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ITS evaluation in classroom: the case of the AMBRE ITS

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Abstract

This paper describes the evaluation of an Intelligent Tutoring System (ITS) designed within the framework of the multidisciplinary AMBRE project. The aim of this ITS is to teach abstract knowledge based on problem classes thanks to the Case-Based Reasoning paradigm. We present here AMBRE-AWP, an ITS we designed following this principle for additive word problems domain and we describe how we evaluated it. We conducted this evaluation in classroom with 76 eight-year-old pupils, relying both on human computer interaction and cognitive psychology techniques.

Keywords: Intelligent Tutoring System evaluation, learning evaluation, additive word problems, teaching methods, Case-Based Reasoning

Introduction

This paper describes studies conducted in the framework of the AMBRE project. The purpose of this project is to design an Intelligent Tutoring System (ITS) to teach methods. Derived from didactic studies, these methods are based on a classification of problems and solving tools. The AMBRE project proposes to help the learner to learn a method following the steps of the Case-Based Reasoning (CBR) paradigm.

We applied this principle to the additive word problems domain. We implemented the AMBRE-AWP system and evaluated this system with eight-year-old pupils in different manners.

In this paper, we first present the AMBRE principle. Then, we describe its application to additive word problems and two experiments intended with eight-year-old pupils in laboratory and in classroom to evaluate the AMBRE-AWP ITS.

The AMBRE project

The purpose of the AMBRE project is to design an ITS to help learners to learn methods [0]. In a domain, method is based on didactic studies. The AMBRE principle

is to use the Case-Based Reasoning paradigm to use problems already met during learning, in order to facilitate the method learning.

In this section, we first present what is a method. Then, we describe how we use the CBR paradigm in the AMBRE project. Last, we present the design cycle of the system.

Method learning

The methods we want to teach in the AMBRE project were suggested by mathematic didactic studies [0] [0]. In a small domain, methods are based on a classification of problems and of solving tools. The acquisition of these classifications enables the learner to choose the solving technique that is best suited to a given problem to solve.

The AMBRE project aims at designing an ITS the purpose of which is to have the learner acquire a method.

However, in some domains, it is not possible to teach explicitly problem classes and solving techniques associated with those classes. So, the AMBRE project proposes to enable the learner to build his own method using the case-based reasoning paradigm.

Guiding learning using the Case-Based Reasoning paradigm approach

Case-Based Reasoning [0] can be described as a set of sequential steps (elaborate, retrieve, adapt, revise, store) that is often represented by a cycle [0] [0] (Fig. 1).

In the AMBRE project, CBR is not used by the system, but proposed to the learner as a learning strategy. The learner has to retrieve a case himself. Moreover, the complete CBR cycle is used from elaboration to storing.

Thus, in order to help the learner to acquire a method, we propose to present him a few typical worked-out examples (serving as case base initialization). Then, the learner is assisted in solving new problems. The environment guides the learner's solving of the problem by following each step of the CBR cycle (Fig. 2): the learner reformulates the problem in order to identify problem structure features (elaboration). Then, the learner retrieves a typical problem from the case base (retrieval). Next, the learner adapts the typical problem solution to the problem to solve (adaptation). Finally, the learner stores the new problem in the case base (storing). The steps are guided by the system, but done by the learner. In the AMBRE ITS, revision is included in each step of the cycle, as it is explained in part 3.

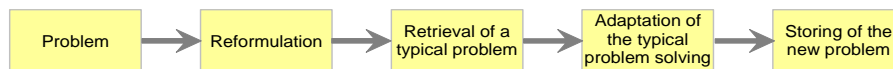


Fig. 2. The CBR cycle adapted to the AMBRE project

Design process

In this section we present the design process used in the AMBRE project. Figure 3 shows the AMBRE project development cycle adapting a diagram proposed by Bruillard & Vivet [0] that highlights users, tests and validations. The preoccupation with validating multidisciplinary design choices and detecting problems of use as early as possible leads us to the adoption of an iterative design process based on the implementation of prototypes that are tested and then modified.

Before the AMBRE design, the SYRCLAD solver [0] was designed to be used in ITS. SYRCLAD solves problems according to the methods we want to teach [8]. This solver was tested by researchers (Fig. 3, 1).

To begin the AMBRE design, we specified the objective of the project (to learn methods) and the approach to be used (CBR approach) (Fig. 3, 2a). Then we developed a first simple prototype (AMBRE-counting) for the numbering problems domain (final scientific year level, 18 year-old students) (Fig. 3, 2b). This prototype implemented the AMBRE principle with a limited number of problems, and limited functionalities (the Artificial Intelligence modules were not integrated). This prototype was evaluated (Fig. 3, 2c) in classroom using experimental method of cognitive psychology to assess the impact of the CBR paradigm on method learning. The results did not show significant learning improvement using the AMBRE ITS. Nevertheless, we identified difficulties experienced by learners during the system use [14]. These results and complementary studies of cognitive psychology led us to recommendations and new specifications (Fig. 3, 3a).

