Steiner, C. M., Nussbaumer, A., & Albert, D. (2009). Supporting Self-Regulated Personalised Learning through Competence-based Knowledge Space Theory. Policy Futures in Education, 7(6), 645-661.

Preview Version.

Supporting Self-Regulated Personalised Learning through Competence-based Knowledge Space Theory

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Abstract:
This paper presents two current research trends in e-learning that at first sight appear competing. Competence-based Knowledge Space Theory (CbKST) provides a knowledge representation framework which, since its invention by Doignon and Falmagne, has been successfully applied in various e-learning systems (e.g. ALEKS, ELEKTRA) providing automated personalisation to learners' current knowledge and competence level. Principles of self-regulated learning (SRL), pioneered by e.g. Zimmerman, however, argue for increased learner control, thus resulting in giving learners greater responsibility over their e-learning. The research presented in theis paper shows that skill-based visualisations in the tradition of CbKST and SRL-based autonomy are noway conflicting but rather complementing each other towards an integrated approach of self-regulated personalised learning. The respective research has been carried out and technologically translated into a set of visual tools for supporting the whole learning cycle in the scope of the iClass project.

Keywords: Competence-based Knowledge Space Theory, self-regulated learning, personalisation, iClass, visual tools

1. Introduction

Currently, different trends are followed in the field of e-learning emphasising different aspects of technology-enhanced learning experiences, such as adaptivity (Brusilovsky, 1999), learner control (Kay, 2001), metacognition (Kirsh, 2005), concept mapping (Steiner, Albert, & Heller, 2007), gaming (Mitchell & Savill-Smith, 2004), collaboration (Stahl, Koschmann, & Suthers, 2006), mobile learning (Kukulka-Hulme & Trayler, 2005) etc. This paper takes up two concrete approaches, personalised learning in the tradition of Competence-based Knowledge Space Theory (Albert & Lukas, 1999; Doignon & Falmagne, 1999) and self-regulated learning (Zimmerman, 2002). After presenting these two different and at first sight conflicting lines of research and development, it is illustrated how these trends can be harmonised and complement each other towards an e-learning approach of self-regulated personalised learning. Research considerations on the support of self-regulated personalised learning are presented and technical implementation resulting of this research are outlined.

2 Self-regulated learning

2.1 Basics of self-regulated learning

Self-regulated learning (SRL) describes the ways in which individuals regulate their own cognitive processes in educational settings and therefore refers to learning experiences that are directed by the learner (Puustinen & Pulkkinen, 2001). Zimmerman (2002) views SRL as an activity that learners carry out for themselves in a proactive manner. Self-regulation is considered as self-generated thoughts, feelings, and actual behaviour for attaining goals. Self-regulated learners are aware of their own strengths and weaknesses and guide their learning based on personally set goals and task-related strategies. During learning, one's own behaviour is consciously monitored and reflected. SRL can be seen as a cyclical process consisting of three phases, forethought, performance, and self-reflection (see Figure 1).

<<< insert Figure 1 about here >>>

The forethought phase involves activities of goal setting and strategic planning carried out before learning. Furthermore, it involves processes of self-motivation based on self-efficacy beliefs, outcome expectations, intrinsic interest and values. The performance phase refers to the actual process of learning and involves strategies aimed at fostering the quality and quantity of learning performance through self-instruction, self-control, and self-observation. The self-reflection phase involves processes of self-evaluation, causal attribution (i.e. referring to beliefs about cause of error and success), and self-reaction. These processes influence the forethought with respect to subsequent learning efforts. In sum, SRL can be seen as learning that is guided by metacognition, strategic action, and motivation to learn.

Zimmerman argues that SRL fosters self-satisfaction and motivation of learners to continue improving their learning methods. Due to this superior motivation to learn self-regulated learners are assumed to be more likely to succeed academically and view their futures optimistically (Zimmerman, 2002).

2.2 Self-regulated learning in e-learning

The idea of SRL has also been taken up in the context of e-learning, arguing that learners should be enabled to take responsibility over their learning. Consequently, there is a trend to leave the learner more and more control over all aspects of the learning process. Attempts have been made to identify implications for designing computer-based scaffolds for SRL (Azevedo & Hadwin, 2005). Learning systems are being built in order to support self-regulation through providing tools that scaffold different self-regulatory processes (Dabbagh & Kitsantas, 2005; Narciss, Proske, & Koerndle, 2007). For example, collaborative and communication tools such as e-mail, and chat have been identified to be suitable for supporting learners' goal setting and task strategies; concept and mind mapping tools can scaffold learners in organising and self-recording their learning etc. Learners are enabled to explore, design, construct, make sense and use e-learning systems as tools, while at the same time acknowledging also the importance of the learner's social context. Consequently, e-learning environments increasingly tend to provide the learner with a range of learning tools, peers for collaborative learning, different types of on-demand learning, controllability over the system's components and even the possibility to control the extent of control (Kay, 2001). Also the user model is increasingly put into the hands of the learners' responsibility. These 'enriched' e-learning facilities promise the possibility for learning how to learn and improve learning effectiveness. To prove these beneficial effects, however, the conduction of appropriate evaluations is critical. Correspondingly, there have been research attempts to create evaluation approaches and instruments for measuring a learning system's potential to support self-regulated learning (Steffens, 2006).

2.3 Possible drawbacks of self-regulated learning

Although the issue of giving the learner more control and regulation over their learning processes appears attractive and effective, it bears also some drawbacks and risks. If the learner is enabled to self-regulate and control his learning, this might lead to misuse of this enablement. They can (consciously or unconsciously) fill the user model with inaccurate information, lack the needed self-discipline to actually apply themselves to learning, and may manage to reduce teaching and learning effectiveness. If asked to self-assess their own knowledge, learners may under- or over-estimate themselves (Kay, 2001). Most commonly, these problems will arise when the learner has poorly developed self-regulatory competence. Self-directing one's own learning requires the availability of self-regulatory and metacognitive skills, which a learner not necessarily posseses (Baumgartner & Payer, 1994). This is of course also the case with SRL in online or e-learning environments (Artino, 2007). Increased control necessarily will put also additional load on the learner; the multiplicity of choice options provided may overburden him/her – and this may even lead to a distraction from actual learning (Kay, 2001). Furthermore, based on educational hypertext research it may be argued that learners also require a certain amount of domain-specific skills in order to be able and willing to navigate through e-learning material in a flexible and self-regulated manner (e.g. Conklin, 1987; Shapiro & Niederhauser, 2004). It has also been shown that in knowledge domains and learning subjects that are very complex learners have difficulties to effectively regulate their learning without support (Azevedo & Hadwin, 2005). Moreover, it may be the case that the curriculum or school and teacher orientation do not allow a too high degree of self-regulation, but rather require retaining more structured teaching and therefore need to put some constraints w.r.t. self-regulation. At a different level, even learners may not want to have more control, and instead prefer to be guided (Kay, 2001). As a result, most often there will be the need of some scaffold for learners to help them in their self-regulation.

3 Competence-based Knowledge Space Theory

3.1 Basics of Competence-based Knowledge Space Theory

Competence-based Knowledge Space Theory (CbKST) constitutes a psychological, mathematical framework for modelling, structuring, and representing domain and learner knowledge on the level of skills (Albert & Lukas, 1999; Doignon & Falmagne, 1999; Heller, Steiner, Hockemeyer, & Albert, 2006). It builds upon the framework of Knowledge Space Theory (Doignon & Falmagne, 1985, 1999) which is purely behaviouristic and focuses solely on observable behaviour, and enriches this original approach by taking the latent cognitive constructs (i.e. skills) underlying performance into consideration. CbKST is a knowledge representation model that incorporates an activity-oriented understanding of teaching and learning, and thus comes up to a learner-centred perspective of dealing with learning objectives (Marte, Steiner, Heller, & Albert, in press).

