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A Semantic Web-based authoring tool to facilitate the planning of collaborative learning scenarios compliant with learning theories

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A B S T R A C T

When the goal of group activities is to support long-term learning, the task of designing well-thought-out collaborative learning (CL) scenarios is an important key to success. To help students adequately acquire and develop their knowledge and skills, a teacher can plan a scenario that increases the probability for learning to occur. Such a scenario defines pedagogically sound structures that prevent off-task behavior and engage students in more meaningful interactions. The main difficulty in designing effective CL scenarios is transforming the teacher's intentions into elements that constitute the learning scenario. This problem is frequently observed when novice teachers attempt to improve the quality of learning and instruction by blending collaborative activities with individual activities without careful planning. With the goal of helping teachers in planning collaborative scenarios, we have developed an intelligent authoring tool referred to as CHOCOLATO using Semantic Web technologies (e.g. ontologies) in order to represent knowledge about different pedagogies and practices related to collaboration. Through the use of this knowledge, CHOCOLATO can provide intelligent guidance that helps teachers to create theory-based CL scenarios which has proven to be effective in a variety of situations. We evaluated it by conducting two experiments. We were interested in verifying whether the recommendations given by CHOCOLATO help novice teachers to design pedagogically sound CL activities, and if these activities help students to learn collaboratively in real classroom settings. The first experiment had the participation of 58 pre-service teachers that created CL scenarios with and without our authoring tool and the second experiment was carried out in a Brazilian public school together with 218 students. The results suggest that the guidance provided by CHOCOLATO do help novice teachers plan, understand and share CL scenarios more easily. They also suggest that the continuous utilization of well-designed theory-based CL activities create favorable conditions for students (particularly less knowledgeable ones) to improve their overall performance throughout the school year.

1. Introduction

Although traditional pedagogical practices used in the classroom rely mostly on individual learning, well-structured collaborative learning (CL) activities have been shown to be better in a variety of learning situations (Kobbe et al., 2007; Strijbos, Martens, & Jochems, 2004). CL denotes pedagogical approaches that involve learning in a social situation that satisfies some basic requirements. According to different studies (Scheuer, Loll, Pinkwart, & McLaren, 2010; Stahl, Koschmann, & Suthers, 2006, pp. 409–426), CL helps to deeply understand the content by giving students the opportunity to practice argumentation and critical thinking through interaction with peers. Despite that, the designing of pedagogically sound group learning activities is still a complex task. It requires skills and knowledge to use different characteristics of students (e.g. cultural background, preferences, etc.) and match those with tools and pedagogical practices that support

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design of activities and lead to robust learning. Thus, a good CL design aims to support teachers to easily *orchestrate* (or conduct) the interaction between students and assure (or at least increase the chances) that students will learn the desired content in a limited amount of time through a sequence of well-thought-out learning activities. The product of this design is known as a learning scenario.

Creating CL scenarios is particularly difficult for novice teachers who do not have experience in creating and carrying out collaborative tasks. However, well-designed computer tools can help teachers in the specification of these collaborative tasks. Computer-Supported Collaborative Learning (CSCL) is an emerging branch of the learning sciences concerned with studying how people can learn/teach together with the help of computers (Stahl et al., 2006, pp. 409–426). The CSCL community has developed scripts and authoring tools that help novice and expert teachers to design more effective and sound CL scenarios. Some of these tools have advanced capabilities that provide user guidance to select appropriate tasks, learning objects and teaching practices (Hernandez-Leo et al., 2006). Although the number of technologies that support collaboration has increased considerably in the past years (Soller, Martínez-Monés, Jermann, & Muehlenbrock, 2005), only a few CL authoring tools have been developed to deal with multiple pedagogical perspectives (in Section 2.3 we present some CL authoring tools). Laurillard (2009) pointed out in her work that many CL systems that support collaboration do not possess a "comprehensive" pedagogical framework that can work as a foundation to create and deliver genuinely enhanced CL experiences. By pedagogical framework, we mean an underlying structure that can support the description of the main concepts extracted from learning theories. These concepts define some of the essential conditions in which learners are able to learn more effectively (Anderson, 1982; Bandura, 1977; Rumelhart & Norman, 1978, pp. 37–53; Vygotsky, 1978). The lack of pedagogical frameworks to create tools to support CL is disturbing, since creating or using mechanisms for collaboration without pedagogical considerations does not necessarily improve learning outcomes and may even possibly harm learners' development (Dillenbourg & Hong, 2008; Isotani, Inaba, Ikeda, & Mizoguchi, 2009).

In this context, authors' previous work has focused on developing a pedagogical framework, referred to as *Collaborative Learning Ontology* (or just CL Ontology), that explicitly and formally represents the core characteristics of learning theories (such as *Anchored Instruction* and *Peer Tutoring*) using ontologies. Furthermore, these characteristics are linked with information that can be obtained from students and the learning environment. Thus, intelligent authoring systems can use the CL Ontology to assist with the assignment of roles, selection of learning activities, definition of learning strategies, formation of groups and so on. This possibility allows for teachers to create unique CL experiences based on well-grounded theoretical knowledge.

The CL Ontology has been developed over a decade (Inaba, Supnithi, Ikeda, Mizoguchi, & Toyoda, 2000; Isotani, Inaba et al., 2009) and has been used as the basis for developing a Web-based authoring tool to design CL scenarios (Isotani, Inaba, Ikeda, & Mizoguchi, 2010; Isotani & Mizoguchi, 2007, 2008; Isotani, Mizoguchi et al., 2010). Through the use of ontologies and other Semantic Web technologies, this authoring tool, referred to as CHOCOLATO, can use information from students and the environment to recommend theory-based settings that aim to guarantee the quality of the learning process (Isotani, Bittencourt, Mizoguchi, & Costa, 2009). However, as same as most authoring tools, CHOCOLATO does not orchestrate a CL scenario. The teacher plays a central role in transforming a set of recommendations into a real CL scenario. Furthermore, the teacher is also responsible for carrying out the scenario and coordinating the interactions in order to increase the chances of fruitful collaboration among students. Thus, to check the benefits of CHOCOLATO, two important questions should be answered. First, is a novice teacher able to understand the recommendations of CHOCOLATO and design pedagogically sound CL activities? And second, do theory-based CL scenarios suggested by CHOCOLATO support learning in real classrooms?

To answer these questions, first, as background notions, this paper will briefly present previous works related to CL design from an instructional planning viewpoint, followed by a brief overview of ontologies and some related works. Then, we will give an overview of CHOCOLATO, the proposed Semantic Web-based authoring tool. In particular we will introduce the pedagogical framework (CL Ontology) of CHOCOLATO. Finally, we will present the results of two experiments. The first experiment has the participation of 58 pre-service teachers and was designed to verify if our tool can help novice teachers to create CL scenarios. The second was a two-year experiment carried out by one teacher and 218 students to verify the long-term impact of using our tool and CL activities in real classroom environments. The results suggest that CHOCOLATO can help novice teachers to more easily design theory-based CL scenarios. They also indicated that the long-term use of the designed CL scenarios created good conditions for students to interact more effectively, improving their overall performance throughout the year.

2. Background and basic notions

This section will provide an introduction to the necessary background. Section 2.1 provides an overview of CL from an Instructional Planning Viewpoint. Section 2.2 introduces the concept of ontologies and its application in CL. Finally, Section 2.3 presents three CSCL Authoring Tools with Pedagogical Support as related works.

2.1. Collaborative learning from an instructional planning viewpoint

CL can be sometimes understood in a broader sense as any activity in which students work in groups. Nevertheless, from our perspective, students working in groups without any consideration about *what*, *why*, and *how* they are doing a group activity (free collaboration) does not configure a well-designed CL scenario. From such a viewpoint, the basic requirements that constitute a CL scenario are: (*i*) intentional design, (*ii*) collaboration as an interdependent relationship among peers, and (*iii*) learning as a direct result of the occurrence of planned interactions.

By **intentional design** we mean the teacher's intention in creating a particular learning scenario with the objective of producing *intended* learning benefits. Free collaboration does not always produce satisfactory learning results (Barron, 2003; Dillenbourg, 2002). Some of the reasons for this are that learners do not know why they are collaborating (goals) or how they can behave in order to learn (strategies). Teachers frequently ask students to work in groups without any suitable instructional preparation (Barkley, Cross, & Major, 2005). As a result, the chance of learning decreases considerably. Such a claim is based on the fact that many researchers have reported that the inadequate design of CL activities (or no design at all) is one of the main causes of unsuccessful group learning (Fiechtner & Davis, 1985; Stribjos et al., 2004).

Through the design of CL scenarios, the teacher can define a structure that increases the chance for learning to occur. For example, structures increasing the chance for learning include grouping learners through a comprehensive examination of their needs, selecting the learning goals for each group or individual, planning the sequence of interactions that should be followed, and choosing the best pedagogical approach to support learners. Therefore, the effectiveness of CL depends on the transformation of the designer's intentions into elements that will constitute the learning scenario.

The second requirement, **collaboration as an interdependent relationship among peers**, copes with the authors' understanding about the definition of collaboration in the context of education. According to the Cambridge dictionary, *collaboration* occurs "*when two or more people work **together** to create or **achieve the same thing**.*" From our viewpoint, to complete an activity *together*, participants need to discuss, share their knowledge, request/give opinions, take/assign responsibilities, provide arguments, supervise others, propose conjectures, create a hypothesis, etc. In other words, they must build their knowledge through interactions. Furthermore, in the educational scope the phrase "*achieve the same thing*" refers to learning. Thus, the definition of collaboration in the educational context can be rephrased as "a group of people interacting to achieve the same thing which is *to learn*". In a designed CL scenario, *learning* can be understood as the acquisition of intended learning benefits (stated goals), which may differ for each individual in the group.

Finally, the third requirement denotes that learning should *not* occur as a side effect of accidental interactions. **Learning should happen as a direct result of the occurrence of planned interactions**. Thus, linking these requirements to characterize a CL situation, all group members are requested to engage actively and interactively toward stated goals. If only one group member works to complete a task while the others watch or inadequately contribute to the task, then it is not CL. Similarly, if each group member works on different sub-tasks of a major task, but barely interacts with the others, then it is not CL either. Barkley et al. (2005) emphasizes that:

> "*The task assigned to the group must be structured to accomplish the learning objectives of the course. Shifting responsibility to students, and having the classroom vibrate with lively, energetic small-group work is attractive, but it is educationally meaningless if students are not achieving intended instructional goals...*"

Thus, a CL scenario can be considered ***effective*** if it fulfills the requirements presented in the previous paragraphs (intentional design, collaboration as an interdependent relationship among peers, and learning as a direct result of the occurrence of planned interactions). From such a perspective, the more in line with these requirements, the more effective the scenario will be. Smith (1996) and Johnson, Johnson, and Smith (1998) emphasize that an effective CL scenario helps to create positive interdependence among students, individual and group accountability, mutual support among group members, development of teamwork skills, and group self-evaluation skills.

Although the creation of effective CL scenarios is desired, such a task is not trivial. Creating well-thought-out CL scenarios requires experience with and knowledge about different pedagogies and practices related to collaboration. Inexperienced designers/teachers who may not have all the necessary knowledge to formulate pedagogically sound CL plans may thus have difficulties in designing CL activities.

For example, learning theories are an important source of information when creating effective CL scenarios. Each learning theory is an attempt to understand, explain and describe the process of learning. It defines some of the essential conditions in which learners are able to learn more effectively (Anderson, 1982; Bandura, 1977; Rumelhart & Norman, 1978, pp. 37–53; Vygotsky, 1978). By explaining the learning process, besides trying to explain what happens inside of a learner, a learning theory also gives, either explicitly or implicitly, the ***context*** in which ***learning activities*** have been taking place, the target ***knowledge/skill*** that has been tackled, and the ***roles*** played by learners (Isotani, Inaba et al., 2009). Another good source of information to create effective CL scenarios is *CL best practices*. These practices are techniques that have been used and tested by many teachers and have been shown to aid the design of environments where collaboration (and learning) can occur smoothly (Barkley et al., 2005; Hernandez-Leo et al., 2006). Nevertheless, only experts in the field have the adequate knowledge and skills to discern the pros and cons of each theory or best practice, select one adequately according to a particular circumstance, and extract useful information from them in order to transform their narrative into well-designed CL activities.

2.2. A brief overview on ontologies in CL

Computer science borrows the term *ontology* from a branch of philosophy (metaphysics) that studies the nature of "being" and "existence." In computer science, an **ontology** can be defined as a set of fundamental concepts and their relationships that captures how people understand (or interpret) the target world, and enables the representation of this understanding in a computer-understandable manner. According to Swartout and Tate (1999), an "*ontology is the basic structure or armature around which a knowledge base can be built*." An ontology can be modeled to allow knowledge sharing and reuse across different applications (Guarino, 1997).

