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5	Corresponding Author	Family Name	**Pifarre**
6		Particle	
7		Given Name	**Manoli**
8		Suffix	
9		Organization	Universitat de Lleida
10		Division	Department of Pedagogy and Psychology
11		Address	Av. De l'Estudi General, 4, Lleida E-25001-Lleida, Spain
12		e-mail	pifarre@pip.udl.cat
13	Author	Family Name	**Cobos**
14		Particle	
15		Given Name	**Ruth**
16		Suffix	
17		Organization	Universidad Autónoma de Madrid
18		Division	Department of Computer Science
19		Address	Madrid 28049, Spain
20		e-mail	ruth.cobos@uam.es
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Promoting metacognitive skills through peer scaffolding in a CSCL environment

Manoli Pifarre · Ruth Cobos

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Abstract This paper aims to better understand the development of students' metacognitive learning processes when participating actively in a CSCL system called KnowCat. To this end, a longitudinal case study was designed, in which 18 university students took part in a 12-month (two semesters) learning project. The students followed an instructional process, using specific features of the KnowCat design to support and improve their interaction processes, especially peer-learning processes. Our research involved both supervising the students' collaborative learning processes throughout the learning project and focusing our analysis on the qualitative evolution of their interaction processes and of their metacognitive learning processes. The results of the current research suggest that the pedagogical use of the KnowCat system may favour and improve the development of the students' metacognitive learning processes. In addition, the implications of the design of CSCL networks and related pedagogical issues are discussed.

Keywords Metacognitive learning · Self-Regulated learning · Peer interaction · Peer scaffolding · Qualitative research

Introduction

The evolution of technology and the explosion in the design of specific collaborative software has assisted in designing CSCL networks. Recent studies have revealed that appropriate pedagogical use of CSCL environments can facilitate a natural setting for explanation, knowledge articulation, argumentation, and other demanding cognitive

M. Pifarre (✉)
Department of Pedagogy and Psychology, Universitat de Lleida, Av. De l'Estudi General, 4, Lleida, Spain, E-25001-Lleida
e-mail: pifarre@pip.udl.cat

R. Cobos
Department of Computer Science, Universidad Autónoma de Madrid, Spain, 28049 Madrid
e-mail: ruth.cobos@uam.es

activities that can foster higher-level processes of inquiry-based interaction (Hakkarainen et al. 2002; Weinberger and Fischer 2006). Q1

Although CSCL could support communication and collaboration learning processes, neither research nor field observations consistently confirm that they actually work (Kreijns et al. 2003; Häkkinen et al. 2004). Among the factors that may cause this discrepancy, the following three are highlighted:

a) Computer-supported collaborative processes are over-generalized and simplified in many studies.
b) There is an assumption that a high level of interaction will automatically happen in a CSCL environment, although many studies report that discussion threads are short, participation rates are low, and interactions deal with descriptive and surface-level knowledge instead of finding deeper explanations for the phenomena under study.
c) It is taken for granted that social interaction will automatically occur just because technology allows it (Häkkinen et al. 2004).

Technology enables new ways of working collaboratively with knowledge, but these possibilities also call for the development of higher-order thinking skills among participants. Metacognitive skills related to strategy use, planning, monitoring, and regulating the learning processes necessary to accomplish a collaborative task are central to taking full advantage of the benefits of computer-supported learning environments. Recent research has also focused on the characteristics of the students, their tasks, scaffolds, and learning environments and how these characteristics may relate to the development of the students' metacognitive skills with computer-supported learning (Winter et al. 2008). This line of research highlights the necessity to understand both the role of metacognitive skills in computer-supported collaborative settings and the pedagogical variables that could have the potential to support students in the development of metacognitive skills (Hadwin et al. 2005; Azevedo and Jacobson 2008).

In view of this, this research study focuses on the analysis of the students' development of metacognitive processes in the context of joint learning activities supported by a knowledge-building environment called KnowCat (Alamán and Cobos 1999; Cobos 2003). Specifically, this paper examines the evolution of scaffolding metacognitive processes among peers when they collaboratively solve a task supported by KnowCat and when they were instructed to help each other to use the best learning processes to carry out successfully a specific collaborative computer-supported activity.

Background: The development of metacognitive learning processes in collaborative learning environments

Recent educational research focuses on the value of specific cognitive and metacognitive processes that students acquire while working in electronic discussion groups on collaboration tasks (Schellens and Valcke 2005; Van Joolingen et al. 2007). In educational literature, many references claim that the development of metacognitive learning activities is essential to the explanation of successful learning because it enables individuals to direct the overall cognitive activity, managing and controlling their cognitive activities in order to solve specific problems (Flavell 1992; Pintrich and García 1994; Schraw 1989). Q2

Metacognition is a complex psychological concept, but researchers agree that it concerns metacognitive knowledge as well as metacognitive skills. Metacognitive knowledge can be defined as knowledge concerning one's own metacognitive skills and products or anything related to them. Metacognitive skills determine the extent to which students set goals for this learning and then attempt to plan, monitor, and control their cognition, motivation, and behaviour (Brown 1987; Flavell 1992).

