How to support students learning in mathematical bridging-courses using an ITS? Remedial scenarios in the European project Math-Bridge

Rolf Biehler, University of Paderborn, Germany, biehler@math.upb.de
Pascal R. Fischer, University of Kassel, Germany, fischer@mathematik.uni-kassel.de
Reinhard Hochmuth, University of Kassel, Germany, hochmuth@mathematik.uni-kassel.de
Johan Jeuring, Open Universiteit, The Netherlands, johanj@cs.uu.nl
Thomas Wassong, University of Paderborn, Germany, wassong@math.upb.de

Abstract: The goal of the European Math-Bridge project is to combine content for mathematical bridging-courses from several European partners, encode it in a unified format, enrich it with metadata, improve the intelligent tutoring system ActiveMath used by Math-Bridge in order to better support self-guided learning, and evaluate the results in several bridging-courses all over Europe. Math-Bridge will provide high-quality content in different languages enriched by pedagogical metadata (competencies, difficulty level) which is embedded in a knowledge-structure (relations between LOs). It will also implement several pedagogical remedial scenarios for supporting the learner in self-guided learning. These pedagogical remedial scenarios deal with both the automatic generation of books depending on the current competencies of the learner, and the diagnosis of competencies of the learner, with concrete suggestions for further learning. In this paper we present the pedagogical requirements for remedial content collected by the Math-Bridge partners and the pedagogical remedial scenarios that have been developed within Math-Bridge.

Introduction

The goal of the European Math-Bridge project, which runs from 2009 to 2012, is to combine content for mathematical bridging-courses for several subjects from several European partners, and to offer this content to users all over Europe. Math-Bridge will encode content in a unified format, and will offer this content in various languages, such as English, German, Dutch, Finnish, French, Spanish, and Hungarian. The content is enriched by pedagogical metadata (competencies, difficulty level) and is embedded in a knowledge-structure (relations between LOs). The Math-Bridge project uses the intelligent tutoring system ActiveMath to encode and deliver content. ActiveMath will be improved to better support self-guided learning. The results will be evaluated in several bridging-courses all over Europe. Since bridging courses use several different approaches to learning, Math-Bridge will implement various pedagogical remedial scenarios for supporting the learner in self-guided learning. These pedagogical remedial scenarios deal with both the automatic generation of books depending on the current competencies of the learner, and the diagnosis of competencies of the learner, with concrete suggestions for further learning. In this paper we present the pedagogical requirements for remedial content collected by the Math-Bridge partners, and the pedagogical remedial scenarios that have been developed within Math-Bridge.

We start with a discussion of **the goals and scenarios in which the Math-Bridge material is used** to define the different cases of use. Since Math-Bridge uses the intelligent tutoring system ActiveMath, in which several remedial scenarios have already been developed and implemented in context of the LeActiveMath project, we also briefly describe **the potential of the ActiveMath system** and discuss our use of **remedial scenarios**.

The interactive content provided by the Math-Bridge partners requires the introduction of a new structure element, which we call **Complex Learning Object (CLO)**. We give the definition and several examples of the use of CLOs. Afterwards we will describe **new remedial scenarios using CLOs**.

Moreover we will describe the need for a **learning advice component**, which gives advice to students using Math-Bridge on their own. Since Math-Bridge supports self-guided learning, the learning system should offer the possibility to give both general advice about self-guided learning, as well as individual advice to students about which topic to study, the competencies of the student, and his progress in learning. The latter kind of advice can only be given using extensive domain descriptions and advanced assessment tools, and will very likely only be developed for a few domains within the Math-Bridge project.

Goals and Scenarios for Using the Math-Bridge Material

Goals of Math-Bridge

Math-Bridge aims at designing, using and testing learning materials for remedial learning of school mathematics in preparation of university level mathematics. This learning material can be used in two general learning formats: in self-directed learning by individuals, or in a "bridging course", which is taught at many European universities. These courses often make use of some form of blended learning. Math-Bridge will support various variants of both learning formats.

Math-Bridge Partners' Remedial Course Scenarios

We have identified several blended learning scenarios with varying eLearning content in existing bridging courses at the project partners' universities (cf. Biehler Fischer, Hochmuth, & Wassong, 2010a). In most of these courses the structure of the learning material and its representation is fixed: the partners use books or multimedia-enriched learning material, in which the various components have a predefined order designed by a pedagogical expert.

Learners use the remedial material in various ways, but most uses follow one of the following two scenarios:

- A blended learning scenario in which large parts of the material are studied via eLearning or distance-learning. Here the student decides about the intensity, the sequencing and the time allocation independently, often with some help of a teacher. A teacher supports the learner in structuring his learning and provides feedback. The teacher selects and provides the learning material.
- A classical scenario, in which most learning takes place in the classroom. Elearning or distance learning plays a minor role at most in this scenario. The teacher selects and provides the content, but also decides upon which content is learned when, and for how long. A student has almost no possibility to influence these learning aspects.

