An Exploration of Correlative Elements to Support Cognitive Advancement in the Design of Collaborative Learning Tools

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Abstract. Cognitive advancement in collaborative learning is diverse, complex and interdisciplinary, involving research in technology, pedagogy, psychology and sociology. The state-of-the-art computer-supported collaborative learning (CSCL) tools mainly focus on promoting communication between learners whilst they are engaging in collaborative learning activities. In order to explore the elements that support cognitive advancement for the design of CSCL tools, we have undertaken a literature-based analysis of both technological and non-technological perspectives on CSCL, and have derived several essential design elements from the analysis. We propose a new conceptual model by combining these elements, which aims to provide encompassing support for collaborative learning activities and to address the correlative functions that the derived elements can provide for the design of CSCL tools for cognitive advancement. We also discuss implementation issues which affect the conceptual model and suggest how our collaborative learning tool can be built as a multi-agent system.

1 Introduction

Collaborative learning (CL) is a learner-centered educational approach [1] which involves intellectual interactions between students, or students and instructors. The 'learner-centered' nature makes CL practitioners develop methods and tools which focus on the benefits of collaborative learning for learners. Srinivas summarized 44 benefits (see `http://www.gdrc.org/kmgmt/c-learn/44.html`) of collaborative learning based on previous pedagogic research, including the ones that can best promote the cognitive process such as stimulating higher level thinking skills of students [2], encouraging students to clarify their ideas in discourse [3], and developing diversity understanding [4]. Additionally, for a long time it has been known that collaborative learning can enhance the cognitive and attitude levels of learners in a number of ways [5] [6].

Computer-Supported Collaborative Learning (CSCL) is an interdisciplinary research area that focuses on how technology can facilitate collaborative learning.

Much effort has been made in the CSCL field to enhance interactions between individual learners. CSCL tools have been established to provide various communication functions (e.g. explanation, argumentation and elaboration) [7] [8] [9]. Tools have also been built for solving problems related to discussions, for example, Fuks and Pereira De Lucena have identified the sources of "chat confusion" in discussion sessions and made successive versions of a mediated chat tool to counter these causes [10]. However, to enhance learners' cognitive abilities is more than to promote the communication functions of software tools. For designing a computer environment to support collaborative learning, there are technological issues (such as asynchronous and synchronous communication) and non-technological issues (such as pedagogical and sociological issues) that need to be considered for providing encompassing support for the learning activities. A global view of the design elements of collaborative learning tools that can support learners' cognitive advancement is currently lacking.

In order to explore the essential design elements, this paper investigates three areas that are highly focused in CSCL with regard to cognitive advancement: scaffolding social interaction, building collaborative knowledge and assessing collaborative learning. Six groups of design elements for scaffolding collaborative learning activities are identified from an analysis of these three areas by comparing existing theories, methods and tools. A new conceptual model is proposed that combines the elements derived from the analysis. Furthermore, the implementation issues of the conceptual model are discussed. Finally, a usage scenario is presented to demonstrate how the conceptual model can support the accomplishment of a collaborative learning activity.

2 Methodology

We conducted a literature-based analysis to explore the design elements. The criteria for including work in our review are as follows:

- it is a well-documented and published research article;
- the article focuses on CSCL;
- it was published within the past three years;
- the article was published in a high quality journal, proceedings of international conference, or an academic book related to educational technology research and development;
- the research method described in the article is either theoretical or empirical.

We chose articles in the *International Journal of Computer-Supported Collaborative Learning* (ijCSCL) from 2006 to 2008 and the *Proceedings of the International Conference on Computer-Supported Collaborative Learning* (CSCL) in 2005 and 2007 as the main sources for our investigation because they fulfill the criteria listed above. Other sources for the analysis process include *Educational Technology & Society*; *the Proceedings of the International Conference on Advanced Learning Technology* (ICALT); *Technology, Pedagogy and Education*; *Educational Psychology Review*; *Learning and Instruction*; and two monographs.

Table 1 shows the sources, the timeframe, the number of articles reviewed for each source and the proportions of the articles in each source over the total number of articles reviewed.

Table 1. Characteristics of the literature sources included in the analysis process

Source	Years covered	Number of articles reviewed	Proportions over the total number of articles reviewed
ijCSCL	2006 – 2008	63	21.3%
Proceedings of CSCL	2005 and 2007	227	76.7%
Other Sources	2006 and 2007	6	2%
Total	2005 – 2008	296	

3 Design elements for cognitive advancement

The following three areas in CSCL are highly focused with regard to cognitive advancement: scaffolding social interaction, building collaborative knowledge, and assessing collaborative learning. They have different roles in the support of cognitive advancement. First, social interaction is viewed as a crucial source of cognitive advancement [11]. Computer-supported collaborative learning in itself provides a type of interactive learning environment (see `http://www.aace.org/PUBS/jilr/scope.html`). Not only can it help an individual learner build up self-esteem from the learning interactions [2], but it also gives individual learners the chance to compare, clarify and justify their own ideas by interacting with their peers [3].

Second, collaborative efforts are of central importance for knowledge advancement [11]. Individual learners may become constrained when completing a complicated task due to their limited attention, memory or understanding [12]. Building collaborative knowledge is a way to expand one's own memory and understanding in order to assist in completing a complex learning task.

Third, assessment is a principal means of observing a learner's cognitive advancement. In terms of assessing collaborative learning, methods for assessing learning outcomes [13] and collaborative process [14] can be used to monitor and track the progress of individual learners. Instructors can also provide feedback (see `http://www.aect.org/edtech/29.pdf`) to individual learners based on the results of the assessment and learners can make further improvements based on the feedback provided.

Each of the above areas provides us with several significant elements which contribute to the design of collaborative learning tools for cognitive advancement. Our analysis is presented in the following three sections which correspond to the three areas. The essential design elements that are derived from the analysis process are then described later in the paper.

3.1 Scaffolding social interaction

Panitz views collaborative learning as a philosophy of interaction (see `http://www.londonmet.ac.uk/deliberations/collaborative-learning/panitz-paper.cfm`). The 'philosophy of interaction' means that group members share the authority and responsibility for the groups' actions; and the premise of collaborative learning is consensus building other than individuals' defeating other group members.