In this paper, we will focus on studying the processes related to the second dimension of metacognition that students develop while they actively participate in a CSCL environment. In this study, the definition of metacognitive skills emphasizes the presence of self-regulation components related to planning, monitoring, controlling, and using strategies (Moos and Azevedo 2008) to solve a collaborative task. These regulation components have been highlighted as important for leaning in computer-supported environments (Hadwin et al. 2005; Azevedo and Jacobson 2008).

Research on metacognition has produced information on how an individual uses metacognitive knowledge and metacognitive skills to become aware of his thinking and to exert control over his own cognitive actions (e.g., Brown et al. 1983; Flavell 1992; Schraw 1989). An emphasis on the social aspects of learning allows researchers to expand the theories of metacognitive processes and to view metacognition not only as an individual activity, but also as an essential part of socially shared discussions. Recent research on metacognition indicates that others (both adults and peers) play a central role, which suggests that metacognition is a part of the collaborative-learning process. Here, metacognition regulation is considered as a group-level activity as well as an individual performance (Goos et al. 2002; Zimmerman 2000).

The foundations of viewing metacognition as part of the collaborative learning situation could be grounded on the theoretical idea of socially shared cognition, in which thinking and cognition are seen as social practices. It is argued that thinking can be regarded as a socio-cognitive activity in which thinking and cognition can be shared through the learning environment among participants (Resnick et al. 1993). A key feature of a social-cognitive model of metacognition is the interdependent roles of social, environmental, and self influences (Zimmerman 2000). The social context that supports and frames the learning task becomes a core mechanism to understand the development of students' self-regulation processes related to task definition, goal setting, planning, enacting, and evaluation (Hadwin et al. 2005).

The social environment is viewed by social-cognitive researchers as a resource for self-enhancing forethought, performance, volitional control, and self-reflection. Therefore, the successful completion of tasks involves personal perceptions and efficacy, as well as environmental conditions such as support and task feedback from others. From this perspective, scaffolding is a primary mechanism for enhancing the development of self-regulation processes. It is hypothesized that self-regulatory processes exist first at the social level, where students interact with adults and others who provide modelling, instruction, social guidance, and feedback. The students can subsequently internalize these behaviours at the individual level (Gallimore and Tharpe 1990). A scaffold has traditionally been defined as the intentional assistance provided to the "other" for learning ends. Scaffolding also involves two additional mechanisms. First, scaffolding involves the gradual withdrawal of the master's control and support as a function of the student's increasing mastery of a given task. A second mechanism involves creating intersubjectivity by constructing rationales and explanations of plans, goals, and activities (Gallimore and Tharpe 1990).

Many researchers have demonstrated that when students and teachers are involved in shared tasks in which shared responsibility for regulating learning and tasks takes place and in which appropriate scaffolds emerge, students begin to develop realistic self-regulation processes and products (Hadwin et al. 2005).

Expanding on these ideas, it is hypothesized that in networked collaborative learning environments with an appropriate CSCL pedagogical model, there are metacognitive processes that can be stimulated by peers (Hurme et al. 2006). It follows, then, that CSCL environments might provide effective tools to share task resolution and to enhance scaffolding mechanisms. In recent design research on interactive learning environments, this notion of scaffolding has been generalized to refer to aspects based on software tools to assist learners in making progress on task solving (Reiser et al. 2001). In the design of interactive learning environments, two situations to scaffold learners in task solving may be found:

a) A situation whereby a software program provides additional assistance to help a learner accomplish a specific task. For example, the software might provide prompts to encourage students to take steps, or supply a graphical organizer to help students plan and monitor their problem-solving process or offer representations that help learners track the steps taken in the problem-solving process (Azevedo et al. 2004; Kramarski and Mizrachi 2006).
b) A situation whereby students use software tools to provide each other with explicit assistance to accomplish a specific task. CSCL enables students to work collaboratively with knowledge objects, see online fellows' solutions, and provide them with specific widgets for explicit assistance to improve on their task through process solving and knowledge creation or through online discussions of how to solve the task.

The software used in our research study tackles the latter scenario. KnowCat software enables students to collaborate by working with shared knowledge objects and to give each other assistance to improve and to construct collaboratively the shared knowledge.

Our study is grounded on the hypothesis that students could benefit from computer-supported collaborative learning because they are using their metacognitive skills more actively in task solving—planning, organizing, and coordinating working processes; they are making visible and reflecting on the working process; they are managing social relations around shared objects and linking people (Minna et al. 2009). Furthermore, such skills are more visible and explicitly explained and communicated to other CSCL community members, who can be given suggestions and assistance with a view to improving their own work.

