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DEVELOMENT OF A PROCESS-ORIENTED SCAFFOLDING AGENT IN AN OPEN-ENDED INQUIRY LEARNING ENVIRONMENT

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Based on the theories of metacognition and inquiry-based learning, we developed a process-oriented scaffolding agent (POSA) to support inquiry-based learning processes in complex domains centered around emerging learning objects. The objectives are to provide process guidance on time and on demand, and to help the students to reflect on and possibly re-plan their learning processes by monitoring and analyzing students' actions and by using knowledge captured in a task model, a strategy model, a learner model and a scaffolding model. We demonstrate the technical feasibility to implement such a domain-generic and lightweight pedagogical agent and to integrate it into a flexible, open-ended inquiry-based learning environment. Furthermore, we report a pilot study to investigate the learners' acceptance of the POSA based on the Technology Acceptance Model. The results reveal that most of the participants found the POSA generally useful in a flexible, open-ended inquiry learning process.

Keywords: Inquiry-based learning; metacognition; process-oriented scaffolding agent; Technology Acceptance Model.

1. Introduction

In inquiry-based learning, teachers are no longer lecturers or examiners. Instead, they use various methods to scaffold students to actively engage in learning. Scaffolding can be defined as the support provided by a teacher, peer, or other resource that enables students to move within their zone of proximal development (Vygotsky, 1978) and perform tasks that they cannot perform independently (Wood, Bruner, & Ross, 1976). Hannafin, Land, & Oliver (1999) divide scaffolding into four types: conceptual, procedural, metacognitive, and strategic scaffolding. The goal of scaffolding is two-fold: to provide temporary support to students as they perform tasks that they have difficulty performing unaided, and second, to help students gain competency such as higher order thinking so that they can complete those tasks unaided in the future (Puntambekar & Hubscher, 2005; Hmelo-Silver, Duncan, & Chinn, 2006).

Recently many researchers have studied how to integrate scaffolding structures in the computer-mediated inquiry-based learning environment (Pea, 2004; Puntambekar & Hubscher, 2005). Computational scaffolding mechanisms tend to be built in the basic functionalities of the software as additional features and embedded in the computer-mediated learning environment to explicitly promote intended user activities and cognitions (Lakkala, Muukkonen, & Hakkarainen, 2005). Students can get scaffolds when human tutors and peer students are not available. In the past decade, there has been much work on computational scaffolding to support inquiry-based learning processes, but there are still many questions and challenges, in particular, regarding the support of metacognition. As Azevedo (2005) pointed out, it is needed to do research work on the conceptual, theoretical, empirical, and design issues related to using computers as metacognitive tools to foster learning about conceptually rich domains.

In order to scaffold inquiry learning management, there are two broadly different approaches to decompose activities: unordered and ordered activity decompositions (Quintana et al., 2004). Many inquiry learning environments such as Symphony (Quintana, Eng, Carra, Wu, & Soloway, 1999) and Process Coordinator (Manlove, Lazonder, & de Jong, 2006) have been developed by adopting an unordered activity decomposition approach. These systems provide a set of unconnected entries for activity possibilities, so that students can access the possible activity spaces freely. This approach emphasizes the ill-structured and open-ended nature of inquiry learning, but provides less process guidance. Some other systems such as KIE (Bell, Davis, & Linn, 1995) explicitly describe the learning path. The students have to complete one activity and can then start the next one. This approach guides students, at least novice and intermediate students, to use scientific inquiry process skills and improve learning efficiency. However, this approach restrains students, in particular skilled students, to think and decide on their own learning plan. In fact, there is an additional approach in between these two extremes. The decomposed activities are displayed as a list as done in WISE (Linn & Slotta, 2000) or connected as lines/arrows in the main work space. On the one hand, the explicitly provided learning sequence is not used to control the work process; on the other hand it provides hints for the students to take a suggested learning path to achieve the learning goal. Although this approach meets the two conflict requirements to some extent at the same time, it provides insufficient support for self-regulative activities.

This paper describes our work on devising computer-based support to foster the learning processes associated with individual learning management in inquiry-based learning. This research work was done in the context of an EU FP7 project "Science Created by You" (SCY website). SCY aims to take science education to the next level by developing a flexible, open-ended learning environment that engages and empowers adolescent learners (SCY website). Within this learning environment, called SCY-Lab, students are engaged in constructive and productive learning activities through embarking on authentic research tasks, called SCY missions. The SCY philosophy of learning is "learning by designing artifacts". The artifacts are "emerging learning objects" (ELOs) (Hoppe et al., 2005; de Jong et al., 2010) that can be saved in a repository and can be re-used by students themselves and by other students. SCY-Lab provides adaptive support for learning through providing students with pedagogical scaffolds, collaboration facilities, peer assessment and social tagging tools (SCY website). In SCY-Lab, learning takes place in a personalized place, in which students can find activities to undertake. Related tools, services, and resources are available, which scaffold them in performing these cognitive activities. On the aspect of learning management, SCY-Lab provides a mission map at the entry of the personalized place. Like the third approach described above, all decomposed activities are hierarchically organized in a set of Learning Activity Spaces (LASs) in the mission map. Some arrows connect LASs and the arrows provide hints for students to perform cognitive activities following appropriate learning sequences. More explicit process guidance is provided in the instruction of each cognitive activity. Moreover, SCY-Lab provides flexibility for students to select activities freely and enables them to perform activities according to their preferred learning sequences.

Considering the importance of the metacognitive aspects of inquiry, we think it is necessary to provide more support for students to develop their self-regulation competencies and to provide scaffolding for students to be able to navigate inquiry practices. In this paper, we propose to develop a domain-generic and lightweight process-oriented scaffolding agent (POSA) to support learning processes in a flexible, open-ended inquiry-based learning environment. We argue that it is technically feasible to implement such an agent to engage students in self-regulative activities and to improve their learning efficiency through providing process guidance on time and on demand.

The paper is organized as following. First we characterize inquiry-based learning on the aspects of process structure and metacognitive scaffolding and identify technical requirements for supporting process-oriented metacognition. Based on the theoretical implications, we developed the POSA that consists of four models and an Agenda tool. We present the design of the models and the tool in detail and briefly describe how the POSA is implemented and integrated in a flexible, open-ended inquiry learning environment. Then we present a pilot study to investigate students' acceptance of the POSA and show the results of the study. Finally, we present our conclusive remarks and indicate the future work.

2. Theoretical Implications

Our development work is based on theoretical implications. This section characterizes the inquiry learning process and metacognition and identifies the requirements for supporting process-oriented metacognition in inquiry-based learning processes.