In other words, collaborative learning itself is a form of building common understanding via the interactions among a group of people. As Resta and Laferriere point out [11], on-site and online social interaction are crucial sources of cognitive advancement.

In our analysis, we identify that the following ways have been proposed for enhancing the social interactions in collaborative learning processes:

- establishing a theory or conceptual model of social interaction;
- developing software to support online interaction activities such as argumentation;
- using interaction analysis to seek variables that influence learning effects.

The first method provides the educational and sociological basis for the development of computer-supported tools to support social interactions, and has been adopted by Kobbe *et al.* [15] and Stahl [12]. The second approach, used for example by Clark and Sampson [16], provides a practical view of how online interaction can help students to compare, clarify and justify their ideas with group members. This starts by examining existing theories in subjects such as cognitive psychology, sociocultural psychology and activity theory, and then derives the functionality of the software systems from the those theories. The third way, which has been adopted by Suh *et al.* [17] and Shih and Swan [18], reflects on the practice of developing software systems to provide further guidance for the design of CL tools to support social interaction.

In the following scenarios we discuss the main features of the representative theoretical models, software prototypes and interaction analysis techniques corresponding to each of the above areas, and we consider their limitations for enhancing learners' cognitive levels in collaborative learning.

Social interaction theory for CL Social interaction theories provide the foundations for defining learning strategies that can be used for collaborative learning activities. Such learning strategies are methods for structuring interactions among different participants. The approaches for describing learning strategies may be divided into two categories: one focuses on describing the *specific activities* that learners participate in, and the other one concentrates on outlining the *general phrases* of group processes and how they are related to individual cognitive processes.

The former approach is known as *CSCL scripts* and has its origin in the scripted cooperation approach [19]. As discussed by Kobbe and Fischer [15], CSCL scripts form a model which shapes the way that learners interact with each other, such as question asking, justifying opinions, articulating reasoning or elaborating knowledge. Kobbe *et al.* note that specifying CSCL scripts also involves describing task distribution, group formation and interaction sequencing [15].

The latter approach refers to the theory of group cognition [12]. Unlike CSCL scripts, the group cognition approach does not consider the problems of task distribution, group formation and interaction sequencing, but describes a two cycle process of formulating individual cognitive artifacts through the combination of an individual cognitive process and a group collaborative process.

The former approach is more predictive of the learning outcomes than the latter one because not only does it specify what the learners have to do, but it also describes the mechanisms for completing the learning process (i.e. mechanisms for task distribution and interaction sequencing). However, neither of these approaches considers the intrinsic differences of individual learners which will influence their learning.

Software systems to support social interaction activities The role of software systems in supporting social interaction activities is twofold. First, software systems are able to support group collaboration by providing communication instruments such as formulating seed comments in online discussion [7]; constructing single arguments and argumentation sequences in online discussions [8]; and composing messages via sentence openers in online peer-to-peer interaction [20]. Second, software systems are able to assist in structuring the learning process [21], for instance, to provide a particular workflow for a particular learning task.

State-of-the-art software systems which support social interaction activities play the former role, i.e. providing different communication functions for the learners to interact with each other. An example of this is the online discussion system proposed by Clark and Sampson [16]. Their system helps students construct scientific principles for a thermodynamics curriculum based on predefined phrases and elements. These personalized principles serve as seed comments in subsequent online discussions. Articulating the scientific principles develops around the different perspectives represented in the seed comments through a process of comparison, clarification, and justification by learners with differing thoughts and opinions.

However, current software systems do not structure the collaborative learning process to include formulating learning strategies based on individual learners' preferences, providing technological facilities for social practice, and evaluating the cognitive progresses of the learners.

Interaction analysis Computer-supported interaction analysis is a way to obtain additional information, such as patterns of peer interaction and communication relations, from technology assisted activities (see `http://ltee.org/adimitr/?page_id=64`). The methods or tools supporting interaction analysis are diverse, but the most common technique in CSCL is Social Network Analysis (SNA) (see `www.analytictech.com/networks/whatis.htm`).

By analyzing the outputs of CL interaction analysis, various indications of the collaborative learning processes can be generated. For instance, Suh *et al.*'s study [17] suggests that prior knowledge and personal intelligences (verbal-linguistic intelligence, interpersonal intelligence and intra-personal intelligence) of a learner can affect their learning outcomes in collaborative learning. Shih and Swan's study [18] reveals that social presence is an important variable influencing person-to-person communication in distance education.

Although various criteria can be inferred from the collaborative learning process, CL tools which scaffold social interaction seldom make use of them in their design. In future development of CL tools to support cognitive advancement, these can be incorporated into their design. For instance, a new CSCL tool may be designed to build up a new learner model incorporating learners' characteristics such as prior knowledge and personal intelligence. Such a learner model can be used to assign an individual learner to an appropriate learning group based on the learner's characteristics. It can also be used to show the presences of different learners and enable an individual learner to be aware of their own appearance in an online learning community.

Table 2 summarizes the limitations of each of the three ways of scaffolding social interaction and the criteria derived from them for the design of our conceptual model.

3.2 Building collaborative knowledge

Building knowledge refers to the process of learning. At the higher education level, three critical factors in the use of technology for building collaborative knowledge have been identified: *individual reflection* [22], *quality group interaction* [12], and *contextual resources* [23]. A brief analysis of the typical models that emphasize each of these factors is given below.

Seddon and Postlethwaite designed a model [22] to support the collaborative construction of knowledge via reflection on the individual's own contributions, rather than via an external evaluation of individual progress. However, the learning effects of the learners who follow this model are fully dependent on their autonomy for learning and their learning abilities.

Stahl observed that building collaborative knowledge is a core process in collaboration [12], in which a group may construct a new degree of understanding about the topic that they are investigating. The 'new degree of understanding' comprises the knowledge and skill which group members together assemble and no one member would likely have constructed alone. In Stahl's model, a public cycle of social knowledge building can eventually lead to the production of shared cultural artifacts, which can be internalized by individual participants, increasing their resources of cognitive artifacts (such as personal memories, intellectual resources, and mental abilities).