Even though computer-based environments could engage students in collaborative learning activities, the role of metacognition in a collaborative framework supported by networked technology is not clear. As pointed out by some educational researchers, there is a need for research on how and what metacognitive learning processes evolve in computer-supported collaborative contexts and how others can scaffold these processes (Salovaara 2005; Hadwin et al. 2005; Arvaja et al. 2007). The research study presented in this paper falls within this line of work. Our aim was to analyze how and what metacognitive skills related to planning, regulating, and monitoring task resolution evolve while students solve learning tasks using the specific collaborative knowledge-building software called KnowCat. Students collaboratively solved different learning tasks using KnowCat in two regular courses over a one-year project at the Universitat de Lleida (UdL, Spain). In our study, we designed a pedagogical use of KnowCat to improve scaffolding processes among equals. Students were instructed to monitor and model explicitly each other's work as a strategy to improve their collaborative-learning processes and products. We examined changes in the metacognitive skills used to plan, regulate, and monitor students' work from the beginning to the end of a long-term learning project.

Our study started from the following research questions:

- Does the pedagogical use of KnowCat support and increase the use of students' metacognitive skills?

- Which metacognitive skills do students develop during the resolution of the different collaborative tasks using KnowCat?
- Do students' metacognitive skills change from the beginning to the end of the learning project?

KnowCat: The collaborative learning system

KnowCat, an acronym for "Knowledge Catalyser," is a knowledge-building environment, whose main purpose is to enable crystallisation of collective knowledge as a result of user interaction without an editor managing the task (Alamán and Cobos 1999; Cobos 2003). It was developed in 1998 and has been actively used since then at the Universidad Autónoma de Madrid (UAM) and since 2003 at the Universitat de Lleida (UdL) with several communities in higher education (see the studies and results presented in Pifarré and Cobos 2009; Cobos and Pifarré 2008; Diez and Cobos 2007; and Cobos and Alamán 2002).

KnowCat provides affordances for collaborative knowledge construction. It encourages communities to share their knowledge and, progressively, construct knowledge sites of reasonable quality. These knowledge sites, accessed through a specific URL, are organised around the following three knowledge elements:

a) A knowledge tree: a hierarchical structure of topics, which facilitates the organization of the community knowledge.
b) A set of documents contained in each topic, which provides alternative descriptions of the topic.
c) A set of annotations contained in each document, which expresses explanations, comments, and opinions about the content document.

In Fig. 1, we can see an illustrative screenshot of the "Instruction" KnowCat site.

The users participate in the common task of constructing the community knowledge through the following main operations:

a. Adding documents. A document reflects its author's knowledge on a specific topic. Once a document is added to a topic of the knowledge tree, the document will compete against the others to become the best document on that particular topic. This competitive environment is achieved by the Knowledge Crystallisation mechanism of KnowCat (see below for details).
b. Voting documents. A user can express through a vote his degree of satisfaction with a document.
c. Adding an annotation to a document. A user contributes an annotation (note, for short) to a document in order to make suggestions and/or give comments or opinions. In our study, we used these notes as explicit scaffolding messages—that is, the assistance mentioned above. A note is composed of a text stating the type of assistance provided by the user to the author of the annotated document and a note type. The following is a detailed explanation of the note types supported by KnowCat:

    a. "Clarification" note: used to clarify some parts of the document. This note type is normally made by the author of the annotated document.
    b. "Support" note: used to express satisfaction with the document.
    c. Review" note: used to make suggestions about adding, removing, or changing some parts of the document, or to make comments on it. The note types for a

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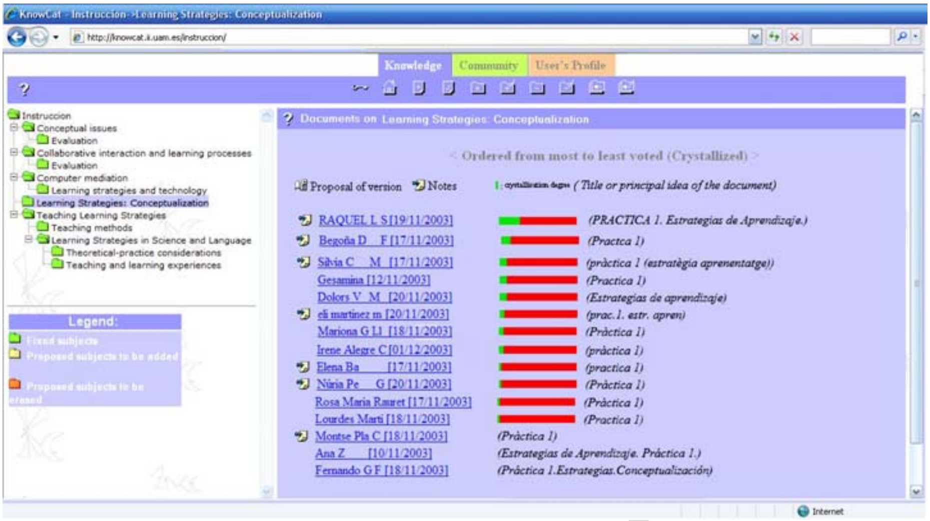


Fig. 1 Example screenshot of the "Instruction" KnowCat site

review note are the following five: 1) "*Addition*" note: used to suggest additions to the document; 2) "*Delete*" note: used to suggest deletions to the document; 3) "*Correction*" note: used to suggest changes to the document; 4) "*Criticism*" note: used to criticize the document; and 5) "*Question*" note: used to ask open questions about the document.

d. Adding a new version of a document. The author of a document can contribute a new version of his/her document at any time.