Ontologies have recently attracted the attention of many people, particularly researchers in the field of the Semantic Web (Devedzic, 2002; Dicheva, Mizoguchi, & Greer, 2009). Two of the main reasons are: first, it provides a common conceptual structure on which we can develop sharable and reusable knowledge bases. Second, it facilitates the interoperability and allows integration of data from different sources (mash-up), enabling us to create powerful and intelligent computational applications. These two characteristics are essential to equip computers with the capability of understanding the meaning of the information available on the Web and to share this meaning with other computers using a standard formal language.

Currently, ontologies have been applied to support the design of CSCL scenarios in different ways (Babi, Wagner, & Parali, 2008). For example, Vega-Gorgojo et al. (2010) have used ontologies to integrate tools to dynamically compose a desired CL scenario. However, the composition of a CL scenario depends of pedagogical components as well. Thus, Villasclaras-Fernandez, Hernández-Leo, Asensio-Perez, and Dimitriadis (2009) and Villasclaras-Fernandez, Isotani, Hayashi, and Mizoguchi (2009) have defined a comprehensive approach to compose a CL scenario using instructional components with different granularities (macro and micro scripts). To design CSCL scenarios using instructional components and learning theories Isotani, Inaba et al. (2010) have investigated and proposed an infrastructure that enables computers to reason on pedagogical knowledge and provide intelligent support for instructional designers. Finally, built upon previous results, Chacón, Hernández-Leo, and Blat (2011) have proposed an ontological approach for representing CSCL patterns that can be used to describe CL scenarios.

Although the benefits of describing CL scenarios using ontologies is well accepted by the CSCL community, there is a lack of authoring tools that offer intelligent support to use ontologies effectively as a knowledge base and as a language to structure, share and pedagogically-validate CL scenarios. In the next section, we will present some of the most well-known authoring tools for CL design.

2.3. Related work: CSCL authoring tools with pedagogical support

New technologies have been developed to explore the use of pedagogies in order to create better learning scenarios (Griffiths, Blat, Garcia, Vogten, & Kwong, 2005). Nowadays, there are many authoring tools that focus on supporting the design of learning scenarios, such as SMARTIES[1] (Hayashi, Bourdeau, & Mizoguchi, 2009), LAMS[2] (Dalziel, 2003), DialogPlus (Conole & Fill, 2005), CoSMoS (Miao, 2005), and RELOAD Learning Design Editor[3] (Milligan, Beauvoir, & Sharples, 2005). These tools can support the design of simple CL scenarios. Nevertheless, they are not suitable to create complete and complex CL scenarios (Hernandez-Leo, Asensio-Perez, & Dimitriadis, 2005).

Currently, the CSCL community has developed three well-known authoring tools that help teachers to create structured CL scenarios based on interaction flows with pedagogical justifications. These tools are referred to as Cools Modes (Pinkwart, 2003), Collage (Hernandez-Leo et al., 2006) and Learning Design Palette (Inaba & Mizoguchi, 2004). The target users them are CSCL researchers, expert teachers and instructional designers who want to design and share well-thought-out CL scenarios within the CL community.

Cools Modes was developed by the COLLIDE group at the University of Duisburg-Essen (Pinkwart, 2003). The name "Cool Modes" is an acronym for **CO**llaborative **O**pen **L**earning and **MODE**ling **S**ystem. The system was initially developed to support discussions and cooperative modeling processes in various domains. Nonetheless, due to its capability to include plug-ins, Miao (2005) created a diagram-based tool to support graphical development of CSCL scripts as a plug-in for Cool Modes. Although the diagram-based tool does not possess capabilities to guide users during the design of CL scenarios, it is suitable for expert users to create complex CL processes and design collaboration scripts more easily. Cool Modes is an important tool for expert users, however, it is not have functionalities for supporting novice users (e.g. novice teachers) who want to create CL scenarios based on pedagogies. It also does not use ontologies and Semantic Web technologies to formally represent CL scenarios or to provide intelligent support during the authoring task.

Collage is a graphic-based learning design authoring tool for CL developed by the Intelligent & Cooperative Systems Research Group at the University of Valladolid, Spain (Hernandez-Leo et al., 2006). It was created as a plug-in for a general learning design editor RELOAD (Milligan et al., 2005). To help users create CL scenarios, the system implements and uses interaction patterns based on CL best practices. Thus, instead of creating a scenario from scratch, a user can use these best practices that are provided as templates for guiding the design. Currently, it implements six interaction patterns, including brainstorming, jigsaw, pyramid, simulation, TAPPS – Thinking Aloud Pair Problem Solving, and TPS – Think–Pair–Share. The interface of Collage helps novice designers and teachers create CL scenarios by adapting interaction patterns to their needs. To design a scenario in Collage is quite simple. The user selects the main objectives for a CL session and the system can identify the interaction patterns that support the achievements of these objectives. Then, the user can choose and instantiate an interaction pattern to fit in a specific domain. It is also possible to associate CL activities with available learning resources. Recently, a Web version of this tool was presented by Villasclaras-Fernandez, Hernández-Leo et al. (2009) and Villasclaras-Fernandez, Isotani et al. (2009) incorporating the support for assessment design. The benefits of Collage for novice users have been demonstrated by the authors of this tool. However, there is plenty room for improvements. For example, the tool does not provide intelligent support for the various tasks that are required when designing a CL scenario (e.g. group formation and role assignment). It also does not use ontologies and Semantic Web and cannot use information about students as an input to create better scenarios.

Learning Design Palette (LDP) was designed to support novice users to create learning scenarios for individual learning, CL, and a merge of the two (blended learning). This tool was created in the Mizoguchi Laboratory at the University of Osaka, Japan (Ikeda, Hoppe, & Mizoguchi, 1995; Inaba & Mizoguchi, 2004). LDP is an authoring tool which uses a pedagogical framework based on ontologies to represent learning theories. LDP has three main functions. First, it reduces the complexity of designing learning scenarios through a structured sequence of steps that guide users throughout the whole process. Second, it creates learning designs in compliance with international standards. Third, it provides a list of interaction patterns inspired by learning theories that can be used as templates to create effective CL scenarios. The LDP is the first tool that uses learning theories, ontologies and Semantic Web technologies to support novice teachers to design CL scenarios. Nevertheless, its development was discontinued. This work extended the work of Inaba and Mizoguchi (2004) by further developing their pedagogical framework and creating new and better ways to formally represent learning theories, reason on their information, and match those with specific teachers' needs and students' characteristics.

One of the reasons for the limited number of tools that are "aware" of pedagogies (e.g. learning theories) is the difficulty of representing pedagogical knowledge and principles in a computer-understandable way. As a result, none of the cited authoring systems has the desired functionality to retrieve appropriate learning theories for automatically selecting methodologies that "match" a specific situation (e.g. students' current knowledge state), or to provide pedagogical principles, based on multiple theories, for structuring CL environments.

In order to create tools that are aware of theories and best practice and are able to use their information to assist novice teachers during the design of effective CL scenarios, it is necessary a pedagogical framework that can represent theories using a common structure and vocabulary.

In this direction, the next section, we will give an overview of CHOCOLATO, an authoring tool that has been built to use a pedagogical framework referred to as CL Ontology in order to support intelligent guidance during the creation of CL scenarios.

3. CHOCOLATO: a theory-aware authoring tool for CSCL

As shown in Subsection 2.3, some systems for authoring CL activities have been successfully developed and used. However, according to Baghaei (2007) the modeling of the theoretical knowledge that guides them is still in its infancy. Usually, authoring systems that possess the functionality to give pedagogical recommendations to designers use a set of heuristics to represent an instructional/learning theory in the code (programming languages). This means that the programmers, not the systems, have an understanding of the theoretical knowledge being used. As a result, the work of Mizoguchi, Hayashi, and Bourdeau (2009, pp. 59–76) indicates that these systems face a lack of flexibility

[1] http://edont.qee.jp/omnibus/doku.php.
[2] http://www.lamsinternational.com/.
[3] http://www.reload.ac.uk/ldeditor.html.

to change or extend their knowledge base in order to address the teachers' needs. In addition, Mizoguchi et al. also point out that without a well-designed pedagogical knowledge base it is difficult to convince teachers to follow the tool's recommendations. To develop authoring tools with some degree of *intelligence*[4] to support CL design, it is crucial to have an explicit and formal representation of various instructional/learning theories. It is also important to develop techniques to use these theories efficiently for enabling the extraction of knowledge flows from theory to practice.

To address these problems we have been developing a Web-based theory aware authoring tool for CL called ***CHOCOLATO*** – *a **C**oncrete and **H**elpful **O**ntology-aware **Co**llaborative **L**earning **A**uthoring **To**ol* (Isotani, Inaba et al., 2010; Isotani & Mizoguchi, 2007, 2008; Isotani, Mizoguchi et al., 2010). To allow for the application of multiple theories during the authoring process, CHOCOLATO uses the results of previous achievement in creating a pedagogical framework based on ontologies that describe learning theories and collaboration formally (more about ontologies in the next sub-section). The formal representation of theories using ontologies allows for the utilization of Semantic Web technologies, such as reasoners, to check the consistency and validity of CHOCOLATO's recommendations. Some of the benefits of this approach are: (a) preventing unexpected interpretations of the theories while designing CL scenarios; (b) providing a common vocabulary to describe these scenarios; and (c) offering enough information for computational semantics to allow for "intelligent" guidance with theoretical justifications during the authoring process.

3.1. The pedagogical framework: collaborative learning ontology

The authors have worked to develop a comprehensive pedagogical framework that work as the basic structure to describe theory-based CL scenarios and their processes. To create this framework we use ontologies. In this context, ontologies provide the necessary formalization to represent collaboration, while learning theories provide the concepts to justify and support the development of CL scenarios that stimulate the occurrence of meaningful interactions. Such formalization enables us to establish an engineering infrastructure that allows for (a) the creation of models that clarify how individuals learn in social environments; (b) a more systematic approach to designing pedagogically sound CL scenarios; and (c) the development of intelligent authoring tools that support effective collaboration. This pedagogical framework is known as the **Collaborative Learning Ontology** (or just CL Ontology) and has been developed, used and tested by different researchers. According to previous achievements (Barros, Verdejo, Read, & Mizoguchi, 2002; Devedzic, 2006; Ikeda et al., 1995; Inaba & Mizoguchi, 2004; Isotani, Inaba et al., 2009; Isotani, Inaba et al., 2010), the CL Ontology is equipped with appropriate information to create favorable conditions that, on one hand, help instructors to propose a principled group formation and effective CL scenarios and, on the other hand, help learners to perform CL activities more smoothly, thus increasing the chances of learning.

The CL Ontology is quite complex, however, in this paper we focus our explanations on the definition of a CL scenario. The CL Ontology defines a CL scenario as a concept composed by two other concepts: the *CL process* and the *learning strategies*. The *CL process* explicitly clarifies how students should interact during the learning session to achieve their common goals. This concept is also composed by two other concepts: the *group goal* and the *interaction pattern*. The concept of *learning strategy* is represented as a mutual relation between two or more learners. These learners play specific *CL roles* to carry out the strategy accordingly. In the ontology these roles are referred as the *I-role* and *You-role*. The *I-role* represents the role of the learner in focus at a given moment and the *You-role* represents the role of the learner with whom the learner in focus is interacting. For example, if you have two students collaborating, L_A and L_B, and they respectively play the role of tutor and tutee. If you focus on L_A, the *I-role* is tutor and the *You-role* is tutee, but if you focus on L_B, then the *I-role* is tutee and the *You-role* is tutor. This flexibility in the ontology is very important to allow for the designing of CL scenarios considering different viewpoints of instruction. Moreover, the *individual goal* concept is part of the learning strategy because students are using a strategy and playing a specific role with the objective of achieving their individual goals. Fig. 1 shows part of the concept *CL Scenario* and its relationship with other concepts represented in the CL Ontology. The term *p/o* in the figure indicates a *part-of* relation between concepts and the term *a/o* indicates an *attribute-of* relation.

To instantiate these concepts we extracted core information from learning theories. This approach helps us to formally describe theory-based CL scenarios using a common structure and vocabulary. To illustrate the use of these concepts to support the representation of theory-based CL scenarios, let us describe a scenario based on the theory of Cognitive Flexibility, where a learner (female) interacts with another learner (male) during collaborative tasks. In this scenario, from the viewpoint of the female learner who express an idea, she is using the learning strategy called "*learning by self-expression*"; her role is known as the "*Panelist*," the role of the male learner who listens the presented idea is known as an "*Audience*," and her individual goal is to develop skills for self-expression at the Associative Stage. On the other hand, from the viewpoint of the male learner acting as *Audience*, he is following the strategy "*learning by reflection*" to interact with the Panelist to acquire content specific knowledge at the Restructuring level. To play these strategies and interact harmoniously, the learners should possess the requirements to play their respective roles and externalize the appropriate behaviors. Such an arrangement facilitates the spread of skills across group members (group goal). Then, to support a structured interaction among participants, the interaction pattern of the theory is also explicitly provided. A short version of a CL scenario for the theory Cognitive Flexibility represented using the CL Ontology is graphically shown in Fig. 2.