2.1. *Inquiry-based learning*

Inquiry learning emphasizes on constructivist ideas of learning. Knowledge is built in a step-wise fashion. Teachers do not begin with a statement, but with a question. They should provide students with challenges and encourage them to learn through making inquiries. On the one hand, an inquiry learning process, rather than following a routine, is usually dynamic and unpredictable. Because the question/problem faced by the students is usually open-ended and ill-structured, there is no fixed target or prescribed result, which students have to achieve. On the other hand, students should learn and use the scientific inquiry skills when they do inquiry.

There are various models for inquiry learning introduced in educational literature (e.g. Irving, 1985 and Hakkarainen, 2003). Researchers have highlighted the similarities between the learning processes that characterize inquiry learning in scientific disciplines and the activities and cognitive processes leading to scientific discovery. De Jong (2005) pointed out that, “In scientific discovery learning learners more or less take the role of scientists who want to design theory based on empirical observations”. He and his colleagues developed a well-known inquiry learning model in scientific disciplines based on models of scientific discovery. This model consists of five learning processes (de Jong, 2006). The first is orientation, in which the student coarsely analyzes the problem to be solved. The next two processes are hypothesis generation and experimentation. Experimentation process can be further decomposed into sub-processes: design, prediction and data interpretation. This process will be followed by the process of conclusion, in which the student decides on the validity of the hypothesis tested by means of experimentation. Finally, the student engages in a reflection on the learning process and the domain knowledge acquired in evaluation process. De Jong (2006) emphasized that the inquiry learning processes may occur in an iterative fashion. As an inquiry is an open-ended process, one process may be initiated before the previous one has been completed. He also pointed out that metacognitive processes (including monitoring and planning) complement the inquiry cycle.

Another important characteristic of inquiry learning is the students’ rich interaction with learning objects. Students not only receive learning materials, but also produce artifacts (e.g. problem definitions, hypotheses, and inferences), which emerge in learning processes (De Jong et al., 2010). The artifacts evolve in the learning process and their states reflect on the work processes. An artifact may depend on other artifacts directly or indirectly. For example, a hypothesis is associated with a given research question, and a design of an experiment is for testing a hypothesis. The change of an artifact (e.g. research questions) may cause the need to modify its effecting artifacts (e.g. hypotheses and inferences). Learning and producing artifacts in appropriate sequences may improve the effectiveness and efficiency of the learning.

In summary, inquiry-based learning is usually a flexible and open-ended process that is similar to the scientific inquiry process. It is implied that scaffolding mechanisms should not enforce the students to strictly follow a pre-defined learning path in such artifact-rich and ill-structured processes, but should help them to manage science inquiry processes in a more disciplinary way.

2.2. *Metacognition*

Metacognition refers to higher order thinking, which involves active control over the cognitive processes engaged in learning. Activities such as planning how to approach a given learning task, monitoring comprehension, and evaluating progress toward the completion of a task are metacognitive in nature. Flavell (1976) defined metacognition as “one’s knowledge concerning one’s own cognitive processes and products or anything related to them”. Informally speaking, metacognition can be referred to “thinking about thinking". Metacognitive skills are therefore domain independent abilities that are an important aspect of knowing how to learn in general. According to the influential model developed by Nelson and Narens (1990, 1994), metacognition is defined as the monitoring and control of cognitive processes. By this view, metacognition is essential for the supervision of our perceptions, thoughts, memories, and actions. They described metacognition as a cyclical, iterative process between the cognitive processes that take place at the object-level (information processing operations) and the processes at the meta-level (overseeing operations). The role of the meta-level is to evaluate object-level activations and to initiate feedback control based on this evaluation.

Flavell (2000) divided metacognitive theory into two areas of study: metacognitive knowledge and executive processes. Metacognitive knowledge consists primarily of knowledge or beliefs about what factors or variables act and interact to affect the course and outcome of cognitive enterprises. These factors or variables fall into three major categories: person, task, and strategy. The person category encompasses general knowledge about how human beings learn and process information, as well as individual knowledge of one's own learning processes. Knowledge of task variables includes knowledge about the nature of the task and the type of processing demands. Strategy variables are about what strategies are likely to be effective in achieving what goals in what sorts of cognitive undertakings. The executive processes refer to sequential processes that one uses to control cognitive activities, and to ensure that a cognitive goal has been met. These processes help to oversee and regulate learning, and consist of monitoring and planning cognitive activities, as well as checking the outcomes of those activities. Zimmerman (2000) characterized the metacognitive processes in terms of planning, setting goals, organizing, self-monitoring, self-evaluating and self-reflection during the learning process. According to Hacker (1998), monitoring processes involve one's decisions that help: (a) to identify the task on which one is currently working, (b) to check on current progress of that work, (c) to evaluate that progress, and (d) to predict what the outcome of that progress will be. In addition, regulation processes involve one's decisions that help: (a) to allocate one's resources (e.g. time) to the current task, (b) to determine the work sequence to complete the tasks, and (c) to set the intensity or (d) the speed at which one should carry out the tasks.

In summary, metacognition consists of both metacognitive knowledge and metacognitive experiences or regulation. It is implied that scaffolding mechanisms should help students to manage metacognitive knowledge about persons, tasks and strategies and to engage them in self-regulative activities.

2.3. *Metacognitive scaffolding*

Metacognitive scaffolding supports the underlying processes associated with individual learning management, providing guidance in how to think during the learning activities. It might remind the students to reflect on the goal(s) or prompt them to relate the use of a given resource or tool to the completion of the currently worked task at hand (Hannafin et al., 1999). Researchers such as Choi, Land, and Turgeon (2005) and Manlove et al. (2006)

suggested that the learning environment should foster students to perform metacognitive tasks, such as directing students to explicitly plan their activities and justify their choices for action, or arrange the opportunities to reflect on the quality of their planning and how well they executed their plan. Related methods and mechanisms of metacognitive scaffolding are summarized by Hannafin et al. (1999) as: a) suggesting students to plan ahead, to evaluate the progress, and to determine needs; b) modeling cognitive strategies and self-regulatory processes; and c) proposing self-regulating milestones and related monitoring. Students should actively engage in problem orientation, goal setting and strategic planning. Monitoring can occur at any moment during task execution, depending partly on the students' actions and the results (Salovaara & Jarvela, 2003). As the nature of these cues is difficult to be anticipated, monitoring can be supported by generic prompts (Wichmann, & Leutner, 2009) that encourage students to mentally check and adjust performance. Evaluation of learning processes involves any reflection on the quality of their planning, how well they executed their plan, and how well they collaborated (Manlove et al., 2006). Ertmer and Newby (1996) argued that reflection is an important component of metacognition and therefore is essential for the development of skilled students. They articulated that by employing reflective thinking tools to assess one's learning labor, one can increase awareness of effective learning strategies. They also suggested that awareness leads to deliberate choice of strategies, control and monitor strategies to achieve learning objectives.