The Knowledge Crystallisation mechanism takes into account the user's opinions about the documents and the evolution of the opinions received to determine which documents are socially acceptable (in which case they remain in the knowledge site) and which are unsatisfactory (in which case they are removed from the knowledge site) (Cobos 2003).

Whether or not a document is socially acceptable is determined by its "degree of acceptance" as calculated by the Knowledge Crystallisation mechanism. More specifically, the degree of acceptance of a document is formulated using the explicitly received opinions concerning the document: the received votes, how these votes were received, the received annotations and their respective types, and the implicitly received opinions regarding access to the document.

As seen in Fig. 1, the knowledge tree is shown on the left of the screen. The right side of the screen shows the documents for the selected topic "Learning Strategies: Conceptualization." The documents are identified by the author's name, arrival date, and title. They are ordered according to their degree of acceptance, which is shown to the right of the identification heading of each document (on the green-red bar). On the left side of the identification heading of each document are icons indicating whether a document has received notes and whether a new version of the document is available. For example, the document identified by "RAQUEL L S … [19/11/2003] (PRACTICA 1. Estrategias de Aprendizaje) [Practical work 1. Learning Strategies])" shows the highest degree of acceptance on the selected topic. This document has received notes and a new proposal of a document version—as shown by the corresponding icons.

Research methodology

Our study took the form of a longitudinal case study conducted in an authentic university environment. The purpose was to follow the students' metacognitive skills over a twelve-month learning project, by collecting and analyzing data during and at the end of the learning process. The study was conceived as a field study, which would allow us to better understand the complex factors involved in computer-mediated learning in university contexts. The study then analysed changes in metacognitive skills from the beginning to the end of the learning project. To achieve this, we registered and analyzed all student contributions in the KnowCat learning environment, and made use of a coding scheme which would allow comparison between initial (first semester) and final (second semester) qualitative and quantitative results.

Participants

Eighteen university students participated in the research. They used KnowCat during a two-term period in two regular university courses in the Psycho-pedagogy degree. Each course ran for 12 weeks totalling 160 h. The two courses were "Instructional Psychology" and "Learning Strategies." The contents of both subjects were closely related in that the contents of "Learning Strategies" could be considered as part of "Instructional Psychology." Two instructors participated in the study; both of them taught in "Instructional Psychology" and only one of them taught in "Learning Strategies." Both courses shared the same pedagogical methodology, as explained in the next section.

Intervention: Main pedagogical characteristics of the collaborative learning instructional environment

A number of educational studies highlight the role of task or instructional characteristics in conveying a real collaboration and supported the development of metacognitive skills in computer-based environments (Moos and Azevedo 2006; Stahl et al. 2006). In order to design the collaborative tasks and the pedagogical use of KnowCat as a tool to scaffold metacognitive learning processes among peers, we built on the results of research into pedagogical and contextual settings, by taking into account the design of successful collaborative-learning environments. Among the pedagogical prerequisites, the following four can be highlighted, all of which have been taken into account in the design of our instructional process: a) the creation of common ground, b) the design of open-ended learning tasks and a goal-orientated approach, c) the facilitation of a student-centred education in which the role of the teacher is to guide the student's knowledge construction, and d) the need to structure student collaboration (Arvaja et al. 2000; Stahl 2001, 2003; Woodruff 2001; Dillenbourg 2002). These pedagogical prerequisites were introduced in our study as follows:

- We supported the creation of a common frame of reference before using the KnowCat system. One of the main tasks that students accomplish using KnowCat was related to peer-review processes. Students should read each other's task resolution and give each other assistance to improve it. To help students in this task, both students and instructors shared and exchanged ideas about *what* to scaffold (Azevedo and Jacobson 2008). In particular, they were encouraged to create a social learning environment where students monitored and modelled each other's application of cognitive and metacognitive strategies as part of their normal learning practice. As a result of this debate, the instructors and the students jointly elaborated some guidelines to verify what the most relevant aspects in note-taking and peer-review processes were. The guidelines referred to the next five aspects: content adequacy, personal elaboration of the ideas, organisation of the ideas, presentation strategies, and conclusions. These guidelines aimed, on the one hand, to help the students think about how to elaborate, organize, and personalise their ideas in note-taking processes and write an appropriate piece of writing. On the other hand, they act as a script that would guide and structure the writing of the students' scaffolds—for example, KnowCat notes—in order to help their classmates improve their written documents.

