Using Metacognition to Enhance Web-based Collaboration: a Case Study in Engineering Education

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Abstract. In this work the use of metacognition for the enhancement of web-based collaboration is presented. In particular the work focuses on the enhancement of the collaborative skills by means of developing metacognitive strategies. Through such strategies the individual is expected to be able to monitor his/her collaborative interactions and adjust them in order to enhance the effectiveness of his/her collaborative activity. The adoption of metacognitive strategies is a conscious procedure therefore it is translatable through metacognitive interactions. Modeling of the metacognitive interactions using the intermediate variables approach is presented in a case study that refers to Lin2k, a web-based collaboration environment. Experimental uses of Lin2k allowed the investigation of the impact of metacognition on the collaborative activity. Discussion on the experimental results proves the potentiality of the presented approach and stimulates further thoughts on the role of metacognition within the collaborative procedure.

1 Introduction

Educational Web-based collaborative environments provide the participants with opportunities to improve their collaborative skills, and thus be prepared for future relevant experiences at the professional level. Considering the divergent characteristics of the participants, such training requires provision of proper support. Quite often however, these environments foresee support on the task that is jointly performed. Provided that the focus is on the collaborative skills themselves, the collaborative process may be seen as an opportunity for experiential learning on how to collaborate. This approach in turn, may influence the outcome of the collaboration, as it increases the ability of the participants to sustain the quality of the collaborative procedure.

Recent studies ground the designing of the support to be provided by the system, on the analysis of the participants' collaborative interactions [1]. Such analysis, as far as the system is concerned is either of a 'static' form, e.g., statistical analysis of the collaborative interactions [2], or of a 'dynamic' one e.g., intelligent inferences upon the collaborative interactions [3]. Moreover, as far as the participant is concerned the support is quite often of a 'passive' character e.g., s/he receives evaluative results upon his/her activity [2]. On the other hand, support of a 'participatory' character may engage the participant in an active self-supporting procedure. The latter approach when combined with intelligent systems results in the formulation of an adaptive support. This type of support may challenge mental effort to the participants and thus, by means of their engagement in monitoring and management of the collaboration, the initial aim of improvement of their collaborative skills is promoted. This approach entails the idea of the use of metacognition upon the experiential learning of how to collaborate. Works in this area include self-explanations [4], manipulation of graphical representations of cognitive objects [5], graphical representations of the collaborative activity [3].

The above concepts motivated the investigation of the role of metacognition for the enhancement of the web-based collaboration. In particular, the integration of the participant's metacognitive strategies and its impact to the collaborative procedure are examined.

The rest of the paper is organized as follows. In Section 2 the term metacognition is defined. In Section 3 the theoretical framework for the integration of metacognition within a web-based collaborative environment for the enhancement of the collaborative skills is presented. In next Section, a case study i.e., the development of a web-based tool that was used in the engineering education with the aforementioned characteristics is described. Experimental issues and results from the above case study are discussed in Section 5, whereas Section 6 concludes the work.

2 The Role of Metacognition in the Educational Process

2.1 Definition

Flavell introduced the term metacognition in 1979 [6]. His idea introduced the notion of thinking about one's own thought. Thought is considered as a flow of information in and out of a system of mental structures (memory). Later on, many researchers have investigated the way in which information is stored and retrieved from these structures, the impact of human development on these structures and the way in which saving and retieving procedures are contorted by the person him/herself. According to Flavell's model, metacognition mainly comprises of metacognitive *knowledge* and metacognitive *experiences* [6, 7]. Metacognitive knowledge refers to the knowledge of how a person learns, the different learning strategies s/he can apply and their efficiency. Metacognitive experiences refer to the practice of the metacognitive strategies. Such strategies foresee that the person [8]:

- Defines the working task and makes predictions.
- Plans his/her actions during the learning procedure and chooses learning strategies to complete the task.
- Monitors and readjusts his/her working activity on the basis of his/her knowledge and regulates his/her working pace.
- Evaluates the learning procedure.