The Math-Bridge material must be usable for these kinds of course scenarios.

The Potential of the ActiveMath System

The project partners have chosen the ActiveMath platform as the central eLearning system for Math-Bridge. We give some features of ActiveMath that make it suitable for Math-Bridge.

In ActiveMath, content is formally represented in so-called (atomic) Learning Objects (LO). These learning objects are enriched with metadata about for example related topics, prerequisites, and the type of the LO. All LOs from a single domain are structured in collections, internally they are stored in a database. LOs can be organized and structured in books in two different ways:

An author and a teacher (and a learner) can build their own books by ordering the LOs in a particular way and group them into pages, sections and chapters by hand. Pedagogical expert knowledge is necessary for this.

ActiveMath can also automatically generate books following certain principles, called "formal remedial scenarios". A remedial scenario then describes a formal structure of an automatically generated book and is based on pedagogical knowledge.

A learner gets access to learning material through predefined books and through automatically generated books for the learning goals he has specified. He can also use the extensive semantic search to get access to specific LOs.

The system collects information about the learning progress of the learner by assessing the solutions to exercises of a learner. The ActiveMath learner model is a complex structure of domains and competencies. To build up a learner model, ActiveMath uses the evaluation of the exercise results in the Item-Response-Theory and the Transferable-Belief-Model (cf. Faulhaber & Melis, 2008). This learner model is used by the system for selecting appropriate examples and exercises adapted to the learning progress of the individual learner.

Remedial Scenarios

The automatic generation of books is based on "formal remedial scenarios", which describe how LOs for a certain topic are selected, ordered, combined and offered to learners in the form of books. A formal remedial scenario is a kind of workflow in which a particular book structure is described.

Developing such a formal remedial scenario amounts to defining a clear didactical structure of LOs with a particular pedagogical goal in mind. This structure of LOs needs to be usable for many topics and therefore needs to be defined independent of a specific domain. Using this structure ActiveMath can automatically generate a book for a topic the learner has chosen, assuming that the necessary LOs are available. For this the system uses information from the user's current learner model in combination with the metadata of the LOs. This enables the ITS to select appropriate LOs taking the learner's abilities and learning goals into account. To enable this adaptive behavior of the system, each scenario needs certain decision rules.

Within the LeActiveMath project some formal remedial scenarios have been developed (Reiss, Moormann, Groß, & Ullrich, 2005) and implemented. These scenarios have different pedagogical targets, like LearnNew, Rehearse, Workbook or ExamSimulation. For Math-Bridge we adapted those scenarios for the use of atomic LOs.

The Need for Complex Learning Objects

All content partners have to implement their content in the ActiveMath system to use it for Math-Bridge. For this purpose, content is sliced into atomic LOs such as examples, exercises, definitions, interactivities etc, and is afterwards recombined by the system into books as described above.

An analysis of the partner's learning material showed that some of the sequences of atomic LOs should always be ordered in the same way as in the existing material. Some sequences of atomic learning objects belong strictly together for didactical reasons. For instance, an "introduction" or an "explanation" form holistic units of learning. They may contain several atomic learning objects and intermediate texts. The individual learning objects are reusable in other contexts, but this holds for the whole learning unit as well. We call such units "complex learning objects".

A complex learning object consists of one or more ordered atomic learning objects, which together build a coherent learning complex whose structure is obtained from didactical needs. A complex learning object can be related to a certain definition or theorem. The order of the atomic learning objects is an integral part of a complex learning object. Moreover, it is impossible to abstract from this content specific order of atomic learning objects to obtain a general formal remedial scenario. Using a formal remedial scenario instead will not always ensure that the structure of well-evaluated coherent learning units is preserved. That is why we want to keep these complexes of atomic learning objects as a single entity.

Since we have identified many occurrences of complex learning objects in the content of the partners, we introduce a new structure element called "complex learning object" (CLO) that can be implemented within ActiveMath as a subgroup, and can be used as an atomic learning object itself. With this new element, the partners' material can be sliced and recombined without loosing the didactical structure of certain content elements. As an example of encoding material using complex learning objects, we started with encoding the content of the VEMA-project (cf. Biehler, Fischer, Hochmuth, & Wassong, 2010b; http://www.mathematik.uni-kassel.de/vorkurs). In the following we will classify the most important CLOs we identified in this material.

Classification of CLOs

In this paragraph we describe what different types of CLOs appear in the existing content from the VEMA project. The order of atomic LOs within a certain CLO is determined by the didactical purposes of the author. This order is specific and cannot be generalised. The types of the CLOs are classified as follows:

Introduction CLO

This CLO introduces a learner to a particular concept. It may function as an introduction to several definitions or theorems. The introduction CLO is usually based on other conceptual prerequisites. It may consist of examples, exercises, interactivities, problems or motivations in a didactically well-chosen manner, where no formal generalization is possible.