- We used a student-centred approach and goal orientation. The pedagogical approach used in this study focused on problem-based, goal-oriented activities, increasing learning, competence, and performance as tools to guide students toward the use of more self-regulatory processes. There is vast empirical evidence that confirms the role of goal orientation in problem-based activities to promote self-regulated learning (Pintrich 2000).
- We combined face-to-face meetings (25% of course time) with asynchronous and virtual work (75% of course time). Two instructional objectives were achieved in face-to-face meetings: a) to serve as master classes to teach specific course contents and b) to serve as support classes to negotiate with students how to use the KnowCat features to reach the common learning objective set out at the beginning of the study, namely, to help their fellow students improve their learning processes.
- The collaborative KnowCat system was also used in neatly structured activities in which students shared the project's common values and pedagogical goals. The collaborative tasks were coordinated in advance—that is, the tasks and the timetable were agreed on previously by instructors and students.
- The main procedure of the students' work with the KnowCat system was as follows: a) Students individually read some information about a specific topic course. b) The students wrote an individual report (document) about the topic and entered it into KnowCat. These reports contained a personal reflection on the content of the articles read, or suggested a personal solution to a specific problem. c) The students read a peer's report and annotated it—that is, by giving assistance—in order to help a fellow classmate improve on it. As in peer-review process, students' notes referred to strengths and weakness of each other's work and gave assistance on how to improve it. For each individual topic, the students were asked to annotate a minimum of one classmate's report and write at least three notes (these three notes could be done on one or more documents). During the study, the students were strongly encouraged to annotate the reports of different classmates. Despite this recommendation, the students' documents received a different number of notes, but none of the students' documents received less than three notes. d) The document's author read the notes concerning his report, taking into account his classmate's scaffolds, rewrote the report and entered it back into the system again. e) The students voted for the best document on a topic.

Data analysis

One of the most common trace methodologies to analyze students' cognition while participating in a CSCL activity is the content analysis of the students' notes posted in the system (De Wever et al. 2006; Naidu and Järvelä 2006). In our study, we registered all students' note contributions. We carried out a detailed study on the content of the notes written by the students who participated in our study at two different time periods: One was made in the middle of the first semester with students who used the KnowCat system, and the other, in the middle of the second semester. Both time periods correspond to two different topics, but both topics belong to a common discipline, Instructional Psychology. Both topics share the same pedagogical framework, the same learning objectives, and the same type of task: to construct knowledge from a theoretical topic. Furthermore, at both time periods, the students showed a high level of active and passive participation in the system (Veldhuis-Diermanse 2002). To be precise, we analysed 108 written notes during the first period and 87 during the second one.

In our study, a coding scheme was used to study possible changes in the notes and in the metacognitive processes required in writing these notes, from the beginning (first semester) to the end (second semester) of the learning project. The coding scheme was based on the metacognitive skills developed by Veldhuis-Diermanse (2002), a schema used extensively by its creators to analyze computer-supported collaborative processes in higher education (e.g., Laat and Lally 2003). This coding scheme analyzes the regulation of group processes aimed at stimulating collaborative learning and establishes three categories of metacognitive skills:

– *Planning*, when students present or ask for an approach or procedure to carry out the task and fulfil their objectives of the task. This presentation is followed by an argumentation or an illustration. An example of this category is presented below:

> I find the objectives set out appropriate but, before listing them, I would suggest you should write a schema of your intervention: objectives, teaching methods to use and learning evaluation procedures that would help to explain and understand how you would treat Joan's learning difficulties.

– *Keeping clarity*, when students ask for an explanation, synthesis of information, clarification, or illustration as a reaction to certain information in the document or a certain strategy used to solve the task. They give an example and/or add a new point to specific information. An example of this category is given below:

> The activities you suggest are very specific and, therefore, an educator should supervise them, as they could be difficult to do in class with a class group. How would the teacher work with the child if he/she needs to take care of the whole class group? With small groups? Working on different corners of the class? You should clarify all these aspects.

– *Monitoring*, when students monitor the original planning or aim. The students either mention the work done by their classmates and propose how to improve on it or they reflect on their own actions or certain contributions to the database. An example of this category is shown here:

> I take this opportunity to thank you for the annotation on my planning, I have learned lots from it and I've also sorted some contents from your report. Thanks!

The coding process consists of two steps: a) dividing the messages into meaningful units (Creswell 1998) and b) assigning a code to each unit. We decided to segment the notes into units of meaning by using semantic features such as ideas, argument chains, and discussion topics, or by regulative activities such as making a plan, asking for an explanation, or explaining unclear information (Chi 1997; Laat and Lally 2003).

To ensure objectivity in the coding process, validity and reliability aspects were considered in the study. Two evaluators of our research group with experience in this type of coding participated in the segmentation and categorization process. In the first step, the two evaluators categorised 5% of the total notes separately. In order to develop the coding rules and achieve reliability, the evaluators negotiated those notes which were categorised differently. In the second step, the two evaluators categorised 25% of the total notes separately. The Cohen's Kappa coefficient for both was as high as .87 (Lombard et al. 2005). The rest of the notes were coded by the two evaluators separately. We analysed the data with the help of nVivo software (Qualitative Solutions and Research 2002).