The main aim of teaching a certain knowledge or subject domain is that learners acquire skills in the respective field. In curricula educational goals are therefore commonly defined in terms targeted domain-specific skills and competencies that are to be acquired In other words, skills serve for formulating learning objectives in terms of intended learning outcomes and what learners will be able to do as a result of instruction (Anderson et al. 2001). Among certain skills of a knowledge domain naturally dependencies will exist, such that a certain skill (e.g. to apply the Pythagorean Theorem) requires to first acquire certain other skills (e.g. to know about right triangles, to understand the calculation of the area of a square). Such dependencies may arise from logical prerequisites or also from curricula that may prescribe the set of topics to be covered during a school year or/and certain instructional orders (within or across different levels of education) to which the lecture has to stick to.

CbKST utilises these common educational principles and practices to systematically represent and structure knowledge domains. It grounds on the assumption that a knowledge domain (subject domain or subdomain) can be represented by a set of skills that provide a fine-grained description of the capabilities relevant for the respective field of knowledge. Based on this, a learning goal is defined in terms of the set of skills that are to be acquired (i.e. competence goal). The so-called competence state of a learner can consequently be represented by the subset of skills that he or she possesses.

Dependencies among the skills representing a domain are captured by the so-called prerequisite relation. Two skills *A* and *B* are in a prerequisite relation whenever the availability of skill *A* is a prerequisite for acquiring skill *B*. Correspondingly, a competence state will contain also skill *A* whenever it contains *B*. A prerequisite relation among skills can be straightforwardly visualised in form of a graph (a so-called Hasse diagram), where ascending sequences of line segments indicate a prerequisite relationship among two skills – such that moving from a skill indicated on the lower level to a linked superior skill means to follow the recommended instructional sequence. For illustration the Hasse diagram depicted in Figure 2 shows a tiny example of three skills. As can be seen from the figure both skills, 'to know about right triangles' and 'to understand the calculation of the area of a square' are prerequisites for the skill of 'applying the Pythagorean Theorem' – and therefore need to be taught and acquired before the skill on the Pythagorean Theorem can be accomplished. For skills that are not in a prerequisite relation and therefore unrelated in the graphical representation, there is no recommended sequence and the teacher or learning system may either choose the sequence of teaching those skills or leave the decision open to the individual learner.

<<< insert Figure 2 about here >>>

In order to relate the skills representing a domain with actual learning content and behaviour, the skills of a domain are associated with learning objects or activities that teach the respective skills. For example, there might be a learning object that introduces how to calculate the area of a square. Correspondingly the respective skill can be assigned to this learning object. Another, more complex, learning object possibly teaches about what right triangles are and introduces how to apply the Pythagorean Theorem and will therefore be assigned with the respective two skills. Through those skill assignments the relationship between learning activities and skills can be established, which is necessary to ensure that a learner accomplishes learning activities that actually convey the skills to be acquired. Similarly, assessment items (problems or questions) are related to skills, assigning those skills to an assessment item that are required for solving it. The skill assignments to assessment problems allow to evaluate whether the respective skills have actually been acquired. The skill assignments inherit the prerequisites of the skill level and thus impose structures on the level of the learning objects and assessment items. Setting up such skill assignments is a rather straightforward process for teachers, as what they do in their ordinal teaching practice is nothing else but that – selecting and preparing learning material that teaches the targeted learning objective and assembling exams that test them.

In this way, a three-legged knowledge domain representation is established through CbKST, capturing skills of a domain, the learning activities teaching those skills, and the assessment items testing them (Albert, Nussbaumer, Steiner, 2008; Görgün, Türker, Ozan, & Heller, 2005; Heller et al., 2006). Such a representation of a knowledge domain is denoted as 'domain map' and allows to set learning goals and create personalised learning plans in terms of skills, and to assess whether the targeted skills have been acquired during learning, i.e. are part of the learner's current competence state.

3.2 Competence-based Knowledge Space Theory in e-learning

CbKST provides a powerful framework for domain and learner knowledge representation and can be applied for realising intelligent, adaptive e-learning. CbKST has been successfully applied in the Web-based learning environments APeLS (Adaptive Personalised Learning Service; Hockemeyer, Conlan, Wade, & Albert, 2003) and ELEKTRA (Enhanced Learning Experience and Knowledge Transfer; Kickmeier-Rust, Peirce, Conlan, Schwarz, Verpoorten, & Albert, 2007). When implementing CbKST in e-learning, the assignment of skills is reflected in the metadata of the problems and learning objects. The consideration of skills facilitates adding new learning content or assessment problems to the existing material. The original framework of Knowledge Space Theory has been implemented in e-learning, too, for example in the AdAsTra (Adaptive Assessment and Training; Dowling, Hockemeyer, & Ludwig, 1996) system and the RATH (Relational Adaptive Tutoring Hypertext; Hockemeyer, Held, & Albert, 1998) system. The most prominent Web-based educational technology that grounds on Knowledge Space Theory is the commercial ALEKS (Adaptive Learning with Knowledge Spaces; Canfield, 2001) system.

In general, learning systems utilising and implementing Knowledge Space Theory and Competence-based Knowledge Space Theory exploit the prerequisite structures defined for knowledge domains for adaptively assessing what the learner already knows, what he/she is ready to learn next and for presenting learning material in an adaptive, personalised way. This means, adaptive assessment procedures are carried out in order to identify the current knowledge or competence state of a learner. By taking into account previous answers of the learner (i.e. mimicking the examination behaviour of a private teacher) and by exploiting the prerequisite structure on problems and skills (i.e. inferring solving behaviour on other problems), the current knowledge and competence level can be determined by presenting him with a minimum number of assessment items (Doignon & Falmagne, 1999; Dowling & Hockemeyer, 2001). In the ELEKTRA system, which is actually realising game-based learning, even a non-invasive, continuous monitoring of a learner's skills is realised (Kickmeier et al., 2007). Based on the results of adaptive assessment, a learning system then can select and present learning material that corresponds to the current knowledge of the learner as well as the learning goal, and thus, realise steps of learning that constitute meaningful learning paths respecting existing prerequisites (Heller et al., 2006). In sum, CbKST is well suited to personalise learning in the sense of an automated tailoring of the learning system and process to learner's knowledge. Such an automated adaptation to learner's characteristics is argued to improve usability of hypermedia and is claimed to improve also learning performance (Brusilovsky, 1999, 2003), which is of course again a matter that needs to be proved in the individual case through evaluation.

3.3 Possible drawbacks of CbKST

CbKST provides a powerful framework for realising adaptive and personalised learning experiences. There are, however, some general drawbacks related to the issue of adaptive learning. First of all, there is the risk of having the learning process controlled too much by the system, while at the same time lacking learner involvement. The fact, that the learner is automatically presented and 'served' with the learning experiences and decisions are taken by the system on his behalf, he might get the feeling of being forced to do things that he might not want to do. Consequently, the learner might lack the feeling of perceived autonomy and competence, which are necessary conditions for intrinsic motivation (Ryan & Deci, 2000). As a result, adaptive learning experiences are at risk to be accompanied with a lack of learner motivation. This might also be the case in learning environments where CbKST has been implemented. Up until now the structures and algorithms underlying personalisation have been completely kept back from the user. The learner is completely unaware of the personalisation process that is taking place behind the scenes, but is only presented with its result without any explanation or justification. Another possible risk of automated customisation of learning in general, and in the context of CbKST in particular, is that if the models and structures underlying the personalisation process are invalid, the resulting adaptation might actually be inappropriate, which might result in what De Bra (2000) reflected rather accurately with the words 'Bad guidance is worse than no guidance'.

