Feedback in ActiveMath Exercises

George Goguadze and Erica Melis
University of Saarland
and
German Research Institute for Artificial Intelligence (DFKI)
66123 Saarbrücken, Germany
email: george@activemath.org, melis@dfki.de

Abstract

The ActiveMath platform for web-based and adaptive learning environments has a large number of theoretically and empirically justified features that serve the learning of students as well as the needs of teachers. Most design decisions in ActiveMath are driven by pedagogical and cognitive considerations, some decisions are driven by economical considerations, and others by technological and scalability considerations.

In this paper, we concentrate on the design of interactive exercises and the technology that 'plays' these exercises. Interactive exercising is one of the major ingredients of technology-enhanced learning. It reaches its full potential only, when appropriate feedback is given to the learner. This paper describes a principled approach for presenting and processing interactive exercises and feedback in ActiveMath and its theoretical and empirical background. In particular, we describe how feedback can be adapted and which knowledge is necessary for this.

keywords: research-oriented, design choices for technology related to cognitive aspects of mathematics and to the learning of mathematics, feedback, adaptation

1 Introduction

The ActiveMath is a platform for web-based and adaptive learning environments. We collaborated with mathematics educationalists in the LeActiveMath project and with teachers from various European countries in order to base our technological developments on modern pedagogical and psychological results on the learning of mathematics. This resulted in the formalization of pedagogical knowledge in scenarios that can be chosen and in several opportunities for moderate constructivist learning in the LeActiveMath learning environment that is built on the platform ActiveMath [14].

Some design decisions are driven by economical considerations, e.g., the principled design for the reuse of content in various contexts and ActiveMath's multi-linguality [13]. Last but not least – since technology is accepted only if it is useful, scalable and reliable – technological aspects are stressed, see, e.g., [21, 5], as well as tools for assisting teachers for assembling content [7] and for information about her students' learning [19] in ActiveMath and its applications.

2 Feedback in Interactive Exercises

Interactive exercises are a crucial ingredient of technology-enhanced learning and so is feedback to the learner's input. Feedback is considered an important instructional factor for effective learning (e.g., [4]). Feedback needs at least two ingredients, the evaluative (correct/incorrect) which has a controlling function[9] and additional information on the topic, the task, the errors, on solutions that guides a learner to task completion. The impact of different feedbacks has been investigated by a number of psychologists, see summaries,e.g., [8, 11, 17]. The actual value of feedback depends on how well its function, content, and form match the characteristics of the learner and of the instructional context including the learning goal.

Most of today's e-learning systems lack elaborate feedback in interactive exercises and none does adapt the feedback's content, form, and strategy to the learner and a particular situation, although research in cognitive psychology suggests that this can greatly improve learning and motivation.

ActiveMath's exercise system is not specifically using the traditional paradigm of teaching with right/wrong (flag) feedback. In the opposite, the described system it is designed to allow for a large number of feedback types including system feedback that is not verbal at all but realized by any changes in the user interface, such as changing visual representation, changing the state of an artefact, etc. Even the interactive elements presented to the learner can contain feedback in form of the given structure of the input (see the right screenshot in the Figure 2).

Among our main research questions are:

- generic knowledge representation for interactive exercises which allows reusing the same exercise with different tutorial and presentation strategies
- methods of automatic application of tutorial strategies to exercise knowledge representation
- methods for adaptation of presentation of exercise steps and feedback that correspond to the latest psychological findings

The overall design of ActiveMath is based on moderate-constructivist framework [14] that aims at a balance between guided training for building schemata and guided generation of meaning and fully self-guided learning. On one hand, ActiveMath offers a learner a collection of tools for constructing his knowledge. On the other hand, guidance is present in the system in form of human devised tutorial strategies for global feedback in the system as well as local feedback within exercises.

Learning is perceived as construction and re-constructions of meaning and as schema construction.

Our ultimate goal is a psychologically sound exercise system that provides most useful feedback and adapts it to the learner's competency and motivation.

2.1 Theoretical Foundations

The work on feedback generation presented in this article, is based on Susanne Narciss' psychological theoretical framework for informative feedback ITF [16]. The ITF-framework conceptualizes feedback as a multi-dimensional instructional activity that aims at contributing to the regulation of a learning process such that learners acquire the knowledge and skills needed to master learning tasks.