From the aforementioned it is evident that the human can be agent of his/her own thought [9]. However, the ability of the human to monitor and control his/her thought successfully depends on the type of the task, his/her cognitive background and his/her opinion about his/her ability to control his/her thoughts. Thus, emotional factors are also engaged in the metacognitive procedure [10]. This finding resulted in a better definition of metacognition, according to which, metacognition includes individual's awareness of his/her own knowledge, actions, and emotional situation, along with the ability to monitor and consciously adjust them during a learning procedure (e.g. collaboration) [10, 11].

2.2 Characteristics

The above definition includes two basic characteristics, i.e., individual self-appraisal and self-management of his/her thought [11]. These characteristics underline the necessity of the *active participation* of the human to structure his/her thought.

Metacognition can be taught [12], yet not only through knowledge provision but also through experiences on the implementation of cognitive and metacognitive strategies and evaluation as well. Under this perspective, metacognition is a *conscious* procedure; therefore it is *reportable* and *countable* [12-14].

2.3 Impact on academic performance

Metacognition has been linked to academic performance both theoretically and empirically [15]. In general the difference between the 'good' and 'bad' learners is, among other, due to fact that the good students do more self-monitoring and regulation of their strategy to ensure that the task is performed properly. These findings have been verified for all ages, from elementary school to individuals who perform at higher levels in academic domains [15].

The level of student performance can be improved through metacognitive interventions [11]. Moreover, empirical findings suggest that metacognition has the potential to improve near-transfer i.e., successful performance to a similar, yet a more difficult task. This is of great importance especially when training of adults is concerned, who often do not focus on the process through which they solve problems and can use in other situations [15].

2.3 The challenge

From the aforementioned concepts it is evident that when metacognition is used in the education process, it contributes to the fulfillment of desirable educational goals i.e., management of one's own learning, empowerment of self-esteem and improvement of academic performance. Thus, the educational environment should provide opportunities for theoretical but also experiential learning of metacognition.

Research on metacognition followed four directions [9]. The studies of the first direction investigate the cognitive monitoring, i.e., the preciseness of the way the subject monitors his/her thoughts, the studies of the second direction investigate the regulation of one's own thinking processes to cope with the demands of a new situation, the third direction comprises of studies which combine elements from the above approaches of monitoring and regulation, whereas the fourth includes studies on the ways in which the metacognitive theory can improve learning when applied within the normal educational procedure instead of the laboratory.

The challenge that emerges from the so far analysis is the integration of aspects of metacognition within a web-based educational environment, to enhance the collaborative performance of the collaborators.

3 Integrating Metacognition within a Web-based Collaborative Environment

Computer mediated collaboration allows distant participants to perform a joint task. Due to the fact however that collaboration is mediated, communication tools allow specific collaborative interactions to occur, thus they establish a communication protocol. By means of this protocol, sessions of collaboration may be developed for a step-by-step approach of the task.

Each collaborative session provides the participants with the opportunity to practice their collaborative skills. In this case, the overall collaborative procedure can be seen as a linear process of successive experiential learning sessions. This approach coincides with most theorists in the area of adult learning, who agree that adults learn more effectively through experience [16]. Moreover, the sessions' setting allows the designing of processes that facilitate the participants (adults) to learn, from their experience, how to collaborate.

In particular, the processes according to which individuals understand their experiences in order to learn from them and consequently improve their performance, has been described by Kolb in his well known model of the adult learning cycle [17]. This model has been used by many researchers and it predicts four phases of any learning experience: a) concrete experience, b) reflective observation of the experience, that is, the deliberate and conscious mental reconstruction of the experience, so that the adult may realize the learning benefits from it, c) abstract conceptualization of the theory behind the experience, and d) planning, which enables the adult to assimilate the new understanding and translate it into how further relevant experiences are to be handled.

Furthermore, when the experiences are related to the adult's interests or needs they strongly motivate him/her to learn more effectively [16]. Motivation is the *wanting* phase that Race underlines as the main process during experiential learning. He also argues that although the four phases of the learning cycle - *wanting*, *acting*, *feedback* and *digesting* - are in fact interlinked, they serve as a basis for the development of educational environments. As Race states many educational environments quite often provide opportunities only for the three first phases, whereas they should allow time for the completion of the latter, the metacognitive one. It is noteworthy that Race underlines that the above phases are interconnected; yet, their distinction serves the educational purpose of designing an educational environment.