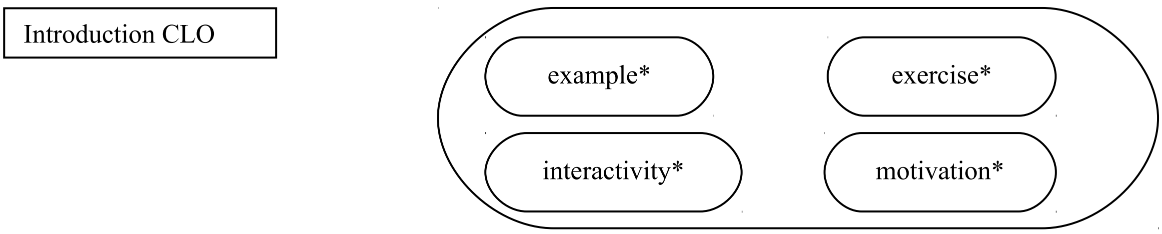


Figure 1. Introduction CLO

Info/ Interpretation/ Explanation CLO

The Info/ Interpretation/ Explanation CLO is designed to develop the learner's comprehension of a certain definition or theorem. It is usually written for just one definition or theorem and may consist of examples, explanations, counterexamples, proofs, and interactivities.

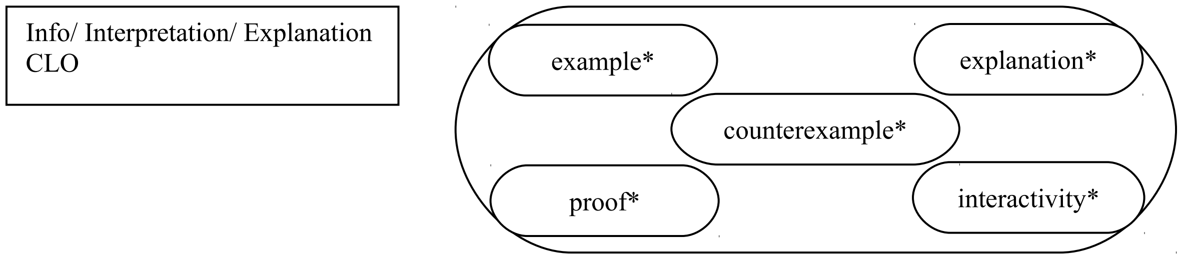


Figure 2. Info/ Interpretation/ Explanation CLO

Application CLO

An application CLO gives insight in a mathematical concept by means of real world applications. It may be developed for a single definition or theorem, but it may also refer to several such. The application CLO can contain examples, exercises or interactivities.

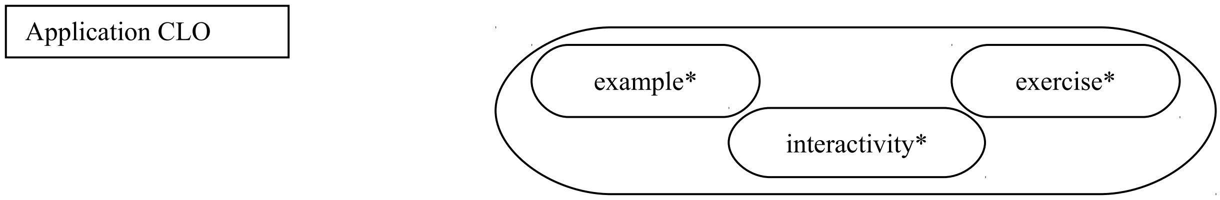


Figure 3. Application CLO

Misconception CLO

The misconception CLO consists of examples, exercises or interactivities that show typical mistakes learners make, or misconceptions learners have about a particular concept.

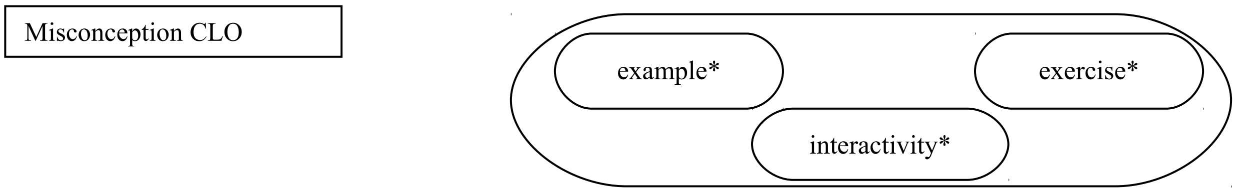


Figure 4. Misconception CLO

Practice CLO

A practice CLO is a sequence of well chosen exercises according to pedagogical and/or content criteria, in which the knowledge and competence about a set of certain concepts is practiced. As ActiveMath allows switching off the feedback component of interactive exercises, a practice CLO can also be used for assessment purposes.