Schoenfeld's (1985) study showed that students, who are required to periodically stop during problem-solving and ask themselves metacognitive or reflective questions, are more likely to focus on the inquiry learning process and have better performance in problem-solving. Question prompts provide a means of externalizing mental activities that are usually covert (Scardamalia & Bereiter, 1985). Prompts designed for procedural guidance provide students with specific procedure hints or suggestions that facilitate the completion of the learning. They also would offer guided stimulation of higher-order processes of planning, transcribing, diagnosing, and revising, which novices are not likely to activate on their own (Zellermayer, Salomon, Globerson, & Givon, 1991). Question prompts can be designed to ask reflection questions to foster self-monitoring, self-explaining, and self-evaluation in scientific inquiry processes (Xie & Bradshaw, 2008).

As Quintana et al. (1999) pointed out, novice students lack the knowledge about the activities that constitute inquiry and the procedures for performing these activities, and they lack the knowledge needed to select activities and coordinate the inquiry. Specific support should be provided in the learning environment to foster the advancement of students' self-regulative competencies and meta-skills for regulating inquiry activities (Lakkala et al., 2005). In contrast to novices, skilled students have self-regulation profiles that are characterized by high levels of forethought, self-motivation, self-monitoring, and self-evaluation (Zimmerman, 2002). As students employ the inquiry strategies during a series of inquiry activities, it is likely that the students internalize these strategies from repeated uses, and then metacognitive scaffolding can be faded (Puntambekar &

Hübscher, 2005). Pea (2004) argued that effective fading mechanisms should differ between high and low achieving students. It is implied that scaffolding should be provided appropriately according to the skill levels of the students.

In summary, scaffolding mechanisms should present information and prompts properly to guide inquiry learning process and help students (1) to set goals and strategies by making and maintaining dynamically the work plan, (2) to monitor work progresses by checking the state of activates/artifacts, (3) to evaluate learning processes by organizing the information produced and by composing reflective products at process level. Moreover, as students gain more self-regulative skills, it would be better to provide less guidance, but foster students to do more self-regulative activities.

3. Development of the POSA

In the light of the influential model (Nelson & Narens 1990, 1994) and Flavell's metacognition model presented in section 2.2, we extend SCY-Lab by developing the POSA that helps students to monitor and control inquiry learning processes. Figure 1 illustrates the conceptual architecture of the system. The POSA is designed to capture and analyze students' actions performing cognitive activities within SCY-Lab and then to provide scaffolding and foster self-regulative activities in inquiry learning processes. As illustrated in Figure 1, the POSA consists of four models and an Agenda tool. The four models are designed for helping students to manage relevant knowledge about inquiry processes such as tasks and strategies and to generate process-oriented scaffolding; while the Agenda tool is designed for presenting scaffolding and fostering students to perform self-regulative activities such as monitoring and planning. For novice learners, managing such knowledge and performing self-regulative activities are implicit. It is expected that the use of POSA can make such implicit activities more explicit to learners.

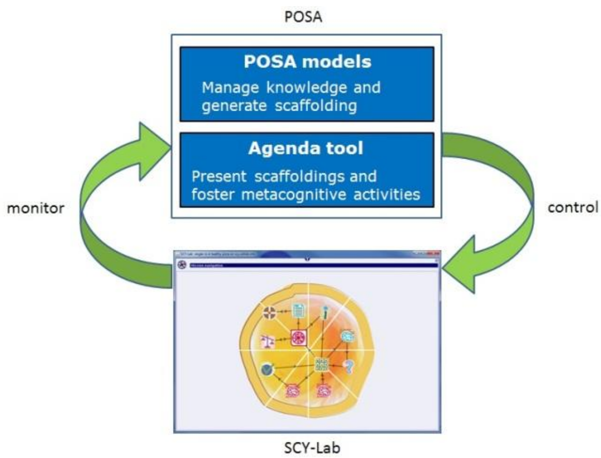

Figure 1. Conceptual architecture of the system.

3.1. *POSA models*

In this sub-section, we present the development of the four models of the POSA. The relevant metacognitive knowledge about learners and inquiry learning activities is captured and managed by using a task model, a strategy model, and a learner model and the process-oriented scaffolding is generated by using a scaffolding model.

3.1.1. *Task model*

As analyzed in section 2.1, an inquiry learning process consists of various tasks and produces rich artifacts. In order to provide process-oriented scaffolding, it is required to develop mechanisms to manage knowledge about tasks and artifacts. The task model is developed to specify knowledge about learning tasks and artifacts according to the mission meta-model. As shown in Figure 2, a SCY mission consists of a set of typed LASs. In SCY there are 13 LASs: *Orientation, Management, Information, Conceptualization, Debate, Reflection, Analysis, Design, Build, Experiment, Evaluation, Regulation,* and *Reporting*. Each LAS (e.g. experiment) contains a set of learning activities (e.g. conducting an experiment and interpreting data) and associated ELOs (e.g. experiment-data and inferences). An ELO will be produced in an activity by using a certain tool such as a simulator, a concept-mapping-tool, or a text editor. It is obvious that some activities (e.g. presenting case) are preceded by other activities (e.g. identifying problem). An ELO (e.g. inferences) may be dependent on another ELO (e.g. experiment-data). A task model in SCY specifies all LASs, activities, ELOs, resources, and their organizational relations according to the mission meta-model. The task model of a mission is pre-defined in the mission specification as an XML file. Note that every activity has attributes for characterizing the task (e.g. type, tool-type, difficulty-level, and expert-estimated execution time) and has four possible work-states: *enable, activated, completed,* and *need-to-check* (see Figure 4). These four activity states correspond to the four states of the associated ELO: *expected, in progress, finished,* and *need_to_check*. An ELO has attributes for characterizing properties such as estimated volume (e.g. the size of a text-based ELO or the total number of nodes/links of a concept-map), samples, and some thresholds.