With the use of the CL Ontology, it is possible represent theory-based CL scenarios explicitly and formally through a semantically-rich structure that contains pedagogical concepts and uses a common vocabulary. This makes the theories more accessible and understandable by both computers and humans. Thus, it is possible to propose techniques for reasoning on these theories, which contribute to define the foundations of an authoring tool that can use different learning theories to help users (particularly novice users) to design pedagogically sound CL scenarios.

The complete CL Ontology has been developed using the ontology editor HOZO (Mizoguchi, Sunagawa, Kozaki, & Kitamura, 2007) and a more detailed explanation and representation can be found in Isotani, Inaba et al. (2009), Isotani, Inaba et al. (2010).

[4] In computer science, intelligent behavior can be defined as a set of actions that a computer program takes to maximize the chances of successfully supporting or completing a specific and non-trivial task.

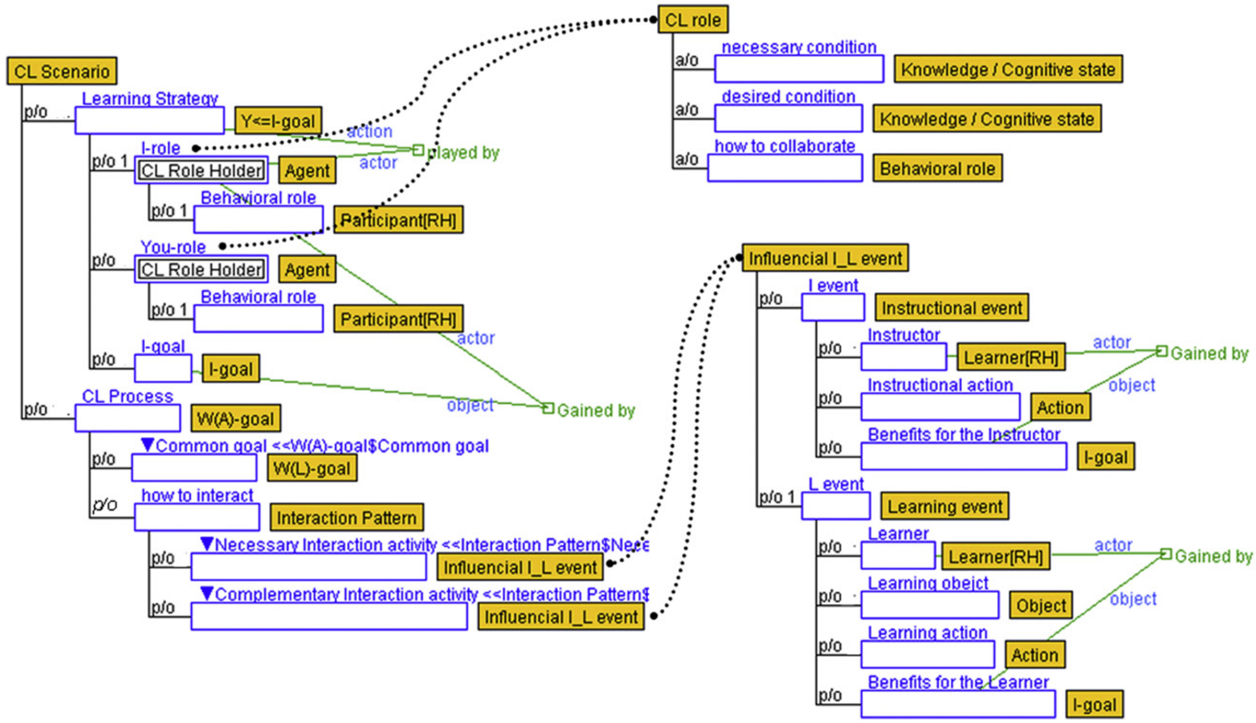


Fig. 1. Part of the concept CL scenario represented in the CL Ontology.

3.2. Overview of CHOCOLATO functionalities

The CHOCOLATO authoring tool was initially conceived to assist novice teachers. However, the infrastructure on which our tool is built allows for experts to create rich and fruitful interactions. Thus, both novice and expert users can benefit from our results. With a friendly interface, CHOCOLATO enables novice teachers to select different learning theories. Furthermore, a guided step-by-step process helps teachers to understand more about the theories and how they can be applied to adequately set up a CL scenario. Another function in the tool is the automatic recommendation of theories, strategies, roles and group activities that can be performed by learners in order to achieve desired learning goals. This recommendation can be customized to satisfy environment constraints, teachers' and students' preferences, particularities in the content, and so on. Finally, the pedagogical framework created with ontologies offers a common language and structure to formally represent complex CL scenarios. These scenarios allow for the definition of rich interaction flows with theoretical justifications, which is not supported in current computational tools developed to date.

The core technology of CHOCOLATO is the CL Ontology described in Section 3.1. Using this ontology, a basic architecture of an intelligent authoring tool was developed (Isotani & Mizoguchi, 2007). This architecture is composed of independent components and algorithms that process information from the environment (e.g. input of users) using Semantic Web technologies. To support reasoning and intelligent guidance through ontologies, we developed a set of procedures to deal with RDF with support of ARC2.[5] These producers facilitate the searching of patterns that can efficiently find the best CL scenarios, given a set of values in the learning environment. The MySQL database has been utilized to store the data of the learner model, ontologies, learning resources, and other information. The queries to retrieve information follow the SPARQL.[6] For example, the component for *CL design support* implements an algorithm that determines which learning theories can help the achievement of desired group learning goals. The algorithm receives the user input (selected group goal) and information about the environment (e.g. stored learning theories) to match theories and goals using the semantic relationships between concepts on the CL Ontology as shown in Fig. 3. As well as the component for CL design support, other components of CHOCOLATO can provide help to (a) the formation of groups and assignment of roles, (b) the recommendation of learning materials, (c) the analysis of individual and group outcomes, and (d) the identification of a learner's stage of development. The main goal is to enable any teacher (expert or not) to design pedagogically-valid CL scenarios based on learners' conditions, desires, and requirements.

The user interface utilizes an extension of an open source learning management system referred to as Claroline.[7] This interface was selected due to its flexibility in modeling different types of interactions. Furthermore, to develop the functionalities of CHOCOLATO, we have been using standards languages for programming on the Web, such as HTML, AJAX, and PHP.

The main interface utilized to design CL activities using CHOCOLATO is shown in Fig. 4. It contains three blocks (rows) numbered from 1 to 3. Each block consists of three boxes that have their content adapted depending on the elements of the environment (e.g. knowledge of students, topic, and etc.) and the user selections. The first block provides support for the selection of goals and theories to design CL

5 http://arc.semsol.org/.
6 http://www.w3.org/TR/rdf-sparql-query/.
7 http://www.claroline.net/.

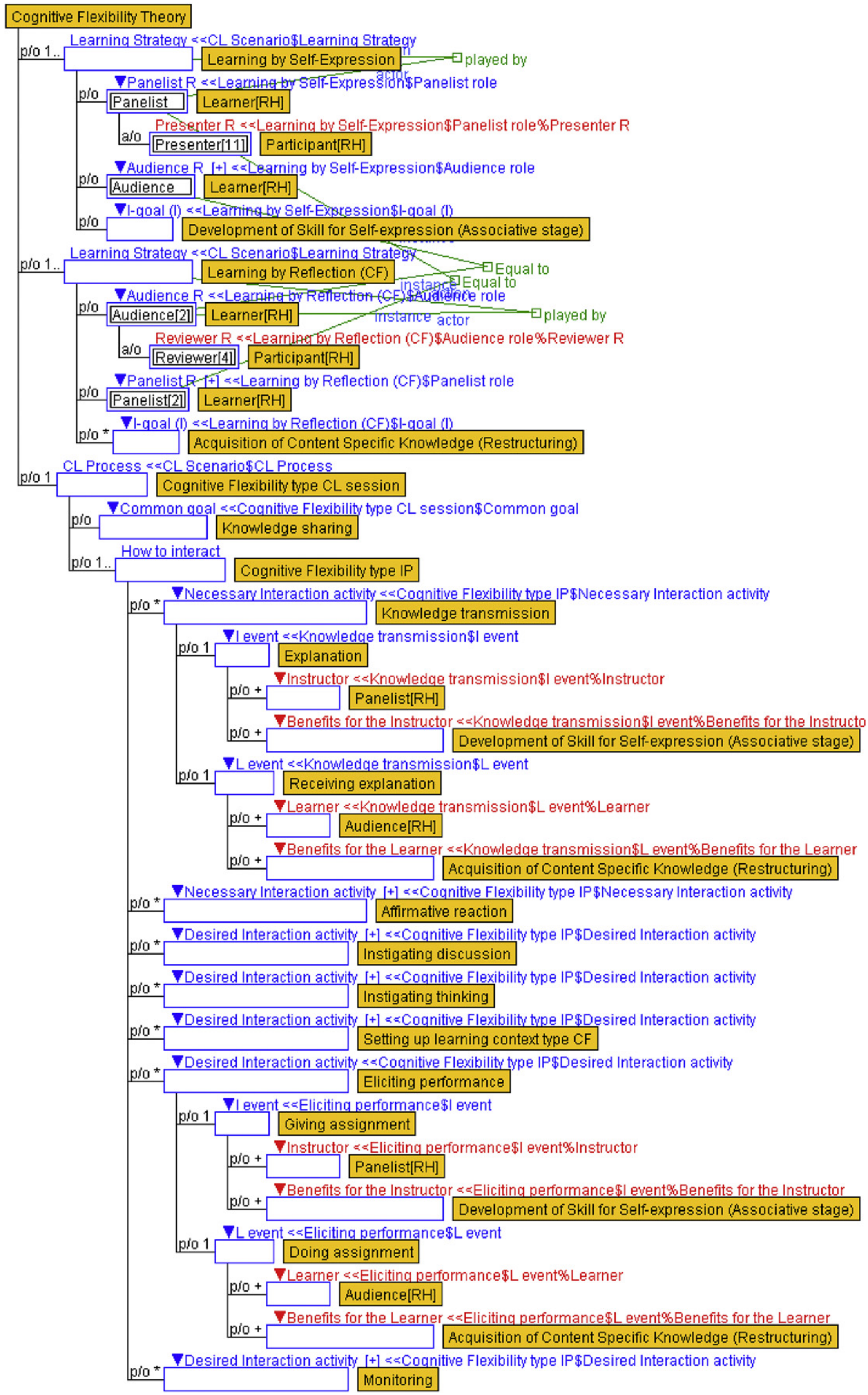


Fig. 2. A learning scenario built using the CL Ontology and concepts from the theory of cognitive flexibility.

```
/*******************************************************************
Return the relation among theories (CL sessions) and Group Goals
Given a Group goal it returns the name of the theories related to it
********************************************************************/

function matchGroupGoalIntoTheory($store, $groupGoal){
   if($store == NULL) return NULL;

   //return all theories if no goal is selected
   if($groupGoal == ''){
     $q = '
  SELECT ?theoryName WHERE {
      ?theory  "'. $this->subClass.'" "'. $this->CLSession .'";
          "'.$this->label.'" ?theoryName .
          } ORDER BY ?theoryName';
     }else{


                 $q = '
  SELECT ?theoryName  WHERE {
          ?theory  "'. $this->subClass.'" "'. $this->CLSession .'"; "'.$this->label.'" ?theoryName .
          ?theory  "'. $this->subClass.'" ?class .
          ?class "'.$this->onProperty.'" "'.$this->hasCLProcess.'";
          "'.$this->allValuesFrom.'" ?clprocess .
          ?clprocess  "'. $this->subClass.'" ?class2 .
          ?class2 "'.$this->onProperty.'" "'.$this->hasCommonGoal.'";
          "'.$this->allValuesFrom.'" ?commonGoal .
          ?commonGoal "'.$this->label.'" "'.$groupGoal.'"
  }  ORDER BY ?theoryName';



        }
    //echo $q;

                 $rows = $store->query($q, 'rows');
                 return $rows;
```

Fig. 3. An algorithm to match group goals and learning theories using the CL Ontology.

scenarios; the second block helps to connect the domain content into the CL ontologies; the third block facilitates creation of groups semi-automatically.