Combining this approach with the educational aim of training in 'proper' collaborative skills, the educational environment may be comprised of the following components:

- The collaboration environment. It materializes the virtual workspace, the communication protocol and generally provides the setting for the collaboration to take place, thus facilitates the development of the concrete collaborative experience.
- The feedback component, which by means of monitoring, logging and analysis of the collaborative interactions, makes inferences as far as the collaborative skills is concerned, and presents them to the interested collaborators. The function of this component is of the 'passive' type of support and mainly serves the aim of triggering thoughts on the preceded collaborative activity, yet, with doubtful efficiency.

- The reflection component, which challenges, further on, each collaborator to mentally reconstruct his/her collaborative performance. This procedure assists each participant to describe, objectively as possible, what has taken place in the collaborative experience, without any interpretations and analysis [18].
- Finally, the metacognition component, which asks each participant to plan the improvement of his/her collaborative performance during the next session of collaboration. This function however, necessitates each participant to realize his/her deficiencies comparing his/her collaborative performance to the ‘proper’ one as it is described by the system. Hence, this component extents the reflection procedure, reinforces the idea of the adoption of metacognitive strategies and provides knowledge on ‘proper’ collaborative performance. Moreover, by means of logging and analysis it follows the metacognitive performance of each participant.

The framework that has been described above has been materialized in the case study that is described in the following Section.

4 A Case Study in Engineering Education

Engineering education needs to provide the students with skills and competencies that will allow them to proceed easily to the professional life. The collaborative skills are necessary prerequisites in many real-life engineering projects, where a multidisciplinary approach is necessary, i.e., in environmental engineering. Moreover, the dispersion of the Internet makes feasible the scenarios of distance collaborations among engineers. These concepts motivated the development of an educational web-based tool, namely Lin2k, which is examined here as a case study as far as the integration of metacognition within the learning process is concerned.

Lin2k foresees two adult peers who collaborate, in an asynchronous and written mode, in order to write a technical report on a semi-structured problem. Collaboration is completed within six sessions. The system support focuses on the improvement of the collaborative skills rather than the quality of the technical report, which is evaluated outside from the tool, by an evaluator. The provided support aims at balancing the collaborative activity of the two peers. This approach is based on the concept that the effort towards this balance challenges the best dynamic of the specific social construct, i.e., the specific pair. This leads to a better quality of the collaboration and presumably to a more qualitative technical report. The aforementioned components, which coincide with the adult learning cycle phases, are materialized in Lin2k is as depicted in Figure 1 and described below:

- The collaboration environment (Figure 1(a)). A series of virtual, individual or common sight workspaces facilitate the collaboration. Semi-structured interfaces materialize the communication protocol. For the development of the interfaces the MS FrontPage 2000 (Microsoft) was used. A more detailed description can be found in [19, 20].
- The feedback component (Figure 1(b)). All the interactions that take place are logged in an MS Access 2000 (Microsoft) database. By means of a fuzzy logic based expert system, analysis of the collaborative interactions, takes place at the end of each collaborative session. In particular the collaborative interactions are

being weighted to intermediate variables that describe the collaborative activity. Upon the values of these variables, the expert system infers the percentage of each peer's contribution to the pair collaborative activity, namely C_n^s (where $n = A, B$ are the peers and s the session of collaboration). Thus, the divergence between the peers' collaborative activity is easily calculated from the C_n^s values, which are complementary as they sum up to 100%. The C_n^s percentage is depicted through a graph to each peer, along with the zone that defines the accepted divergence (40%-60%) of the C_A^s and C_B^s values, namely Balanced Collaborative Activity (BCA). This feedback information is expected to challenge thoughts on the quality of the collaborative skills as they were practiced during the preceded collaborative session. More information on this system, which was developed with Matlab 6.1 (Mathworks, Inc.), can be found in [21].