This model emphasizes that constructing group meaning has advantages over individual reflection because it produces the 'new degree of understanding'. How-

Table 2. The limitations of the three ways of scaffolding social interaction and their criteria for the design of our conceptual model

Ways of scaffolding social interaction	Limitations	Criteria for the design of our model to support collaborative learning
Social interaction theory for CL	Neither CSCL scripts nor group cognition theory consider the influence that the intrinsic differences of individual learners will have on the adoption of learning strategies.	Learning strategies should be defined according to individual learners' characteristics. Social interaction theories provide theoretical fundamentals to define learning strategies for collaborative learning.
Software systems to support social interaction activities	Lack of software systems which provide overall support in structuring the collaborative learning process.	New software systems to support collaborative learning should include basic modules for formulating learning strategies based on individual learners' preferences, providing technological facilities for social interactions and evaluating the cognitive progresses of individual learners.
Interaction analysis	The outputs of interaction analysis are seldom used in the design of CL tools.	Indicators such as analysis results should be incorporated in the design of CL tools.

ever, there is no detailed description on how such group discourse and interaction can be structured.

Arvaja *et al.* [23] emphasize the importance of contextual resources in the construction of collaborative knowledge. They suggest that the knowledge construction activity is grounded in wider contexts and mediated during discussion by contextual resources. This model refers to the three general categories of contextual resources defined by Linell [24]: co-text; surrounding concrete situations in which the participants act; and background knowledge, assumptions or beliefs about the things talked about in a given discourse. With regard to the role of contextual resources in collaborative knowledge building, Arvaja *et al.* note that students (on a teacher training course) had convergent conceptions and general knowledge about the issues at hand owing to their similar earlier experiences from the practice period as well as their earlier background knowledge, which might derive from formal teacher education [24]. The study also suggests that previous exchange (i.e. co-text) can be used as a basis for further elaboration on a given theme.

Although the role of contextual resources in collaborative knowledge building have been analyzed and developed, contextual resources have not been widely used in computer-supported collaborative learning.

Table 3 summarizes the limitations of the prevalent models of building collaborative knowledge and the criteria they suggest for the design of our conceptual model to support collaborative learning.

Table 3. The limitations of the prevalent models of building collaborative knowledge and the criteria they suggest for the design of our conceptual model

Models of building collaborative knowledge	Limitations	Criteria for the design of our model to support collaborative learning
Seddon and Postlethwaite's model [22]	Learning is fully dependent on the autonomy of individual learners and their abilities to learn.	Learner behaviors such as self-reflection form the individual elements that can influence cognitive advancement.
Stahl's model [12]	It lacks detailed description about how to structure group interactions.	Group members' cognitive levels are one type of group element that can influence cognitive advancement.
Arvaja *et al.*'s model [23]	Lack of computer-supported methods to explore better use of contexts in collaborative learning.	Contextual resources as well as communication functions are able to form foundations for knowledge construction activities.

From the practice of collaborative knowledge building [22] [12] [23], collaborative efforts are seen to play an important role in cognitive advancement as well as individual efforts. Individual elements intrinsically empower an individual learner to make breakthroughs in cognitive advancement while group elements broaden individual viewpoints. Additionally, context resources are the grounded factors that influence the cognitive advancement of a learning community. The design of an effective CSCL tool to support cognitive advancement should incorporate these elements.

3.3 Assessing collaborative learning

Effective assessment not only provides an instructor with information on learners' learning progress, but also enables computer-supported learning tools to support the teaching and learning processes more effectively. The purposes of assessments vary in collaborative learning settings, though research in this area focuses on the assessment of learning outcomes and the assessment of collaborative process.

Assessment of learning outcomes The assessment of learning outcomes seeks to verify the cognitive levels of learners. It is a process interweaved with the learning process that needs both the support of an educational approach and the use of an educational tool to apply that approach.

We have summarized the educational approaches, the characteristics of the approaches and the support tools. As shown in Table 4, the educational approaches for assessment include *automatic* assessment, *self-, peer- and collaborative-* assessment, and assessment *by the instructor*.

Table 4. Educational approaches, characteristics of the approaches and tools to support assessment (adapted from Gogoulou *et al.*'s study [13])

Educational approach for assessment	Characteristics of the approach	Computer support tool
Automatic assessment	Automatically assess a learner's answers in closed questions (e.g. multiple choice, true-false, fill-the-blank)	COMPASS environment [13]
Self-, peer- and collaborative-assessment	In self-assessment, learners make judgements about their own performance; in peer-assessment, learners judge the performance of their peers; in collaborative-assessment (or co-assessment), learners and instructors collaborate in order to clarify criteria, discuss any misunderstanding that exist.	PECASSE environment [25]
Assessment by the instructor	Instructor makes judgements on the learners' performance	Different instruments are used such as paper-based tests and oral examinations.

Feedback is a formative way to give learners the assessment results and it can gradually help learners progress. We categorize feedback into three types: *informative* feedback, *tutoring* feedback and *reflective* feedback (Table 5). The feature of each type of feedback is explained in Table 5.

Gogoulou *et al.* observe that an effective CSCL tool for cognitive advancement should combine both the learning and assessment process as its educational functions [13], and suggest that future development of CSCL tools includes combining both the learning and assessment functions.

Assessment of collaborative process In addition to the assessment of learning outcomes, many researchers in CSCL consider that the collaborative process should be paid close attention to [14]. Methods to support assessment of collaborative process include the following [26].

Table 5. Types of feedback (adapted from Gogoulou *et al.*'s study [13])

Type of feedback	Explanation on the feature of the feedback
Informative feedback	Correctness-incorrectness of response; performance of learners
Tutoring feedback	Explanatory — Give a description or a definition Exploratory — Give an image, an example, advice or a case study
Reflective feedback	Belief prompt; rethink write and error; task related questions

- *Discourse analysis* is a complex interdisciplinary field involving linguistics, anthropology, and sociology — studies of naturally-occurring conversation in context.
- *Social network analysis* focuses on the way people interact with each other, especially the relationship between participants rather than the content of discourses.
- *Quantitative log files* serve as an easily accessible source for analyzing collaborative process, but Nurmela *et al.* note that the analysis of log files should be combined with an analysis of their contents, especially the content of collaborative dialog or discourse [14].
- *Content analysis* is a procedure to generate valid inferences from text. Wever *et al.* [27] give an overview of different content analysis schemes that reflect the theoretical diversity, the amount of information about validity and reliability, and the choice for the unit of analysis.

