

# LeActiveMath

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**Abstract.** LeActiveMath (Language-Enhanced, User-Adaptive, Interactive eLearning for Mathematics) is an interdisciplinary European effort that develops an internationalized Web-based intelligent e-Learning system for mathematics that can be used in high school and university as well as for self study. The many technological innovations serve a moderate constructivist and competency-based pedagogical approach. LeActiveMath integrates a number of services and tools and advances the state-of-the-art in semantic search and other usages of semantic representations, presentation of maths on the Web, course generation, coherence of material, exercise selection, modeling of motivation, modeling of competencies, annotation and structure of exercises, feedback and tutorial dialogues in exercises, First evaluations are completed and large ones ahead.

## 1 Introduction

LeActiveMath (*Language-Enhanced, User-Adaptive, Interactive eLearning for Mathematics*) is a European research project (STReP) funded by the 6th Framework Programme-Priority “Information Society Technologies”, key action *Technology-Enhanced eLearning* in call FP6/2002/IST/1. This project is coordinated by the German Research Center for Artificial Intelligence.

The goal of LeActiveMath is to develop an innovative Web-based intelligent e-Learning system for mathematics that can be used in high school and university as well as for self study. The content and some input evaluation tools are specific for mathematics, but the main technology is not restricted to mathematics. The benefits of the new technologies are demonstrated with mathematics for which currently moderate constructivist approaches to education are even less common than for other domains. On the one hand, mathematics has the advantage of being clearly structured and to address concepts with a relatively clear semantics. Mathematics, on the other hand, poses additional challenges, e.g., in the delivery of formulas on the Web.

Since Web-technologies alone are insufficient LeActiveMath is a multidisciplinary effort which includes disciplines such as artificial intelligence, pedagogy,

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techniques and experiences from Intelligent Tutoring Systems (ITS) and representations developed for eLearning and the semantic Web. LEACTIVE MATH provides a synthesis of both worlds – ITS and eLearning – and it is one of the few mature and ready-to-use, multi-lingual, intelligent Web-based learning environments (not to be confused with Learning Management Systems). LEACTIVE MATH features generic technologies and services that are interoperable and can be reused.

LEACTIVE MATH effectively supports learning and stimulates the learner’s initiative by providing interaction tools, (multi-modal) feedback and tutorial dialogues. It can suggest different levels of guidance, can follow a chosen pedagogical strategy, and reacts to the learner’s motivational state. It puts the student in a more responsible position for her learning, grants students’ self-guidance and supports meta-cognition where possible.

## 2 Pedagogical Fundament of LEACTIVE MATH

The purely instructivist approach seems to fail in many learning situations. Learning mathematics should not only aim at *solving* the problem but also at *thinking mathematically* and *arguing* about the correctness or incorrectness of the problem solving steps and involved methods, to perform simple and complex *computations*, etc. This is the idea behind **competency-based** pedagogy which provides dimensions on what to train and to evaluate, e.g., in the PISA studies.

The constructivist view of learning is based on the theory that knowledge cannot be directly taught to a student but has to be constructed by every single student with respect to her prior knowledge and experience [5]. Recent research suggests that the instructivist point of view is less efficient than a **moderate constructivist** view on learning and instruction. The term *moderate constructivism* defines a teaching and learning approach that mixes many of the fundamental features of (pure) constructivism with more instructional elements. For an eLearning environment this definition translates to a mixture of constructivist and instructivist elements in a problem-oriented learning environment. Learning is conceived as an individual, mostly active and self-regulated, situational and social process that is strongly influenced by the student’s motivation and zone of proximal development.

Moreover, moderate constructivism addresses authentic problems, multiple contexts and perspectives, and learning with instructional support. It reconciles the strict constructivist with cognitive and instructional principles. This model suits the practical requirements of schools and its effectiveness has been shown in numerous empirical investigations.

## 3 How to Work with LEACTIVE MATH

With LEACTIVE MATH a student can choose one or several learning goals, a context and a pedagogically granted learning scenario. After such ‘planning’ activities she receives personalized learning material including dynamically produced

narrative bridges such as summaries and introductions, as well as personalized suggestions. This helps in classroom differentiation as well as in focused self-learning. Even more actively, the learner can assemble her course manually from elements of existing courses.

An adaptive pretest with the integrated Siette system initializes the student model. The student can inspect her student model and this can help to motivate and guide meta-cognitive activities. The student's motivation and affects, e.g., being bored, unfocused, or overwhelmed, is monitored and reacted to, e.g., by providing more animated or less difficult examples and exercises, by changing the tutorial dialogue strategy, or by providing more or less interaction facilities in menus.