4. Harmonisation of self-regulated learning and Competence-based Knowledge Space Theory towards self-regulated personalised learning

As can be seen from the previous chapters, SRL and CbKST constitute two apparently competing approaches and trends in e-learning, both with their particular benefits and drawbacks. While SRL might run the risk of overloading the learner with control and choice, adaptive learning realised through CbKST might risk to override learners' involvement and will. In the context of the European iClass (Intelligent Distributed Cognitive-based Open Learning System for Schools) project (www.iclass.info), research and development aimed at finding a balance between 'the system decides everything' and 'the learner decides everything', and consequently at empowering learners and teachers. In an attempt to harmonise the approach of SRL with the tradition of adaptation and personalisation, a comprehensive pedagogical model has been defined and accompanying methodologies for school change management and classroom pedagogy have been set up (Aviram, Ronen, Somekh, Winer, & Sarid, 2008). The key pedagogical process of this model is self-regulated personalised learning (SRPL), which aims at realising "personalization embedded in self-regulation and the enhancement … [of] intrinsic motivation" (Aviram et al., 2008, p. 7). SRPL therefore stands for providing learners with the opportunity to self-regulate their learning process and supporting them in this self-personalisation through adaptation technologies. SRPL thus also builds upon the typical cyclic phases of an SRL process, characterised by planning (forethought), learning (performance), and reflection. Consequently, the learner is enabled to consciously experience and direct his own learning cycle, while at the same time being provided with choice and exploration opportunities but also with adaptive scaffolding. The learner therefore experiences sense of autonomy, competence, and acceptance – the psychological needs building the basis for intrinsic motivation. The iClass pedagogical model in general comes up to differing degrees of self-regulation and openness, depending on the given orientation and constraints in each specific context and in light of varying pedagogical approaches. In general, however, the pedagogical model and accompanying methodologies aim in advancing and transforming school education from more traditional, formal learning to more open learning.

With the iClass project, in CbKST new ground has been broken in order to identify ways to support SRPL through this theoretical framework, which was originally devised for realising personalised, adaptive learning in terms of automatically tailoring the learning process by the system to the individual learner, while depriving the learner from information on the underlying principles and structures of this adaptation process. New ways of utilising CbKST have been embarked for enabling the user to scrutinise and assume control over this process. Through uncovering the underlying structures of a knowledge domain and visually presenting them to teachers and learners, the whole cycle of SRPL can be supported, and the personalisation process can be opened up to the user while at the same time providing scaffold based on the CbKST adaptation principles. The research efforts carried out in this context have been technologically translated and implemented in a range of tools, the so-called CbKST Tools, to assist the teaching and learning process (Albert, Nussbaumer, & Steiner, 2008; Nussbaumer, Steiner, & Albert, 2008). These tools have been integrated into the iClass system for supporting varying degrees of user-regulated structured learning.

5. Competence-based Knowledge Space Theory and the self-regulated personalised learning cycle

In iClass CbKST has been utilised in novel ways for supporting the user in the SRPL cycle through skill-based visualisations. Through the use of visualisations of a knowledge domain's skills, their prerequisite structure, and their relationships to learning material visual assistance and feedback can be provided to teacher and learner. In the sequel, the specific ways of scaffolding that can be provided through CbKST and the corresponding tools in the cyclical phases of SRPL are outlined.

5.1 Plan

The iClass pedagogical model and system is designed to increase self-regulation of both, the learner as well as the teacher. Therefore, the teacher is not confined to the knowledge domains and structures predefined and existing in the system, but rather may utilise the system for teaching any knowledge or subject domain he desires. Correspondingly, teachers are enabled to create domain maps for the knowledge domains they want to teach. This can be done by modifying existing domain maps already available in the system or adding and defining new knowledge domains through the use of a visual tool, the so-called Domain Map Editor (see Figure 3). The Domain Map Editor allows to define, modify, and extend the vocabulary of a knowledge domain, which is made up of domain concepts (e.g. right triangle, Pythagorean Theorem etc.) and action verbs (state, apply etc.). The action verbs constitute cognitive activities with respect to and applying the domain concepts. These action verbs are associated with the levels of cognitive processing according to Bloom's revised taxonomy for learning activities and objectives (Anderson et al., 2001). The concepts and action verbs of a knowledge domain constitute the building blocks for defining skills. A skill is defined by a pair consisting of an action verb and one or several concepts (Heller et al., 2006; Marte et al., in press); the skill 'state Pythagorean Theorem', for instance, is made up by the action verb 'state' and the concept 'Pythagorean Theorem'. Once the skills of a knowledge domain have been defined, prerequisite relationships may be established among them (based on logical dependencies, but possibly also mirroring certain instructional sequences preferred by the teacher or prescribed by the school/curriculum).

The action verbs and their association with the levels of the Bloom taxonomy are meant to support this structuring process, as these levels constitute a cumulative hierarchy of cognitive processing. Hence, for two skills involving the same concept(s), but featuring different action verbs prerequisites can easily be assumed based on the respective action verb category (Marte et al., in press). The skill 'state the Pythagorean Theorem', for example, will most probably constitute a prerequisite to the skill 'apply the Pythagorean Theorem' – corresponding to the differing (cognitive processing) levels of involved action verbs. The richness of the prerequisite structure that can be established on the skill level will depend on the particular knowledge domain, as for different knowledge domains a differing degree of structure can be established. In principle, though, a domain map can be created for any domain. The skills can be associated with learning objects and assessment items already available in the system or imported/created by the teacher. During the creation of such a domain map, the teacher is visually supported, as all modifications are immediately translated to the visualisation. The established domain map can subsequently build the basis for skill-based planning.

<<< insert Figure 3 about here >>>

In the actual planning phase, using the so-called Skill-based Planner (see Figure 4), skill-based visualisations help the user to get an overview of the knowledge domain and its inherent skills and make him aware of prerequisites existing among those knowledge elements. Based on the visualisation of the skills and their prerequisite structure, the competence goal may be defined through choosing the skills to be acquired. The targeted skills constitute subgoals of the learning plan. In sequencing those subgoals prerequisites need to be taken into account, such that a meaningful and appropriate sequence results; on that condition the user can choose the order of subgoals in a self-directed manner. Subsequently, learning activities that teach the respective skills can be searched and added to the plan. For a skill most commonly different learning activities will be available, from which the learning activity that actually has to be accomplished can be selected. The learning activities are added to the plan until all skills are covered and thus, the plan is complete. Furthermore, in a skill-based plan there may also be foreseen different types of skill-based assessment.

<<< insert Figure 4 about here >>>

This planning process can on principle be carried out by both, teacher and learner. The level of openness and self-regulation corresponding to the teacher/school orientation and realised in classroom will determine at which step the learner can take a hand in the planning. Following a very traditional and closed-ended teaching approach, the teacher may set up the complete skill-based plan. In a more open learning environment the teacher may for example only define the skills to be acquired, and based on this the learner may decide on the sequence of subgoals and the learning activities for accomplishing the competence goal. An even higher degree of openness can be reached when only indicating the overarching learning goal or subject while leaving the learner the freedom on how to configure the learning process etc.

5.2 Learn

A skill-based plan is used in the subsequent learning phase by successively working through the planned learning activities and in this way acquiring step by step the targeted skills. Realising a skill-based plan is able to well support the learning process. The learning activities are based on learner's choice, such that the learner can feel autonomous and intrinsically motivated. At the same time it is ensured that meaningful sequences of learning activities are done, taking into account prerequisite relationships among the learning material and the underlying skills that correspond to the teacher's or curriculum's specifications, and thus provide a suitable level of challenge. A skill-based plan is not a self-contained entity, rather, such an established plan can further on be complemented and enriched by further, more open and informal subgoals and learning activities.