Compared with other methods, content analysis is widely used to analyze and assess the collaborative process with the assistance of tools in CSCL. A framework of content analysis for collaborative process (Figure 1), generalized from work by Li and Huang [28], consists of three components as follows.

- *Data Importing and Transforming* component imports data composed of discussion transcripts, from sources like online collaborative learning forums, into a database and translates different data formats into a standard one.
- *Analysis and Coding Support* component provides basic statistics about participation and inter-personal relationships and statistics relating to transcripts; it also provides coding support (for example, keyword highlighting).
- *Result Export and Visualization* component exports the analysis results into persistent files and provides visualization of analysis results.

Software tools can be developed to support the above components. First, tools for data importing and transforming can transform the original data from the discussion transcripts, which may be in HTML format, databases or text files, into a standard relational database. In addition to the data transformation, pre-processing such as the establishing of coding schemes and rules should

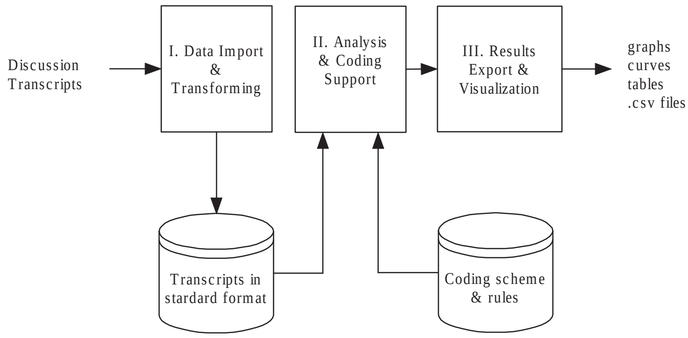

Fig. 1. A framework of content analysis for collaborative process (adapted from Li and Huang [28])

be completed before coding discussion transcripts, a procedure for tagging segments of each transcript with an identifying code. Example coding schemes for analyzing educational discourse can be found in [29]. Second, tools for participation analysis can provide statistical results on the number of posts, replies and keywords used in a discourse by individual learners. Tools for analyzing inter-person relationships can also be developed by using social network analysis techniques. Finally, the analysis results can be visualized using graphs, curves, and tables, or exported into "comma separated" text files for further quantitative explanation.

4 A new conceptual model to support collaborative learning

Investigation of the three areas in CSCL field for supporting cognitive advancement in collaborative learning (i.e. scaffolding social interaction, building collaborative knowledge and assessing collaborative learning) indicates different problems to be addressed in our model to support collaborative learning:

- how to describe learners in a way that is meaningful to the collaborative learning activities (from the criteria for the design of our model to support collaborative learning summarized in Table 2 (refer to 'social interaction theory for CL') and Table 3 (refer to 'Seddon and Postlethwaite's model'));
- how to structure the collaborative learning process for individual learning groups (from the criteria for the design of our model to support collaborative learning summarized in Table 2 (refer to 'software systems to support social interaction activities) and in Table 3 (refer to 'Stahl's model'));
- how to monitor the interactions between learners in the collaborative learning process (from the criterion for the design of our model to support collaborative learning summarized in Table 2 (refer to 'interaction analysis')).

Therefore, our conceptual model aims to specify the basic modules of a collaborative learning tool that can provide overall support for describing the learners, structuring the learning process and monitoring the collaborative learning process. It also aims to address the correlative functions that various elements can provide for the design of CSCL tools.

Our conceptual model (Figure 2) consists of two components: the basic modules that a collaborative learning tool comprises and the design elements to support cognitive advancement that are derived from the literature-based analysis.

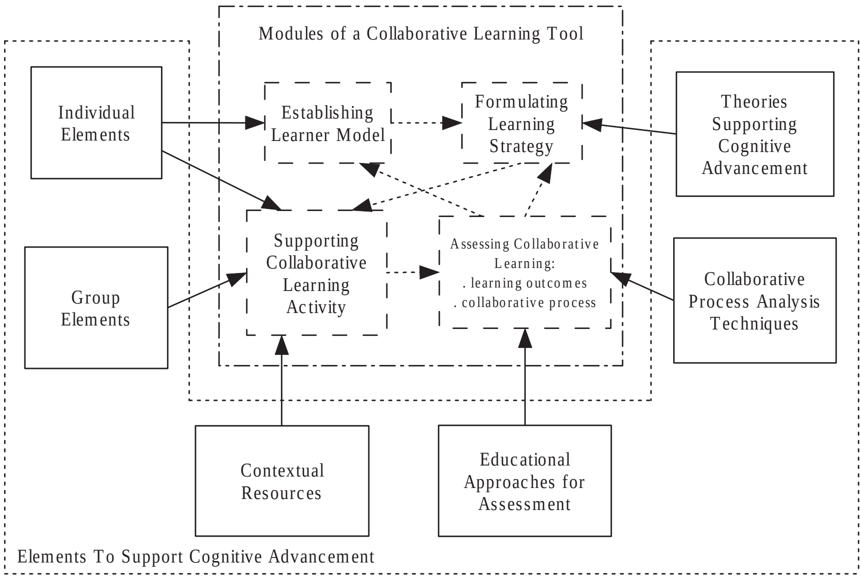

Fig. 2. A new conceptual model to support collaborative learning

In Figure 2, the collaborative learning tool consists of the following modules.

- *Establishing learner model* — establishes the system's knowledge about the learners, their characteristics and learning behaviors.
- *Formulating learning strategy* — forms optimal learning groups for individual learners and recommends optimal learning strategies for individual learning groups.
- *Supporting collaborative learning activity* — scaffolds the interactions between learners participating in the learning process.
- *Assessing collaborative learning* — monitors interactions between learners and assesses the learning outcomes of learners.