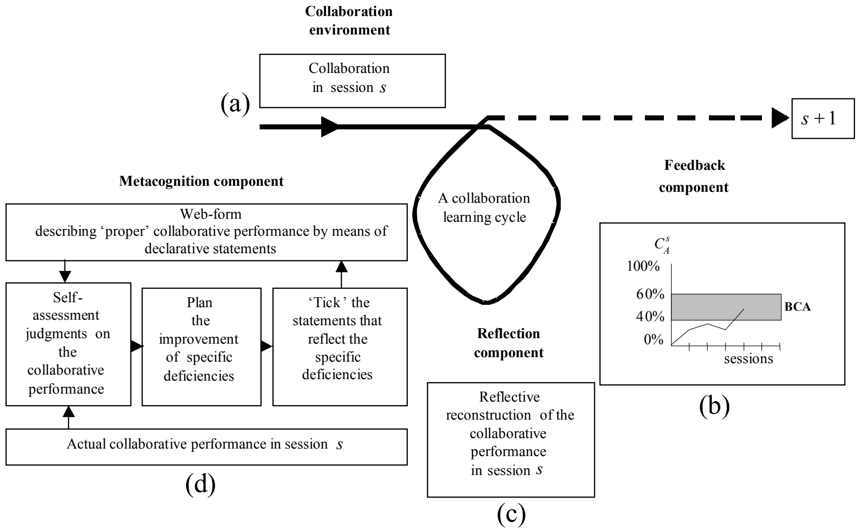

Fig. 1. The components of the learning cycle at session s, which facilitate the four phases, i.e., a) collaboration, b) feedback to each collaborator (here, feedback to the collaborator A, $(n = A)$ in session $(s = 4)$ is depicted), c) reflection, and d) metacognition, respectively

- The reflection component (Figure 1(c)). This is a web-form, which through prompts, encourages each peer to reconstruct the collaborative experience, as far as his/her collaborative activity is concerned. This form includes three categories of invitations/questions. The first concerns the quality of the individual collaborative performance, the second his/her emotional state during his/her performance and the third the impacts of his/her collaborative performance to his/her peer. In this way each peer practices reflection prior entering to the next phase.
- The metacognition component (Figure 1(d)). This component includes a web-form, which is presented to each peer to further self-improve, through action for the strategic planning and management of his/her collaborative activity at the *next* session

of collaboration. This form contains a series of statements, which are declarative, abstract propositions of ‘proper’ collaboration, independently of the task content and the collaborative activity of the previous steps. These statements provide the theoretical knowledge, according to which each peer should adjust his/her collaborative performance towards a balanced pair collaborative activity. In particular, these sentences concern the quality of contributions, argumentation, and attitude to the collaboration and co-ordination issues. Each peer reads the form and ‘ticks’ those statements that reflect his/her deficiencies. In this way the peer declares his/her intention to improve in the specific deficiencies during the forthcoming session of collaboration. Moreover this component of Lin2k includes an MS Access 2000 (Microsoft) database, where the ‘ticks’ are logged. A series of intermediate variables are again weighted to these raw data and a fuzzy logic based expert system evaluates them to infer a percentage, namely R_n^s (where $n = A, B$ are the peers and s the session of collaboration) [21]. This value indicates the peer’s intention to improve (0% denotes no improvement is required-100% a total improvement is required). A comparison of the C_n^s and the R_n^s values reveals the ability of each peer to properly assess his/her collaborative performance and triggers the feedback component to provide a message. It is an encouraging message to proceed to the next session when the peer’s judgments are correct or a warning message when there is a divergence between his/her intention to improve and his/her actual performance.

The aforementioned Lin2k collaboration-learning cycle is repeated in all sessions of collaboration. This learning cycle elicits cognitive and metacognitive activities from the collaborators towards a predefined aim (balance of the collaborative activity). The fulfillment of the above aim is monitored and evaluated by the system by means of fuzzy logic expert systems. The use of the fuzzy logic lends flexibility to the evaluating systems, allowing the alterations not only of the intermediate variables set to describe the collaborative and the metacognitive activity, but of the various parameters that are used at the mathematical level of the materialization of these systems as well. Thus, these systems can easily and at low computational cost reflect the evaluation approach of interest.