3.1.2. *Strategy model*

As analyzed in section 2.1, an inquiry learning process is usually open-ended and ill-structured, but students should learn and use appropriate inquiry strategies. A strategy model specifies suggested learning sequences and dependencies between ELOs within a SCY mission. The suggested learning sequences are defined using "is-preceding" relation between activities according to the mission meta-model. The ELO dependencies are defined using "is-dependent-on" relation between ELOs according to the mission meta-model as well. Figure 3 shows an example of both structures in a simplified inquiry process that includes important activities (drawn in round-eck boxes) and associated ELOs (drawn in ellipses). The relation "A1 is preceding A2" (drawn as a dashed arrow)

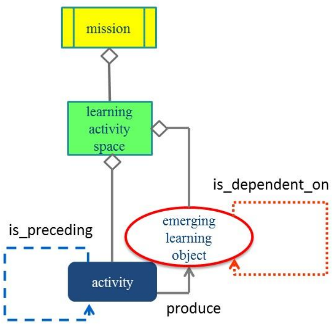

Figure 2. Mission meta-model.

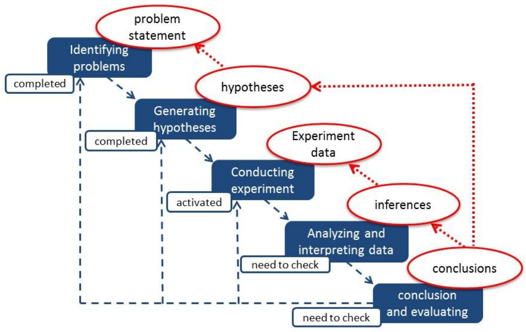

Figure 3. Strategy model and execution information.

means that it would be better to finish A1 before A2. It does not refer to "the completion of A1 will trigger the start of A2", which is widely used in process modeling for automating a work process. Here the arrow indicates a suggested activity sequence for achieving better results or/and for improving learning efficiency in a normal situation. For example, a student would better identify problems before generating hypotheses. However, the student can decide to decline this suggestion or not (e.g. doing both activities in parallel or searching additional problem information in between these two activities). The relation "B1 is dependent on B2" (drawn as a dotted arrow) means that the content of B1 is affected by the content of B2. For example, the conclusions are dependent on the inferences. If the inferences are changed, the conclusions might need to be changed accordingly. As shown in Figure 3, these two structures have similarities but are not identical. The strategy model of a SCY mission represents metacognitive knowledge about how a student would better move through the assignments for increasing effectiveness of learning processes and achieving better results. It will be used to generate procedural guidance and hints. The student is not forced to follow this guidance strictly. For example, a student can make his/her plan of the learning process, and some results can even be achieved without any plan.

The strategy model of a mission is also pre-defined in the mission specification. A segment of strategy model of the "Healthy Pizza Mission" was drawn in Figure 7.

3.1.3. *Learner model*

In order to provide appropriate scaffoldings, as identified in section 2, it is required to manage knowledge about learners and monitor their work progresses. A learner model specifies generic knowledge about students' information (e.g. average students' execution time of an activity and average volume of an ELO) and traces individuals' execution information (e.g. skill level, current activity states, current ELO content and states, personal work plan, scheduled start-/finish-time of activities, actual activity execution time, activity completion time). In SCY-Lab a student can start to work on any activity at any time. It is not necessary to start an activity after the preceding one is completed. All actions that are performed by the student within an activity will be captured together with a time-stamp and the changes to the associated ELO. The student can explicitly declare the completion of an activity (e.g. by clicking the "complete" button) when the student thinks that the associated ELO is finished. This action will generate a "check" or "complete" event (see green transition in Figure 4) to change the activity state into "need_to_check" or "completed" according to the analyses of student's execution information with referenced information (e.g. expert-estimated time and volume, average students' execution time, samples, and thresholds). An appropriate question prompt may be generated accordingly (see the next sub-section). The student can also work on a completed activity to modify a previously finished ELO, because the inquiry learning is open-ended and has a cyclic nature. The student can directly manipulate the associated ELO without the need to explicitly declare a start or modify action. In fact, the events "start" and "modify" are detected through monitoring and analyzing student's actions. For example, when it is detected that the student performs actions in an activity (e.g. interpreting data) and makes some changes to the associated ELO (e.g. inferences) and the volume and execution time have exceeded the thresholds, an event "start" will be triggered. As shown as a yellow transition in Figure 4, this event will change the state of this activity into "activated". If its associated ELO (e.g. inferences) has unfinished dependent ELOs (e.g. experiment data), a procedural hint will be generated to suggest the student to finish the depended ELOs first and then start to perform this activity. In addition, the state change of one activity may result in the state transitions of other activities if they have ELO dependencies. As illustrated as red transition in Figure 4, when the student has made changes to a finished ELO (e.g. experiment data) to some extent (specified by thresholds), s/he will be asked to confirm whether s/he is making a substantive change. If this is confirmed by the student, the event "modify" will be sent to the system. This event not only changes its state to "activated", but also changes the state of those completed activities into "need_to_check", which ELOs (e.g. inferences and conclusions) depend on the ELO of this activity (see Figure 3

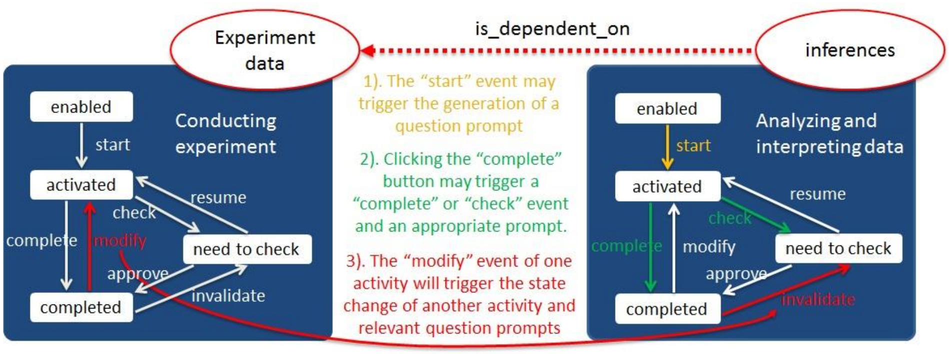

Figure 4. State-transition diagrams of two activities.

and Figure 4). Relevant question prompts will be presented to the student to reflect on work states of those activities (see the next sub-section).

3.1.4. *Scaffolding model*

Following the theoretical implications analyzed in section 2.3, we developed a scaffolding model to generate process-oriented scaffoldings through interacting with the task model, the strategy model and the learner model. This model specifies and applies the rules to handle user's actions, to detect situations, and to generate scaffolding.

The user's actions can be seen as the input of the POSA and can be broadly categorized into process actions, task actions, and regulative actions. Process actions are performed by the student when he or she is entering/leaving a LAS and when he or she is opening/closing/focusing_on/completing an activity. Process actions are captured to trace the student's work process. In particular, the "complete" action will trigger a "complete" event to change the activity state. Task actions are performed by the student while constructing ELOs such as writing a problem statement, representing concepts and relations as a concept-map, or filling a table with a set of data. Examples of task actions are: insert/delete text, add/remove a node/link, or fill/clean a table cell. Task actions will be captured and analyzed to acquire knowledge about the student's work state and can trigger events such as "start" and "modify" that may lead to a change of the state of activities. Regulative actions are performed by the student and make up regulative activities. Examples of regulative actions are scheduling activities or writing a note about student's work on an activity.