For an individual learning group, the established learner model is an important reference for generating the learning strategy; the formulated learning strategy guides the group to carry out the collaborative learning activities; the learners' actions in the collaborative learning activities are used as evidences for assessing the collaborative process; the results of the assessment are used for fine-tuning the learner model.

In Figure 2, there are six groups of design elements derived from the literature-based analysis.

- *Individual elements* are personal characteristics (e.g. multiple intelligences) or behaviors of a learner that will influence the cognitive process in collaborative learning (from the analysis of building collaborative knowledge).
- *Group elements* are elements reflecting group members' characteristics (e.g. cognitive level) or interaction patterns of learning processes (e.g. communicative functions of conversational messages such as informative, elaborative and argumentative) (from the analysis of building collaborative knowledge).
- *Contextual resources* include the group members' previous discourses and actions and beliefs or assumptions about the topic for a given task (from the analysis of building collaborative knowledge).
- *Educational approaches for assessment* refer to the types of assessment and the methods of each for assessing the learning effects (from the analysis of assessing collaborative learning).
- *Collaborative process analysis techniques* include discourse analysis, social network analysis, the analysis of computer-generated quantitative log files, and content analysis (from the analysis of assessing collaborative learning).
- *Theories supporting cognitive advancement* mainly include social interaction theory for collaborative learning which provides the fundamentals for defining the learning strategies (from the analysis of scaffolding social interaction).

These elements are not directly inter-connected, but they are connected in the sense that they operate on different function modules and these function modules interact. The individual elements such as prior knowledge and personal intelligence are incorporated in the learner model. Both the individual elements and group elements are incorporated in the module for supporting collaborative learning activity. Contextual resources provide materials for enhancing communications between participants in the module of supporting collaborative learning activity. Educational approaches for assessment provide possible assessment methods for assessing the learning outcomes. Additionally, different analysis techniques can be adopted by the assessment process to conduct a complex assessment of the learning process. Finally, the theory supporting social interaction provides theoretical fundamentals on how to formulate an appropriate learning strategy.

The proposed new conceptual model is extensible — new design elements can be added to the model and new functional modules can also be added to the proposed collaborative learning tool.

5 Implementation issues

In our conceptual model for collaborative learning, four basic modules are proposed for constructing a new collaborative learning tool. The implementation of the conceptual model can be divided into four corresponding parts. Furthermore, each group of the design elements in the conceptual model is an abstraction of a particular category of elements to support cognitive advancement. Specific elements should be defined for each group before designing the four modules. Our method for implementing the proposed conceptual model is based on a multi-agent system, and we discuss the implementation issues in the following subsections.

5.1 Establishing learner model

A learner model establishes the system's knowledge about the learners who are involved in the system. As presented in the conceptual model (Figure 2), the individual elements, which form an abstraction of the intrinsic elements that affect learners' cognitive performance, are used to establish the learner model, and this raises the following questions.

- What are the *specific individual elements* that the learner model includes?
- What is the *procedure* to establish the learner model?
- What is the *technique* used to establish the learner model?

In the proposed conceptual model, the individual elements that affect the learners' cognitive advancement include personal characteristics and learner behaviors, and the learner model should therefore incorporate these two aspects. The specific personal characteristics defined for the learner model include a learner's individual identity, knowledge level, learning style and personality type. The learner behaviors defined for the learner model refer to the ways learners may interact with the system.

The procedure of establishing the learner model is divided into three parts: the acquisition of initial data about learners' characteristics, the recording of learner behaviors and the fine-tuning of the learning styles and personality types in the learner model.

At the initial stage, the system collects data about the learners' identity and knowledge level from the learners themselves. A user interface is provided for learners to input these data into the system. Psychology tests are also provided through the system for evaluating learners' learning styles and personality types. For example, Felder and Soloman's Index of Learning Styles questionnaire with 44 two-choice questions (`http://www.engr.ncsu.edu/learningstyles/ilsweb.html`) is a common psychology test for evaluating learners' learning styles and the Myers-Briggs Type Indicator (MBTI) assessment (`http://www.humanmetrics.com/cgi-win/JTypes2.asp`) with 72 two-choice questions is common for testifying one's personality type. The collected data about the learners' characteristics is then stored in a database.

Whilst a learner is participating in a collaborative learning activity, the learner's behaviors (which are the way that they interact with the system, such as the number of messages that sent to peer learners in the same collaborative learning group) are inferred from the system by a Group Agent. These interaction patterns can be recorded in a database and further used for fine-tuning the learner model.

In the learner model, the learning styles and personality types are initially evaluated through the psychology tests. These psychology tests provide practical instruments to assess individual learners' preferences. However, the results of these tests are not fully reliable. It was reported that people come out with three or four type preferences the same 75% to 90% of the time (see `http://www.myersbriggs.org/my-mbti-personality-type/mbti-basics/reliability-and-validity.asp`). There may be discrepancies between the evaluation results and the real values of learners' preferences. The fine-tuning process can make the evaluated learning styles and personality types resemble the real values. A Learner Agent with case-based reasoning ability is proposed to accomplish the fine-tuning process. When data about an individual learner's behavior is provided, the Learner Agent retrieves similar cases (i.e. learner behavior and corresponding learner preferences) from the case data store, and uses this information to revise the learner preferences in the learner model.

Through establishing the learner model, the collaborative learning tool is able to describe the characteristics of individual learners and form optimal learning groups for individual learners based on learner's characteristics in the module for formulating learning strategy.

5.2 Formulating learning strategy

A Learning Strategy for collaborative learning refers to the structure of interactions between learners in a learning activity. The design element of 'theories supporting cognitive advancement' is applied in this module. It is a group of theories guiding the sequence of collaborative learning activities for a formed learning group. Similar to establishing the learner model, we propose the following questions for formulating the learning strategy:

- What is the *specific theory* that guides the sequence of collaborative learning activities?
- What is the *procedure* to formulate the learning strategy?
- What is the *technique* being used to formulate the learning strategy?