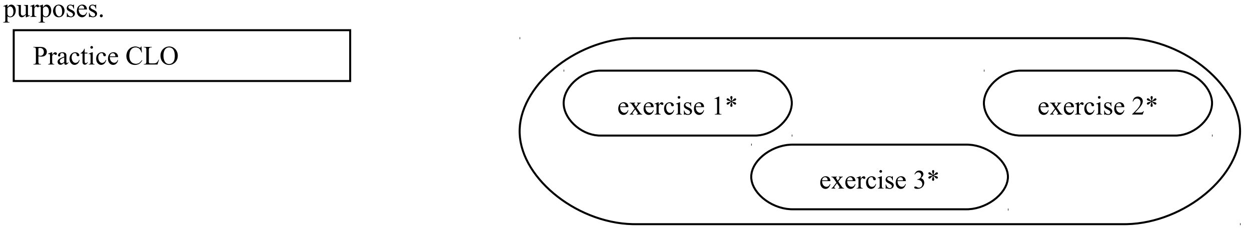


Figure 5. Practice CLO

Supplement CLO

The supplement CLO provides additional learning material that is not obligatory for a certain learner and topic, but interesting for a learner who wants to deepen and expand his or her knowledge. A supplement CLO may consist of definitions, explanations, examples, exercises, problems, proofs or interactivities.

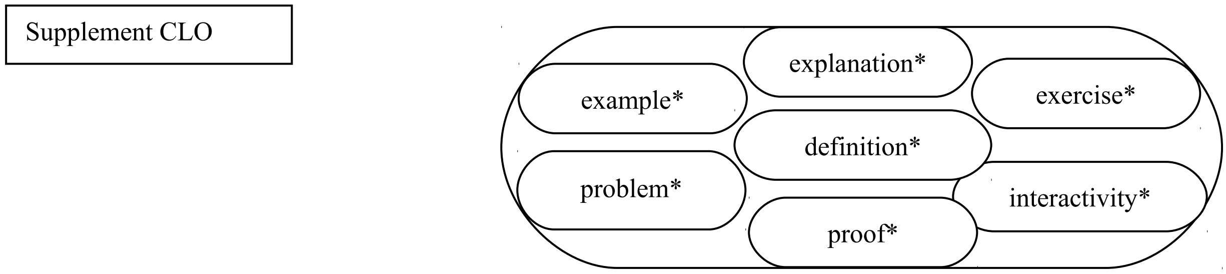


Figure 6. Supplement CLO

These classes of CLOs are obtained from analysing the VEMA material. Although these classes describe many important and widely-used approaches to comprehensive learning, the project partners may need additional classes of CLOs, which can easily be added to the above classes. New CLOs will be added upon demand.

Formalized Remedial Scenarios using CLOs

Now that we have introduced and classified CLOs, we describe the formal remedial scenarios for using the VEMA material. These scenarios can be used to combine CLOs as well as atomic learning objects. Conversely, scenarios designed for atomic learning objects can also be used for CLOs with the same didactical intentions. Using both atomic and complex learning objects we now describe the desired technical features of Math-Bridge with respect to the implementation of different remedial course scenarios.