The first block of the interface is connected with the CL design support system, which enables users to select appropriate theories to design theory-based CL scenarios. Within this block, the first box (labeled as "Select the group goal") is connected with the group goal concept in the CL Ontology. Thus, this box shows the possible group goals that are currently represented in our ontology (e.g. knowledge construction or spread of a skill). If the ontology is updated, then the system automatically updates the list of group goals presented in this box.

The second box (labeled as "Select applicable theories") shows the theories that users can utilize to create CL scenarios. Like the first box, this information is extracted from the CL Ontology. Furthermore, when the user selects a goal in the first box, the system will only show the theories that can support the development of the chosen goal in the second box. This functionality is implemented by using the semantic connection between concepts in the ontology, as shown in Fig. 5.

The user's selection in the first box (Fig. 5(1)) generates a constraint that needs to be satisfied. To do that, our algorithm works as follows:

1. Identify the concept in the ontology which corresponds to the user's selection (Fig. 5(2));
2. Search values of the CL scenario concept, verifying whether the property "common goal" has the same value as the concept identified in step 1 (Fig. 5(3));
3. Return the name of the theory utilized by the CL scenario that satisfies the constraint presented in step 2 (Fig. 5(4)).

With the theories presented in the second box (Fig. 5(5)) the user can select which theory he/she wants to use to create theory-based CL scenarios. However, this choice is not easy, especially for inexperienced teachers who may not have knowledge of learning theories or CL. Thus, when a user selects a theory in the second box, the third box (Fig. 5(6)) gives a summary of how to apply the theory and some recommendations, such as the number of roles that should be attributed to the students, the behavior that each student should externalize, and the desired number of participants in each group, besides other various information that can be visualized when clicking in the link "more about this theory." It is worth to note that all information is obtained from our ontologies.

The second block of the interface (Fig. 4(2)) facilitates the mapping of domain-specific content into the ontology. By domain-specific content we mean the real content that a teacher will work with. This mapping is needed because the CL Ontology is domain independent. Therefore, in order to use it in concrete situations, one should first map the concepts in the ontology into the real information of the domain. For example, what kind of materials will be used and what skills will be mastered during the activities? The process of mapping

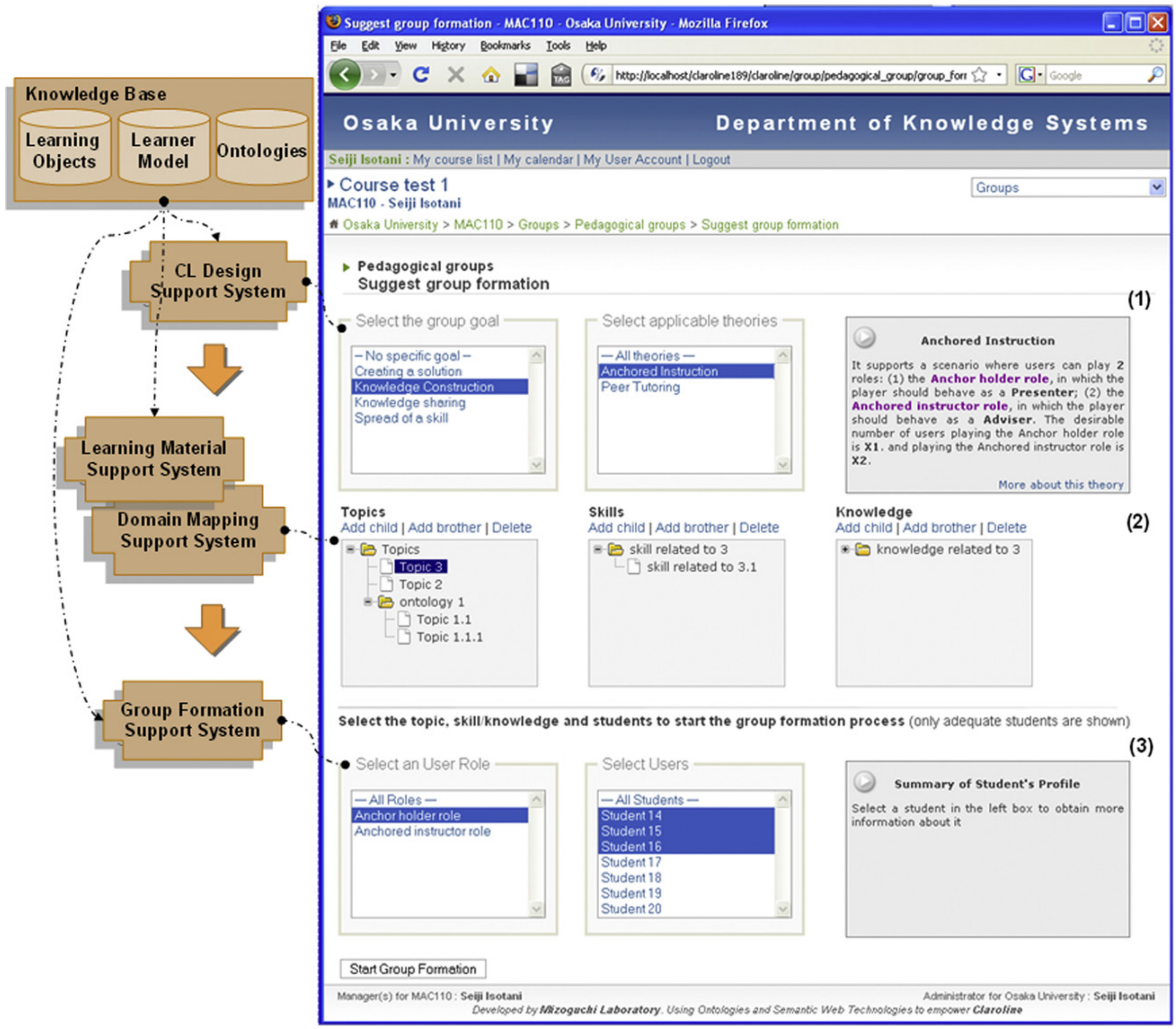


Fig. 4. The right side is a screenshot of the main interface of CHOCOLATO. The left side includes some of the components in CHOCOLATO's architecture that run on the background.

follows the idea of creating a decomposition tree to connect ontologies and domain content (Isotani & Mizoguchi, 2008). The first box corresponds to the topics (or domain-dependent learning goals). Each topic can be decomposed into sub-topics. For each topic, the user needs to separate the skills to be developed from the knowledge to be acquired. Furthermore, each knowledge/skill can be connected with some learning resources to be utilized. Such a simple interface to create trees hides the complexity of mapping content into ontologies and facilitates the use of our system in real situations.

Finally, the third block of the interface supports the group formation process. In our tool, group formation is part of the CL design process. Thus, in our interface, when the user selects the group goals and a theory, the information in the box labeled as "Select a user role" (bottom-left of Fig. 4) is automatically updated, presenting only the roles that the selected theory utilizes.

Furthermore, by clicking on one of the roles, the second box labeled as "Select users" (bottom-center of Fig. 4) shows the learners registered in the environment who are able to *adequately* play the selected role. To verify adequacy, CHOCOLATO checks in the ontology for the necessary and desired requirements to play a role. Then, by using the stages of knowledge/skills in the learner model, it identifies the learners who are able to play the selected role in the domain specified previously.

Fig. 6 shows two examples in which the teacher selected the group goal as "spread of a skill." In the first example (Fig. 6a) the user chose the theory Cognitive Apprenticeship. Thus, the bottom of Fig. 6a shows on the left the roles of master (selected role) and apprentice. The teacher can select one of these roles to check which students can play a certain role. In the case of the master role, the ontology specifies that only students who have experience in using the target cognitive and metacognitive skills can effectively perform the role. Thus, using a Semantic Web inference engine, the authoring tool will find all students that can play the role and show them on the bottom-right of Fig. 6a (students with ID 12, 13, 18, 19 and 20). In the second example (Fig. 6b) the selected theory is LPP, which uses the full and peripheral participant roles. The selected role is full participant, and therefore only the learners who can play this role are presented on the bottom-right of Fig. 6b (students with ID 18, 19 and 20). Then, to complete group formation, the user can select all or only some learners to start the group formation process.

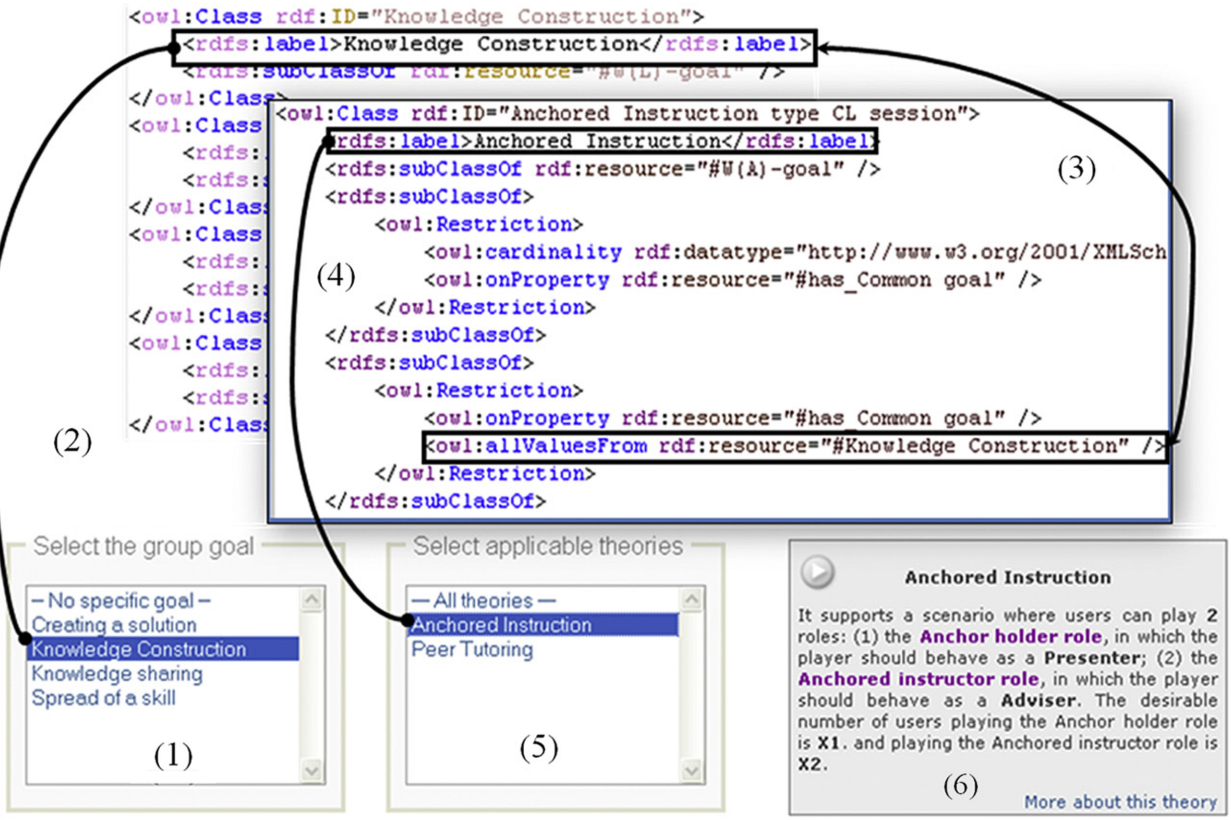


Fig. 5. Elements in the interface and their connections with concepts in the ontology (top).

It is important to note that all information about students' needs to be added by the teacher (e.g. student knowledge state in a given period of instruction). Currently CHOCOLATO is not equipped with capabilities to automatically analyze students' interactions and to assess their work. However, it provides a guideline that facilitates the inclusion of students' information in the system in a systematic and standardized form (Isotani, Inaba et al., 2010). In future versions of CHOCOLATO we intend to add the functionality of automatically assessing students work in online CL environments. An interesting approach that can be leveraged to analyze students' interaction with the learning content in Semantic Web-based environment is present by Jovanovic et al. (2007).

After the steps described in the previous paragraphs, the group will be formed and displayed on the screen, as shown Fig. 7a. The algorithm utilized to compose the group uses ontologies and Semantic Web inference engines to set the group scenario using the best resources available in the environment (e.g. students, theories, strategies, etc.). This algorithm was developed by Isotani, Inaba et al. (2009) and has demonstrated to be useful in semi-automating the creation of theory-based CL groups. CHOCOLATO uses the algorithm to suggest group compositions. Each group formed has a name followed, by the name of the theory that was used to create the group. For example, in the Fig. 7a, Group 1 was created using the theory of Distributed Cognition and is composed of 6 students; Group 2 was created using the theory Peer Tutoring and is composed of 3 students; and so on. It is also possible to check each group and user in more detail, as shown in Fig. 7b. This figure shows the roles that users are playing and the groups they belong to. For example, Group 3 was created using the theory Cognitive Apprenticeship and is composed by the students with ID numbers 3, 4, 8 and 18. The student with ID #18 plays the master role while the others play the role of apprentice.

