case, the students must recognize the conflict and restart a phase of accommodation or reflection on the others' perspectives.

The search for the correct response as a group objective is implicit in a large part of the collaborative process. The students work individually and then collaboratively towards this objective. If they fail to choose the correct answer, the system notes this error, causing the process of collaboration to restart. The students must then elaborate new opinions, and new conflicts, negotiations and agreements are produced.

Producing Shared Artifacts—Promoting Coherence

Work in the proposed collaborative dynamic is governed by the MCQ system. The questions must generate dissonance that allows each student to contribute his or her own vision in the shared construction space, producing moments of conflict, discussion and negotiation necessary to generate the phenomenon of learning.

Each discrepancy ought to be resolved in the shared discussion space, giving rise to coherent positions within the group with regard to the selected response.

In addition, each MCQ fulfils a function of formative assessment, contributing as much to the necessary feedback for the students as to that required by the teacher in order to be able to intervene in cases where the group's answers are not those expected. To facilitate this role, the teacher receives feedback through a grid displayed on his or her PDA indicating in real time both the progress of each group and the degree of correctness of each response. This allows him or her to intervene and assist a group that is experiencing particular difficulty with the activity [25].

agree that "well written multiple choice questions can test up to the sub-synthesis levels of cognition, that is, knowledge, understanding, application and analysis."

In addition, in the proposed dynamic, isolated questions ought not to be used. In the measure that each question is linked to the previous question, the process is enriched from a constructionist perspective, since the new learning is constructed on the basis of the student's previous learning [28].

Melzer and Mannivannan [29] use a similar perspective to introduce problems of greater complexity in an MCQ scheme, subdividing them into simpler parts. They note that, "it is possible, to take a fairly complicated problem, involving several different concepts, and break it down into conceptual elements".

To exemplify what has been stated, let us consider the following problem associated with a course in Programming Language:

A list in Prolog is: (1) the empty list, denoted by [], or (2) an expression [head|tail], where the head is a component (considering only letters of the alphabet), and the tail is a list.

Thus, a list with the elements: a, b, c and d can be written in Prolog: [a|[b|[c|[d|[]]]]]

The syntax BNF of the Prolog list is:

(a) <list> ::= [] | [<list>|<list>]

<comp> ::= a | b | c | ... | z

(b) <list> ::= [] | [<comp>|<list>]

<comp> ::= a | b | c | ... | z

(c) <list> ::= [] | [<list>|<comp>]

<comp> ::= a | b | c | ... | z

(d) Options 2 and 3 are correct

(e) All of the options are correct

MCQ FOR IMPROVING COLLABORATION AND LEARNING

The use of MCQ may involve knowledge recall questions, as suggested by East and Fienup [27], but these questions are not the most appropriate for generating discussion and thus, collaboration. Questions that are from a higher level of cognition according to Bloom's scale produce greater degrees of dissonance, and thus produce conflict, negotiation and agreement, and improve the collaboration process. Woodford and Bancroft [17]

This is a question requiring knowledge application. Students must resolve the problem by applying previous knowledge, facts, techniques and rules [7]. In this particular case, they must know how to describe formally (BNF) the syntax of a subset of a programming language.

Afterwards, the following question is asked:

> Now consider the property ListPair which is fulfilled if the Prolog list has an even number of components.

Assume that the empty list agrees with the ListPair.
Using axiomatic semantics specifies the property ListPair

(a) $$[\,] : \text{ListPair} \qquad \frac{E : \text{Element} \quad L : \text{ListPair}}{[E|L] : \text{ListPair}} \qquad \frac{E : \text{Element} \quad L : \text{ListPair}}{[E|L] : \neg\,\text{ListPair}}$$

(b) $$[\,] : \text{ListPair} \qquad \frac{E : \text{Element} \quad L : \text{ListPair}}{[E|L] : \text{ListPair}} \qquad \frac{E : \text{Element} \quad L : \neg\text{ListPair}}{[E|L] : \text{ListPair}}$$

(c) $$[\,] : \text{ListPair} \qquad \frac{E : \text{Element} \quad L : \text{ListPair}}{[E|L] : \text{ListPair}} \qquad \frac{E : \text{Element} \quad L : \neg\text{ListPair}}{[E|L] : \neg\text{ListPair}}$$