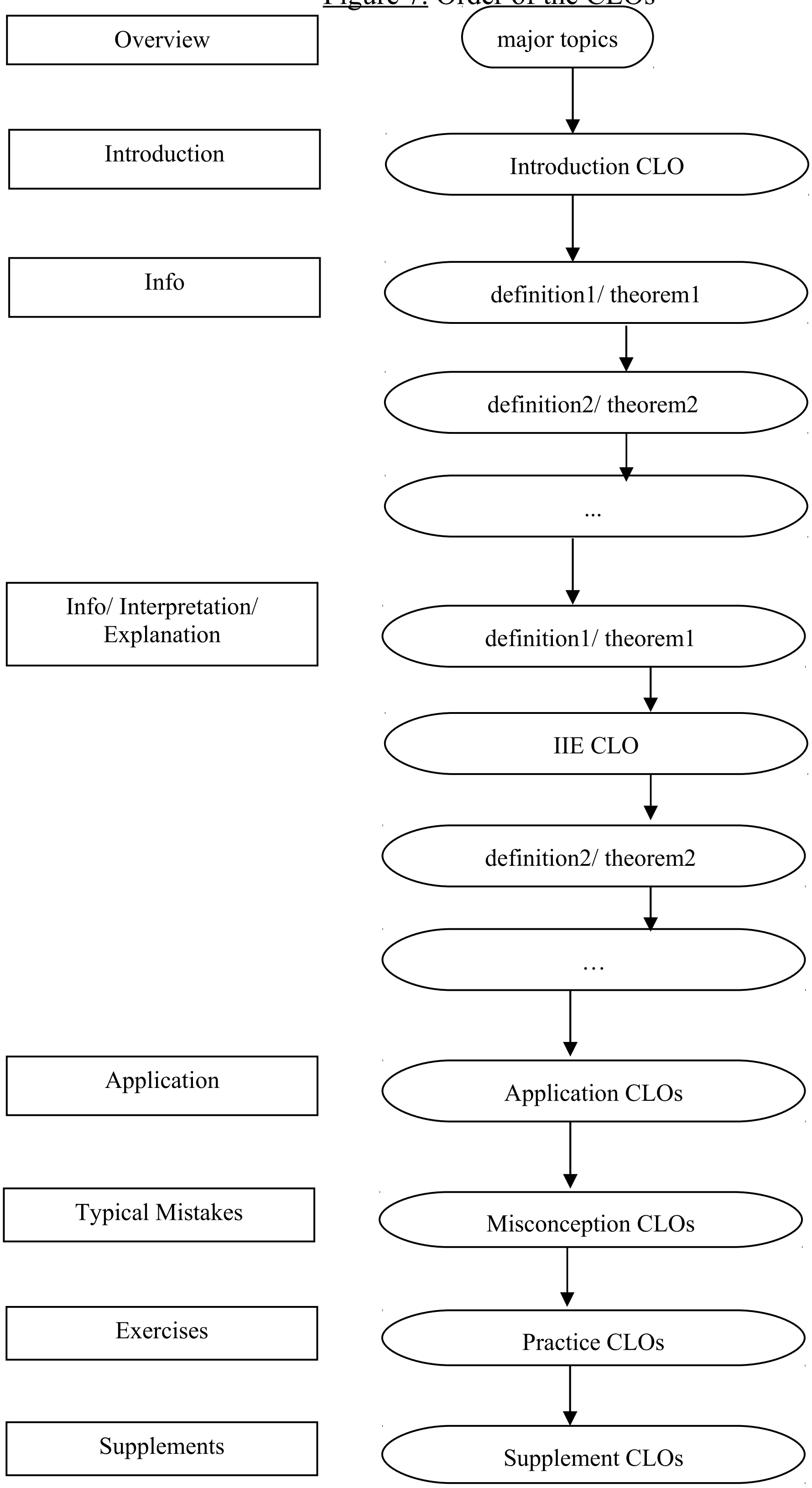
Although CLOs have a fixed order in which they present their components, they may be adaptive in the sense that a CLO can be replaced as a whole by another (C)LO, or some of the atomic learning objects within a CLO may be replaced by another learning object. This means that the structure of a CLO stays the same while specific atomic LOs, e.g. exercises, within the CLO may be replaced based on the learners abilities and preferences. Such adaptivity may use information from the learner model. This requires that the metadata of a CLO is structured in a particular way. Since CLOs have not yet been added to ActiveMath, it is at this moment unclear how, and to what extent CLOs will be adaptive. We assume that metadata of a CLO is structured in the same way as metadata of an LO.

CLOs are combined, ordered and presented to learners using formal remedial scenarios. The main idea of the remedial scenario described in the following subsection is to reimplement the structure of the VEMA material using the advantages of an ITS. Based on this structure we develop an order in which (C)LOs are combined into several pages (the rectangles on the left side in Figure 7). In the second subsection we will discuss ideas about how the scenario will be presented to the learner and what options he will have.

Combining CLOs

The VEMA learning material requires a particular order between the various CLOs. As figure 7 shows, the learning material starts with a page that gives a brief overview of the central concepts to be learned. This supports the learner in focussing on the important aspects of the content to be learned. The next page is the Introduction CLO. After the introduction all definitions and theorems are briefly listed in a fixed order on the Info page. The following Info/ Interpretation/ Explanation (IIE) page gives all definitions and theorems followed by appropriate CLOs which may contain examples, explanations, counterexamples, proofs and interactivities.

Figure 7. Order of the CLOs



In the next step, the learner gets information about applications of the concepts by means of one or more Application CLOs. An Application CLO refers to at least one definition or theorem, and may also refer to a combination of them. Application CLOs do not exist for all definitions or theorems.

Typical mistakes related to the concepts are presented on the Misconception page. The Practice page contains various kinds of exercises: exercises which are automatically scored as well as exercises that are corrected by the learner herself. In each case at least sample solution is presented to the learner after she submitted her solution to enable her to diagnose herself and to check her own solution approach to the exercise.

The final Supplement page presents learning material is presented that is not obligatory. This page is designed for ambitious learners who want to learn more than just the pure requirements of their fields of study.