5.3 Reflect

The reflection phase of the learning process is based upon and nourished from different types of skill-based assessment and their visually presented results.

An adaptive assessment of skills may be carried out using the Adaptive Assessment Tool (see Figure 5). This means that assessment problems are posed to the learner by exploiting prerequisite relationships among problems and skills and taking into account previous answers of the learner. In this way the skills that a learner has available can be determined efficiently by presenting him/her only a minimum number of questions. During this assessment the learner is on demand provided with visual feedback, which constitutes one of the aspects of learner control realised for the skill assessment. This assessment procedure may also be carried out in a more self-reflective way, through requesting the learner to indicate his confidence of being able to solve the respective problems (instead of actually working on them). In this case, the assessment procedure is carried out based on the learner's self-assessment, which requires the learner to meta-reflect on his own competence and well corresponds to an increased level of openness.

<<< insert Figure 5 about here >>>

Furthermore, in the light of the pedagogical model, alternative, even more open forms of skill assessment have been (re)searched, that are independent of the availability of assessment problems and realise a high level of self-evaluation on the knowledge acquired during learning. One way fostering intensive reflection on one's own skills has been implemented with the Self-Evaluation tool (see Figure 6), where the learner reflects on the competence acquired so far and the level of expertise and in this way generates a simplified form of a domain map. Formally, the learner defines acquired skills using concepts and action verbs, however, in contrast to the teacher (who uses the Domain Map Editor) the Self-Evaluation tool provides a guided procedure for this task. The result of this self-evaluation is subsequently compared to the teachers domain map and the skills that the learner assumingly has available are mapped.

<<< insert Figure 6 about here >>>

The result of the adaptive skill assessment is reported to the learner and teacher with the Learner Knowledge Presenter tool (see Figure 7), where it is compared to the learning goal and thus scaffolds the learner in reflecting on the question 'What did I learn?'. The learning activities done so far and the associated skills are visualised in chronological order. Hereby skills actually acquired and verified through assessment are depicted in a different colour than those skills not yet acquired. The latter ones are also indicated separately as skills that still have to be learnt. In this way, the learner is confronted with and can easily identify an eventual competence gap, which needs to be addressed in further learning and thus builds the starting point for the next circle of planning. The Learner Knowledge Presenter also visualises the concepts involved in the skills through a tag cloud. In an alternative view, the skills acquired are illustrated in the prerequisite structure on the skills, which again allows to monitor the learning progress and to immediately recognise discrepancies between current knowledge and the competence goal.

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6. The CbKST Tools from a technological point of view

As already indicated in the previous section different tools have been developed to support the phases of the self-regulated learning process (see Figure 8): The Domain Map Editor (DME) for creating and modifying domain maps, the Skill-based Planner (SBP) for creating skill-based plans, the Self-Evaluation Tool (SET) for realising a self-evaluation process, the Adaptive Assessment Tool (AAT) for conducting adaptive knowledge assessment, and the Learner Knowledge Presenter (LKP) for presenting the learner with what has been learned.

<<< insert Figure 8 about here >>>

Basis for all tools are domain maps which contain information about knowledge domains in a structured way. This structure is grounded on a domain knowledge model in the tradition of CbKST and as depicted in Figure 9. It is an ontological model consisting of five element classes which are activity (learning object), problem (assessment item), skill, concept, and action verb. In contrast to the latter three elements, which are verbally defined, and in contrast to problems, which are described in a simplified IMS QTI format, activities are defined by relations to external content objects in the resource database. Using a controlled vocabulary, specific interrelationship types between these elements are defined. Internally, structural information and populated semantic information are treated by the tools as object-oriented data model. For interoperability purposes domain maps are converted to Web Ontology Language (OWL, 2004) format for their exchange with other iClass system components.

The learner knowledge model contains several elements which are necessary for the personalisation of the learning experience: The competence goal defines what the student should learn in terms of skills, the competence state defines which skills a learner has acquired, the plan defines which activities a learner should perform, and the knowledge state defines which problems a learner can solve. The learner model is based on the domain model and refers to several elements of it (see Figure 9). Both, competence goal and competence state are defined as sets of particular skills of a specific domain map. The plan is defined as a list of activities and the knowledge state is defined as a set of problems which the learner is capable of solving.

Learner and domain knowledge model together form the knowledge representation model. Each of the developed CbKST Tools deals with specific parts and aspects of the knowledge representation model depending on the purpose of the respective learning tool. They consume, visualise, and produce knowledge data and use them for interaction with other system components. The SBP creates competence goal and skill-based plan data and passes them to the iClass front-end where the learner can view the learning content. The AAT consumes the competence goal (for defining the scope of the assessment) and creates knowledge and competence state by assessing the learner's knowledge. The SET also consumes the competence goal (for setting the scope) and creates the competence state. The LKP consumes the skill-based plan and the competence goal and state in order to display them in a comprehensive manner.

<<< insert Figure 9 about here >>>

An open and flexible architecture has grounded the development of the CbKST Tools (see Figure 10). The tools have been implemented as Java applets and loosely integrated into the iClass system. They are launched by the main front-end at specific points of the SRPL cycle. Data exchange (learner information and domain maps) is partly done with the front-end over the DOM structure of the Web page, however, primarily model-based data is stored to and retrieved from the iClass Web services over SOAP. For example, the domain maps are stored on the Content Repository Service (CRS) where other iClass components can access them.

The tools themselves are designed in an open and extensible way by separating models, visualisations and logic of the several learning tools (model-view-controller (MVC) design pattern approach). Domain knowledge and learner information model are implemented as object-oriented data models which can be converted from and to OWL (domain model) and custom XML (learner model) format. The several tools have implemented the respective program (and learning) logic, include specific visualisations and make use of the general infrastructure (such as accessing iClass Web services over SOAP). The visualisation components are responsible for visualising specific parts of the knowledge representation model, for example the prerequisite structure of skills or the relationship between activities and skills. They enable the learner to directly interact with model-based data. Furthermore, they are not dependent from specific tools, but they are included in the tools where it is appropriate. For example, the prerequisite structure visualisation is included in the SBP for supporting the creation of a plan and in the LKP for displaying the competence state on this visualisation of skills.

<<< insert Figure 10 about here >>>

7. Reflections on the use of CbKST in SRPL

The iClass pedagogical model and the learning system based thereupon are designed to enhance and sustain self regulated personalised learning in learners. However, to scaffold the development of self-regulatory skills, ways of supporting self-personalisation are necessary. CbKST provides a framework and visual tools that are suitable for providing this scaffold and for supporting varying degrees of user-regulated structured learning. In the context of the iClass project, therefore innovative and novel ways of supporting growing levels of openness and self-regulation by CbKST have been identified and realised. Consequently, the whole cycle of SRPL can be framed and accompanied by CbKST support, which is realised through using the CbKST Tools providing visual support, guidance, feedback, and reporting (see Figure 8).

Based on the visualisation of a knowledge domain's underlying structure, skill-based self-personalisation can be realised in terms of a skill-based planning process. Using the visualisations provided by the CbKST Tools, learners and teachers get aware of the structure inherent to a knowledge domain and building the basis for the self-personalisation process. In the planning process, the multiplicity of options provided to the learner can be reduced to a meaningful range, such that dependencies are considered and appropriate learning sequences are created. In this way, the cognitive load put on the learner in his self-regulation can be meaningfully reduced, while at the same time leaving the learner the freedom to choose. When furthermore taking into account the result of prior skill assessments this can also contribute to reduce the choice options in the planning process to only meaningful ones, as skills already acquired and corresponding learning material can be factored out.

The skill-based personalisation and planning process allows to realise differing and growing levels of openness. While initially, the planning process will be done to a larger extend by the teacher, the learners can gradually be encouraged to take over more responsibility over their planning, as they increasingly feel and get competent to self-direct their learning to a greater extent, until they are able to take responsibility of their whole planning phase from setting their own goals to the choice of learning activities.