(d) $$[\,] : \text{ListPair} \qquad \frac{E : \text{Element} \quad L : \text{ListPair}}{[E|L] : \emptyset\ \text{ListPair}} \qquad \frac{E : \text{Element} \quad L : \neg\text{ListPair}}{[E|L] : \text{ListPair}}$$

(e) $$[\,] : \text{ListPair} \qquad \frac{E : \text{Element} \quad L : \text{ListPair}}{[E|L] : \emptyset\ \text{ListPair}} \qquad \frac{E : \text{Element} \quad L : \neg\text{ListPair}}{[E|L] : \neg\text{ListPair}}$$

(f) $$[\,] : \text{ListPair} \qquad \frac{E : \text{Element} \quad L : \neg\text{ListPair}}{[E|L] : \text{ListPair}} \qquad \frac{E : \text{Element} \quad L : \neg\text{ListPair}}{[E|L] : \neg\text{ListPair}}$$

For this question it is necessary to have understood and worked on the initial question. Recognizing how a list is constructed allows the student to specify a property of the lists. Moreover, it becomes necessary to apply specific knowledge (axiomatic semantics in this particular case) to solve the problem.

If the learning from the initial question was successful, then the following question can be answered. If the initial learning was insufficient in order to generate a viable model upon which new knowledge can be constructed, then the group will make its problems visible for its own feedback as well as for the teacher via the systems' on line report. In such situations the teacher should intervene to guide the learning process.

The description of our collaborative proposal has been based on the description of the process of the construction of a common response from group members for an MCQ problem. However, in this section, we have shown that it is necessary to consider the set of problems that have been designed for the class, since the learning to be achieved in each of these collaboration processes associated to each MCQ question should be integrated in such a way as to meet the objective of the class.

Hence the correct design of the class, that is to say, of each question prepared for the class, should be destined not only to build new knowledge, but also to reinforce or question what has been learned. From this perspective, the collaborative process that is used to work on each MCQ question is immersed in another process, which cyclically incorporates new questions that also articulate, reinforce and use the knowledge constructed in the previous questions.

CONCLUSIONS

In this article we have described a proposition for collaborative work based on work carried out in small groups that interact in the search for a common solution to problems put in an MCQ format.

In our proposal, the shared work space is smaller than in the proposed Classroom Communication Systems whereby collaboration occurs at a whole-class level. However, the use of small groups enables better participation of each individual, given the number of members, and requires consensual solutions between the group members to continue working on the activity.

Our proposal has been described on the basis of a continuum of processes that begin with social presence, and culminate in the production of a shared artifact, that is, the response to the MCQ. These processes show how the phenomenon of collaboration is produced, and in our particular proposition, how this is enriched by a mCSCL environment. The use of a wireless PDA network as a technological support for our proposed collaboration allows a freedom of movement for group formation. At the same time, the reduced size and portability of these devices provides the transparency that is necessary to produce the interactions required for face-to-face collaboration. The support this technology provides for MCQ activities allows them to be employed for formative assessment in such a way that the mCSCL system feeds back, in real time, the members of the group regarding their progress. Finally, its use as a feedback mechanism by the teacher allows him or her to intervene, correcting students' possible erroneous concepts which arise during the class.

The design of each MCQ question should be done in such a way as to provoke discussion within each group, contributing to the production of the processes associated with collaboration. These ought to be linked in such a way, that the knowledge of each group is constructed on the basis of previous experiences. Finally, the overall set of questions ought to be oriented to meet the objectives of the class. Whilst the

Table 1 Analysis of the Experimental Results

	Control		Experimental		Comparison	
Exam	*M*	*SD*	*M*	*SD*	*P*	*Cohen's d*
Exam 1	4.5	0.857	5.0	1.048	0.1699	0.52
Exam 2	3.4	1.361	5.1	1.537	0.0015	1.18
Response						
I have had more communication with the professor thanks to the technological tool	2.6	1.4	3.7	0.8	0.0356	1.04
I have had more communication with the other students thanks to the technological tool	2.1	1.0	4.3	0.8	0.0	2.50
I would take another course which used this technological tool	3.4	1.5	4.6	0.5	0.0197	1.337
I would recommend this course to other students	2.9	1.1	4.0	0.7	0.0118	1.292

design process can be arduous work, the questions can be stocked and reused and improved for future courses.

