

# A Methodology for Adaptive Competence Assessment and Learning Path Creation in ISAC

Alexander Nussbaumer<sup>1,2</sup>, Christian Gütl<sup>2,3</sup>, Walther Neuper<sup>2</sup>

<sup>1</sup> University of Graz, <sup>2</sup> Graz University of Technology, <sup>3</sup> Curtin University of Technology

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## Abstract:

*In this paper a technique is presented how to realise adaptive competence assessment and the creation of adaptive learning paths for the ISAC system. ISAC is an intelligent tutoring system which supports the learner in solving problems in applied mathematics. It is able to monitor and support the learner in each calculation step. However, it does not support building user and competence profiles and sequencing of problems and learning objects based on the personal needs. Therefore, a technique has been developed and integrated with ISAC, which allows for assessing the competence profile of learners and creating learning paths adaptively based on the assessed competences. Development has been done in a modular way which also provides other features such as goal setting and visual feedback of skill gaps and progress.*

## 1 Introduction

Computer tools for numeric and symbolic mathematics have gained increasing interest in different educational settings. Application scenarios in secondary education focus mainly on the support of solving physical and engineering problems and e-assessment scenarios. In most cases learners are provided with domain-specific support for solving such problems.

In e-learning a lot of pedagogical and psychological approaches have been developed and successfully applied. In the research area of adaptive e-learning systems sophisticated approaches have been developed which allow for modelling learner knowledge or adapting learning paths to learners based on their current knowledge and preferences. These techniques are domain independent meaning that they are generic and can be used for all domains. Competence-based Knowledge Space Theory (CbKST) is one method which allows for assessing the competences of a learner and for adapting the content and learning paths based on the competence state. Furthermore, goals can be set in terms of skills to be achieved and skill gaps can be identified by comparing current competence state with the goal.

In this paper the ISAC computer algebra system is used as an example to demonstrate this approach of integrating CbKST concepts and methods in a mathematics system. ISAC is introduced and shortly described from the learning perspective in the next section. In order to integrate the features from CbKST into ISAC, the concepts and methods of CbKST are related to the techniques and elements used in ISAC. The main part of this paper deals with that integration on a conceptual level, which is the basis for the implementation.

## 2 Problem Solving with ISAC

Most educational tools for formula-based mathematics are based on numerical computation or on symbolic computation, in the latter case on computer algebra systems (CAS). A major drawback of these systems is, that they have the mathematics knowledge built into the code and thus not in a readable format. Computer theorem provers (CTP) have knowledge on a separate language layer in a human readable format. CTP also allow to prove, that some user input can be derived from a certain state of a calculation.

The ISAC (ISAbelle for Calculations in Applied Mathematics) system [4] is a single stepping system which is based on the CTP Isabelle [3]. To fulfill educational purposes, ISAC meets the following requirements which are not given in traditional algebra systems [8]: (1) problems of 'applied math' are automatically solved from a given formalization; if nothing is given, support for interactive formalization is provided; (2) calculations are presented close to paper and pencil work and relations to underlying knowledge is shown; (3) calculations can be traced down to elementary steps; (4) the user can do all steps him- or herself and gets feedback on these steps or can switch to a demonstration mode; (5) explanations are generated automatically on request of the user.

ISAC has been developed based on these requirements in the last years and implementation is still ongoing. Users get a worksheet for each problem where they can solve the respective problem step by step similar as they would do it with paper and pencil. This is done by transforming mathematical terms by applying theorems of algebra and logics. Each new term is proved by ISAC for correctness and respective feedback is provided. Independently of the result, the user can get more information and background knowledge on the applied theorem. If the user fails to transform a term, he or she can require the automatic transformation from ISAC. In this case, ISAC searches for a suitable theorem, applies it and also reveals it to the user. Automatic transformations can also be done until the final solution of the calculation is reached. In each step the user gets feedback (which theorem has been applied), support (a theorem can automatically be applied) and explanation (background knowledge of a theorem).

In contrast to other assessment systems, ISAC not only 'knows' if the result calculated by the user is correct or not, ISAC has also the possibility to introspect the several steps. For example, if a result is not correct, but several steps are correct and at a certain step the user fails, than ISAC can provide help for exactly this step though explanation of the underlying and needed theorem. Furthermore, it is then known where exactly the user fails.

In order to provide feedback to the user, the CTP Isabelle [3] maintains a logical context within a calculation. The context allows for proving correctness of user input. For step-by-step calculations a rewriting mechanism is implemented which makes use of mathematical theorems. These theorems are applied to mathematical formulas in order to transform a formula or term to a more useful one. Rewriting is very close to what humans do when applying certain theorems to certain formulas [8].