5 Experimental Issues, Results and Discussion

The role of metacognition in the collaborative procedure was investigated through an experimental use of Lin2k. The 44 students who participated in the experiment were randomly selected from the 10th semester from the Department of Civil Engineering, Aristotle University of Thessaloniki, Greece. None of them had ever used Lin2k before, so they received preparatory training on its use. The pairs collaborated on a semi-structured problem from the environmental engineering field.

The 22 pairs of students were equally divided and randomly assigned to experimental (EXP) and control (CTRL) pairs with varied support. The control pairs performed the three phases of the Lin2k learning cycle i.e., they completed the reflection phase (Figure 1(a)-(c)). The experimental pairs practiced the whole educational process of Lin2k, including the fourth phase i.e., metacognition (Figure 1(a)-(d)).

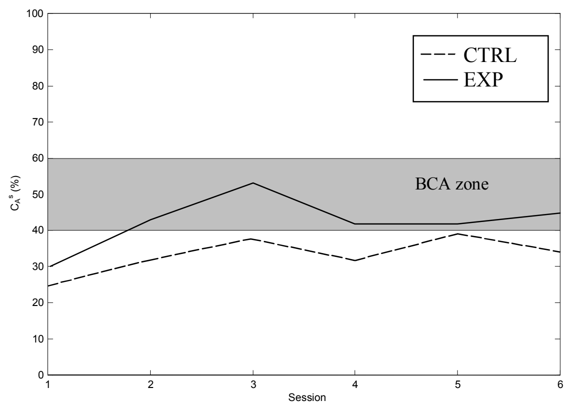

Fig. 2. Convergence to the BCA zone of the average C_A^s value along the $s = 6$ sessions: CTRL without metacognition, EXP with metacognition

A comparative analysis of the average C_n^s values along the six steps for all the EXP and CTRL pairs is presented in Figure 2. Considering the fact that the C_n^s values of the two peers are complementary, Figure 2 depicts the values only for $n = A$.

From the overall experimental results that are presented in Figure 2 it is revealed, in terms of tendencies observed, that the use of metacognition in the Lin2k collaborative process plays a significant role, as far as the convergence to the BCA zone is concerned. It is evident that the experimental pairs performed better collaboration and converged the C_n^s values to the BCA zone from the second session. Moreover they kept them within the BCA zone until the end of the collaboration.

From the aforementioned preliminary results, it is evident that at each step, through the integration of the metacognition component, which materializes the fourth phase of the adult learning cycle, the concept of equivalent collaboration (50%-50%) was reinforced. This was achieved through the practices of self-evaluation, improvement planning and motivation building for the next session's pair work. Thus, the approach that was adopted managed to actively engage the participant in a self-supporting procedure.

The repetition of the learning cycle along sessions contributes to better practice of the metacognitive strategies. This approach increases the possibilities for near-transfer of the collaborative skills under different collaborative setting. The last assumption along with the so far findings will be verified through further experimental uses.

6 Conclusions

The role of metacognition in the enhancement of web-based collaboration is investigated in this work. According to the literature review metacognition significantly contributes to the academic performance. Moreover, it can be taught, through educational procedures that include provision of metacognitive knowledge and facilitate metacognitive experiences.

The above approach was used for the enhancement of the collaborative activity within a pair-work of distant collaborators. To this purpose, a web-based collaborative tool, which served as a case study, was used. Considering as an indicator of the quality of the collaboration the balance between the two peers' collaborative activity, implementation of metacognitive strategies by each participant (i.e., self-assessment, planning and self-adjustment procedures) was promoted, towards converge of their collaborative activity to equilibrium (50-50%). In particular, along with the system support, each peer was challenged to become agent of his/her collaborative skills toward this aim.

The efficiency of the presented approach was tested through experimental use of the web-based collaborative tool. Preliminary results proved the potentiality of the proposed approach and verified the role of metacognition as a promising component in a computer mediated collaborative environment.

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