Scaffolding will be generated in three situations: (1) when a learner explicitly expresses the need (e.g. by clicking a specially designed button), the scaffolding will be presented to the learner on demand; (2) when a learner completes an activity and needs to think about his/her strategic plan and determine what to do as the next step for approaching the learning goal. Providing scaffolding at this time can help the learner to move out from a cognitive activity into a high level reasoning about a tactical or/and strategic plan to achieve a milestone or/and the overall learning goal; and (3) when a learner is not aware of the need, but s/he is doing something without complying with the artifact-dependent structure. The reason why the student does so is either being unfamiliar with the inquiry process or starting a new cycle of inquiry. As explained in the last sub-section, there are two cases in such a situation: a) when the student starts to work on an artifact without finishing its dependent artifacts, the student will be suggested to work on the dependent artifacts first and then to start this activity; b) when the student has confirmed that s/he is modifying a finished artifact after finishing its effected artifacts, the states of the effected artifacts and their associated activities become "need_to_check". Then the student will be asked to check whether to resume those activities. If s/he confirms by expressing "resume", the state of this activity will become "activated". If the student is not going to change an effected artifact, s/he can choose "approve".

Based on these three situations, we define three levels of scaffolding for the students who have different levels of metacognitive skills and inquiry knowledge. A novice student can choose the high level of scaffolding and then will received scaffolding in all three situations. For an intermediate student the actively provided scaffolds are not necessary anymore. S/he can choose the medium level of scaffolding, in which the third situation is excluded. For an “expert” student the scaffolding on demand is enough. The more skill a student gains, the less s/he may need scaffolding although scaffolding remains available.

The forms of scaffolding presented to the student are prompts, awareness information and functions. For example, when the student explicitly declares the completion of an activity (e.g. analyzing and interpreting data) by clicking the “complete” button as mentioned in the last sub-section, the POSA will evaluate his/her ELO “inferences” in the “experimentation” LAS through analyzing his/her execution time, the volume and the content of his/her ELO. According to the student’s work state and relevant information, a question prompt will be presented such as: “Are you sure that you have worked out ‘inferences’?”, “Would you like to see the ‘inferences’ of your peer students?” or “It seems that your ‘inferences’ are finished. Could you please start to work on conclusions?” As mentioned in the last sub-section, scaffolding prompts provided in other situations could be: “It seems that you are working on the ‘inferences’. However, you may not finish ‘collecting experiment data’. Could you please complete that assignment and then start to perform this activity?” and “It seems that you are modifying ‘experiment data’. If you make a significant change to it, could you please check whether you should make corresponding changes to the finished ‘inferences’?”.

As described above, in our design, novice students will receive more guidance or suggestions in the learning process than more experienced users. As the students internalize strategies and gain regulation skills, the guidance will be reduced. However, the agent will be adapted to the skill level of the student to provide more awareness information (e.g. work state, difficulty-level, individual’s execution time, expert-estimated execution time and volume, and students’ average execution time) and enables the student to monitor the work state and to perform metacognitive activities (e.g. adjust activity sequence, schedule time, attach a short note to an activity, and write evaluation). Thus, the students can compare their personal execution information with reference information, in order to evaluate his or her work process, to consider his/her work strategies, or to re-plan reminder learning activities.

3.2. *Agenda tool*

The Agenda tool provides an interface for the student to receive prompts and awareness information and to perform self-regulative activities. It consists of two parts (see Figure 5). The first part is used to verbally present questions, feedback, explanations, suggestions, and relevant process awareness information. The second part is a list of activities with related information such as the states and completion times. The student can operate on this list. The list can include either all activities or a subset of activities that are related to the currently focused activities. It stimulates the student to reflect on

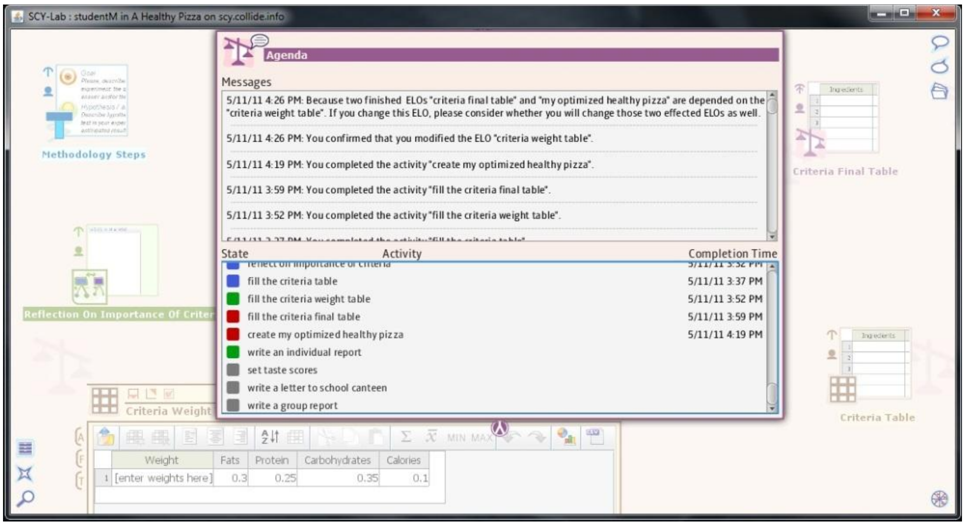

Figure 5. A screenshot of the Agenda tool that is embedded in SCY-Lab.

the overall process or recent work progress. Figure 5 shows a screenshot of the Agenda tool.

In order to meet the requirements identified in section 2.3, the user interface of the Agenda tool will be adapted to the skill level of the student. For novice students, it provides more scaffolding and engages them in less self-regulative activities. As students gain more self-regulative skills, it will provide less guidance, and will enable students to do more self-regulative activities. For example, the functions of the activity list can be added for the student to evaluate work progress by enabling the student to attach a short note to each activity and to write evaluation about the overall process as well. Activities can be listed in a suggested sequence or an actual work sequence. The student can change the suggested learning sequence according to her/his concrete situations. If a change causes conflicts to the specification in the strategy model, the student will be informed. The student can decide to withdraw or insist on the change.