Building on models of self-regulated learning (e.g., [1, 23]) and on the approach of [2], the ITF-framework distinguishes between cognitive, motivational and meta-cognitive controlled variables.

From a system theory point of view, two interacting feedback loops must be considered for an instructional context with external feedback as depicted in Figure 1: an internal feedback loop that processes internal feedback, i.e., the actual values of the learner's state [15] to which the learner has direct access (e.g., confidence in answer, perceived effort, actual effort) and an external feedback loop that processes the actual values that are determined by the learning medium (e.g., the instructor, learning program and/or experimenter).

The nature and effect of external feedback is determined by at least three interrelated facets of feedback: (a) a functional facet related to instructional goals and objectives, (b) a content-related facet, and (c) a presentation facet of the feedback message (e.g. frequency, timing, mode, amount, form). By combining these facets a large variety of elaborate feedback strategies can be developed.

The internal loop factors include

- learner's representation of task requirements which is determined a great deal by the learner's prior conceptual and procedural knowledge
- the learner's meta-cognitive skills in assessing their responses

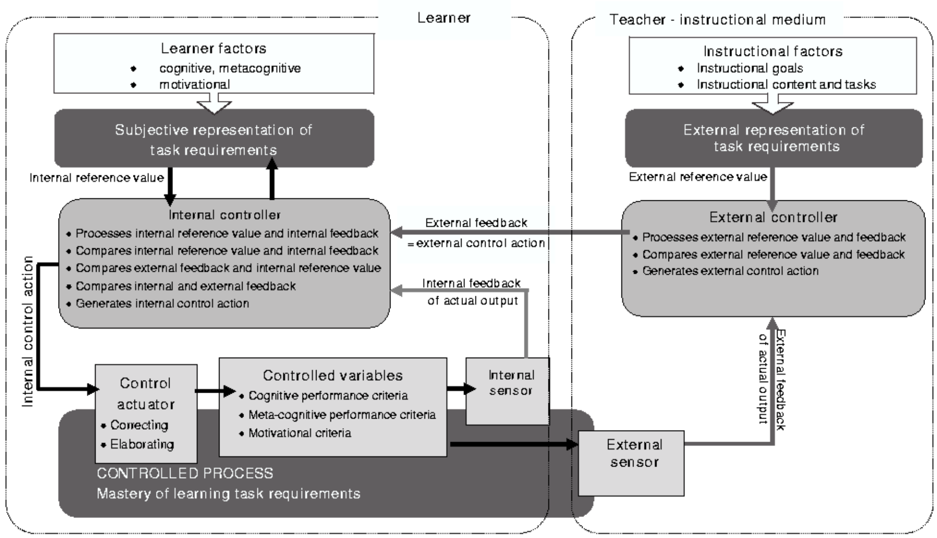

Figure 1: Overview on the basic components of the informative tutorial feedback model

- the learner's cognitive and meta-cognitive skills and strategies for analyzing and comparing internal and external information and for identifying corrective actions
- the learner's skills and motivation in applying these corrective actions

The assumptions of the ITF-framework lead to the conclusion that the efficient regulation of task processing may be affected by factors of both, the internal and the external feedback loops.

Another strand of theoretical and empirical foundations for our work is the pedagogical and psychological work on misconceptions and conceptual change [20, 22, 12] as well as on Grundvorstellungen[1] for fractions [10, 18, 3]. We base our ontology on these results (relations of Grundvorstellungen and misconceptions to concepts, examples, exercises), build the diagnosis of student actions on these results, and design and choose system feedback according to the systems belief about the student's Grundvorstellungen and misconceptions.

2.2 Technology for Adaptive Feedback

Adapting the content and form of feedback as well as the tutorial strategy to the different needs of learners in maths education requires a generic knowledge representation for interactive exercises (from which diverse presentations can be generated) as well as a flexible architecture and modules for generating the feedback.

An exercise in ActiveMath is represented as a finite state automaton. It consists of states representing tasks and transitions representing reactions upon the learner's answer. The exercise subsystem architecture allows for playing the exercise according to the given tutorial strategy. A tutorial strategy is an algorithm transforming the exercise automaton adding/removing states and transitions to/from the exercise. It can use feedback authored for this exercise or, if necessary, it requests the `Feedback Generator` component to generate feedback of different types. The characteristics of feedback to be generated depend on the tutorial strategy and on the diagnosis upon the learner's answer. For adaptation purposes, information from learner model can be requested.