After that, we implemented a system for additive word problem solving (AMBRE-AWP) taking into account the previous recommendations and specifications. This system includes a new interface, the SYRCLAD solver, and help and diagnostic functionalities.

This system was evaluated by developers and teachers, and used by children in laboratory. Then it was used by pupils in classroom (Fig. 3, 3c).

In next sections, we present in more details AMBRE-AWP and we describe the evaluation of the system.

AMBRE-AWP : an ITS to solve additive word problems

AMBRE-AWP is an ITS for additive word problem solving based on the AMBRE principle. This ITS is designed to be used individually in classroom in primary school by eight-year-old pupils. We chose the problems to solve and we adapted the vocabulary to these users.

We chose additive word problems domain because this difficult domain for children is suitable to AMBRE principle. Learners have difficulties to visualize the problem situation [0]. Didactic studies proposed additive word problems classes [0] identifying problem type (add, change, compare) and place of unknown that can help learners to visualize the situation. Nonetheless, it is not possible to teach these classes explicitly. AMBRE principle might help the learner to identify problem's relevant features (the problem class).

In this section, we present AMBRE-AWP functioning: we describe the steps that enable the learner to solve the problem.

Reformulation of the problem: In AMBRE-AWP, once the learner has observed examples and read the problem to solve (e.g. “Julia had 17 cookies in her bag. She ate some of them during the break. Now, she has 9 left. How many cookies did Julia eat during the break?”), the first step consists in reformulating the problem to be solved. The learner is asked to build a new formulation of the submitted problem identifying the relevant features of the problem to be solved (i.e. problem type and unknown place). We chose to represent problem classes by diagrams that we adapted from didactic studies [0] [0] (Fig. 4). The reformulation no longer has most of the initial problem’s surface features, and becomes a reference for the remainder of the solving.

Retrieval of a typical problem: The second step of the solving consists for the learner in comparing the problem to be solved with the typical problems by identifying differences and similarities in each case. The typical problems are represented by their wording and their reformulation. The learner should choose the problem that seems the nearest to the problem to be solved, such nearness being based on reformulations. By choosing a prototype problem, the learner implicitly identifies the class of the problem to be solved.

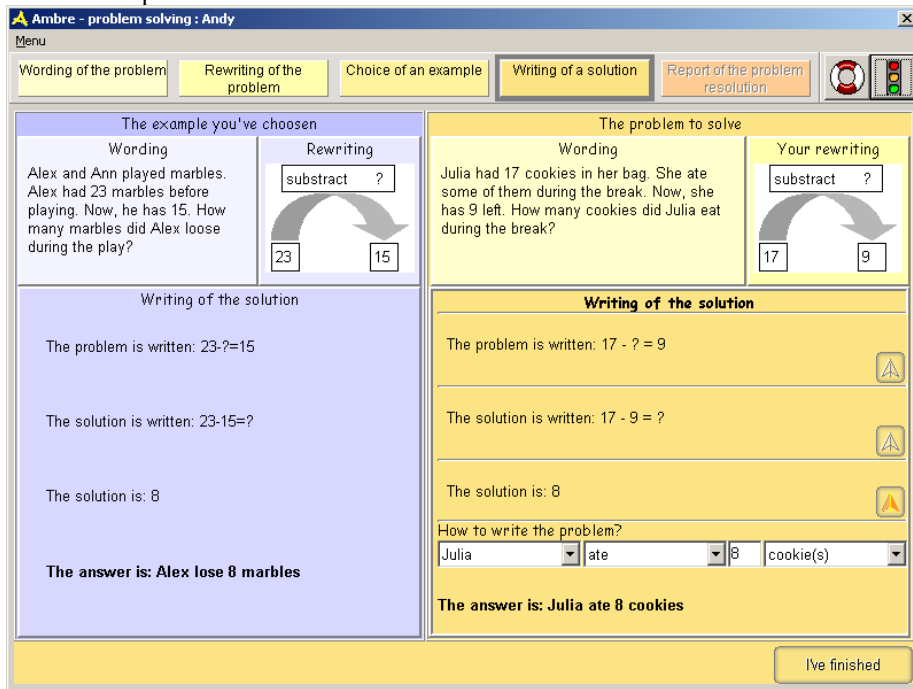


Fig. 5: Adaptation step in AMBRE-AWP

Adaptation of the typical problem solution to the problem to solve: In order to redact the solution, the learner should adapt the solution of the typical problem he chose in the previous step to the problem to be solved (Fig. 5). If the learner uses the help functionality, the system can assist the adaptation by outlining with colors similarities between the typical problem (Fig. 5: left side) and the problem to solve (Fig. 5: right side). The solution writing consists first in establishing the equation

corresponding to the problem. Then, the learner writes how to calculate the solution and then calculates it. Finally, the learner writes a sentence to answer the question.