Finally, after these steps are completed, all necessary information to create a theory-based CL scenario is set up. Then, the system will run an algorithm in the background to recommend interaction patterns that can aid the user to create effective CL activities (Isotani, Inaba et al., 2010; Isotani, Mizoguchi et al., 2010). To provide better user experiences while using our tool, the complexity of ontologies and reasoning processes are completely hidden from the user. For this reason, through a simple interface, CHOCOLATO offers a more effective, intelligent, and structured guidance that helps users during the designing of CL scenarios.

4. Experiments

CHOCOLATO has been developed to help teachers introduce pedagogically sound CL activities in real environments. To test its pedagogical usability and effectiveness we designed experiments to be carried out throughout the school year with two main objectives. The first objective is to check if the recommendations provided by the authoring tool help novice teachers to plan theory-based CL scenarios. The second is to verify if these scenarios can be used in real classrooms to help long-term learning. It is worth noticing that the objectives of the experiments are neither to compare the usefulness of the developed tool with other authoring tools nor compare the learning benefits between CL activities with or without authoring tools.

Fig. 6. Two examples that show changes in the information displayed on the interface to support theory-driven group formation.

4.1. *Experiment 1: does CHOCOLATO help novice teachers to plan theory-based CL scenarios?*

4.1.1. *Participants*

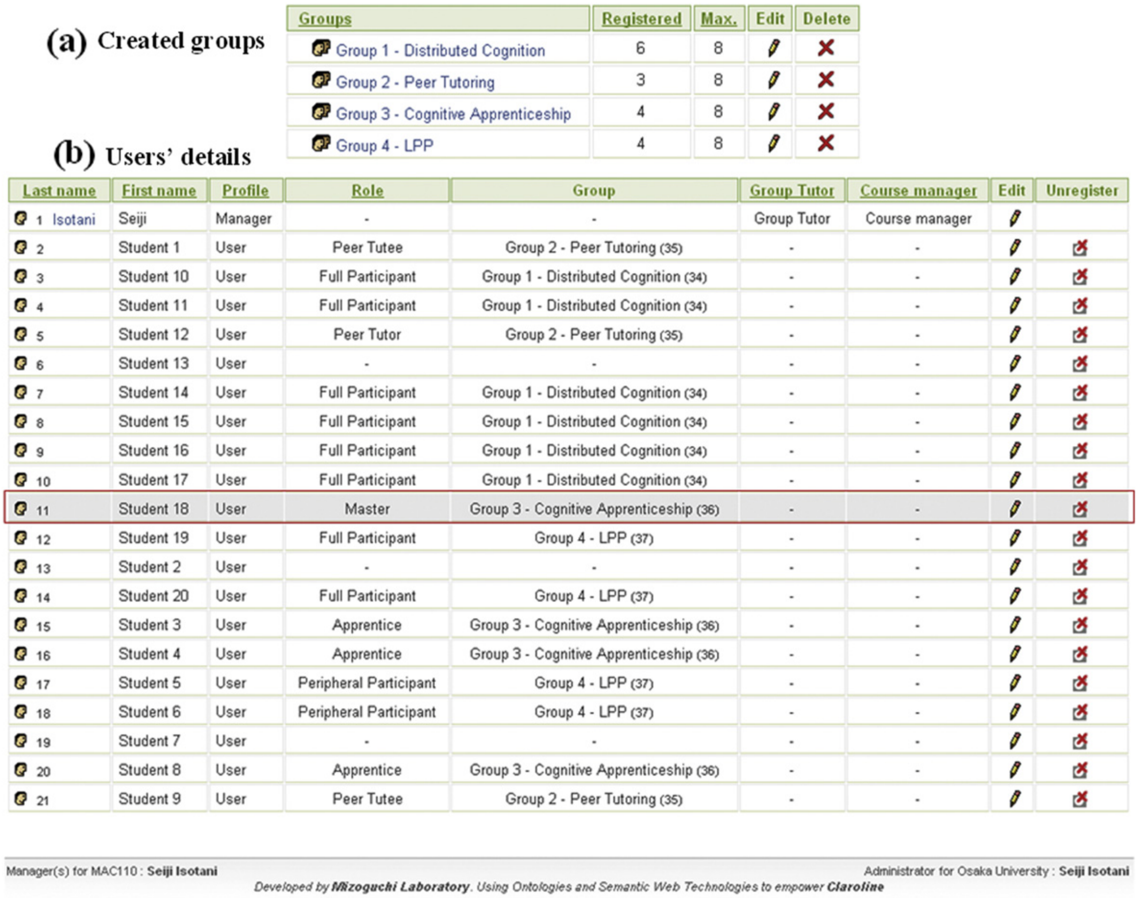
Fifty eight (58) pre-service teachers studying to obtain their teaching license in Mathematics participated in the study.

4.1.2. *Procedures and materials*

The experiment comprises of five steps carried out in four consecutive days: (a) design a CL scenario, without CHOCOLATO, to support the learning of Decimals; (b) Answer questions about the concepts applied to create the CL scenario; (c) design a similar CL scenario for the same topic with support of CHOCOLATO; (d) exchange CL scenarios with other two teachers; (e) understand and evaluate the developed CL scenarios of others.

Teachers were allowed to ask clarification questions and consult any supporting material such as books and the Internet during the experiment. In each step teachers had three hours to work individually and, at the end, produce a document with text, tables, links and graphics. To collect data we used the think-aloud protocol and explicitly ask teachers to explain as much as possible every decision they made.

In the first day we executed the first step of the experiment where teachers had to create a CL scenario to support learning of decimals. This scenario was freely developed by each teacher and, therefore, no restrictions or guidelines were imposed. In the second day, we interviewed teachers to get more information about the design rationale behind the created scenarios. We used a series of Yes/No questions based on the best practices for designing instructional scenarios to identify if teachers were aware of the basic concepts of CL design and instructional planning such as short and long term learning objectives, individual accountability, positive interdependence, coordination, monitoring, assessment plans, role assignment, and so on (Dick, Carey, & Carey, 2001; Dillenbourg, 2002; Isotani, Inaba et al., 2009; Reigeluth, 1999; Strijbos et al., 2004). In the third day, teachers created a new scenario using our authoring tool CHOCOLATO. We asked them to create a scenario as similar as possible to the first one. In this step, teachers had to follow all recommendations given by CHOCOLATO to design their scenario which includes: identifying goals and sub-goals; connecting them with specific tasks, student's roles and CL activities; selecting the most appropriated learning theories to support the designing process; and defining sequence of interactions based on a well-structured pedagogical framework. In the fourth day, we asked teachers to exchange their created scenarios (with and without support of CHOCOLATO) with other two teachers. Then, we ask teachers to analyze the scenarios created by their fellow teachers to check if they could understand them. Finally, teachers were asked to give a score between 1 (worst) and 5 (best) and explain their decision.



(a) Created groups

Groups	Registered	Max.	Edit	Delete
Group 1 - Distributed Cognition	6	8		
Group 2 - Peer Tutoring	3	8		
Group 3 - Cognitive Apprenticeship	4	8		
Group 4 - LPP	4	8		

(b) Users' details

Last name	First name	Profile	Role	Group	Group Tutor	Course manager	Edit	Unregister
1 Isotani	Seiji	Manager	-	-	Group Tutor	Course manager		
2	Student 1	User	Peer Tutee	Group 2 - Peer Tutoring (35)	-	-		
3	Student 10	User	Full Participant	Group 1 - Distributed Cognition (34)	-	-		
4	Student 11	User	Full Participant	Group 1 - Distributed Cognition (34)	-	-		
5	Student 12	User	Peer Tutor	Group 2 - Peer Tutoring (35)	-	-		
6	Student 13	User	-	-	-	-		
7	Student 14	User	Full Participant	Group 1 - Distributed Cognition (34)	-	-		
8	Student 15	User	Full Participant	Group 1 - Distributed Cognition (34)	-	-		
9	Student 16	User	Full Participant	Group 1 - Distributed Cognition (34)	-	-		
10	Student 17	User	Full Participant	Group 1 - Distributed Cognition (34)	-	-		
11	Student 18	User	Master	Group 3 - Cognitive Apprenticeship (36)	-	-		
12	Student 19	User	Full Participant	Group 4 - LPP (37)	-	-		
13	Student 2	User	-	-	-	-		
14	Student 20	User	Full Participant	Group 4 - LPP (37)	-	-		
15	Student 3	User	Apprentice	Group 3 - Cognitive Apprenticeship (36)	-	-		
16	Student 4	User	Apprentice	Group 3 - Cognitive Apprenticeship (36)	-	-		
17	Student 5	User	Peripheral Participant	Group 4 - LPP (37)	-	-		
18	Student 6	User	Peripheral Participant	Group 4 - LPP (37)	-	-		
19	Student 7	User	-	-	-	-		
20	Student 8	User	Apprentice	Group 3 - Cognitive Apprenticeship (36)	-	-		
21	Student 9	User	Peer Tutee	Group 2 - Peer Tutoring (35)	-	-		

Manager(s) for MAC110 : **Seiji Isotani** Administrator for Osaka University : **Seiji Isotani**
*Developed by **Mizoguchi Laboratory**. Using Ontologies and Semantic Web Technologies to empower **Caroline***

Fig. 7. Two screens showing the outputs of the function to create theory-based groups in CHOCOLATO. The top of the figure shows the created groups and the bottom shows more information about users and their roles in each group.

4.1.3. Results and discussion

In the first step, in which we asked teachers to design a CL scenario without any support, most of them have struggled to get this task completed. We observed that pre-service teachers do have knowledge about the target topic, decimals. Nevertheless, their knowledge about how to create CL scenarios and activities can be considered shallow knowledge, which means that these novice teachers do not have adequate deepness and fluency to use it meaningfully in real situations. Thus, during the entire first task, teachers did present difficulties to write down the specifics of the scenario and have spent more than half of their time looking up for information in different books and on the Internet to gather some ideas for CL activities. A comment of a teacher illustrates the problem "*I know how to use collaborative learning. I usually define a complex task that cannot be easily completed by an individual and ask students to form groups of three or four. Then, students can coordinate themselves to decide how to split the task in sub-tasks. I studied some collaborative learning approaches such as jigsaw and think-pair-share, but I have never planned and specified in detail a collaborative learning scenario based on them before. Gosh! It is not trivial!*" As a result most scenarios created by the teachers lack the required concepts for designing well-thought-out CL scenarios. Some of the main identified problems in the created scenarios were: inconsistencies in the structure and sequence of activities (pedagogically incorrect); ambiguous information; the absence of specific individual learning goals and sub-goals; lack of connection between CL activities; inaccurate role definition and assignment; and inadequate assessment plans. Furthermore, most teachers exceeded the maximum time (3 h) to complete this task.

In the second step of the experiment we interviewed teachers to fill a yes/no questionnaire designed to obtain specific information about basic concepts related to CL design and instructional planning. Based on teachers' response we were able to identify which concepts were more frequently used to create the CL scenarios and which concepts were "left behind". The answers given by the teachers are shown on Fig. 8. More than 80% of them defined in their scenarios the group size, what students needed to deliver at the end of each CL activity, the criteria for the group success and the learning goals and sub-goals. Nevertheless, although many of them defined learning goals, less than 20% differentiate individual learning goals from group learning goals. And only two teachers defined these goals in terms of essential knowledge and skills. Furthermore, most teachers did not define any criteria for individual success although they have defined criteria for group success. In other words, when designing a CL scenario teachers seem to not (explicitly) consider the individual gains of students. This is an important problem, since a CL scenario is created to offer an environment that supports students collaborate effectively and, as a consequence, help them to learn (i.e. obtain individual gains). Besides this problem, we also verified that many other important concepts to consider when designing a CL scenario were not addressed. Less than 30% of teachers thought about how to form groups, assign roles to students, make a link between CL activities and create guidelines to help students collaborate. And only 38% of teachers remembered and applied instructional best practices to make decisions about how to plan their scenario.