Results and discussion

In our research, we designed a pedagogical use of KnowCat knowledge elements that emphasized the use of the KnowCat notes as improved scaffolds among peers and, therefore, in studying the presence of metacognitive skills, was related to planning, monitoring, regulating, and strategising use in these scaffolds. Our main study focus was analysing changes over a period of time in external regulative learning, which can help students to run group processes, to make plans aimed at successfully carrying out the task, to monitor their learning processes, and to assist each other in achieving learning ends.

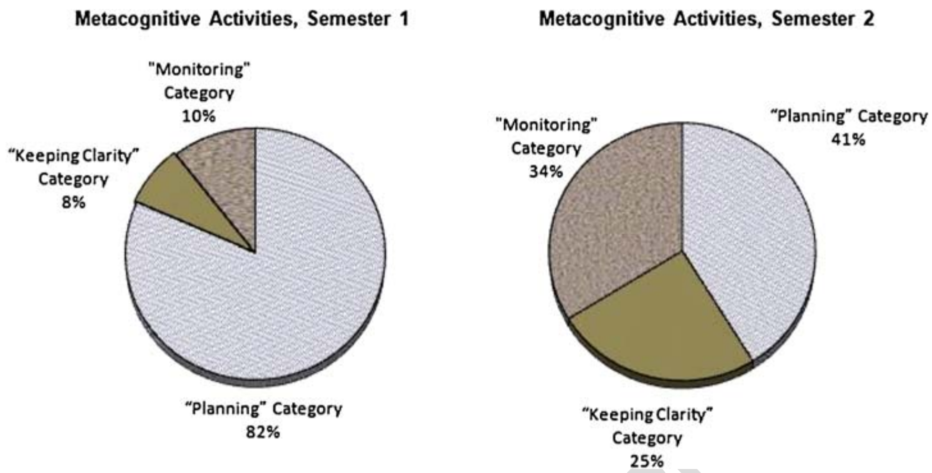
The first finding of our study is an increase in metacognitive skills over time. When analyzing the number of meaningful units referred to as metacognitive skills (total metacognitive skills in Table 1), we observed an increase in these skills in the second semester. A mean comparison test was run in SPSS software in order to analyze whether the improvement observed in metacognitive skills was statistically significant. The Wilcoxon matched-pairs signed ranks test showed a statistically significant difference (95% significant level) between the metacognitive skills observed during the first and second semester of our study (n=18, z=−2.46, p=0.014). Table 1 presents the main descriptive statistics.

These results showed that metacognitive processes take place and they show an increase during the KnowCat collaborative learning project. Many studies report on how metacognitive learning activities could be developed by means of the pedagogical use of a CSCL environment (e.g., Järvelä and Niemivirta 2001; Kreijns et al. 2004; Hurme and Järvelä 2005). In order to achieve an in-depth analysis into this area, our study pursues a detailed analysis of the characteristics of the metacognitive skills developed during the KnowCat collaborative learning project and what changes can be seen as a result of students' participation in the KnowCat learning project.

When analyzing the results obtained by the students in the three subcategories of metacognitive skills defined in our study, the data showed that activities related to planning others' work ("Planning" category) were the most frequent metacognitive skills in both semesters—see Fig. 2. In the "Planning" category, there were coded meaning units whereby

Table 1 Total frequencies of the different metacognitive skills, mean and standard deviation of the data in the two semesters

Metacognitive categories	1st Semester n=18			2nd Semester n=18			Wilcoxon test
	Total frequency	Mean	Standard deviation	Total frequency	Mean	Standard deviation	
Planning	31	1.55	1.58	28	1.28	0.96	Z=−.466 p=.641
Keeping Clarity	3	0.17	0.38	17	0.89	1.13	Z=−2.36 p=.018
Monitoring	4	0.17	0.38	23	1.28	0.75	Z=−3.34 p=.001
Total Metacognitive Skils	38	1.89	1.64	68	3.44	1.65	Z=−2.46 p=.014



Q5

Fig. 2 Percentage of each metacognitive learning process in the two semesters of our study

students either asked for a new approach or procedure to carry out the task or students presented or illustrated a new approach or procedure to perform the task, such as:

> When you talk about chronogram, you refer to the number of sessions per week and the type of activity (individual and in group) but you don't specify which aspects you will work on first, which ones you'll work on next, etc. I mean the sequencing of the contents you'll work on… My suggestion is to start from auditory-discrimination activities, then mobility activities, and then those that refer to preverbal language, i.e. perceptive, mobility-related, cognitive, with a view to satisfying initial conditions for language acquisition.

As demonstrated in other studies, in our study students were aware of the importance of planning skills in regulating students' learning and facilitating better task performance (Kramarski and Mizrachi 2006; Azevedo 2007). Students regulated their peers' problem-solving processes by providing alternative procedures or solutions. Most of the students' notes consisted of reflections about how to solve the task more effectively, that is, which approach or procedure to carry out the task was the best one to accomplish the objectives of the task more effectively.