Optional scenarios for the selection of the pages

Based on the order of the CLOs and pages as presented above, we now introduce scenarios that can be changed by individual learners. Like in most of the scenarios described above, a learner first chooses a topic he wants to study. Then the system shows the complete list of pages that are available for the topic as shown in the diagram below.

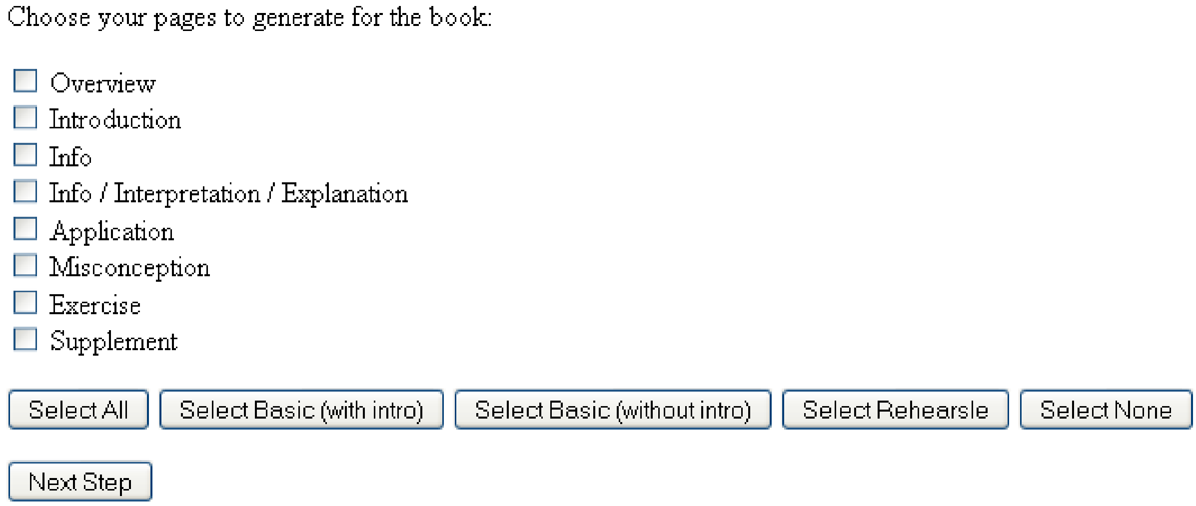


Figure 8. User-interface for the selection of the pages

A learner can now individually design his learning by choosing those pages that he wants to use in his learning or use one of the scenarios that are predefined: Select All, Select Basic (with intro), Select Basic (without intro), Select Rehearse. These predefined scenarios activate different pages as described below and are designed to support the learner in structuring his learning. All of these scenarios can freely be exchanged by the learner by activating further pages or deactivating chosen ones. Hence the student is supported in his choice, but he is free to change it before starting the book generation. We will now describe these four preselections:

Select All

The scenario Select All selects all pages. Hence the user gets a complete description of the topic, which may be useful for learning an unknown concept or for a deeper comprehension of the topic. The definitions and theorems can be studied in the Introduction on a non-formal level to obtain some intuition about them. This intuition will be further formalized later on. Thus the learner develops an intuitive and problem-related understanding of a concept before a formal presentation is given.

Select Basic (with intro)

The scenario Select Basic (with intro) gives an Overview and the Introduction page, proceeds with the Info page, and then presents the Info/ Interpretation/ Explanation page, and concludes with the Exercises page.

Skipping the Application, Typical mistakes and Supplement page the learner only gets the basic content that is most important for revising or studying known concepts. The Introduction supports the comprehension of the topic.

Select Basic (without intro)

The Select Basic (without intro) scenario is exactly the same as the Select Basic (with intro) scenario except for the Introduction, which is skipped. Instead the learner starts in a top-down approach with an overview of all definitions and theorems, which are explained and justified afterwards.

The learner has full access to all central components necessary for learning. Since this reduces the amount of learning material, this scenario is especially suitable for those students who want to briefly repeat a certain topic, but do not need any introduction to the topic.

Select Rehearse

The Select Rehearse scenario is the shortest scenario, in which only the Info page containing the definitions and theorems, and the Exercise page are listed. The learner does not get any introductions, explanations, examples or proofs and therefore can briefly check the central concepts and practice them with the exercises.

Self-directed learning not only requires abilities (or support) in structuring the content but also abilities in self-regulation and self-assessment. In order to help our students develop these abilities we developed a learning advice component which is described below.