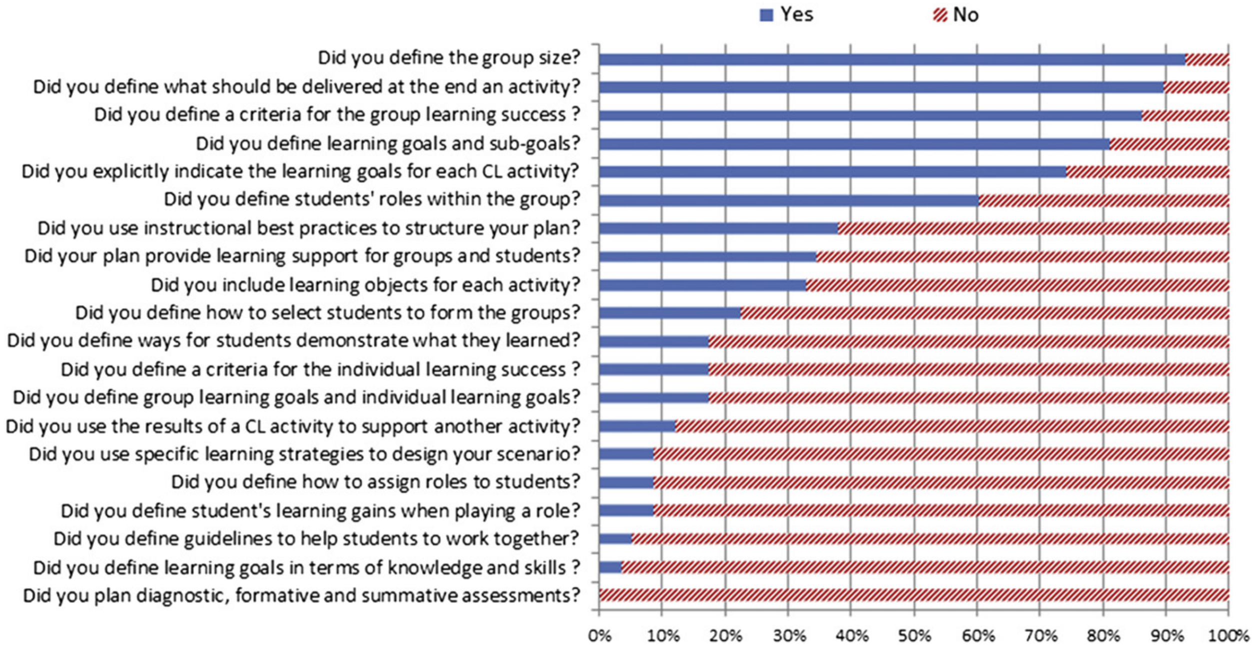


Fig. 8. Answers of a questionnaire created to verify whether novice teachers are aware of the basic concepts related to CL design and instructional planning.

In the third step, teachers tried to create a CL scenario that is as similar as possible to the previous one. However, they had to follow the step-by-step guidance and recommendations of CHOCOLATO (presented in Section 3.2). After following all the necessary steps to create a scenario, teachers were not allowed to make any changes. Although, this could be considered a restriction of our tool, only a few teachers have complained about it. We have observed that teachers could easily decide the groups goals based on the recommendations of CHOCOLATO. They also explored different possible theories to work with and check their similarities and differences. Furthermore, the window that gives a summary of how to use a selected theory to create CL scenarios was widely used by teachers. In this window they were able to verify the key components (concepts) of the scenario and how they were instantiated to support students to obtain the desired learning goals. Another functionality that attracted teachers' attention was the automatic assignment of roles to students. A teacher said "*It would be impossible for me to do that in a classroom with 30 kids. How can this thing do that so fast?*" Another teacher emphasized the benefit of CHOCOLATO to design CL scenarios: "*It is very difficult to think in all variables to design a collaborative learning scenario. I need to think about the topic, the learning goals of the collaboration and the activities, how these activities are connected, how I will evaluate the groups; I also need to consider the students' behavior and background, and everything must be pedagogically sound. It is too much to think at the same time. I think CHOCOLATO gives important directions and removes some of these variables helping me concentrate on what is important, the creation of fun and effective collaborative activities that engage students in a deeper thinking process. That will help students to construct their knowledge and definitely will make an impact on long-term learning.*"

In the last day of the experiment teachers evaluated scenarios created by other two teachers. Thus, each teacher was responsible to evaluate two scenarios created using CHOCOLATO and two others created with no support. When analyzing the scenarios with no support of CHOCOLATO all teachers agree that exchange scenarios using a document based mainly on text (natural language) is very hard to understand. The problem of misunderstanding what has been written and ambiguity of concepts were the major complains when analyzing scenarios created with no support. Furthermore, although the teachers did not have experience in designing and evaluating CL scenarios, they pinpoint many problems in the scenarios of others, especially regarding the sequence of the CL activities that were not pedagogically sound to achieve the desired learning goals and the lack of information. The overage score of CL scenarios created with no support was 2.2 out of 5. When asked about the comparison about the scenarios created with and without CHOCOLATO, teachers were unanimous in saying that scenarios created with CHOCOLATO were better structured and organized. They also emphasized that the problem of ambiguity and lack of information did not appear in these scenarios. About 95% of the teachers have indicated that they would prefer to use CHOCOLATO rather than create scenarios without computational support. Nevertheless, a few teachers have pointed out problems to personalize the CL scenarios satisfactorily using CHOCOLATO. Therefore, some additional support to adapt CL scenarios according to specific topics (e.g. decimals) need to be investigated in future studies. The overage score of CL scenarios created with CHOCOLATO was 4.3 out of 5.

In summary, the overall results of this experiment have shown some of the benefits that our tool provides to novice teachers during the designing of CL scenarios. However, the question about the potential benefit of these scenarios on learning in real classroom situations is still not an open question. Thus, in the next experiment we addressed this issue.

4.2. Experiment 2: do scenarios created with CHOCOLATO help long-term learning in real classroom environment?

4.2.1. Participants

A mathematics teacher and four 5th grade classrooms with hundred eight (108) students in 2008 and hundred ten (110) in 2009 participated in this study.

4.2.2. Procedures and materials

To prepare and conduct an experiment in a real classroom environment we decide to follow a designed-based research methodology (DBRC, 2003). According to Swan (2006), such an approach allows for making theories operational in authentic educational contexts. Collins (1999, pp. 289–298), Barab and Squire (2004) and Swan (2006) indicate some principles in design-based research that help to carry out experiments in authentic classroom settings: (1) most learning occurs in the ill-structured, buzzing confusion of the real-life environment, therefore, learning tasks should clearly state their benefits so students can see the point of what they are being asked to do; (2) involves multiple dependent variables, such as distractions, content, student motivation, available supportive tools and etc. Thus, learning activities should explore different viewpoints and approaches; (3) learning practices should be constantly revised depending on their success or failure; (4) consider complex social interactions with students sharing ideas and building knowledge over time; (5) look at multiple aspects of experimental design and their impact on learning. We use these principles as guidelines to conduct our experiments.

The experiment putting CL scenarios created with CHOCOLATO to test was conducted at a public school referred to as FITO – Osasco Institute of Technology. It maintains a quite traditional fundamental set of courses in the city of Osasco, Brazil. Due to its conservative philosophy, the teaching method is strongly based on the traditional model of instruction, where the teacher transmits his/her knowledge to students who passively *absorb* the content. Through a partnership with the teacher of mathematics, the authors introduced the use of the CL into four 5th grade classrooms (108 students) at the beginning of 2008 and then again in 2009 (110 students). In order to understand the benefits of introducing our authoring tool in the classroom, we need an understanding of the current learning trends. Thus, it is possible to establish a basis for comparison between the previous method of instruction and the method using CL supported by our tool. Therefore, we analyzed the data of students who attended the 5th grade at FITO from 2000 to 2007. This data is composed by assessments made by the teacher, who evaluated her students using tests, homework, extra activities, grades for behavior in class, among others.

We compare the results of the analysis obtained from 2000 to 2007 with the results obtained in the year of 2008 and 2009, when CL was introduced into the classroom supported by CHOCOLATO. This comparison is feasible, because from 2000 to 2009 all classes had similar average performance scores at the beginning of the school year, and the teaching method, tests, and other activities were all accomplished by the same teacher, with the same learning materials. These materials were built using the 5th grade math standards published by the Brazilian Ministry of Education in order to improve math and critical thinking skills. Some examples of questions used to teach and evaluate students were: straight forward questions that work with the four basic math operations such as “*72 − 68*” or “45*7”; contextualized questions that help students to infer which operation should be used in real life situations such as “*John had R$ 1354.00. In his birthday, John received from Uncle Bob R$ 50.00. How much money John has now?*”; and questions related to numerical transformations such as “*How many hours have a week?*”

4.2.3. Results and discussion: initial data analysis

The objective of this data analysis is to offer a rough idea of what students knew in the beginning of the year and compare it with what they learned by the end of the year. To accomplish that, all scores initially obtained by students who completed the 5th grade were gathered during the period between 2000 and 2007. Then, for each student we compared the score obtained in the first test of the year with the average score in the same year to create a graph. Because of the strong similarity between the graphs for each year, we show only two of them in Fig. 9. Each point in the graph represents a student and his/her scores; the *x*-axis represents the score in the first test and the *y*-axis represents the average score of all activities in the same year. All the graphs from 2000 to 2007 seem to follow a pattern that forms a cloud of points with an angle of 45° in relation to the *x*-axis. The linear regression is shown by the full line that cut the cloud in half and the dashed lines represent the prediction interval (PI) and the confidence interval (CI). The pattern shown in the graphs gives an indication that there might be a correlation between the score obtained in the first test and student development throughout the year.

To analyze the possible correlation among the students’ scores, a method for identifying patterns in the data was utilized. This method is referred to as the **PCA – Principal Component Analysis Method** (Cooley & Lohnes, 1971). It expresses the data in a way that makes similarities and differences more perceptible. According to Jolliffe (2010), PCA not only helps to find patterns in data, but also shows the pattern by reducing the number of variables without much loss of information. This means that the PCA aims at mapping possible correlated variables into another smaller number of variables referred to as principal components.

In the case of a two-dimensional analysis, as is our case, the 1st principal component (PCA-1) shows the projection of the data into a straight line that follows the greatest variance of the points. In other words, PCA-1 is a line that passes through the middle of the cloud of

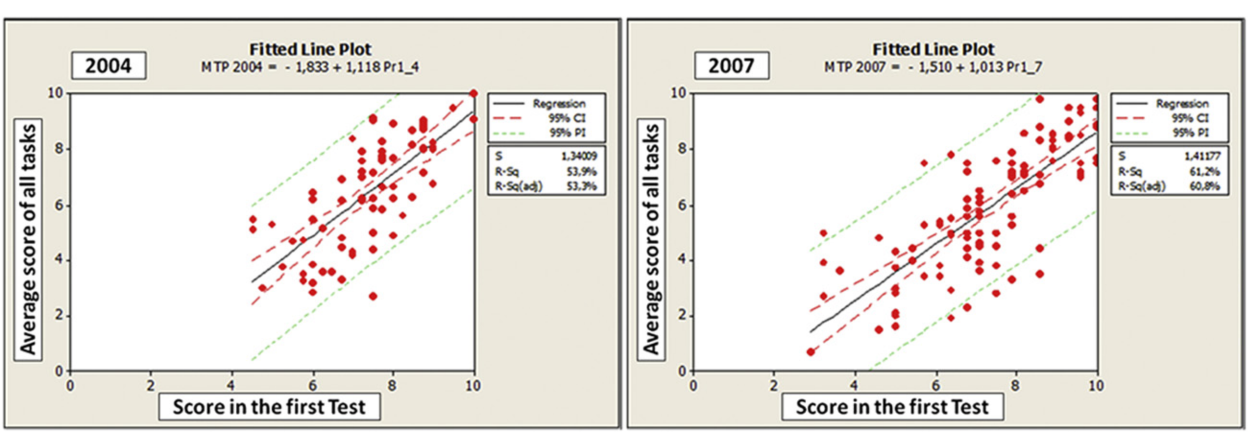


Fig. 9. Graphs showing the correlation between students’ score in the beginning of the year and the average score obtained throughout the year.

points in our data. The 2nd principal component (PCA-2) gives us the variance of the data in relation to the 1st principal component. It shows the pattern of the points that do not follow the PCA-1.

We use the PCA to analyze students' scores during the period of 2000–2007, where the teacher used the traditional teaching method (basically, individual learning). Fig. 10 shows the result of the application of the PCA method in our data. As in Fig. 9, the *x*-axis represents the score in the first test and the *y*-axis represents the average score of all tasks. The points marked with "o" are the students' data, the green line is the projection of students' data into the 1st principal component, the red line is the projection of students' data into the 2nd principal component, and the blue line shows the linear regression (expected value of each point). The most important information is obtained from the green and red lines that represent the principal components. The correlation between the initial and the average scores is shown by the PCA-1, composed by the green line, following a similar path to the linear regression line. The PCA-2 is shown by the red line crossing the PCA-1 *almost* perpendicularly.