3.3. *Integration of the POSA with the SCY-Lab*

In order to demonstrate the technical feasibility, we implemented the POSA and integrated it with the SCY-Lab. When a student starts a mission, a mission execution (or called a mission runtime) will be instantiated and a mission map will be presented to the student in the SCY-Lab window. The mission map consists of LASs that are connected by the arrows (see the left-bottom window in Figure 6). When the student opens a LAS by clicking the icon of the LAS, the icons of the activities in the LAS can be seen in the window. Although the arrows present implicit learning sequences between the LAS, activity sequences are not explicitly drawn in the mission map. As mentioned before, the learning environment does not enforce the student to strictly follow a pre-defined

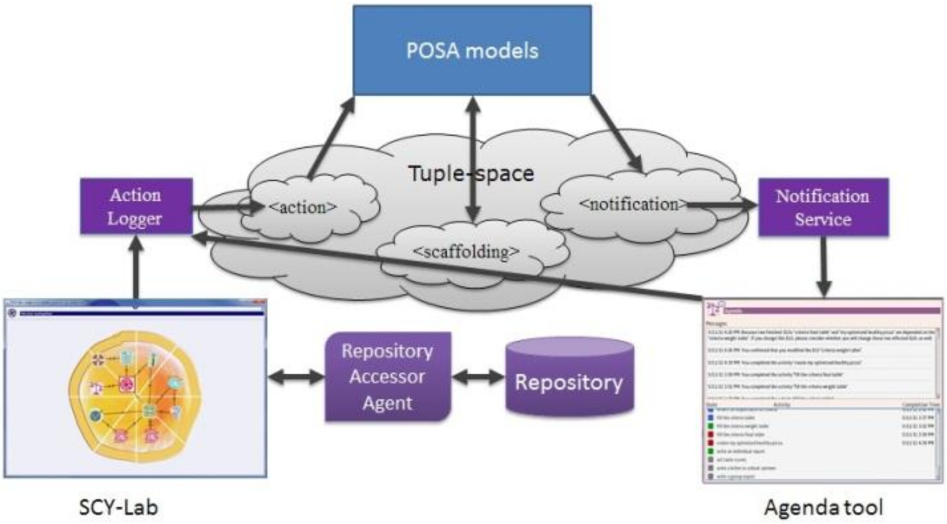

Figure 6. Implementation architecture.

learning path. Instead, students have freedom to perform activities in different learning sequences. As the student chooses an activity by clicking its icon, its associated ELO will be loaded and its associated tool will open. After finishing the activity, he/she can click the "complete" button in the tool. This action may trigger the open of the Agenda tool with a prompt as shown in Figure 5.

Figure 6 shows an overview of the implementation architecture. SCY-Lab stores and retrieves user created learning objects and mission execution information from the Repository of Open Learning Objects (RoOLO). The pedagogical agent framework (Weinbrenner et al., 2010) provides access to the same data for agents through the "RoOLO Accessor Agent". All user actions (e.g. load/save an ELO with a tool, insert/delete text in text-editor, add/remove a node/link in concept-mapper, set a value in a simulator) are logged into the SQLSpaces (Weinbrenner, Giemza, & Hoppe, 2007), an implementation of the TupleSpace. The data about a user action will be stored as a tuple and is accessible for all interested agents. For example, a concept map agent monitors students' progress while using the SCYMapper tool by analyzing users' actions on concept maps. If necessary, scaffolding on developing a concept map will be sent to the client through the notification service. The POSA is also implemented as such a pedagogical agent. It monitors and measures students' overall work progresses by analyzing actions performed by the students from the actions space and provides process guidance if necessary using the command space and the notification service in SCY-Lab (see Figure 6). Like the SCY-Lab and other pedagogical agents, the POSA was implemented in Java and Java FX. Currently, some sophisticated functions of the POSA are not completely implemented.

3.4. *An implementation example*

For a better understanding of the POSA, this sub-section presents an implementation example: “Healthy Pizza Mission” (see SCY Deliverable D VIII.2, 2011). The mission aims at actively engaging students in the right choice of food products through creating a healthy pizza. In this mission, a virtual pizza is an artifact created using a pizza simulation tool to represent a solution to a societal and personally relevant problem. Topics that students encounter in this mission are the nutritional value of food items in general (carbohydrates, fat, proteins, energy, vitamins, etc.), and of various pizza ingredients in particular, the food pyramid and the classification of food products (grains, fruits, vegetables, milk, meat and beans), information on energy (calories) and the human digestive system. ELOs that need to be created on the way to the healthy pizza are, among others, a health passport, a nutrition table, a map of the digestive system, and a food pyramid. In total, the “Healthy Pizza Mission” has 11 LASs, 31 activities, and 31 ELOs.

In SCY-Lab, students perform creative and productive activities to answer the question: “How can we create a healthy pizza?”. Students would create models, design nutrition schemes, experiment with pizzas, create a food pyramid etc. Students could even be given the opportunity to collect data “in the field”, e.g. to go to a supermarket and collect nutrition tables using their smartphones (Giemza, Kuntke, & Hoppe, 2010). These data are then entered into SCY-Lab for further analysis and reflection, and provide the basis for actually creating a healthy pizza (SCY website, 2011). Figure 7 depicts a segment of the learning process that specifies some activity sequences and artifact dependencies. As illustrated in Figure 7, after creating the first pizza “my favorite pizza”, the students are introduced to the concept of nutrients and compare their own diet with the daily nutritional needs of the human body. Further on, they learn about the digestive system and its function, and look at the consequences of an unhealthy diet (note that these activities are not drawn in Figure 7). Then they return to the pizza simulation tool and create a second pizza “my first healthy pizza”. All ingredients of both pizzas combined

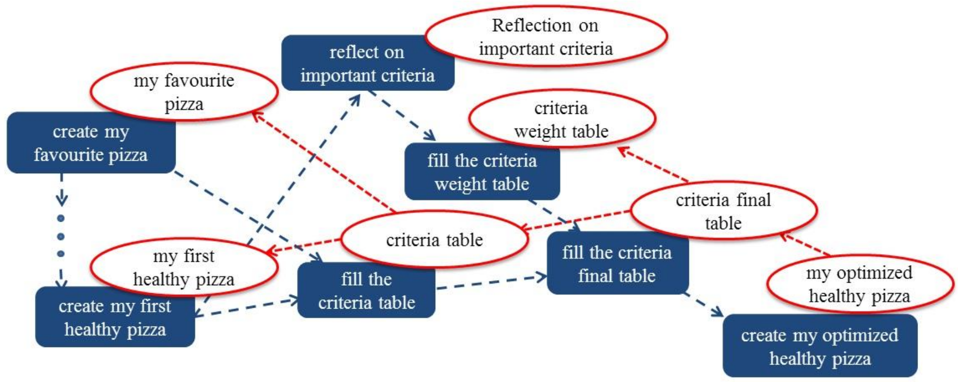

Figure 7. A segment of strategy model in “Healthy Pizza Mission”.

serve as items in the “criteria table”. After assigning weights to each of the criteria in “criteria weight table”, there will be a table with final scores “criteria final table”, so that students may select the healthiest pizza ingredients for their last pizza “my optimized healthy pizza”. Finally, they compare their pizzas with those of their peers and write reports (SCY Deliverable D VIII.2, 2011).