Learning Advice Component

General Learning Advice Component

First-year students are used to attending lectures with a teacher who selects the content and decides on curricular aspects such as restrictions to learning time and the sequencing of content. Hence, for self-directed learning first year university students need competencies in self-regulation as well as in self-motivation in order to design their individual learning process (cf. Niegemann et al., 2008, pp. 65). To select the content to be learned students also need both knowledge of the mathematical requirements of their fields of study, and self-diagnostic abilities to detect their content- and competency-specific knowledge gaps.

Since Math-Bridge is designed for blended learning course scenarios as well as for self-directed learning scenarios, the learning environment should support a student in the development of the required abilities to compensate for the absence of a teacher's advice. Therefore, we want to implement a learning advice component that supports the learner in different aspects related to self-directed learning. This component serves as a starting point for all learning and aims to help a learner in self-regulating his individual learning. The learning advice component starts with an introductory How-to learning object. This How-to describes both the technical usage of Math-Bridge as well as the pedagogical ideas behind learning with the system. It contains recommendations for self-directed learning – such as how to schedule a learning process, how to keep motivated, how to keep focus etc. as well as concrete descriptions of the formalized remedial scenarios, their goals and their intended usage by a learner. The learning advice component can also give specific learning advice for certain concepts. Another important part of the Learning advice component is the self-assessment component which will be described in the next section.

Self-Assessment Component

The self-assessment component supports a learner in assessing his knowledge about a particular topic and to select adequate options of Math-Bridge to enhance his knowledge of this topic and overcome specific deficiencies. For this purpose the system offers two tools: a tool for self-evaluation and a system-provided diagnostic test that covers all four competencies C1 to C4 of Math-Bridge: technical competencies, real-world modelling, mathematical problem solving, and communication (cf. Biehler, Fischer, Hochmuth, & Wassong, 2009).

The implementation of this component for a certain content domain requires a detailed pedagogical and mathematical analysis of the domain. Moreover, elaborated testing instruments for the domain have to be available. The self-assessment component is implemented in Math-Bridge for selected content domains only, where such instruments are already available in the partners' material.

The scenario, as illustrated in figure 9, starts with the users' choice for a certain topic. Then the system shows a brief description of the major concepts and provides all definitions and theorems that will be taught within the topic. In the next step the learner is asked to estimate his own performance in the chosen topic, including all subtopics, and competencies, by indicating a score between 0% (no knowledge) and 100% (perfect knowledge). Afterwards he is offered a diagnostic self-test on the chosen topic, which consists of at least one exercise for each competency. The self-test may contain automatically scored exercises as well as exercises with self-evaluation, or exercises that need scoring by an external tutor.

In the next step, the system gives feedback about four aspects:

1. The results of the test on content knowledge,
2. the results of the test on the four competencies (in figure 9: C1, C2, C3, and C4),

3. a sample solution for each exercise to enable the user to evaluate his own solution, and
4. a comparison with the prediction of the results by the learner.

Hence the user does not only get an external assessment of his performance, but can also compare this result to his own prediction. Based upon the test results the system finally provides recommendations for learning, focussing on content-specific and competency-specific suggestions. In particular, the advice contains recommendations with regard to the remedial scenarios the user should choose for his further learning in the system. From here, the learner can individually choose the next learning scenario. The system will not automatically adapt the content with regard to the results of this scenario.