Skill-based planning provides meaningful scaffolding for self-personalising one's own learning process. The learner is guided in shaping his learning to his own needs and abilities. This applies for unexperienced as well as for experienced learners. In general, a skill-based plan does by no means mean a restriction w.r.t. learning and goal setting to purely formal and well defined learning objectives and activities, rather it constitutes a basic learning plan, that can subsequently be enriched and complemented by further, more open and informal subgoals and learning activities – and in this way discloses another aspect of increased openness.

For using and allowing skill-based planning, the teacher is not confined to the knowledge domains predefined and existing in the learning system, but rather is enabled to customise domain maps according to his teaching objectives and to structure the domain according to his expertise, world-view, and even preferences.

Also the decision on the skill-based assessment foreseen is an issue that allows different levels of self-regulation – of course depending on who takes the decision, but also depending on the type of assessment actually chosen. As the assessment types themselves involve and require more or less self-reflection, they can be selected in accordance with the level of openness in the classroom and the learner's self-regulatory skills. An adaptive assessment procedure requiring to work on problems of course corresponds to a much more structured process of learning performance measurement than a self-assessment of skills where the learner reflects on his problem solving ability or skills acquired so far.

8. Conclusion

This paper has presented two current approaches in e-learning, SRL and CbKST, and how they have been harmonised in the context of the iClass project, thus mediating and balancing between full self-regulation and total system control. Grounding on a pedagogical model that emphasises self-regulation, personalization, and motivation, CbKST – originally devised and applied for realising automated customisation of learning processes – has been elaborated towards empowering the teacher and the learner in SRPL. The research considerations have been translated into a set of visual tools for scaffolding planning, learning, and reflection. From the theoretical-scientific point of view the CbKST Tools are well elaborated and can be seen as best practice based on the state of the art of this research area. However, to prove the learning benefits of these tools, as well as their usability for end-users, further research should be dedicated to the evaluation of the implemented tools. This will allow identifying the practical applicability of the tools in classroom as well as aspects for improvement that can feed further development. In particular, also the evaluation of the CbKST Tools' potential to support self-regulation should be addressed by applying appropriate evaluation instruments.

Acknowledgments. The work presented in this paper is partially supported by the European Community (EC) under the Information Society Technologies (IST) program of the 6th FP for RTD-project iClass (contract no. 507922). The authors are solely responsible for the content of this paper. It does not represent the opinion of the EC, and the EC is not responsible for any use that might be made of data appearing therein.

References

Albert, D. & Lukas, J. (Eds) (1999) *Knowledge Spaces: Theories, Empirical Research, Applications*. Mahwah: Lawrence Erlbaum Associates.

Albert, D., Nussbaumer, A., & Steiner, C. (2008) *Using Visual Guidance and Feedback Based on Competence Structures for Personalising E-learning Experience.* Paper accepted for presentation at the International Conference on Computers in Education (ICCE).

Anderson, L.W., Krathwohl, D.R., Airasian, P.W., Cruikshank, K.A., Mayer, R.E., Pintrich, P.R. et al. (Eds) (2001) *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives.* New York: Longman.

Artino, A. R. (2007) Self-regulated learning in online education: A review of the empirical literature, *International Journal of Instructional Technology and Distance Learning, 4*, 3-18.

Aviram, A., Ronen, Y., Somekh, S., Winer, A., & Sarid, A. (2008) Self-Regulated Peronalized Learning (SRPL): Developing iClass's pedagogical model, eLearning Papers, 9. http://www.elearningeuropa.info/files/media/media15974.pdf

Azevedo, R. & Hadwin, A.F. (2005) Scaffolding self-regulated learning and metacognition – Implications for the design of computer-based scaffolds, *Instructional Science, 33,* 367-379.

Baumgartner, P. & Payr, S. (1994) *Lernen mit Software* [Learning with software]. Innsbruck: Österreichischer Studienverlag.

Brusilovsky, P. (1999) Adaptive and Intelligent Technologies for Web-based Education, in C. Rollinger and C. Peylo (Eds) Special Issue on Intelligent Systems and Teleteaching, Künstliche Intelligenz, 4, 19-25.

Brusilovsky, P. (2003) Developing adaptive educational hypermedia systems: From design models to authoring tools, in: T. Murray, S. Blessing and S. Ainsworth (Eds) *Authoring Tools for Advanced Technology Learning Environment.* Dordrecht: Kluwer Academic Publishers, 377-409.

Canfield, W. (2001) ALEKS: A Web-Based Intelligent Tutoring System, *Mathematics and Computer Education, 35*, 152-158.

Conklin, J. (1987) Hypertext: An Introduction and Survey, *IEEE Computer, 20*, 17-41.

Dabbagh, N. & Kitsantas, A. (2004) Supporting Self-Regulation in Student-Centered Web-Based Learning Environments, *International Journal on E-Learning*, 3, 40-47.

De Bra, P. (2000) Pros and cons of adaptive hypermedia in Web-based education, *Journal on CyberPsychology and Behavior, 3*, 71-77.

Doignon, J.-P. & Falmagne, J.-C. (1985) Spaces for the Assessment of Kowledge, *International Journal of Man-Machine Studies, 23*, 175-196.

Doignon, J.P. & Falmagne, J.C. (1999) *Knowledge Spaces*. Berlin: Springer.

Dowling, C. E., & Hockemeyer, C. (2001) Automata for the Assessment of Knowledge. *IEEE Transactions on Knowledge and Data Engineering*, 13, 451–461.

Dowling, C.E., Hockemeyer, C., & Ludwig, A.H. (1996) Adaptive Assessment and Training Using the Neighbourhood of Knowledge States, in C. Frasson, G. Gauthier, & A. Lesgold (Eds) *Intelligent Tutoring Systems* (pp. 578-586). Berlin: Springer.

Görgün, I., Türker, A., Ozan, Y., & Heller, J. (2005) Learner Modeling to Facilitate Personalized E-Learning Experience, in *Proceedings of Cognition and Exploratory Learning in Digital Age (CELDA 2005)* (pp. 231-237).

Heller, J., Steiner, C., Hockemeyer, C., & Albert, D. (2006) Competence-based Knowledge Structures for Personalised Learning, *International Journal on E-Learning, 5,* 75-88.

Hockemeyer, C, Conlan, O., Wade, V. & Albert, D. (2003) Applying Competence Prerequisite Structures for eLearning and Skill Management, *Journal of Universal Computer Science, 9*, 1428-1436.

Hockemeyer, C., Held, T. & Albert, D. (1998) RATH – A Relational Adaptive Tutoring Hypertext WWW–Environment Based on Knowledge Space Theory, in C. Alvegård (Ed) *CALISCE`98: Proceedings of the Fourth International Conference on Computer Aided Learning in Science and Engineering* (pp. 417-423). Göteborg: Chalmers University of Technology.

Kay, J. (2001) Learner control, User Modeling and User-Adapted Interaction, 11, 111-127.

Kickmeier-Rust, M.D., Peirce, N., Conlan, O., Schwarz, D., Verpoorten, D., Albert, D. (2007) Immersive Digital Games: The Interfaces for Next-Generation E-Learning? in C. Stephanidis (Ed) *Universal Access in Human-Computer Interaction. Applications and Services* (pp. 647-656). Lecture Notes in Computer Science, 4556/2007. Berlin: Springer.

Kirsh, D. (2005) Metacognition, Distributed Cognition and Visual Design, in P. Gardenfors & P. Johansson (Eds) *Cognition, Education, and Communication technology* (pp. 147-180). Mahwah: L. Erlbaum Associates.