4. A Pilot Study

In order to investigate students’ acceptance of the POSA, we conducted a pilot study using the “Healthy Pizza Mission”.

4.1. *Theoretical framework and questionnaire*

The conceptual foundation of the student acceptance aspect of the present study was based on the Technology Acceptance Model (TAM), proposed by Fred Davis (1986, 1989) as a means of predicting technology usage. TAM postulates that two particular user beliefs, “usefulness” and “ease of use”, are predictors of user attitude toward using the technology, subsequent behavioral intentions, and actual usage (Davis, 1993). Perceived usefulness is defined as “the degree to which a person believes that using a particular system would enhance his or her job performance” while perceived ease-of-use is defined as “the degree to which a person believes that using a particular system would be free of effort” (Davis, 1989, 1993).

There are several studies done using TAM to test users’ acceptance in E-learning (e.g. Roca, Chiu, & Martı´nez, 2006; Landry, Griffith, & Hartman, 2006; Liu, Chen, Sun, Wible, & Kuo, 2010). In line with these researches, we adapted the TAM questionnaire, modified the wordings of the standard questions of TAM and then translated from English to German accordingly. To measure the concepts of usefulness and ease of use, no objective measures are available. Hence, we subscribe to subjective measures for which we apply a Likert scale. Subjects have to select one of seven responses. A score is assigned to each response and the scores belonging to a particular concept are combined so that subjects with the most favorable attitude will have the highest concept score, while subjects with the least favorable attitude will have the lowest concept score. Table 1 presents the scale items that were considered for the usefulness and ease of use concept. Note that we designed several reversed items, where the subject will be asked the opposite of a question.

4.2. *Procedure*

The study employed a cross-sectional descriptive survey with the questionnaire described above for data collection. The participants of the experiment were students of the Department of Computer Science and Applied Cognitive Science at the University of Duisburg-Essen, Germany. 13 students (N=13) participated in the experiment and the participation was voluntary. They were not familiar with and even had no knowledge about SCY-Lab and POSA before the experiment.

The experiment was conducted through using the Pizza mission described in the last section. The Pizza mission was originally designed for adolescent students and it will take about 18 hours to complete the whole mission (SCY Deliverable D VIII.2, 2011). Because the participants in our study could only spend two hours for this experiment, we had to re-design the “Healthy Pizza Mission” by reducing the assignments from 31 to 10. The participants started the mission in a role-play, acting as a student that already completely or partially did most assignments and continued his/her work. The result was a simplified version of the Pizza mission including 3 LASs and 9 ELOs. The participants were asked to work on as many assignments as possible, but they were not required to complete even the simplified version of pizza mission in the experiment. Thus, it is difficult to evaluate the learning outcomes in this pilot study.

The study lasted two hours and was comprised of four phases. In the initial phase (a half hour), the participants were introduced to the SCY project, SCY-Lab, the POSA and the “Healthy Pizza Mission”. In the main phase, the participants were asked to perform the learning activities. They produced or revised assigned ELOs. After an ELO was completed, he or she could open the Agenda tool to monitor his/her work state and get guidance to precede the work. The main phase ended in one and a half hour while most participants had not completed the assigned learning activities. Then participants were asked to fill out the questionnaire and all responses were valid. Finally, we had a discussion with feedback from the students.

4.3. *Results and discussion*

This sub-section presents the results from data analysis and discusses relevant issues. First, according to participants’ feedback in the discussion, it seems that they overall liked the idea of the POSA. They suggested opening the Agenda tool instead of the pop-up message and highlight the latest message. Furthermore, they confirmed that it was quite tough to learn a new environment (SCY-Lab), perform the activities and judge about the POSA. Second, the raw data collected from participants’ responses to the questionnaire were analyzed using the Statistical Package for the Social Sciences (SPSS). Before doing statistical work, the responses for the “reversed” items had to be reversed and their scores had to be changed accordingly. Then descriptive statistics such as means and standard deviations were used to analyze the data collected.

As shown in Table 1, most means of the item scores concerning the usefulness of the POSA are around 5, it seems that the subjects weakly agree that the POSA is useful. We investigated the reasons why the result was not as high as expected. In this pilot study, participants used SCY-Lab and the POSA for the first time. They were treated as novice students. According to the rules of adaption, POSA supported their learning processes through presenting the current work state and suggesting a learning path and provided less or even no support for their cognitive activities, so that it should save students’ time to find an appropriate learning path. As a logical consequence, the overall learning efficiency should be improved. However, we cannot expect that the effectiveness to perform cognitive activities in this pilot study can be enhanced. In the TAM-based questionnaire, the items for perceived usefulness can be categorized into three main clusters. The first cluster relates to effectiveness, the second to efficiency, and the third to the importance (Davis, 1989). In our questionnaire, U4 and U7 are questions about the facet of effectiveness, so it is normal if the responses to these questions are just a little higher than neutral. U1, U3, U5, and U6 are questions concerning "efficiency". However, except for U5, the scores of these items are a little lower than 5.0. If we look at the efficiency-related questions carefully, we can see that the question U3 is about whether the POSA can improve the efficiency of cognitive activities. Participants' responses are reasonable because the POSA in this study did not directly support cognitive activities. U1 and U6 are very similar and their means of scores are very close as well. One reason for such responses might be subjected to the simplified version of the pizza mission. The second reason might be too many new things at one time. As mentioned before, in order to make it possible to conduct the pilot study in two hours, the pizza mission was simplified and the number of assignments was greatly reduced (from 31 to 9). The

Table 1. Means and standard deviation of scale items of the usefulness and the ease of use concept.