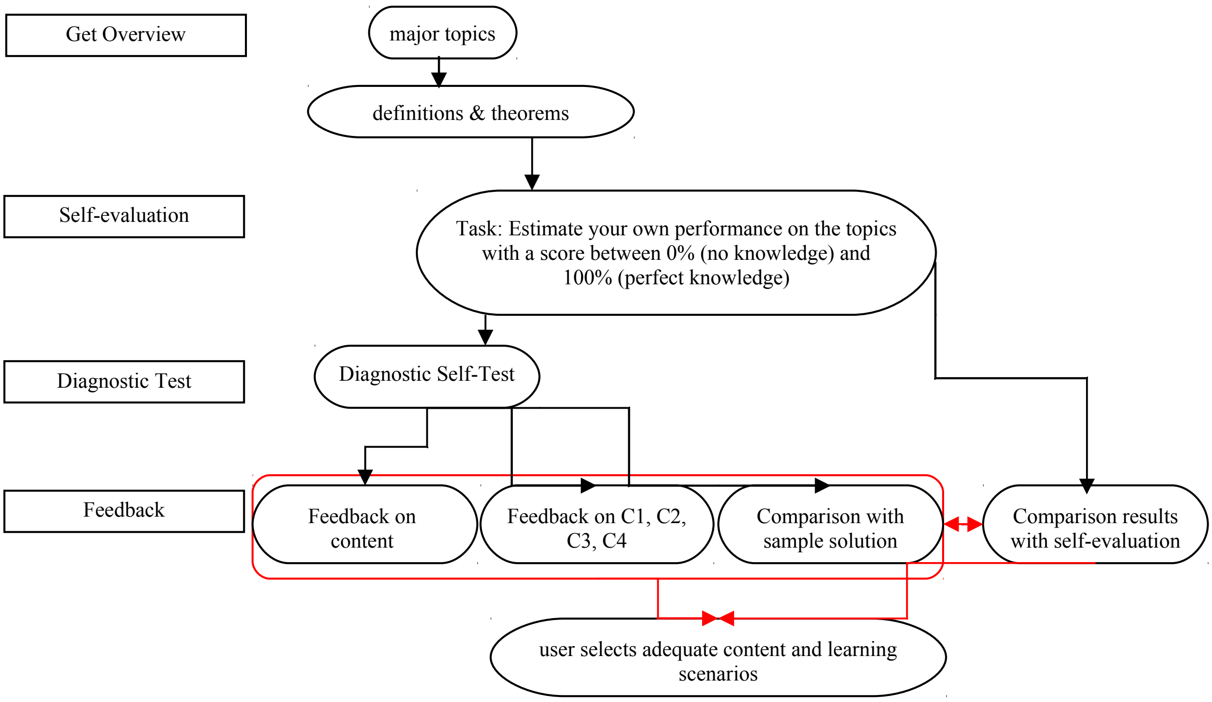


Figure 9. Structure of the formalized learning advice component

This learning scenario can be used by the learner as a preliminary stage to all remedial learning scenarios. It supports the learner in content selection and in structuring his learning process. It also trains his self-assessment and self-regulation competencies. The scenario can be used for self-directed learning as well as for blended learning.

The system only gives feedback on the learner's individual performance during the test and predication of his performance. The test results have no effect on the selection of the learning material, the user decides himself on the next steps to be done. Moreover, the exercises that are chosen for the diagnostic test are the same for every learner and do not change based on the learner's actual learner model. Only the test results will update the learner model.

Summary and Future Work

We introduced the Complex Learning Objects (CLO) as a new structure element and developed new formalized remedial scenarios for CLOs to enable the project partners' content to be implemented within the learning system used for individual remedial course scenarios afterwards. The general learning advice component as well as the self-assessment component introduces a tutorial component to the system that supports a learner in structuring his individual learning. This component is particularly useful for self-directed learning with the system, without a teacher.

Our paper concentrates on learning components related to the current state of the ActiveMath system, and is implicitly based on principles of instructional design. In future work we plan to make the background of the remedial scenarios of MathBridge explicit, based on the international literature on instructional design, for instance the well-known 4C/ID method (cf. Van Merriënboer & Kirshner 2007).

References

Biehler, R., Hochmuth, R., Fischer, P. R., & Wassong, T. (2009). *EU-Project Math-Bridge - D1.1: Target Competencies*. Retrieved on October 15th, 2010, from http://subversion.math-bridge.org/math-bridge/public/WP01_Pedagogical_Preparation/Deliverables/D1.1-target_competencies/D1 1 target_competencies.pdf

Biehler, R., Hochmuth, R., Fischer, P. R., & Wassong, T. (2010). *EU-Project Math-Bridge - D1.3: Pedagogical Remedial Scenarios*. Retrieved on October 15th, 2010, from http://subversion.math-bridge.org/math-bridge/public/WP01_Pedagogical _Preparation/Deliverables/D1.3_pedagogical_remedial_scenarios/ D13_remedial_Scenarios.pdf

Biehler, R., Hochmuth, R., Fischer, P. R., & Wassong, T. (2010). *Self-regulated learning and self assessment in online mathematics bridging courses*. Manuscript submitted for publication.

Faulhaber, A. & Melis, E. (2008). An Efficient Student Model Based on Student Performance and Metadata. In Ghallab, M., Spyropoulos, C.D., Fakotakis, N., & Avouris, N. (Eds.), *Proceedings of the 18th European Conference on Artificial Intelligence (ECAI 2008).* Amsterdam: IOS Press. (pp. 276-280)

Niegemann, H. M., Domagk, S., Hessel, S., Hein, A., Hupfer, M., & Zobel, A. (2008). *Kompendium multimediales Lernen*. Heidelberg: Springer.

Reiss, K., Moormann, M., Groß, Ch., & Ullrich, C. (2005). *D20 for LeActiveMath project: Formalized Pedagogical Strategies*. Retrieved from October 15th, 2010, from http://www.leactivemath.org/deliverables/D20_Formalized_Pedagogical_Strategies.pdf

Van Merriënboer, J.J.G. & Kirshner, P. (2007). *Ten Steps to Complex Learning*. Mahwah: Erlbaum.

Acknowledgement

This work was made possible by the Math-Bridge project (ECP-2008-EDU-428046) of the Community programme eContent*plus*. The paper does not represent the opinion of the Community, and the Community is not responsible for any use that might be made of information contained in this paper.