In the proposed conceptual model, the elements of 'theories supporting cognitive advancement' include social interaction theory for collaborative learning. The two approaches described in the theory are specifying the learning activities that learners have to accomplish [30] and outlining how group processes are related to individual cognitive processes [12]. We adopt a theory which follows the first approach — CSCL scripts [30] — to shape the interactions between learners in a specified structure. CSCL scripts can reduce the coordinative efforts both for the instructors and learners and can be reused once the scripts are programmed. In the rest of the paper, the learning strategy is referred to as *CSCL scripts*.

The procedure for formulating the learning strategy is divided into two stages: forming optimal learning groups for individual learners and recommending appropriate learning strategies for individual learning groups.

In our model, forming learning groups refers to assigning individual learners into groups for a particular collaborative learning activity. An individual learner desires to participate in friendship and interest groups, but members of an individual group are expected to be competent to accomplish the learning activity. It has to be ensured therefore that each learning group is formed in such a way that it meets the aspirations both of the individual learner and of the other members in the group. The grouping is based on their characteristics and the social relations with other learners. In our implementation, computational trust and reputation models are built up based on learners' characteristics and the social relations between them. We can derive similar mechanisms for calculating the reputation of learners from the ReGreT trust and reputation model [31], but in our approach, we use a Trust Agent to maintain the reputation values of the learners. This centralized approach which is different from ReGreT, has the risk of losing some context information from individual Learner Agents, but this is beyond the focus of our study. A higher reputation of a learner indicates a higher tendency that other learners will cooperate with that learner. The constraints for selecting the characteristics and reputation values for constituting an optimal learning group are addressed by the implementation process.

A group profile is established for each learning group which describes the features of the group, including group identity, its members, the group learning goal and group learning position (i.e. a phrase in a CSCL script). A Group Agent is in charge of maintaining and updating the group profile (such as updating the learning position of the leaning group) for each individual learning group.

In our model, recommending the learning strategy for individual learning groups refers to the issue of selecting an appropriate CSCL script for each group. Information matching techniques such as the keyword-based item-to-item matching technique [32] can be used for this process. The principal features of this process are the use of keywords to hold knowledge about the learning goals of the learning groups and the CSCL scripts, and identifying an appropriate script for a learning group which matches its learning goals. A Recommendation Agent is responsible for this process.

5.3 Supporting collaborative learning activity

CSCL scripts are used to structure the learning activity for a learning group, and technique settings are desired for operationalizing the scripts. For implementing this module, the following questions need to be addressed.

- What is the *type of technique settings* that we aim to develop for this module?
- Is there any *existing technology* that our system can be built on for operationalizing the scripts? What functions can they provide?

- How can the *two groups* of design elements 'group elements' and 'contextual resources' be *incorporated* in this module?

The technique settings for our model refers to a platform which consists of a set of tools made accessible through a generic interface. The platform not only provides functions to support communications between group learners, but also incorporates script-related interfaces for certain scripts.

The scripts can be defined by teachers and CSCL specialists. Script examples include MURDER Script [33], Universante Script [34], ArgueGraph Script [34] and Social Script [35]. Creating scripts can be completed via learning design authoring tools such as Omega+ [36]. Workflow models as defined scripts are usually stored as XML files, and runtime engines such as CopperCore [37] are available for executing the workflow models. Our platform can be built on the CopperCore runtime engine, executing XML-based workflow models to support a collaborative learning activity.

Another aspect to be considered in this module is that how the 'group elements' and 'contextual resources' can be incorporated in the platform design. In our design, three group elements are incorporated: the group learning progress, the group member list and other groups that the group members have joined previously. The information in the group profile is used to show the group elements (e.g. group members and group learning position) to individual learners. The Group Agent uses these information for the system to demonstrate it to an individual group. The Learner Agent for an individual learner can pass the list of groups that the learner has participated in previously to the Group Agent. Furthermore, the contextual resources in our design refer to the discourse transcripts in the group discussion and other resources to support the learning activity. These contextual resources are incorporated in a communication tool.

5.4 Assessing collaborative learning

The module for assessing collaborative learning refers to assessment of collaborative process to monitor the interactions between learners in the collaborative learning activities. For assessing the collaborative process, the following questions are addressed.

- What are the *sources* for assessing the collaborative process, and what *types of interactions* can be inferred from these sources?
- What is the *analysis technique* used for this module?

The sources for assessing the collaborative process mainly include the discourse transcripts in the synchronous discussion. Different indicators of interactions can be inferred from analyzing the discourse, including the number of messages sent by individual learners, the type of messages, and the peer-based evaluations among group members.

The discourse transcripts in our design are web pages, and the content analysis technique [27] can be used to infer the indicators from these pages. The framework [28] presented in Figure 1 is adopted for performing the content analysis. The Group Agent for an individual learning group is in charge of analyzing the interactions between the group members, and the results of the content analysis are used by the Learner Agent for an individual learner to fine-tune their learner model.

6 A usage scenario

Our platform prototype is designed as a web-based collaborative learning environment, which includes a platform component, several learning components and a multi-agent component. The platform component provides a portal for the users and the learning groups for collaborative learning activities. A learning component for each individual learning group supports the collaborative learning process for particular learning goals. Several learning components may be executed simultaneously by individual learning groups for performing different learning activities. The interfaces for the platform and the learning components are web pages which individual learners can access. The multi-agent component is a collection of individual interactive agents, which control certain parts of the learning environment, and consists of five types of autonomous agents: the Learner Agent, the Group Agent, the Trust Agent, the Recommendation Agent and the Manager Agent. These agents communicate and interact with each other to accomplish their own goals. There is one Learner Agent for each learner, and an individual learner only directly interacts with their own Learner Agent.

In order to show how the conceptual model supports a certain collaborative learning activity, we present a usage scenario aiming at improving learners' skill in understanding and summarizing complex documents. We consider six new learners who are registering with the system. They are divided into groups by the system and collaborate with peer learners to achieve the learning goal. The global workflow of this scenario is presented below and details of each stage are described later.