[1] Grundvorstellung could vaguely translated as 'meaning' although its is somewhat different so we use the notion 'Grundvorstellungen'. Examples for Grundvorstellungen for fractions are part-of-a-whole, ratio, quotient, measure and proportion

For more information on this architecture and the exercises format see [6].

Exercise automaton can be authored manually or generated automatically by custom extensions of exercise subsystem, that are bound to a particular domain reasoning engine.

The exercises in ActiveMath may have not just one possible solution - in the opposite: where domain reasoners are available many correct and incorrect solutions can be processed. Morover, multiple solutions can be encoded into a manually authored exercise automaton as well.

Both ways of creating exercises can contain pure domain- and pedagogical expertise. Authors can encode transition conditions and feedback corresponding to typical errors empirically investigated for the domain of an exercise. In case of domain reasoner usage, many typical errors can be operationalized by so-called buggy rules.

The domain reasoner approach is in general more flexible then hand-crafted exercise automatons, since it can accept different correct solutions even when the learner combines several steps in one, recognize complex errors, even if several errors were made within one step. Example of such domain reasoner can be found in [24].

Before application of a tutorial strategy, an exercise automaton is relatively simple - it usually consists of a sequence different states of exercise solution with transitions matching correct answers and possibly typical incorrect answers. For matching the answers literal comparisons of learner's answer to the expected one can be used, as well as semantic comparisons with the help of Computer Algebra Systems. Automatically generated exercises can use custom diagnosis components powered by a domain reasoner.

At the moment tutorial strategies in ActiveMath are designed by pedagogues and operationalized in form of programs transforming the exercise automaton.

One of the methods to come up with an effective tutorial strategy that is being used by our partner psychologists in their experiments is to generate buttons for all kinds of feedback available in the exercise step and let the learner choose his feedback. Tracing the behaviour of learners (i.e. which types of feedback and in which sequence they used) and corresponding impact on performance could give a raise to devising an effective tutorial strategy.

Among other methods are discussions with

- teachers
- experts for the teaching of mathematics
- educational psychologists
- tests with students including asking for their satisfaction

In order to facilitate learner's work, so called scratchpad is planned to be implemented within an exercise strategy. It is an area within an exercise window, in which the learner can type any intermediate steps or notes about solution. It will allow the learner construct his solution even without submitting it to the system in each step. The solution can be submitted into the system later step-by-step or at once in case of possessing a domain reasoner.

Why this is an appropriate field for AI. A number of AI-techniques can be applied for the purpose of generating and adapting feedback:

- automatic diagnosis with domain reasoner and integrated CASs
- heuristic search for the most likely diagnosis
- ontologies for representing not only domain knowledge but also educationally motivated elements such as Grundvorstellungen and misconceptions as well as their relations to domain elements
- separation of the exercise representation and the functionalities working for that exercise, such as generation of presentations, generation of feedback, application of tutorial strategies, choice of exercises,
- student modeling for cognitive and motivational student variables

2.3 Feedback Strategies Available in ActiveMath

Currently, we are working on tutorial strategies that support specific cognitive processes for mathematics task and relate to motivational aspects of the learner. This will extend the arsenal of tutorial strategies described below.

Teacher's Strategy in Fractions Application In the Fraction Application several tutorial strategies for adaptive feedback are used. When the strategy 'decompose-into-subgoals' is used, the problem is divided into sub-problems in case the learner is unable to solve the full problem at once.

The strategy 'simpler-version' is suggesting to tackle a problem, similar to the one in which the learner has failed in the step, but technically a simpler one, to remove the overload caused by complicated mathematical terms.

The Figure 2 shows sample application of both strategies to the fraction addition problem. The left hand side screenshot shows the application of 'decompose-into-subgoals'. The right hand side screenshot shows the application of 'simpler-version' to a subgoal of the 'decompose-into-subgoals' strategy.