Kukulska-Hulme, A. & Traxler, J. (2005) *Mobile Learning: A Handbook for Educators and Trainers.* London: Routledge.

Marte, B., Steiner, C.M., Heller, J., & Albert, D. (in press). Activity- and Taxonomy-based Knowledge Representation Framework. *International Journal of Knowledge and Learning.*

Mitchell, A., & Savill-Smith, C. (2004) *The Use of Computer and Video Games for Learning: A Review of the Literature.* London: Learning and Skills Development Agency.

Narciss, S., Proske, A., & Koerndle, H. (2007) Promoting self-regulated learning in web-based learning environments, *Computers in Human Behaviour, 23*, 1127-1144.

Nussbaumer, A., Steiner, C., & Albert, D. (2008) *Visualisation tools for supporting self-regulated learning through exploiting competence structures.* Paper accepted for presentation at the Special Track on Intelligent Assistance for Self-Directed and Organizational Learning at the International Conference on Knowledge Management, 3-5 September, Graz.

OWL (2004) Web Ontology Language (OWL). http://www.w3.org/TR/owl-features/

Puustinen, M. & Pulkkinen, L. (2001) Models of Self-regulated Learning: A Review, *Scandinavian Journal of Edcuational Research, 45*, 269-286.

Ryan, R.M. & Deci E.L. (2000) Self-Determination Theory and the Facilitation of Intrinsic Motivation, Social Development, and Well-Being, *American Psychologist, 55*, 68-78.

Shapiro, A. & Niederhauser D. (2004) Learning from Hypertext: Research issues and findings, in D.H. Jonassen (Ed), Handbook *of Research on Educational Communications and Technology* (pp. 605-620). Mahwah: Lawrence Erlbaum Associates.

Stahl, G., Koschmann, T., & Suthers, D. (2006) *Computer-supported Collaborative Learning: An Historical Perspective*, in R.K. Sawyer (Ed), *Cambridge handbook of the learning sciences* (pp. 409-426). Cambridge: Cambridge University Press.

Steffens, K. (2006) Self-Regulated Learning in Technology-Enhanced Learning Environments: lessons of a European peer review, *European Journal of Education, 41,* 535-379.

Steiner, C., Albert, D., & Heller, J. (2007) *Concept Mapping as a Means to Build E-learning*, in N.A. Buzzetto-More (Ed) *Advanced Principles of Effective E-learning* (pp. 59-111). Santa Rosa: Informing Science Press.

Zimmerman, B.J. (2002). Becoming a self-regulated learner: An overview. *Theory into Practice, 41*, 64-70.

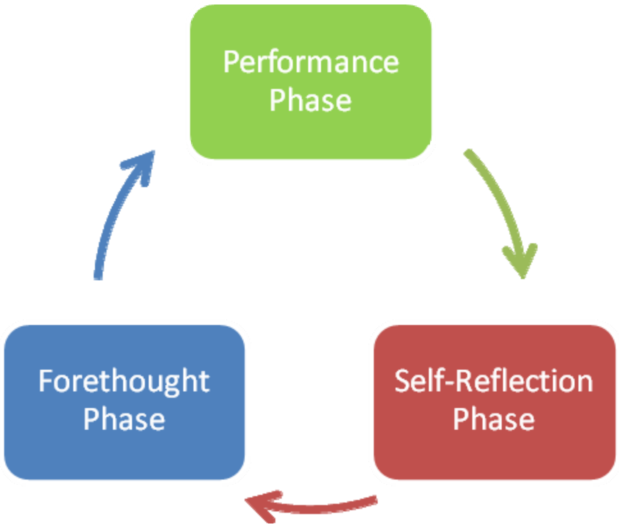

Figure 1: Cyclical model of the self-regulated learning process (adapted from Zimmerman, 2002)

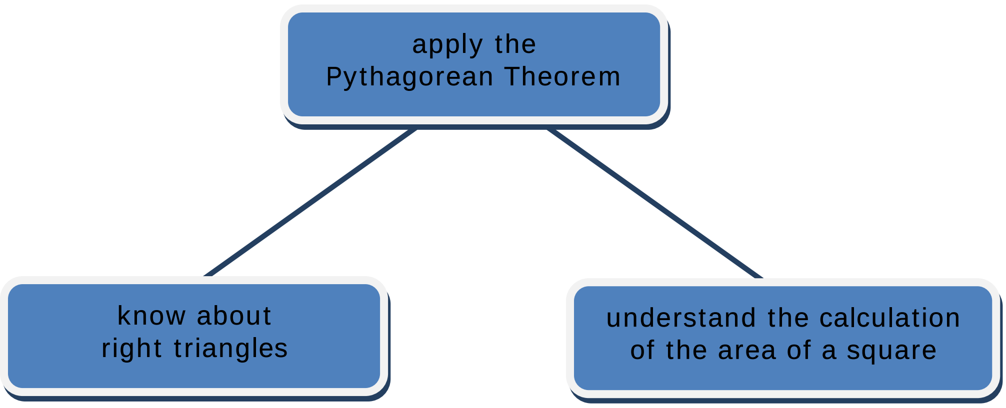

Figure 2: Example of a Hasse diagram visualising the prerequisite relation on a set of three skills on elementary geometry