The PCA-1 is a line that follows almost the same inclination of the linear regression (approximately 45° in relation to *x*-axis), which indicates that there is a linear correlation between the first score and the average score. The PCA-2 indicates that the first score of the students is not equal, but proportional to their average score in the year. This result suggests a pattern where *students with low scores in the beginning of the semester will have low scores at the end of the semester in comparison to his/her peers*. In other words, we could say that a student acquires the content proportionally to his/her knowledge at the beginning of the course.

The ideal graph would be when the linear regression line and the PCA-1 have their initial values starting from six in the *y*-axis and for any point $P = (x, y)$, the value of y should always be equal or higher than the value of x. Furthermore, the PCA-2, which shows the variance of the data, should increase its size. In this ideal scenario, students who get a low score in the beginning of the semester have the chance to obtain a score equal or higher than a six at the end of the year, which is the minimum requirement for passing the final exam. Furthermore, students who get a good score in the beginning will continue getting good scores until the end of the year.

4.2.4. Results and discussion: introducing collaborative learning with CHOCOLATO

The 5th grade math teacher at FITO was willing to test new methods of teaching–learning because of two problems she had to deal with every day. For example, one problem that the teacher dealt with was teaching the same content to all students at the same time. It means that she had to treat less knowledgeable students and more knowledgeable students in a homogeneous way. In this situation, the teacher cannot interrupt her explanations to aid those who have difficulty in following the content. Furthermore, according to Freire (1993), while teachers are explaining the content, less knowledgeable students usually feel uncomfortable asking questions; more knowledgeable students who already understand the content have to wait and follow a slow pace.

The teacher's observation is completely in line with our findings during the data analysis using PCA. Because she could not give adequate support to students using traditional teaching methods, the *students with low scores in the beginning of the semester had few chances of improving his/her performance along the course*.

Thus, to provide the teacher with new pedagogical methods to support learning, CHOCOLATO was introduced at the beginning of 2008 as a way to utilize CL in the classroom. The experiment with CHOCOLATO was carried out until the end of the school year (about 9 months) and then again in 2009. The initial goal of this experiment was to improve the quality of teaching (and thereby improve the performance of students as a long-term goal).

To create CL scenarios that could be applied in classrooms, the teachers had several questions. Among these, the most important questions were the following: (1) how should I group students? (2) How should I plan the group activities? (3) How can I support students while they are working in groups? (4) How can I assess students' learning?

The current version of CHOCOLATO could help the teacher answer the first two questions. With structured guidance using CHOCOLATO's interface, the teacher did not have difficulties setting up goals for groups and choosing theories to work with. The teacher did not have any knowledge about learning theories. Therefore, the information that CHOCOLATO offered was fundamental in helping the teacher identify a good theory-based CL scenario for specific situations. It is worth to point out that in many situations teachers had to create new learning materials that engage students in collaborative activities since most of the content in textbooks were created to be taught and not learned in

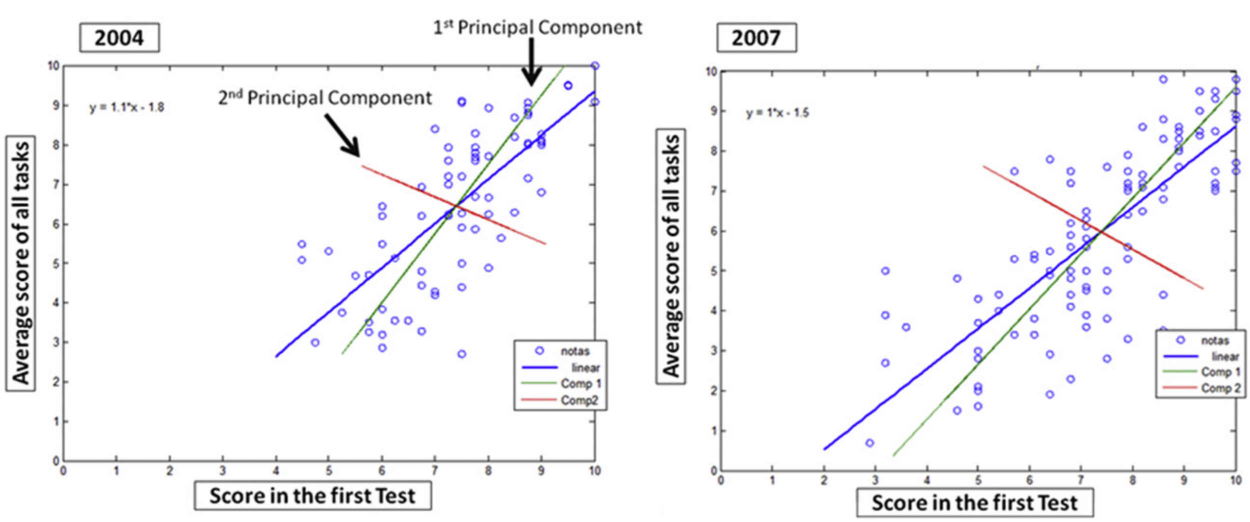


Fig. 10. Result of the application of the PCA method in the students' data to check the correlation between the initial and average scores.

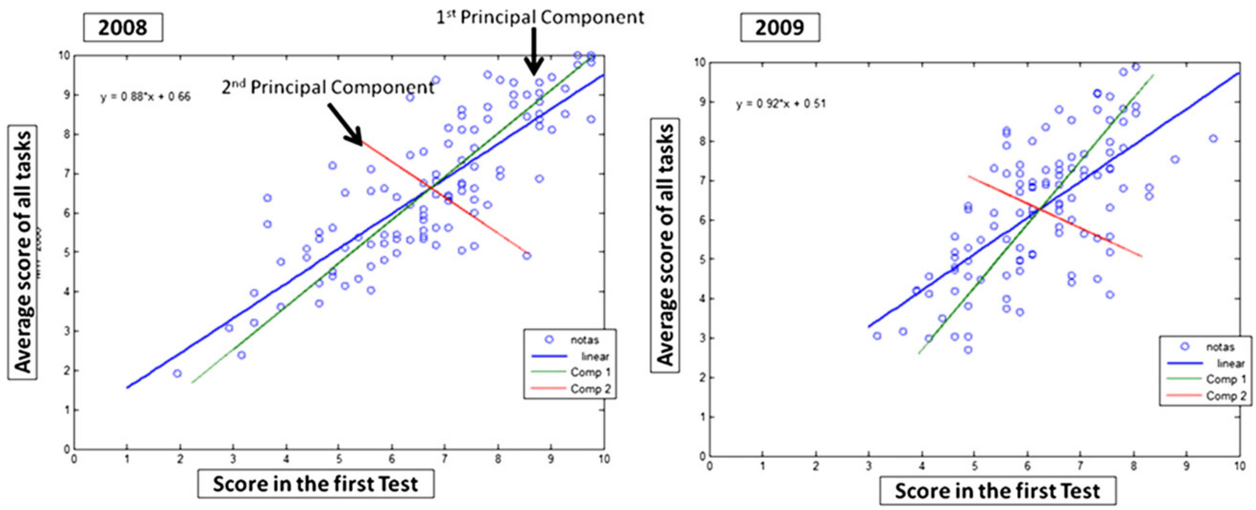


Fig. 11. Result of the application of the PCA method for 2008 and 2009. The inclination of the PCA-1 is smaller than the previous years, which indicates an overall better student performance.

a constructive environment. Regarding group formation, the system could suggest the learners who were able to play certain roles satisfactorily and thus automatically form groups. In many cases teachers could not understand why CHOCOLATO did not let her pair very low performance students with very high performance students. The teacher believed that high performance students would provide better help to other students. However, as shown by Isotani, Inaba et al. (2009), low performance students often cannot follow the reasoning used by high performance students when the difference between the knowledge and skills of these students achieve a certain degree. Thereby, pairing these students would frustrate both the low achievers, because they cannot follow what others are doing, and the high achievers, because they cannot understand why others are not following their rationale. The teachers did some small experiments with others classes that she taught and after the first months she realized such a problem in practice. Finally, CHOCOLATO also provides interaction patterns that help the teacher to design CL activities following pedagogical requirements.

The question related to how best to support students while they are working in groups, and how to evaluate them, cannot be answered with the current version of CHOCOLATO. The reason is because the system has been developed to be an authoring tool that facilitates the creation of theory-based CL scenarios. However, an extension that deals with teachers' support for conducting and analyzing CL activities, currently under development, will be included in future versions of CHOCOLATO.

To provide an example of a CL scenario created by the teacher with CHOCOLATO, we present one of the scenarios based on the theory Cognitive Flexibility. In this scenario, the tool indicated that students would have two roles: panelist role and audience role. As a panelist, students had to present and defend their ideas and viewpoints to solve a problem while the audience had to reflect on the presented ideas and pose questions. The problem selected by the teacher was the following "*Mario bought **3** t-shirts at **R$ 45.00** each and **5** socks at **R$ 17.00** each. How much did Mario spend in total?*" The group size suggested by CHCOLATO was 3–4 students. Students had to follow the interaction pattern of this theory as presented in Fig. 2. By doing so, all students had to play the role of panelist at least once for the given problem and at the end of the CL process present a final solution of the group based on their discussion. Students also present their own solutions and indicate why it was (or wasn't) chosen by the group. As a result of following this scenario, students acquired self-expression skills and knowledge to solve the posed math problem.

In spite of some difficulties faced by the teacher in carrying out CL activities in classroom, the general results were positive. The main gain, according to the teacher, was opening up a pedagogical procedure that allows for helping less knowledgeable students and more knowledgeable ones at the same time. Furthermore, it was observed that CL activities had a positive effect on students' learning and behavior. The teacher pointed out that there was a considerable decrease of unnecessary noise (parallel conversations not related to the content) during the classes because students were engaged while doing their group work. Finally, after the end of the school year we analyzed the results using the PCA method, as we did in previous years. Then, we compared the score obtained by the student on the first test with the average score obtained in 2008 and 2009. Fig. 11 shows the PCA after the introduction of CL using CHOCOLATO. Although many difficulties have occurred while students worked in groups, the inclination of PCA-1 in relation to *x*-axis is much smaller if compared with the other graphs shown in Fig. 10. Furthermore, the linear regression line starts from the value four in *y*-axis, and the PCA-2 is much larger than the previous graphs as well. It means that students who performed poorly on the first test tend to recover and learn better using theory-based CL supported by CHOCOLATO, if compared with the previous seven years in which the traditional method was utilized.

In summary, the results of the experiment suggest that with a principled CL design process, CHOCOLATO creates favorable conditions for learners to perform highly in collaborative environments, and helps instructors to more easily create a sequence of activities that support the achievement of learning goals, thereby improving the performance of students throughout the year.

5. Conclusions

The task of designing pedagogically sound CL scenarios is a great challenge for novice teachers. It requires a deep understanding of instructional/learning theories and skills to organize and refine the CL scenario according to students' learning states, available instructional materials and other elements in the environment where learning is taking place. Yet, there is limited number of authoring tools that are "aware" of pedagogies and can provide intelligent guidance to users due to the difficulty of representing pedagogical knowledge and principles in a computer-understandable manner.

Thus, in this work we use Semantic Web technologies to further develop CHOCOLATO, an intelligent authoring tool equipped with theoretical knowledge to support the design of theory-based CL scenarios. To build this knowledge authors have extract the core concepts from learning theories and represent them formally using ontologies. Based on the semantic connections between concepts, CHOCOLATO can assist teachers to design theory-based CL scenarios by offering recommendations for role assignment, selection of interaction patterns, definition of learning strategies, formation of groups and so on.

To examine the benefits of CHOCOLATO we designed two experiments to answers two questions. First, is a novice teacher (non-expert) able to understand the recommendations of CHOCOLATO and design pedagogically sound CL activities? And second, do theory-based CL scenarios support learning in real classrooms? To answer the first question we designed an experiment with 58 pre-service teachers and asked them to design and evaluate CL scenarios with and without support of our tool. The results have shown that novice teachers have many difficulties to design CL scenarios without help. They also indicated that our tool provides the adequate knowledge and feedback to guide novice teachers during the designing process helping them to create, understand and share CL scenarios. To tackle the second question we used a design-based research approach to conduct an experiment in a Brazilian school together with a math teacher and 218 students. Two functionalities of CHOCOLATO were used (1) the recommendation of theory-based CL scenarios and (2) the automatic group formation. We observed and analyzed teacher and students for over two years using the PCA method and the results were positive. Teacher was able to effectively understand CHOCOLATO's recommendation and transform scenarios extracted from learning theories into complete CL activities. Furthermore, the analysis of PCA has shown significant improvement on overall students' performance. It was also identified that less knowledgeable students were benefited the most throughout the year.