For the purpose of this paper, a very interesting part of this approach is, that ISAC has available a set of mathematical theorems and can apply them on expressions. When solving a calculation step by step, it is known afterwards which theorems were needed. For different calculations different theorems are needed and in this way the calculations can be characterized by the applied theorems. However, since usually different 'ways' to the solutions can be chosen (different theorems can be applied), a calculation is not necessarily characterized by one set of theorems but can be characterized by different ones.

### 3 Integrating Competence Assessment Extension into ISAC

As interactive system ISAC tracks what users are doing, especially if their calculation steps are correct or not and if the final result is correct or not. If a user rewrites a calculation step correctly, it can be concluded that this user understands this theorem. Being able to apply a theorem can also be interpreted as a skill or competence. So a connection can be made between formally expressed theorems which can be used by computer systems and the knowledge and skills of humans. In order to make effective use of this relationship, a model from cognitive psychology has been chosen which can put the relations between assessment items and underlying knowledge (skills to solve them) on a sound basis.

Competence-based Knowledge Space Theory (CbKST) [1] is a psychological framework for representing knowledge and competence states of learners and for adaptively and efficiently testing these states. It incorporates underlying cognitive constructs in order to explain observable behaviour. In this sense skills and competencies can be formally modelled and assigned to problems and to learners [5,7]. In order to use CbKST in e-learning applications, it is necessary to model and to build formal readable relations between content, learning objects, learners, and skills. The skills (and competencies) are the cognitive constructs which are assumed that learners have if problems can be solved. Problems are posed to learners for the reason of assessing their knowledge states. To include the curriculum in this model, knowledge domains are modelled as concept maps and concepts are related to skills by combining concepts with actions verbs, such as understanding or knowing a concept [6].

In order to connect the ISAC model with CbKST, the following approach has been chosen: As indicated above, a skill in CbKST is defined as the combination of declarative knowledge (concepts) and procedural knowledge (actions on concepts). For example, applying a specific mathematical formula is seen as skill where the declarative knowledge is the formula and the procedural knowledge is the application of this formula. If an assessment item requires the application of this formula in order to solve it, then this skill is assigned to that assessment item. Considering the structure of ISAC where theorems can be assigned to mathematical calculations, a matching can be done between calculations and assessment items, as well as between theorems and declarative knowledge. Procedural knowledge is matched to the fact that users apply theorems in ISAC. So the ISAC calculations can be regarded as assessment items and the applications of theorems in ISAC can be regarded as skills.

Using this approach the whole CbKST framework can be used with ISAC. Adaptive assessment can be applied meaning that the sequence of calculations can be determined by the CbKST framework and that not all calculations have to be performed by the user to assess her knowledge and skill state. Learning paths can be created in the same way and goal setting can be done by selecting the skills to be attained. ISAC benefits from this approach, since a user model approach and an efficient algorithm for adaptive assessment can be integrated with ISAC without much effort. On the other hand, CbKST benefits from the fact that also intermediate steps (applied theorems) are reported when learners are solving problems.

The implementation has followed the design approach for integrating CbKST Web Services with Learning Management Systems (LMS) [9]. This approach outlines how user and domain model and the algorithms for adaptive assessment and learning path creation is encapsulated in a Web Service and connected to a LMS (ISAC in this case). Learners can also access this Web Service directly to get visual feedback regarding their knowledge and competence states, their goals and their skill gaps. Opening up such underlying structures has positive effect on meta-cognitive activities of the learner [2].

## 4 Conclusion and Outlook

In this paper approach and implementation has been presented how adaptive competence assessment and adaptive learning path creation can be integrated into ISAC. Further work will be done towards a more tight integration of ISAC and CbKST. Currently the intermediate calculation steps (application of theorems) of learners are not reported to the CbKST Service. Next step will be also to report these intermediate steps and to elaborate how this information can be used. For example, if learners have often problems with the same theorem, special support can be provided. Secondly, if a learner does not solve a calculation correctly, but succeeded with some initial theorems, then these theorems (or skills) can be considered as available and updated in the user model.

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### Authors:

Alexander Nussbaumer, Dipl.-Ing.  
Cognitive Science Section, Department of Psychology, University of Graz, Austria  
Knowledge Management Institute, Graz University of Technology, Austria  
Brueckkopfgasse 1, A-8010 Graz, Austria  
[alexander.nussbaumer@uni-graz.at](mailto:alexander.nussbaumer@uni-graz.at)

Christian Gütl, Dipl.-Ing. Dr. techn.  
Institute for Information Systems and New Media, Graz University of Technology, Austria  
Curtin University of Technology, Perth, WA, Australia  
Inffeldgasse 16c, A-8010 Graz, Austria  
[cguetl@iicm.edu](mailto:cguetl@iicm.edu)

Walther Neuper, Dr. techn.  
Institute for Software Technology, Graz University of Technology, Austria  
[neuper@ist.tugraz.at](mailto:neuper@ist.tugraz.at)