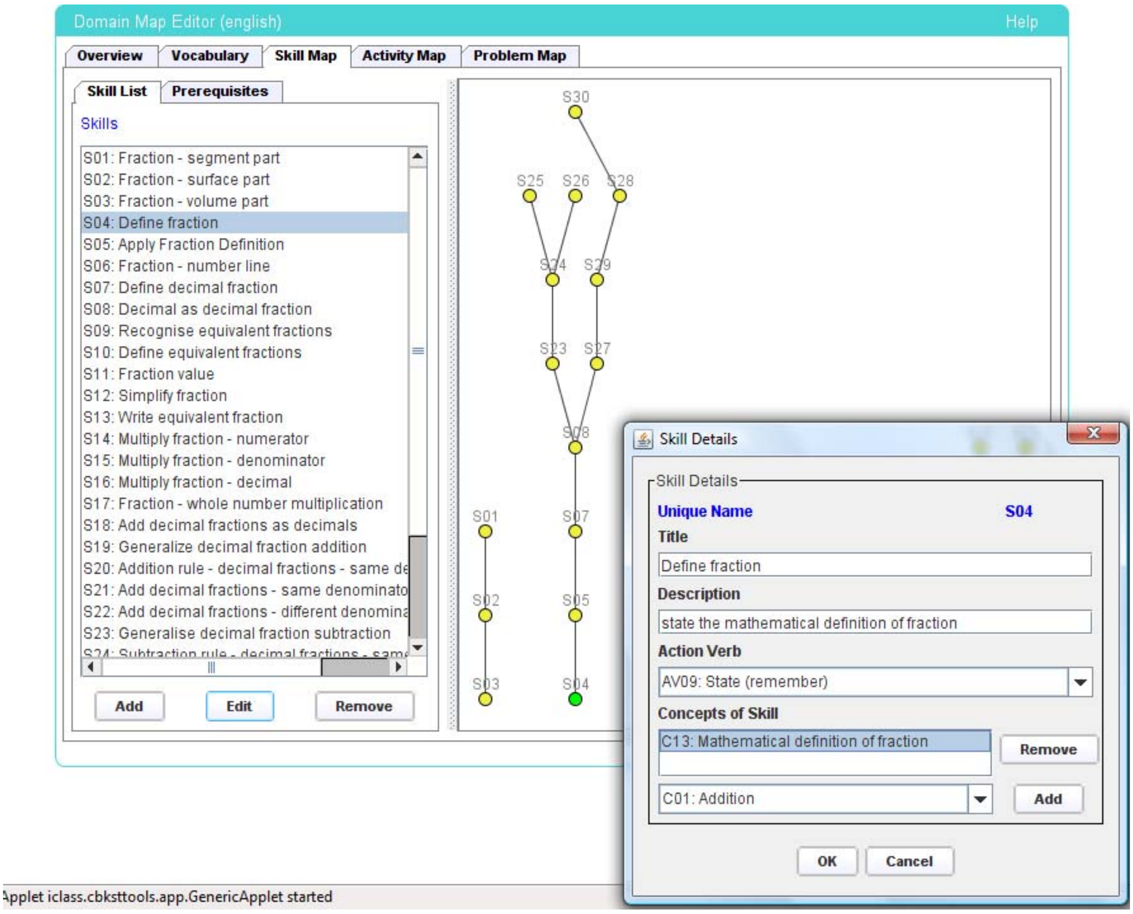

Figure 3: Domain Map Editor

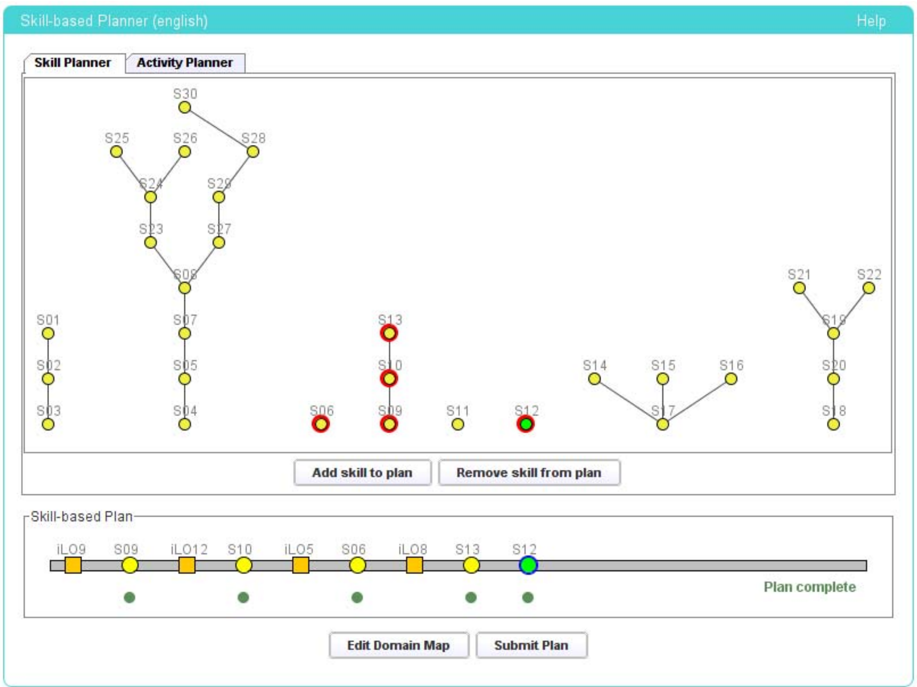

Figure 4: Skill-based Planner

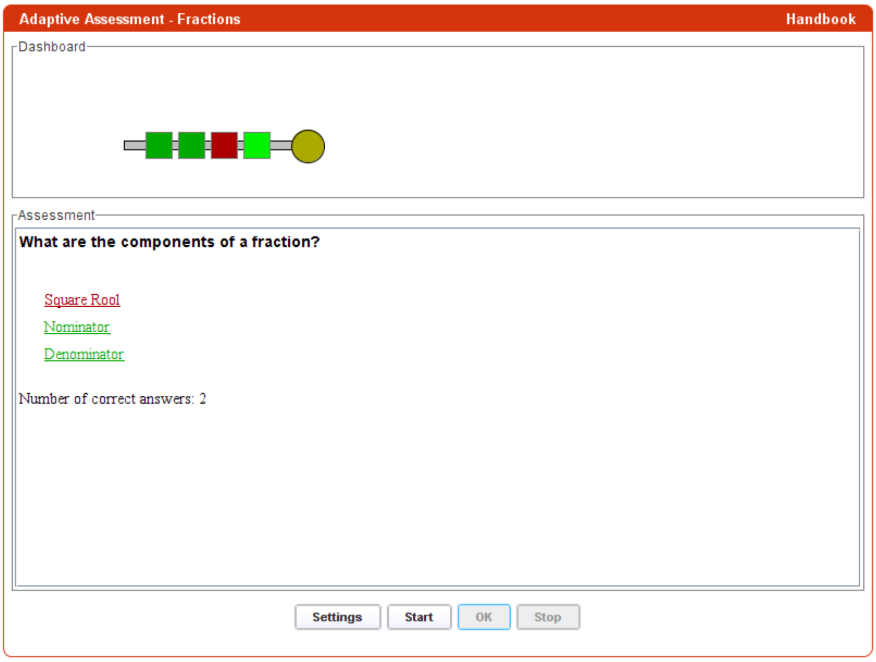

Figure 5: Adaptive Assessment Tool

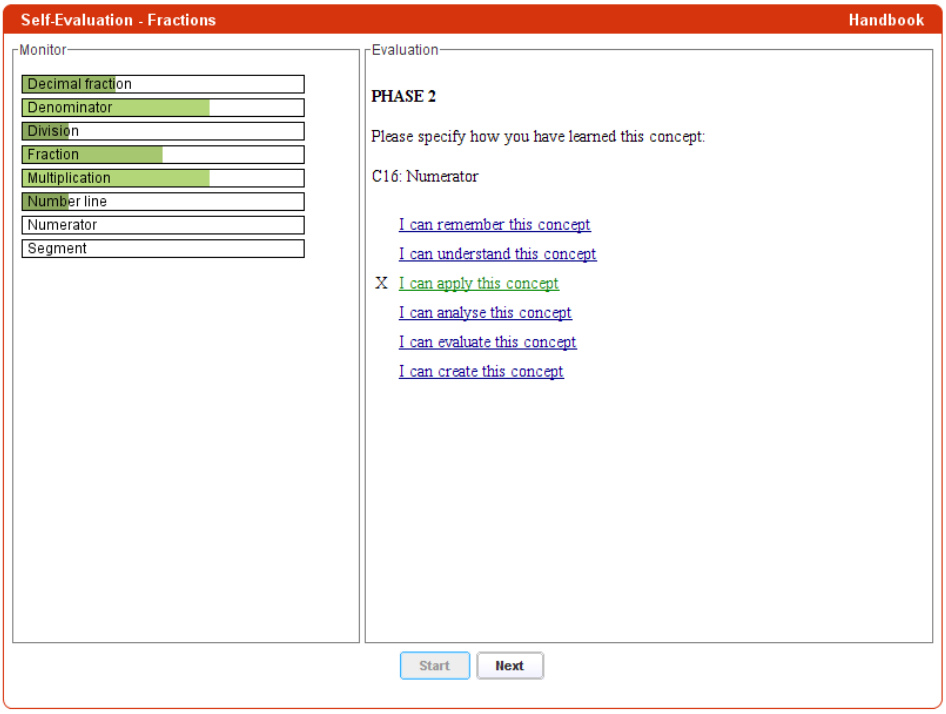

Figure 6: Self-Evaluation Tool

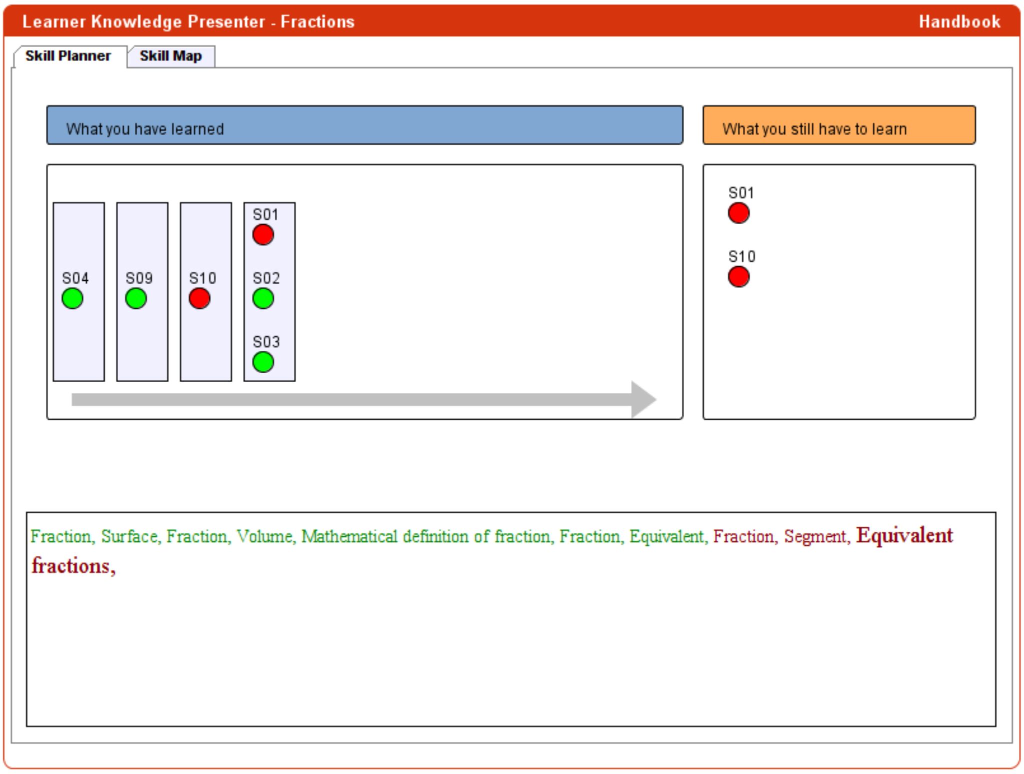