1. New learner registration: the six new learners register with the system through a sub-component of the platform component.
2. Group formation and collaborative script recommendation: the instructor responsible for the learning activity assigns the six new learners into groups through a sub-component of the platform component and the system recommends a collaborative script for each formed group to perform the collaborative learning sessions.
3. Collaborative learning sessions: each individual group of learners performs the learning activity following the recommended script through a learning component.
4. Collaborative process assessment: the system analyzes the group interactions in the learning activities at the end of the collaborative learning sessions.

At the registration stage, personal data is input into the system by the new learners. In this scenario, part of the personal data including the learner's identity and knowledge level is input directly by an individual learner through a web page which interfaces with the platform component; and other personal data including the learner's learning style and personality type is determined from psychology tests on the learners. These tests are incorporated in the system's web pages. We select two psychology tests for evaluating separately a learner's learning style and personality type — Felder and Soloman's Index of Learning Styles questionnaire (`http://www.engr.ncsu.edu/learningstyles/ilsweb.html`) is applied to evaluate the learners' learning styles, and the Myers-Briggs Type Indicator (MBTI) assessment (`http://www.humanmetrics.com/cgi-win/JTypes2.asp`) is used to evaluate the learners' personality types.

The purpose of the registration process is to extract the characteristics of individual learners and thus to establish an initial learner model about the new learners registering with the system. The Learner Agents for each individual learner complete the data acquisition process and store the data into a database.

Table 6 shows the characteristics of the six new learners. Each row of the table represents the values of an individual learner's characteristics.

Table 6. The characteristics of the six new learners

Learners	Identity	Knowledge level[a]	Learning style[b]	Personality type[c]
L_1	ID_1	(S, Low)	(ACT, SEN, VIS, SEQ)	ENTP
L_2	ID_2	(S, Middle)	(ACT, INT, VRB, GLO)	INTP
L_3	ID_3	(S, Low)	(ACT, SEN, VIS, SEQ)	ENTP
L_4	ID_4	(S, Middle)	(REF, INT, VIS, SEQ)	INTP
L_5	ID_5	(S, High)	(REF, SEN, VRB, GLO)	INTP
L_6	ID_6	(S, Middle)	(ACT, INT, VIS, GLO)	ENTP

[a] The knowledge level of an individual learner is a set of pairs of competences and corresponding values. The competence "summarizing complex documents" (S) and its value (Low, Middle or High) is defined as the knowledge level, and the values of S are randomly assigned to the six learners in this scenario. Multiple pairs of competences can be defined by learners for other scenarios.
[b] The learning style represents the learners' preferences on four dimensions: active/reflective (ACT/REF), sensing/intuitive (SEN/INT), visual/verbal (VIS/VRB) and sequential/global (SEQ/GLO). In this scenario, we randomly assign values to the six learners.
[c] The personality type is represented as one of the sixteen personality types described by the Myers-Briggs Type Indicator (MBTI). In this scenario, we randomly assign the two personality types: 'logical, original, creative thinkers' (INTP) and 'creative, resourceful, intellectually quick persons' (ENTP) (see `http://www.personalitypage.com/high-level.html`) to the six learners because they are most relevant to this learning activity.

At the group formation stage, the instructor defines the number of learners for a learning group and allocates learners into groups. The number of participants that should be involved in a learning group for a given learning activity is for the instructor to decide, and can vary depending on the activity. Wessner and Pfister [38] suggest that three to five learners is an appropriate size for group discussion activity to be successful. In our scenario, the instructor adopts three as the size for an individual learning group. Thus, the number of the learning groups (i.e. two) is then determined by the total number of learners (i.e. six) and the size of each learning group (i.e. three). We use G_1 and G_2 to represent the two groups.

After that, a sub-component of the platform is provided for the instructor to define constraints for the Learner Agents to extract the learners' characteristics from the learner model. That is because not all the values of each characteristic in the learner model are necessary for the instructor to assign the learners into groups for a certain learning activity. For example, in this scenario, the dimension 'ACT/REF' of the characteristic 'learning style' of a learner is the element that the instructor used to inform their allocation decision. The Manager Agent obtains the required information from individual Learner Agents and presents the information to the instructor.

Furthermore, in order to ensure an optimal grouping of the learners, the instructor adopts the following criteria to allocate the learners into groups:

1. Group members have similar knowledge level;
2. Each group is preferred to have a combination of ACT learners and REF learners;
3. Each group is preferred to have a combination of ENTP learners and INTP learners.

Figure 3 shows the process that the instructor uses to allocate the six learners into group G_1 and G_2 based on the selected values of characteristics. In Step 1 the instructor applies the first criterion. The similarity between two knowledge levels is compared. The knowledge level (S, Low) is similar to (S, Middle) and (S, Middle) is similar to (S, High), but (S, Low) is not similar to (S, High). Thus, the learners L_1 (S, Low) and L_3 (S, Low) are put into group G_1, and L_5 (S, High) are put into group G_2. In Step 2 the instructor applies the second criterion. The instructor chooses the learner L_4 who has the learning style of 'REF' to join group G_1 because the other two learners (L_1 and L_3) in group G_1 have the learning style 'ACT'. Then the learners L_2 and L_6 are selected to join group G_2. The allocation process for this scenario ends after the second step. However, in other scenarios, further steps may be desirable based on the third criterion since there may be more than two groups to be allocated.

As shown in Figure 3, the group G_1 is allocated with the learners: L_1, L_3 and L_4; and the group G_2 is allocated with the learners: L_5, L_2, and L_6. Individual Group Agents are activated by the Manager Agent for the two groups G_1 and G_2.