In the learning process, the student works on various kinds of interactive examples and exercises with the additional possibility to access dynamically linked factual knowledge and explanations. During the problem solving process she will receive feedback or be involved in a multi-modal tutorial dialogue in which the student or the system asks questions, points to problems, and gives hints. When the student makes a mistake while exercising, feedback and hints support her in discovering and correcting a misconception. Overall, LeActiveMath aims at combating shallow learning through engaging students more explicitly in the knowledge construction process.

Apart from exercises that come with tool support (concept map, search, function plotter, computer algebra systems (CAS)), other tools are available through a tool menu. For instance, she can assemble the material in her own way, she may consult the semantic lexicon, she can acquire printed material, she can engage in an exploration and negotiation process with her student model, or she can use a CAS or another back-engine to solve problems she states herself. An input editor eases the input of mathematical expressions in exercises and the dictionary. Its simple usage helps the student to focus on the problem solving rather than on the handling of the system.

*How are the Pedagogic Ideas Realized?* In LEACTIVE MATH, the following features contribute to the moderate constructivism:

- truly interactive problem solving with back-engine support;
- open, inspectable learner model (OLM) and negotiation that can be initiated by the learner. This fits a Piagetian line and involves the learner continually managing the process of comprehending new information and assimilating/accomodating it.
- inclusion of situational, emotional, and motivational features into the learner model;
- the indication of related concepts and learning objects as one of the results of the semantic search;
- Socratic tutorial dialogue with active turn-taking by student which allows the learner to take the initiative in discussions;
- suggestions that can be actively followed by the student;
- the possibility for the student to actively choose problems and topics to learn and to request more material or information;
- the design of the content.

### 4 Reusable Learning Tools and Components

Quite a number of isolated tools for learning have been developed world-wide: search tools, highlighting tools, exercise back-engines, simulation tools, mind map tools, modeling tools, assessment tools, CASs. Now, LEACTIVEMATH integrates a number of components and tools, and has developed an open architecture and event framework (for asynchronous communication) shown in Figure 1. It eases the integration of components and tools and a collective use and updating of one and the same student model.

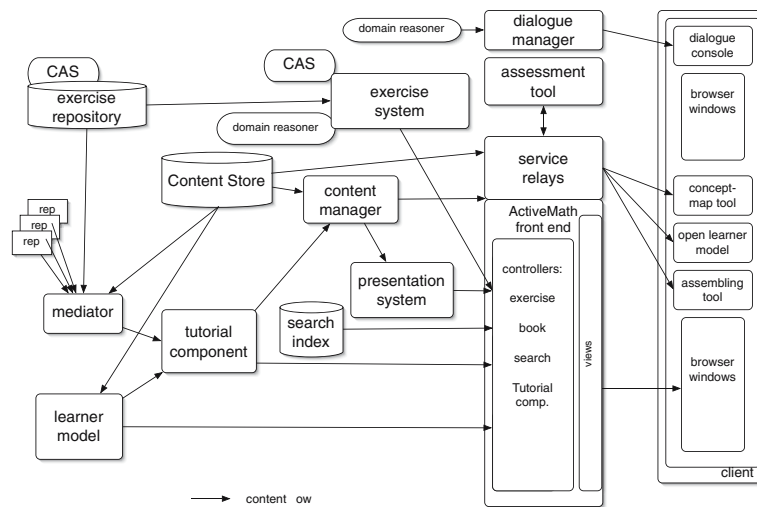


Fig. 1. LEACTIVEMATH' coarse architecture

Technically, some of the components directly interact via procedure calls: e.g., the Tutorial Component and the tutorial dialogue component; the input editor with the knowledge base and exercise back-engines; the interactive concept map with the knowledge base and the student model; the dictionary with the knowledge base and the learner model. All components report events which can be processed by other components. Web services communicate via events and XML-RPC.

Similar to its predecessor system ACTIVE MATH [4], LEACTIVEMATH relies on the semantic XML representation standard for mathematics, OpenMath, which is augmented with pedagogical metadata. The various tools and components build on that foundation and provide/use the semantics and/or the metadata information: the presentation engine adapts the content presentation according to metadata and customizes mathematical notation (e.g., to the country's common notation); the input editor produces OpenMath; the semantic lexicon can search for (a combination of) mathematical expressions, metadata, and text; semantics can be dragged into applications; the interactive concept map evaluates

the user's input against metadata and semantics; the course generator utilizes metadata for its decisions; a mediator translates metadata of external repositories to make the course generation service available externally; the exercise repository is one particular open repository that is used.

*Student modeling.* Student modeling has been a research topic in artificial intelligence since the mid 1970's. Various techniques have been used to recognize and adapt to the student's behavior and knowledge. LeActiveMath takes up some of the most recent research challenges in student modeling:

It investigates the use of a range of factors for student modeling relating to affect, attitude, motivation and the student's goals. It employs Bayesian belief networks for modeling the motivation and affect of the learner. A competency model has been developed which is updated using a variant of Dempster-Shafer. LEACTIVE MATH further investigates open learner modeling which has been shown to improve the involvement and motivation of students, and also to encourage reflection on the student's own state of knowledge [2].