Figure 7: Learner Knowledge Presenter

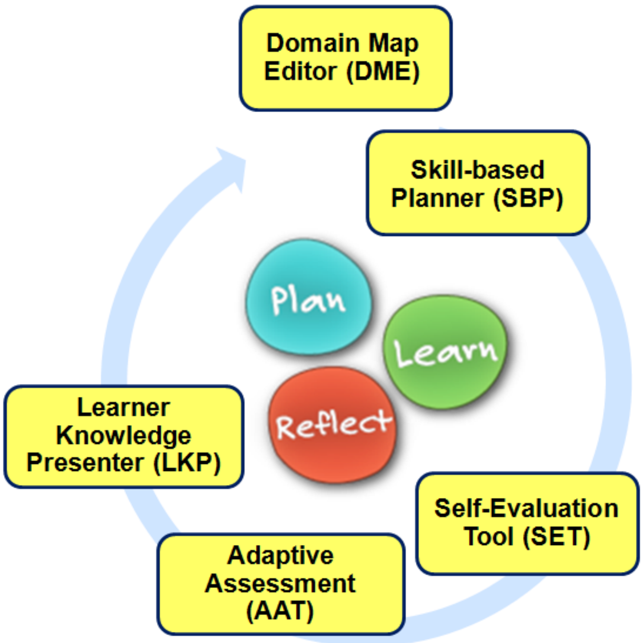

Figure 8: CbKST Tools in the SRPL cycle

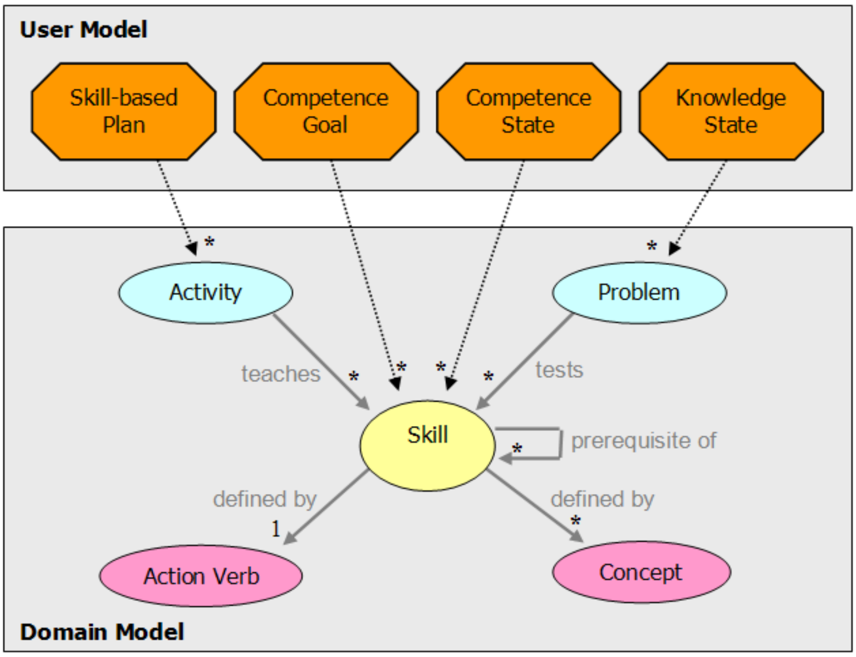

Figure 9: Knowledge Representation Model

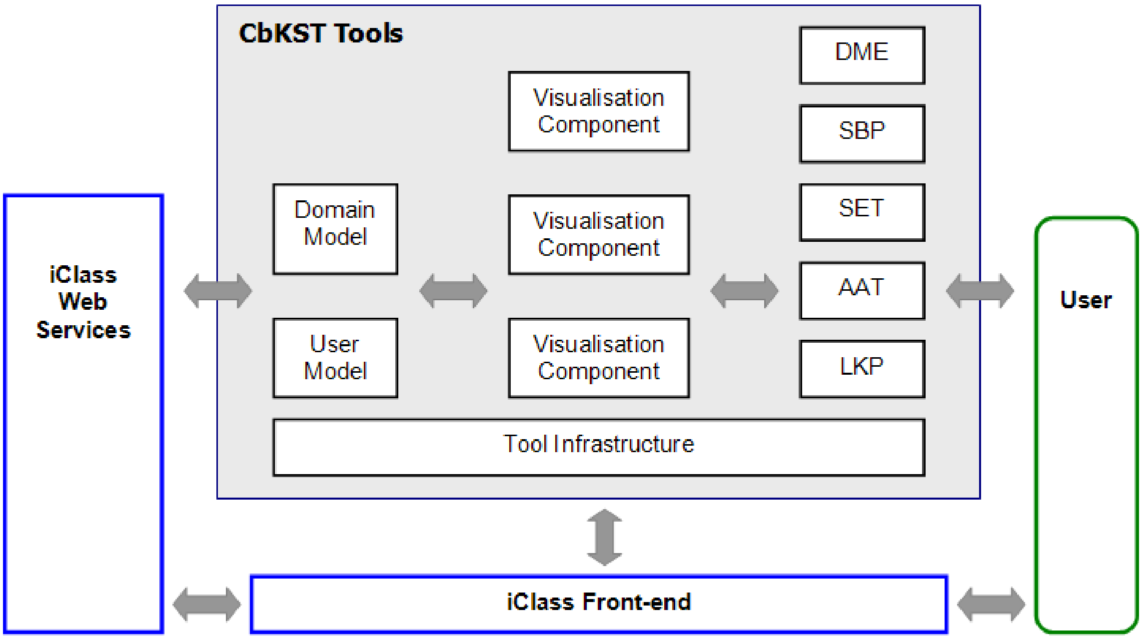

Figure 10: Conceptual architecture of the CbKST Tools