In this scenario, all the learners are new to the system. If the learners were not new to the system (i.e. the learners have previously interacted with other learners in the system), they would be assigned to individual learning groups in a different way. That is, the system forms the learning groups for a certain set

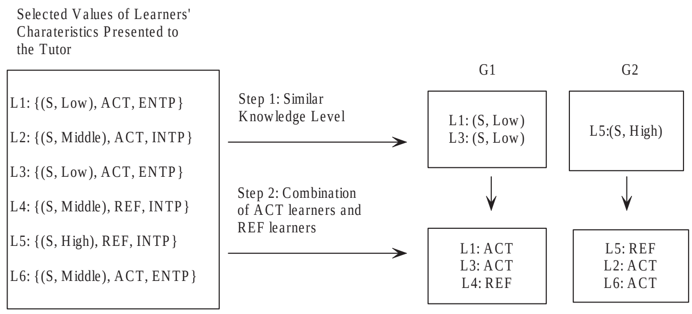

Fig. 3. The process that the instructor allocates the six learners into G_1 and G_2

of learners. The ReGreT trust and reputation model [31] is applied to calculate the reputation of individual learners in the groups based on their reputations among other learners and their characteristics. In the ReGreT system, a final reputation is a numerical value, for example, between 0 and 1. In the multi-agent component of our platform, the Learner Agent for an individual learner calculates the reputation of other learners from its perspective and the Trust Agent summarizes all the values for the reputation of an individual learner from different Learner Agents into a single value.

At the script recommendation stage, the COTEXT script [39] is recommended for both the groups because they possess the same learning goal, i.e. improving the learners' skill to understand and summarize complex documents. A learning component is executed for each of the groups on the platform for the collaborative learning sessions. An explanation on the COTEXT script is given below:

The text is divided into as many sections as there are learners in a learning group (in this scenario, the text is divided into three sections as there are three learners in each of G_1 and G_2). For each section, there is an iteration consisting of two steps:

1. *summarization*: a learner produces a summary of the section;
2. *comment*: the other learners criticize the summary following the EXP method [39].

For a new iteration, the role of the summarizer is taken by the next learner. The iteration ends when there are no more modifications or additions.

After all the sections of the text have summarized, each learner produces an individual summary of the entire text.

At the stage of collaborative learning sessions, for each group, the learners in that group perform the learning activity through a learning page for the group driven by the COTEXT script. The transition from one learning step to another is triggered automatically in accordance with the transition rules of the COTEXT script. A collaborative, contextually embedded chat tool is available for certain steps in the learning page. The tool incorporates contextual resources to assist learners' understanding in the discussion process as well as to provide a communication channel for the learning participants. The working area of aeach individual learning page consists of a group learning process menu showing the group learning position, an explanation of learning steps, a link to the collaborative, contextually embedded chat tool, a view of the group profile and a link to the platform page which provides a global view of the learning groups on the platform. The chat tool is a synchronous text-based, contextually embedded discussion tool which supports the 'comment step' mentioned above.

The chat tool makes explicit what the contextual resources are and how they are incorporated to assist learners' understanding in the discussion process. The contextual resources adopted by the chat tool comprise the types of messages (such as 'correction' or 'acceptance', Figure 4) and references to previous messages (co-text) or to the learning session material. A learner explicitly defines the type of message before sending it to other learners. For example, if the learner wants to point out a mistake in a summary, they need to define the message type as 'correction' before sending it out. In addition, the reference of the message is also explicitly described. Figure 4 shows an example chat discourse of the group G_2.

```
L5>(Correction) The summary does not say that developing countries
are likely to benefit from a free market.
(learning session material)                  //contextual resources

L6>(Acceptance) All right. I change the sixth sentence.

L5>(Comment) Great.
(previous message)                           //contextual resources

L2>(Comment) I also agree.
(previous message)                           //contextual resources

L5>(Supplement) Give evidence that market liberalisation can be also
beneficial in developing countries.
(own opinion)                                //contextual resources
```

Fig. 4. An example chat discourse of the group G_2

At the stage of collaborative process assessment, the discourse transcripts for the two groups are analyzed separately by the Group Agents.

Table 7 shows the analysis results of the chat discourse in Figure 4. Each row in the table displays the number of each type of message sent by an individual learner in the discussion.

The analysis results for the learning groups are recorded in a database. These data are used by the Learner Agents for individual learners in the group to fine-tune the learner model.

Table 7. The analysis results of the chat discourse in Figure 4

Learners	Number of correction	Number of supplement	Number of acceptance	Number of refusal	Number of comment
L_5	1	1	0	0	1
L_6	0	0	1	0	0
L_2	0	0	0	0	1

7 Conclusions

Cognitive advancement in computer-supported collaborative learning is a broad topic which covers far more than developing software tools to promote communications among participants. It is a complex problem involving interdisciplinary research. In this paper, we have explored various elements which support cognitive advancement for the design of collaborative learning tools by carrying out a literature-based analysis of the CSCL field with regard to improving of learners' cognitive processes. We have proposed an original conceptual model to support collaborative learning. The model consists of basic modules for a collaborative learning tool and the derived elements from the literature-based analysis. We focused on three areas in CSCL with regard to learners' cognitive advancement.

First, scaffolding social interaction. Representative theories, software tools and techniques were analyzed, and we identified that software systems to provide support for structuring the collaborative learning process are not currently available. However, the social interaction theory could provide us the educational and sociological fundamentals for structuring the social interactions in the collaborative learning process.

Second, building collaborative knowledge. Three critical factors were identified in the use of technology to support collaborative knowledge advancement: individual reflection, quality group interaction, and contextual resources. These three groups of elements are incorporated in the conceptual model and incorporated in the design of the module of 'supporting collaborative learning activity' in the proposed collaborative learning tool.

Third, assessment of collaborative learning. This area is divided into two sub-fields: assessment of learning outcomes and assessment of the collaborative process. Different educational approaches, characteristics of these approaches and tools to support assessment were investigated for assessing the learning outcomes, and different techniques for analyzing the collaborative process were compared. These methods and techniques as the design elements of 'educational approaches for assessment' and 'collaborative process analysis techniques' are both incorporated in the design of the proposed collaborative learning tool in our model, enabling our model to combine both the learning and assessment processes for supporting collaborative learning activities.

Compared with the existing CSCL tools, the proposed conceptual model provides overall support for the collaborative learning activities, which has advantages in incorporating individual learners' characteristics for designing the learning strategy, structuring the collaborative learning process and monitoring the interactions between learners in the collaborative learning process. We propose that the implementation of such a model should be based on a multi-agent system.

Our future work includes interviewing the lecturers in our university to discover their criteria for forming collaboration groups for different educational goals and modeling the learners' allocation problem in our multi-agent system. The interview enables us to deeply understand the learners' allocation problem and corresponding pedagogical issues.

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