Metacognitive skills related to planning-task resolution appeared as the most frequent strategies used by the students. This was true from the beginning of the learning project and did not increase during the experiment. Differences detected between the two semesters in the number of statements related to "planning" were not statistically significant by 95% ($z=-0.466$; $p=0.641$). One explanation for the "planning" strategies being the most frequent and stable in number during the learning project relates to the fact that the planning category is strongly related to task demands and task content. All these features are easier to debate and discuss in terms of the formal character of collaborative learning than in the context we designed, in which students were asked to help their classmates to rewrite and improve their documents about a topic course. This result is consistent with previous research, where planning strategies were enhanced in different computer-based learning environments and in different scaffolding conditions (Azevedo et al. 2004; De Jong et al. Q6 2005; Schellens and Valcke 2005.

A relevant result obtained in our study is the increase over time of the "Keeping Clarity" category. This category increased significantly in the second semester by 95% ($z=-2.360$; $p=$

0.018). This category consisted of students both asking for a better content structure of their classmate's document and revising key points of their classmate's work, for example, encouraging the other to continue with his/her work, asking for explanations, clarification, and illustration, or formulating a key point. The example below belongs to the latter category:

> … For example, which professional works on the language area? Who does the intervention with the child? Who does the intervention on the family? Methodology used.

The results of our study showed evidence that the students were active in monitoring their understanding and strategy use by asking questions. Previous research showed how asking each other questions and self-questioning constituted successful scaffolds in promoting the development of metacognitive skills (Kramarski and Gutman 2005; Kramarski and Mizrachi 2006). In our study, the students' increase in the number of scaffolds focused on asking their peers to improve, clarify, and reflect on such key task-solving processes as: comprehending the problem, connecting with prior and key knowledge, and reflecting on the solving processes. These kinds of scaffolds are referred to in previous studies as effective behaviour to enhance self-regulated learning (Azevedo et al. 2004; Van den Boom et al. 2004). Q7

Another relevant result of our study is that the data referring to monitoring activities also shows differences between the two semesters. Comparisons of the "monitoring" category between meaningful units written during the first and the second semester were statistically significant ($z=-3.337$; $p=0.001$). In the second semester, we observed an increase in activities related to co-regulation processes (Hadwin et al. 2005). In these processes, students shared the control of task resolution because they scaffolded each other's work. They referred to their own resolution in order to provide assistance which could help their classmates to actively control and reflect on their own learning processes and products. Also, while regulating each other's work—on the social level—students became more aware of their own learning and were able to self-regulate—on the individual level.

Next, we show two examples of these co-regulation processes. In the first example, a student shows awareness of different perspectives in the resolution of the same task and this awareness helped her to justify and be aware of her learning:

> I think we analyze this situation from a different viewpoint; I'll tell you mine, see what you think of it... I give priority to working the language area, as J is the one who has more difficulties with it. Besides, I understand this point may be an obstacle to developing the rest of the areas. In other words, as J does not understand nor is he fluent, he does not interact adequately with his context (work behaviour) and this affects his emotional development (insecurity, low self-esteem, shyness...)

A second example of the monitoring category shows how a student became aware that relevant information was missing from her task resolution through the evaluation of a classmate's report:

> I find the objectives set out appropriate. I think this is an aspect I hadn't considered and, the way you set it out is really important.

The increase in the number of metacognitive skills (which involve clarifying, monitoring and controlling each other's work) achieved in this study is a step forward in metacognitive research, in that our results differ somewhat from previous studies (Hurme and Järvelä 2005; De Jong et al. 2005). Our study reveals a higher increase in the students' monitoring skills after their participation in a CSCL environment. The other studies reported regulated processes among students referring to maintaining common ground and using cognitive strategies, but little referring to monitoring.

From our point of view, the pedagogical use of KnowCat knowledge elements—documents and notes, and especially the use of KnowCat notes as a tool to direct peer assistance in task resolution—has been crucial in developing the students' monitoring skills. Students tended to use the KnowCat knowledge elements as they were encouraged to: giving direct assistance to improve each other's work. While revising their own activity (writing a document which describes adequately a specific topic with the help of interaction from peer documents and notes) in the collaborative learning environment, the students managed to monitor and supervise how their peers were working on the same task. The social interaction around knowledge artefacts was a rich resource to enhance the development of the students' co-regulation processes related to sharing responsibility and control about what they have done and why. It provides leads to improve their work and stimulate self-reflection about what they have done.

Moreover, educational research has shown that one benefit of participation in a CSCL environment is the fact that it requires students to construct and share explanations, which formulate their ideas or construct scaffolds that help others during the collaborative task (Ploetzer et al. 1999). Different studies highlight the fact that among the main characteristics of effective scaffolds are those that foster good behaviour—giving examples, asking for clarity and explanations, encouraging thinking for oneself, and helping in the transition from other- and self-regulation (Mercer and Fisher 1998; Rogoff 1990; Wersch et al. 1984). These features are included in the metacognitive skills developed by the students of our study because they improve significantly on the "keeping clarity" and "monitoring" categories, categories related to these features.