*Natural language enhancements.* Natural language (NL) is used in many places in LEACTIVE MATH, where the novelties include natural language dialogue for the negotiations with the OLM, the generation of bridging and introductory texts that help to establish mental transitions in the generated courses, and tutorial dialogues in exercises.

Since tutorial dialogues have been empirically shown to improve learning in human tutoring [1], tutorial dialogues have been used in the American tutoring systems AutoTutor Atlas-Andes, and Circsim/APE. Now, the tutorial dialogue in LEACTIVE MATH integrates principled and flexible dialogue management based on the "Information State Update" approach of Trindi and planning of multi-turn tutorial dialogue strategies, in the domain of symbolic differentiation. It employs a dedicated domain reasoner as well as NL-understanding and NL-generation and copes with the student's initiative and student input that mixes informal language and mathematical formulae.

## 5 Formative Evaluation

As LEACTIVE MATH brings together a large number of innovative tools and components the successful implementation of these components and their integration is crucial to the success of the system. User-testing, expert evaluation, and usability testing of LEACTIVE MATH have been performed throughout the systems development to ensure that the goals of the system are met. Evaluations have taken place in Germany, Great Britain, and Spain. We include summary results from an initial formative evaluation conducted at the University of Edinburgh, UK. The results of this study has been used to improve the implementation.

*Design.* The formative evaluation focused on the user interface and its associated tools. This evaluation was lab-based with users working collaboratively with the evaluator to critique and assess the system (see [3] for details of this

methodology). The users worked through a series of unguided tasks and were asked to describe their thought processes i.e. “Think Aloud”, critique the system, and discuss improvements whilst they used the system. Users were also required to fill in pre- and post-use questionnaires about their experience of using LEACTIVEMATH.

*Results.* Eleven students (6 male; mean age 19.45 years) from University of Edinburgh first year Mathematics courses took part in the first evaluation. All users were experienced in learning calculus, using computers and the Web, and most had previous experience of maths software although the tasks they had performed were mostly limited to generating graphs and inputting mathematical formulae. These students were considered representative of the university-level target users of LEACTIVEMATH.

Overall the ratings of LEACTIVEMATH were very positive. On average, their experience of using LEACTIVEMATH was rated as “enjoyable”. All but one of the participants said they would use LEACTIVEMATH again and, on average their experience of using LEACTIVEMATH was rated as “better” than that of existing maths software. All participants would recommend LEACTIVEMATH to their peers irrespective of whether they had previous experience of maths software or not.

LEACTIVEMATH was rated as more practical than existing software for performing a variety of tasks: learning a maths concept, solitary tutorials performed in a classroom, solitary tutorials at home, supplementing bookwork, and revision. LEACTIVEMATH was rated as being as practical as existing software for group tutorials at home, entering mathematical formulae, and generating graphs. The only tasks for which LEACTIVEMATH was rated less practical were group tutorials in a classroom and performing mathematical computations although this could be because the participants were not introduced to the CAS.

Ratings were also collected for the ease and usefulness of specific components within LEACTIVEMATH. As mentioned previously (section 3 paragraph 3), LEACTIVEMATH implements a *moderate constructivist* approach to teaching by providing contextualised feedback and hints in response to exercise answers and syntactical errors made when constructing formulae using the input editor. The hints provided during exercises were rated as “quite” useful and the input editor was rated as “very” useful. Users commented found the feedback useful for identifying their conceptual errors and essential for identifying syntactic errors.

LEACTIVEMATH’s semantic dictionary can be used to find definitions of mathematical concepts either via a search interface or by following hyperlinked concepts direct from content pages. The dictionary was rated as “quite” useful and easy to use by users. Several usability issues were identified during the evaluation that made it difficult for users to realise the full potential of the dictionary. However, even with these limitations users quickly developed a strategy of constantly referencing the dictionary for definitions and examples. The design flaws are currently being fixed and the resulting version of the semantic dictionary should function as an integral component of LEACTIVEMATH.

## 6 Conclusion

LEACTIVEMATH brings together a number of "cutting edge" components in an attempt to maximise their benefit to the student. This benefit has been iteratively evaluated during development of LEACTIVEMATH to ensure that each component is optimized in its implementation and remains user-centred. A large-scale trans-national summative evaluation of the system will take place after those optimisations.

Details of the system, its components and tools are described in a number of articles which are not cited because of space limitations. Please visit our web site [www.leactivemath.org](http://www.leactivemath.org) or [www.activemath.org](http://www.activemath.org) for more specific publications.

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