To continue the evaluation of CHOCOLATO, we have already set up two other experiments to be conducted in the following years. In the first, we will compare the usability of our tool with other available authoring tools. We believe that the intelligent capabilities of CHOCOLATO enhance the design of effective and pedagogically valid CL scenarios. In the second experiment we will compare the learning benefits between CL activities with or without authoring tools. Previous results suggest that teachers have difficulties preparing CL scenarios. Thus, it is a reasonable research aim to understand the efficacy of intelligent authoring tools and their effects on users.

For future work we also intend to extend the functionalities of CHOCOLATO. We are particularly interested in developing mechanisms to support students while they are working in groups on online courses and help teachers to automatically assess students' learning. Our approach is to build upon previous research achievements on students modeling (Jovanovic et al., 2007), design of assessment (Villasclaras-Fernandez, Hernández-Leo et al., 2009; Villasclaras-Fernandez, Isotani et al., 2009) and intelligent support for interaction/argumentation (McLaren, Scheuer, & Mikšátko, 2010) to implement a functionality to update students' models on the fly and use them to evaluate students' performance. This feature together with other improvements will be included in future versions of our tool.

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References

Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological Review, 89*(4), 369–406.

Babi, F., Wagner, J., & Parali, J. (2008). The role of ontologies in collaborative systems. In *SAMI 2008 6th international symposium on applied machine intelligence and informatics* (pp. 119–123).

Baghaei, N. (2007). *A collaborative constraint-based intelligent systems for learning object-oriented analysis and design using UML*. PhD thesis in Computer Science. University of Canterbury. Available at http://ir.canterbury.ac.nz/handle/10092/1204.

Bandura, A. (1977). *Social learning theory*. New York: General Learning Press.

Barab, S., & Squire, K. (2004). Design-based research: putting a stake in the ground. *The Journal of the Learning Sciences, 13*(1), 1–14.

Barkley, E., Cross, K. P., & Major, C. H. (2005). *Collaborative learning techniques: A practical guide to promoting learning in groups*. San Francisco, CL: Jossey Bass.

Barron, B. (2003). When smart groups fail. *The Journal of the Learning Sciences, 12*, 307–359.

Barros, B., Verdejo, M. F., Read, T., & Mizoguchi, R. (2002). Applications of a collaborative learning ontology. In *Proceedings of the Mexican international conference on artificial intelligence*. *LNCS, Vol. 2313* (pp. 103–118).

Chacón, J., Hernández-Leo, D., & Blat, J. (2011). From a pattern language to a pattern ontology approach for CSCL script design. In. *Proceedings of the international conference on computational science and its applications, Vol. Part IV* (pp. 547–561). Berlin, Heidelberg: Springer-Verlag.

Collins, A. (1999). *The changing infrastructure of educational research. Issues in education research: Problems and possibilities*. New York: Jossey-Bass.

Conole, G., & Fill, K. (2005). A learning design toolkit to create pedagogically effective learning activities. *Journal of Interactive Media in Education, 8*, Available at http://www-jime.open.ac.uk/2005/08/conole-2005-08.pdf.

Cooley, W. W., & Lohnes, P. R. (1971). *Multivariate data analysis*. New York: Wiley.

Dalziel, J. (2003). Implementing learning design: the Learning Activity Management System (LAMS). In *Proc. of the Australian society for computers in learning in tertiary education conference*.

DBRC. (2003). Design-based research: an emerging paradigm for educational inquiry. *Educational Researcher, 32*(1), 5–8.

Devedzic, V. (2002). Understanding ontological engineering. *Communications of the ACM, 45*(4), 136–144.

Devedzic, V. (2006). *Semantic Web and education*. Springer.

Dicheva, D., Mizoguchi, R., & Greer, J. (2009). *Semantic Web technologies for e-learning*In *The future of learning series, Vol. 4*. IOS Press.

Dick, W., Carey, L., & Carey, J. O. (2001). *The systematic design of instruction* (5th ed.). Addison-Wesley Educational Publisher Inc.

Dillenbourg, P. (2002). Over-scripting CSCL: the risks of blending collaborative learning with instructional design. In *Three worlds of CSCL. Can we support CSCL?* (pp. 61–91). Heerlen: Open University Nederland.

Dillenbourg, P., & Hong, F. (2008). The mechanics of CSCL macro scripts. *International Journal of Computer-Supported Collaborative Learning, 3*(1), 5–23.

Fiechtner, S. B., & Davis, E. A. (1985). Why some groups fail: a survey of students' experiences with learning groups. *Organizational Behavior Teaching Review, 9*(4), 75–88.

Freire, P. (1993). *Pedagogy of the oppressed*. New York: Continuum.

Griffiths, D., Blat, J., Garcia, R., Vogten, H., & Kwong, K. (2005). Learning design tools. In *Learning design: Modelling and implementing network-based education & training* (pp. 109–135). Springer Verlag.

Guarino, N. (1997). Understanding, building, and using ontologies. *International Journal of Human-Computer Studies, 46*(2–3), 293–310.

Hayashi, Y., Bourdeau, J., & Mizoguchi, R. (2009). Using ontological engineering to organize learning/instructional theories and build a theory-aware authoring system. *International Journal of Artificial Intelligence in Education, 19*(2), 211–252.

Hernandez-Leo, D., Asensio-Perez, J. I., & Dimitriadis, Y. (2005). Computational representation of collaborative learning flow patterns using IMS learning design. *Educational Technology & Society, 8*(4), 75–89.
Hernandez-Leo, D., Villasclaras-Fernandez, E. D., Jorrin-Abellan, I. M., Asensio-Perez, J. I., Dimitriadis, Y., Ruiz-Requies, I., et al. (2006). Collage, a collaborative learning design editor based on patterns. *Educational Technology & Society, 9*(1), 58–71.
Ikeda, M., Hoppe, U. H., Mizoguchi, R. (1995). Ontological issues of CSCL systems design. In *Proceedings of int. conference on artificial intelligence in education* (pp. 242–249).
Inaba, A., & Mizoguchi, R. (2004). Learning design palette: an ontology-aware authoring system for learning design. In *Proc. of the international conference on computers in education* (pp. 597–607).
Inaba, A., Supnithi, T., Ikeda, M., Mizoguchi, R., & Toyoda, J. (2000). How can we form effective collaborative learning groups?. In *Proc. of the international conference on intelligent tutoring systems. Lecture notes in computer science, Vol. 1839* (pp. 282–291).
Isotani, S., Bittencourt, I. I., Mizoguchi, R., & Costa, E. (2009). Estado da Arte em Web Semântica e Web 2.0: Potencialidades e Tendências da Nova Geração de Ambientes de Ensino na Internet. *Revista Brasileira de Informática na Educação, 17*(1), 30–42. http://dx.doi.org/10.5753/RBIE.2009.17.01.30.
Isotani, S., Inaba, A., Ikeda, M., & Mizoguchi, R. (2009). An ontology engineering approach to the realization of theory-driven group formation. *International Journal of Computer-Supported Collaborative Learning, 4*(4), 445–478.
Isotani, S., Inaba, A., Ikeda, M., & Mizoguchi, R. (2010). The foundations of a theory-aware authoring tool for CSCL design. *Computers & Education, 54*(4), 809–834, Elsevier.
Isotani, S., & Mizoguchi, R. (2007). Deployment of ontologies for an effective design of collaborative learning scenarios. In *International workshop on groupware (CRIWG). Lecture notes in computer science, Vol. 4715* (pp. 223–238). Springer.
Isotani, S., & Mizoguchi, R. (2008). Adventure in the boundary between domain-independent ontologies and domain-specific content for CSCL. In *Lecture Notes in Artificial Intelligence (LNAI 5179)* (pp. 523–532). Springer-Verlag.
Isotani, S., Mizoguchi, R., Isotani, S., Capeli, O. M., Isotani, N., & Albuquerque, A. R. P. L. (2010). An authoring tool to support the design and use of theory-based collaborative learning activities. In *International conference on intelligent tutoring systems. Lecture notes in computer science, Vol. 6095* (pp. 92–102). Springer.
Johnson, D. W., Johnson, R. T., & Smith, K. A. (1998). *Active learning: Cooperation in the college classroom*. Edina, MN: Interaction Book Company.
Jolliffe, I. T. (2010). *Principal component analysis*. Springer.
Jovanovic, J., Gasevic, D., Brooks, C., Devedzic, V., Hatala, M., Eap, T., et al. (2007). Using semantic web technologies to analyze learning content. *IEEE Internet Computing, 11*(5), 45–53.
Kobbe, L., Weinberger, A., Dillenbourg, P., Harrer, A., Hamalainen, R., & Fischer, F. (2007). Specifying computer-supported collaboration scripts. *International Journal of Computer-Supported Collaborative Learning, 2*(2–3), 211–224.
Laurillard, D. (2009). The pedagogical challenges to collaborative technologies. *International Journal of Computer-Supported Collaborative Learning, 4*(1), 5–20.
McLaren, B. M., Scheuer, O., & Mikšátko, J. (2010). Supporting collaborative learning and e-discussions using artificial intelligence techniques. *International Journal of Artificial Intelligence in Education, 20*(1), 1–46.
Miao, Y. (2005). CoSMoS: facilitating learning designers to author units of learning using IMS LD. In *Proceedings of the international conference on computers in education* (pp. 275–282).
Milligan, C. D., Beauvoir, P., & Sharples, P. (2005). The reload learning design tools. *Journal of Interactive Media in Education, 7*, Available at http://www-jime.open.ac.uk/2005/06/milligan-2005-06.pdf.
Mizoguchi, R., Hayashi, Y., & Bourdeau, J. (2009). *Inside a theory-aware authoring system*. Amsterdam, The Netherlands: Semantic Web Technologies for E-learning, IOS Press.
Mizoguchi, R., Sunagawa, E., Kozaki, K., & Kitamura, Y. (2007). The model of roles within an ontology development tool: Hozo. *Applied Ontology, 2*(2), 159–179.
Pinkwart, N. (2003). A plug-in architecture for graph based collaborative modeling systems. In *Proc. of the int. conference on artificial intelligence in education* (pp. 535–536).
Reigeluth, C. M. (Ed.), (1999). *Instructional-design theories & models a new paradigm of instructional theory*. Mahwah, N. J.: Lawrence Erlbaum Associates, Inc.
Rumelhart, D. E., & Norman, D. A. (1978). *Accretion, tuning, and restructuring: Modes of learning, semantic factors in cognition*. LEA.
Scheuer, O., Loll, F., Pinkwart, N., & McLaren, B. M. (2010). Computer-supported argumentation: a review of the state of the art. *International Journal of Computer-Supported Collaborative Learning, 5*(1), 43–102.
Smith, K. A. (1996). Cooperative learning: making 'groupwork' work. In *Using active learning in college classes: A range of options for faculty* (pp. 71–82). San Francisco: Jossey-Bass.
Soller, A., Martínez-Monés, A., Jermann, P., & Muehlenbrock, M. (2005). From mirroring to guiding: a review of state of the art technology for supporting collaborative learning. *International Journal of Artificial Intelligence in Education, 15*(4), 261–290.
Stahl, G., Koschmann, T., & Suthers, D. (2006). *CSCL: An historical perspective*In *Cambridge handbook of the learning sciences*, . Cambridge, UK: Cambridge University Press.
Strijbos, J. W., Martens, R. L., & Jochems, W. M. G. (2004). Designing group based learning: six steps to designing computer-supported group based learning. *Computers & Education, 42*, 403–424.
Swan, M. (2006). *Collaborative learning in mathematics: A challenge to our beliefs and practices*. National Institute of Adult Continuing Education (NIACE).
Swartout, W., & Tate, A. (1999). Introduction: ontologies. *IEEE Intelligent Systems, 14*(1), 18–19.
Vega-Gorgojo, G., Bote Lorenzo, M. L., Asensio Perez, J. I., Gomez Sanchez, E., Dimitriadis, Y., & Jorrin Abellan, I. M. (2010). Semantic search of tools for collaborative learning with the Ontoolsearch system. *Computers & Education, 54*(4), 835–848.
Villasclaras-Fernandez, E. D., Hernández-Leo, D., Asensio-Perez, J. I., & Dimitriadis, Y. (2009). Incorporating assessment in a pattern-based design process for CSCL scripts. *Computers in Human Behavior, 25*(5), 1028–1039.
Villasclaras-Fernandez, Isotani, S., Hayashi, Y., & Mizoguchi, R. (2009). Looking into collaborative learning: design from macro- and micro-script perspectives. In *Proceedings of the international conference on artificial intelligence in education* (pp. 231–238).
Vygotsky, L. S. (1978). *Mind in society: The development of the higher psychological processes*. Cambridge, MA: Harvard University Press.