In summary, the findings of the qualitative content analysis of computer notes describe the students' networked interaction during the learning project. The results of our study illustrated how students used the KnowCat knowledge elements—documents and notes—to explicitly scaffold and monitor their learning. Over time, students increase the number of scaffolds related to monitoring, regulating, and controlling their problem-solving processes. From our point of view, the results of the current study illustrate how the pedagogical use of KnowCat knowledge elements, which emphasized reflection around shared knowledge objects, might have an effect on the students' cognitive regulation, particularly in monitoring the learning processes. A growing body of research demonstrates the positive effects of CSCL on self-regulated learning. CSCL sets demands and provides unique tools for engaging in specific self-regulation processes and the positive incidence of these processes on the students' learning results (Koschmann et al. 2001; Paris and Paris 2001; Salovaara 2005). These effects are reinforced when collaborative learning is applied to open and well-defined complex tasks embedded in an authentic learning context, as in our study. Solving these task types improves the effectiveness of social knowledge construction (Kreijns et al. 2003).

Conclusions

In this paper, we aimed at understanding the development of students' metacognitive learning processes when participating actively in the collaborative knowledge-building system called KnowCat. In order to do so, our study applied a pedagogical use of the system in regular university courses during one academic year to develop teaching and learning processes in higher education. One of the main activities developed using KnowCat was to assist students' construction of knowledge about a topic through reading and writing critical documents on specific topics. One of the main instructional objectives of the CSCL instructional process was to assist in developing high quality collaborative learning processes among equals. To reach this objective, we made explicit use of the document annotation feature of KnowCat to improve peer scaffolds related with planning, monitoring, and regulating their problem-solving activity.

The results presented in this study showed students used the KnowCat notes as they were encouraged to, namely as explicit scaffolds to help each other use the best learning processes to successfully solve the collaborative task. Students increased the presence of metacognitive skills in their notes from the beginning to the end of the learning project. From our point of view, students increased their awareness of the importance of planning, regulating, and monitoring their learning to reach a better collaborative task performance. Furthermore, students showed relevant changes in the kind of metacognitive skills used during their participation in the learning project. Students increased those metacognitive skills cited in the literature on tutoring as co-regulation processes (e.g., Person and Graesser 1999; King 1999). In co-regulation processes, students share the responsibility for regulating learning and they attempt to indirectly regulate learning, as an intermediate stage to take full control of their own regulation. To do so, the educational literature highlights the relevance of students asking key questions, requesting information and elaborating on the task, devising goals and strategies to solve it, and reflecting about their own work. These metacognitive features were included in the definition of our "keeping clarity" and "monitoring" categories. Both categories increase over time in our study.

From our point of view, the computer-supported collaborative task through shared knowledge—KnowCat documents and notes—and the explicit pedagogical use of KnowCat notes as improved scaffolds among equals proved to be effective to enhance social metacognitive regulation. In our study, students engaged in co-regulation processes, in which they shared control of task resolution and explicitly related it to their own and each other's work.

The results presented in this study have illustrated that the pedagogical use of KnowCat knowledge elements may support shared task resolution and enhance the development of metacognitive learning processes during peer interaction. From our point of view, the main design guidelines of KnowCat, which can be generalized to other CSCL systems, are:

a) Document-based collaboration: The KnowCat knowledge organization into documents, which are, in turn, organized into a table of contents, has been useful as a mirror tool which provided students with different versions to solve the same task. Furthermore, the Knowledge Crystallisation mechanism controls the knowledge evolution and the quality of the knowledge elements in the communities' sites.
b) Opinion-based collaboration: The system supports different ways to express opinions of the users, specifically through votes and annotations. Empirical evidence has shown that the document's annotations improve task-related assistance among peers (content and strategies).

It should be noted that the results of the current study are based on a limited number of subjects and, therefore, the emphasis of the study is on qualitative findings. However, these results illustrate how the students' participation in the KnowCat instructional process may have affected their metacognitive learning processes.

The instructional process emphasised the students' competencies related to analysis and review. These competencies are explicitly included in psycho-pedagogical studies. In order to generalize our results, we are planning the instructional use of KnowCat in other educational contexts whose purpose is to learn contents of other disciplines, in which analysis and review competencies are lateral rather than key issues.

The results obtained in this study show that the students can benefit from knowing about each other's learning processes. In other words, and as expounded by Gross et al. (2005), members of work groups need information about one another, about shared elements, and about the group process (i.e., awareness of others).

We find it necessary to improve the feedback of KnowCat through graphical information capable of acting as a metacognitive mirror of interaction processes (Jerman and Dillenbourg 2008). More specifically, we are considering an extension of KnowCat in order to provide its users with the following metacognitive widgets: i) a radar view in the knowledge tree, which could give concrete information about where and what the online users are doing in the system, ii) detailed and structured action histories for the registered users (what each participant has done in the community space), and iii) a graph which could show how the users annotate documents and the content of these notes (what notes have been posted, where new notes have been posted, what the notes are about).

We are planning new research studies with student groups from both universities, Universidad Autónoma de Madrid and Universitat de Lleida. In these studies, the new knowledge elements will come into play and we will study how they can help KnowCat users and further the Knowledge Crystallisation process supported by the system.

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