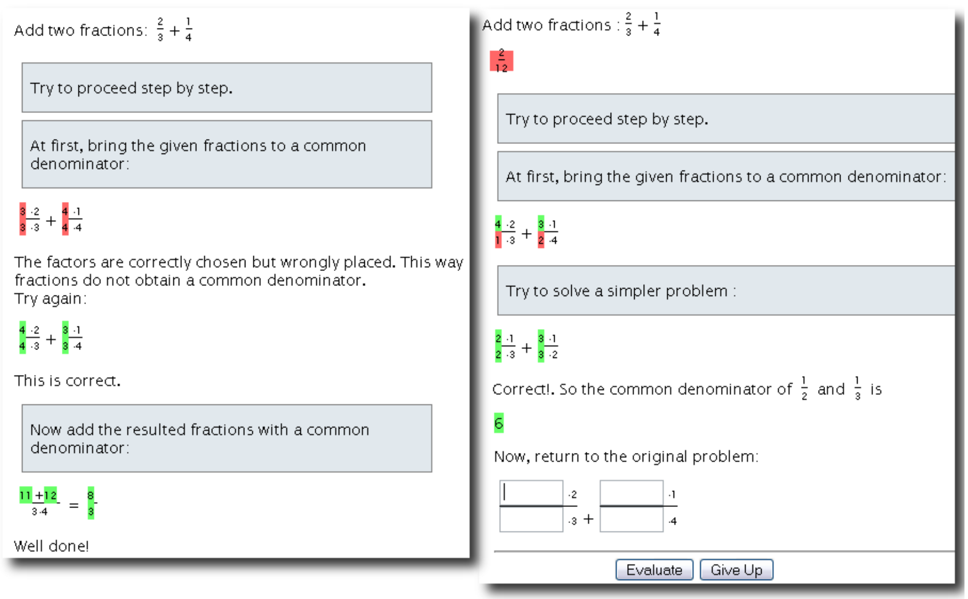

Figure 2: Sample application of 'decompose-into-subgoals' and 'simpler-version'

Educationalist's Strategy in LeActiveMath Sequenced hints of different function and level of detail are given for each important exercise step followed by the solution. The default tutorial strategy of LeActiveMath exercises incorporates several well-researched micro-strategies such as KR (knoweldge of result + position of the error), AUC (answer until correct) and simple hint scaffolding cascaded from general towards more detailed hints.

Another strategy used in LeActiveMath is an assessment strategy for multi-step exercises. This strategy is removing all the feedback and allows the learner to make only correct steps. As soon as the learner makes an error in a step, he fails the entire exercise. Note that this does not mean that there is only one correct solution. If several correct solutions are possible in the exercise, all of them remain valid.

Feedback Strategy in Matheführerschein Within the German Mathe-führerschein a special feedback strategy has been used for exercises. In this strategy, again the correct/incorrect feedback

(KR) is used, followed by a correct solution upon user request.

An important aspect that was used in this strategy is the placement of feedback in the immediate vicinity of the error, if possible. Another pedagogical aspect was to introduce the mathematical equivalence modulo a certain 'context' that was used for the evaluation of the learner's answer.

3 Conclusion

Here we summerize the work already done and discuss some future work.

ActiveMath's subsystem for interactive exercises is fully implemented and running with two tutorial strategies designed by LeActiveMath pedagogists with LeActiveMath content on differential calculus. Also the strategy for Matheführerschein exercises, developed by pedagogists at FH Dortmund is running under the Matheführerschein portal. It runs for wide range of exercises for school mathematics topics.

Capacity of ActiveMath's exercises subsystem for adapting different feedback dimensions is being exploited and tested by our psychology partners from TU Dresden. Feedback strategies 'simpler-version' and 'decompose-into-subgoals' are being imlpemented and a new presentation strategy is being set up for experiments. Until the summer 2008 the implementation of the latter two tutorial strategies will be finalized in the context of fractions domain. Also the semantic scratchpad will be integrated.

In the following step, other strategies, adapting the function, content and form of feedback to the learner characteristics and instructional context will be derived from the results of empiric research at TU Dresden.

Also strategies for self-regulated learning are planned, suggested by pedagogists and cognitive psychologists at TU Darmstadt, who are going to test them in a cognitive experiment.

Acknowledgement The work reported here was funded by the DFG-project ATuF (Me 11 36-75-1). Many thanks go to our collaborator Susanne Narciss.

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