With the aim of measuring the effects of the use of our collaborative proposal, an experiment was designed for a course on Computing Science [25] (Foundations of Programming Language). In the experiment, two groups of students were used, one as an experimental group and the other as a control group. During the course, the experimental group was submitted to 5 mCSCL sessions before the mid-semester exam and 8 mCSCL sessions between this point and the end of the semester. The control group continued with traditional teaching methods.

An analysis of the results obtained (Table 1) showed a better performance by the experimental group in both exams (on an evaluative scale of 1.0 to 7.0), with a statistically significant difference ($P = 0.0015$) in the final exam and a *very large* size effect (*Cohen's* $d = 1.16$) Other aspects, such as attendance (in the control group the attendance was 48.5% compared with 81.7% in the experimental group) and desertion (four students abandoned the control group compared with no students abandoning the experimental group) also indicated a greater interest in the course by members of the experimental group.

In order to measure the social aspects and motivation, both groups were asked to complete a questionnaire at the end of the semester, with a Likert scale of 5 points (based on Ref. [30]). Some answers that produced statistically different responses are shown in Table 1. The first two reflect greater confidence on the part of the experimental group students in the development of their social skills due to the mCSCL tool (in the control group these questions referred to the use of the university intranet). The following two indicate greater satisfaction of the experimental students with respect to the course.

A further interesting aspect to consider arose from the responses to open questions inviting comments on the course. The control group students only referred to meeting the objectives associated with content, whereas the experimental group showed a particular interest in referring to the aspects relating to the development of their social skills, which is a positive reflection on the way in which these aspects were encountered by this group.

REFERENCES

[1] V. Shakhgildian, N. Fomin, and G. Dolin, Tomorrow's engineer has inevitably to be a moderate 'netman', Proceeding of the 30th European Society for Engineering Education Annual Conference (SEFI'2002), Firenze, 2002.

[2] W. Li, Constructivist learning systems: A new paradigm, Proceedings of the IEEE International Conference on Advanced Learning Technologies (ICALT'01), Madison, WI, 2001.

[3] C. M. Duh and L. R. Wen, From collaborative argumentation to knowledge creation, Conference on Information Management 2002 (ICIM 2002), Tamkang University, Tamsui, Taiwan, 2002.

[4] Y. Miao, S. Holst, T. Holmer, J. Freschutz, and P. Zentel, An activity-oriented approach to visually structured knowledge representation for problem-based learning in virtual learning environments, Proceedings of the 5th International Conference on the Design of Cooperative Systems (COOP'2000), Sophia Antipolis, France, 2000, pp 303–318.

[5] J. R. Savery and T. M. Duffy, Problem based learning: An instructional model and its constructivism framework, In Constructivist learning environments:

Case studies in instructional design, B. Wilson (Ed.), Educational Technology Publications, Englewood Cliffs, NJ, 1996, pp 135−148.
[6] T. Roberts, The Use of multiple choice test for formative and summative assessment, Eighth Australasian Computing Education Conference (ACE2006), Vol. 52, Hobart, Tasmania, Australia, 2006, pp 175−180.
[7] K. Woodford and P. Bancroft, Using multiple choice questions effectively in information technology education, In R. Atkinson, C. McBeath, D. Jonas-Dwyer and R. Phillips (Eds.), Beyond the Comfort Zone. Proceedings of the 21st ASCILITE Conference, 2004, pp 948−955.
[8] B. Bloom, Taxonomy of educational objectives, Handbook 1: The cognitive domain, McKay, New York, 1956.
[9] J. Roschelle, L. A. Abrahamson, and W. R. Penuel, Integrating classroom network technology and learning theory to improve classroom science learning: A literature synthesis, Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, CA, 2004.
[10] R. J. Dufresne, W. J. Gerace, W. J. Leonard, J. P. Mestre, and L. Wenk, Classtalk: A classroom communication system for active learning, J Comput Higher Educ 7 (1996), 3−47.
[11] E. Mazur, Peer instruction: A user's manual, Prentice Hall, Englewood Cliffs, NJ, 1997.
[12] I. Beatty, Transforming student learning with classroom communication systems, Educase Center for Applied Research, Research Bulletin, Volume 2004, Issue 3, 2004.
[13] C. B. MacKnight, Teaching critical thinking through online discussions, Educase Q3 (2000), 38−41.
[14] E. Murphy, Recognising and promoting collaboration in an online asynchronous discussion, Br J Educ Technol 35 (2004), 421−431.
[15] D. R. Garrison, T. Anderson, and W. Archer, Critical inquiry in a text-based environment: Computer conferencing in higher education, Internet Higher Educ 2 (1999), 87−105.
[16] L. Kester and F. Paas, Instructional interventions to enhance collaboration in powerful learning environments, Comput Hum Behav 21 (2005), 689−696.
[17] J. Short, E. Williams, and B. Christie, The social psychology of telecommunications, Wiley, London, 1976.
[18] P. Dillenbourg, What do you mean by 'collaborative learning'? In Collaborative-learning: Cognitive and computational approaches, P. Dillenbourg (Ed.), Elsevier, Oxford, 1999, pp 1−19.
[19] B. Leigh and J. T. MacGregor, What is collaborative learning? In Collaborative learning: A sourcebook for higher education, National Center on Postsecondary Teaching, Learning, and Assesment, A. S. Goodsell, M. R. Mahe and V. Tinto (Eds.), University Park, PA, NCPTLA, 1992.
[20] G. Zurita and M. Nussbaum, A conceptual framewok based on activity theory for mobile CSCL, Br J Educ Technol 38 (2007), 211−235.
[21] J. Roschelle, Unlocking the learning value of wireless mobile devices, J Comput Assist Learn 19 (2003), 260−272.
[22] C. Cortez, M. Nussbaum, P. Rodríguez, X. Lopez, and R. Rosas, Teaching training with face-to-face computer supported collaborative learning, J Comput Assist Learn 21 (2005), 171−180.
[23] J. Roschelle, R. Rosas, and M. Nussbaum, Towards a design framework for mobile computer-supported collaborative learning, In T. Koschman, D. D. Suthers, and T. W. Chan (Eds.), Proceedings of the International Conference on Computer Supported Collaborative Learning, Taiwan, 2005.
[24] G. Zurita and M. Nussbaum, Computer supported collaborative learning using wirelessly interconnected handheld computers, Comput Educ 42 (2004), 289−314.
[25] R. Valdivia and M. Nussbaum, Face-to-face collaborative learning in computer science classes, special issue on mobile technologies for engineering education, Int J Eng Educ 23 (2007), 434−440.
[26] G. Zurita, M. Nussbaum, and R. Salinas, Dynamic grouping in collaborative learning supported by wireless handhelds, Educ Technol Soc 8 (2005), 149−161.
[27] J. P. East and M. Fienup, Questions to enhance active learning in computer science instruction, 35th Annual Midwest Instruction and Computing Symposium (MICS), 2002.
[28] K. D. Powers and D. T. Powers, Making sense of teaching methods in computing education, FIE'99: Frontiers in Education Conference, San Juan, Puerto Rico, 1999.
[29] D. Melzer and K. Mannivannan, Promoting interactivity in physics lecture classes, Phys Teach 34 (1996), 72−76.
[30] L. R. Irons, D. J. Jung, and R. O. Keel, Interactivity in distance learning: The digital divide and student satisfaction, Educ Technol Soc 5 (2002), 175−188.

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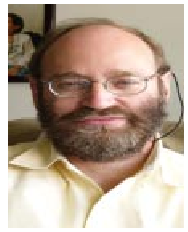

Miguel Nussbaum is full professor of computer science in the School of Engineering at the Catholic University of Chile. His research areas include ubiquitous learning, with projects in mobile learning in Chile, Argentina, Brazil, the United Kingdom, and the United States. He has published more than 30 journal articles in the ISI catalogue.