Perceived Usefulness (U) and Perceived Ease of Use (E)	Mean	Std. Deviation
U1: It would be difficult to choose an appropriate next activity without the Agenda.	4.23	1.423
U2: Using the Agenda gives me greater control over my learning process.	4.85	0.987
U3: The Agenda enables me to accomplish the tasks more quickly.	4.38	1.710
U4: Using the Agenda improves my performance in solving tasks.	4.46	0.967
U5: The Agenda helps me to monitor and evaluate my learning process.	5.15	1.405
U6: Using the Agenda makes it easier to conduct the flexible, open-ended learning process.	4.31	1.316
U7: Using the Agenda enhances my learning effectiveness in a flexible, open-ended learning process.	4.77	0.725
U8: Overall, I find the Agenda useful in a flexible, open-ended learning environment.	5.38	0.870
E1: I don't find it intuitive to use the Agenda.	4.54	1.266
E2: It is easy to learn to use it.	5.15	1.345
E3: My interaction with the Agenda is easy for me to understand.	5.15	1.519
E4: I find it takes a lot of efforts to become skillful at using the Agenda.	5.00	1.683
E5: The Agenda is rigid and inflexible to interact with.	4.00	1.155
E6: It is easy for me to remember how to use the Agenda during the learning process.	4.77	1.641
E7: Interacting with the Agenda requires a lot of my mental effort.	5.00	1.080
E8: Overall, I find the Agenda easy to use.	5.38	1.325

complexity of the whole mission was reduced accordingly. As a consequence, the possibility for participants to find an appropriate learning path without guidance increases and then the necessity and importance to get process guidance decreases. Nevertheless, the scores of U5 and U8 are in between weakly agree and generally agree. U5 was designed to measure an important facet of the usefulness of the POSA and the mean of scores is 5.18 (better than weakly agree). When asked directly about the usefulness of the POSA, the responses of our subjects seem overall a cautiously positive result. In addition, the value of Cronbach's alpha for the usefulness scale is 0.63. The reason for this result might be subjected to the questions about effectiveness and importance as well. The participants have inconsistent opinions. Thus, the reliability level of the usefulness is not high, but it is still in the acceptable range.

As shown in Table 1, most means of the item scores concerning the ease of use of the POSA equal and larger than 5.0. in particular, the means of E8 is 5.38. While two subjects extremely disagreed, most subjects responded positively. Based on this finding, we can conclude that most subjects consider the POSA easy to use. A closer look at the different scale items reveals that: learning to use the POSA is easy for our subjects and their interaction with the POSA is easy to understand. Furthermore, participants don't think it requires a lot of effort to interact with the tool and to become skillful at using the tool. We also found that participants very cautiously agree it intuitive to use and it easy to remember. The only one mean of scores of item E5 is neutral. This result reveals that the subjects think the POSA is neither flexible nor rigid to interact with. In addition, the value of Cronbach's alpha for the ease of use scale is 0.89. According to Nunnally (1978), this result demonstrates that the questionnaire concerning ease of use is a quite reliable.

5. Conclusions and Future Work

An inquiry-based learning environment should help students to learn about not only the underlying content being supported by those of the particular domain (e.g.. healthy food and ecosystems), but also the inquiry practices themselves (e.g. how to do a science investigation and what is involved in science investigations). Based on the theories of inquiry-based learning and metacognition, we have identified requirements for supporting metacognition in semi-structured inquiry-based learning. To meet these requirements we designed a specific pedagogical agent POSA. It consists of four models and an Agenda tool. The four models are: 1) a task model that represents the knowledge about organizational structure of the tasks in a SCY mission and task-relevant information; 2) a strategy model that represents the knowledge about suggested learning sequences and artifact dependencies; 3) a learner model that represents the knowledge about work state, learning trace, and learning plan of the student; and 4) a scaffolding model that specifies the rules to judge situations and provide scaffolding. The Agenda tool provides an interface for the student to receive prompts and awareness information and to perform self-regulative activities.

Other examples of pedagogical agents to support metacognition have been reported in literature such as EA-Coach (Conati, Muldner, & Carenini, 2007) and MetaTutor

(Azevedo et al., 2009). These systems emphasized the sophisticated domain-specific expert models and specific pedagogical models. Thus, these systems are not only difficult to realize with high investment in time, cost, and human effort, but also difficult to be applied in science education of other knowledge domains. Hartman (2001) categorized metacognitive scaffolding in two types: domain-specific and domain-generic. When the problem context is known, scaffolding can emphasize specific ways to think about the problem. In contrast, generic scaffolding focuses on the processes of creating models. Scaffolding is usually implemented through embedding the scaffolding mechanisms in the basic functionalities of computer-mediated learning environments and by tightly coupling it with domain-knowledge (Lakkala et al., 2005; Roll, Aleven, McLaren, & Koedinger, 2007). In the SCY project, the learning environment (SCY-Lab) was designed to support science education in various knowledge domains. Examples of implemented missions are: “Create a healthy pizza”, “Design a house that is CO2-neutral”, and “Make a feeding program for cows, in order to make them produce healthier milk”. In order to provide scaffolding easily for learning various topics, we aim at developing a lightweight and domain-generic POSA with focus on reasoning out task structure/selection/scheduling. The agent is designed as generic mechanisms to manage process-oriented metacognitive knowledge and to extract task knowledge and strategy knowledge from the mission specification. We argue that such a domain-generic and lightweight agent is technically feasible to implement and is useful to improve learning efficiency through providing process guidance on time and on demand.

In this paper, we present the development of a prototype that demonstrated the technical feasibility to provide process guidance on time or on demands in a flexible, open-ended inquiry-based learning environment. As described in the paper, our POSA is not tightly-coupled with the basic functionalities of the inquiry learning environment and is domain-generic to support science education in different fields. It provides rich information, timely question prompts, and relevant functions to stimulate and facilitate the student to reflect on metacognitive activities, deliberate work strategies, and schedule work sequence for achieving learning objectives. It can be adapted to the skill level of the student.

Scaffolding can be differentiated by mechanisms and functions. Mechanisms emphasize the methods through which scaffolding is provided, while functions emphasize the purposes served (Hannafin et al., 1999). In order to evaluate and demonstrate the functions of the POSA, we conducted a pilot study. So far this study has been restricted to investigating the usefulness and ease of use of the prototype regarding the basic functions. In this paper, we present our pilot study with a questionnaire that was based on the Technology Acceptance Model (TAM). Because of time constraints and the nature of the prototype, we created a simplified version of the SCY mission “A Healthy Pizza Mission”. Even so, the students cannot complete the mission in just two hours. Nevertheless, the empirical study showed cautiously positive results. The results reveal that most of the subjects found the POSA generally useful and easy to use for supporting a flexible, open-ended inquiry learning process, although few of them were not fully convinced of the usefulness and ease of use of the POSA.

The future work concerning this research is to implement all sophisticated functions of the POSA. We are aware that a single experiment with a simplified version does not provide conclusive evidence. Hence, it is necessary to evaluate the functions of POSA in real learning settings. Then we will improve the approach according to the feedback from evaluations.

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