Storing of the new problem: Finally, the learner stores the new problem with a typical problem that represents a group of existing problems of the same class. During that step, the learner should identify the group of problems associated with the problem to be solved.

Revision: Contrary to the classical CBR cycle, the revision is not a step in the AMBRE cycle. In our system, the revision step is replaced with a diagnostic at the end of each step. This diagnostic indicates to the learner mistakes he or she made and sometimes additional information. For instance, when an error occurs in the reformulation step, the system generates the problem wording corresponding to the reformulation made by the learner. Thus, the learner can compare the wording generated by the system with the wording of the problem to solve.

AMBRE-AWP evaluation with eight-year-old pupils

To evaluate a system, Senach [0] distinguishes two aspects: the usability and the utility of the system. Usability concerns the capacity of the software to allow the user to reach his objectives easily. Utility deals with the adequacy of the software to the high level objectives of the customer.

In the case of ITS, the user is the learner and the customer is the teacher or the “educational system”. So, we must take into account learner specificity in the usability evaluation. The high level objective of ITS is learning. So, the evaluation of the system utility concerns the evaluation of the learning. In our case, we have to evaluate the method learning. If usability can be evaluated with classical methods developed in Human Computer Interaction (HCI) domain, learning evaluation requires using specific methods.

In this section, we present the AMBRE-AWP evaluation with eight-year-old children. We first describe a pre-experiment in laboratory, which enabled us to evaluate usability. This pre-experiment led to modifications of the system. Then, we present evaluation of AMBRE-AWP utility in classroom, describing our objectives, the method we use and the expected results.

Pre-experiment in laboratory

We evaluated AMBRE-AWP in a pre-experiment in order to observe the appropriateness of the system to the learners and to identify usability problems.

Due to the specificity of the learners (young children, beginner readers, not very familiar with computer), we chose to use one to one testing [0]: we observed in details how each learner interacted with the instructional material and then, we presented him or her a questionnaire.

Experimental method

According to Nielsen [0], the observation of five users allows to detect the main usability problems. So, we observed individually five eight years old learners using AMBRE-AWP. They had to solve two additive word problems with the system during 45 minutes.

During the use of the system, we observed interactions between the children and the system, gestures, non verbal behaviours, and we recorded what users said. After the use of the system, learners filled up a questionnaire (a one short in order to avoid cognitive overload). This questionnaire enabled us to know if learners liked mathematics, if they were familiar with computer use and their satisfaction.

Before the experiment, among existent usability criteria, we referred to the criteria proposed by Bastien & Scapin [0], Nielsen [0] and Schneiderman [0] and we chose criteria adapted [0] to observe AMBRE-AWP usability:

- **Learnability** (the degree to which a user interface can be learned quickly and effectively): How do users understand the system use?
- **General understanding**: do users understand the software principle?
- **Effectiveness** (the degree to which an interface facilitates a user in accomplishing the task for which it was intended): is there some interface elements that lead to systematic errors?
- **Error management**: is there ergonomic problems which lead to errors? Do users understand their errors? How do they react to feedback messages?
- **Help management**: do users use the help functionality and understand the help messages?
- **Cognitive load**: is there a cognitive overload?
- **Satisfaction**: is the system pleasant to use?

Results

We noticed that all users we observed were familiar with computer use (regular use at school or at home) and liked mathematics. Some of them were poor readers.

First, as we expected, observations showed that users passed a lot of time to discover interface elements (e.g.: list-box). Although users encountered difficulties to use the system during the first problem resolution, these difficulties disappeared during the second problem resolution. So, the interface use seemed to be time consuming but well understood. The general understanding of the system seemed to be difficult: users did not understand well the link between solving steps and the AMBRE principle. They began to understand it only at the end of the first use.

Moreover, we observed cognitive overload during the worked-out examples presentation and the adaptation step. Furthermore, in the adaptation step (Fig. 5), learners had difficulties to write how to calculate the solution. This step was not appropriated to eight-year-old learner knowledge.

The observation of the help functionality use showed that help was often used. Nevertheless, children did not well understand help and error messages.

Finally, the questionnaire analysis showed that four users among five were satisfied and consider AMBRE-AWP pleasant to use.

We take into account these results to adapt AMBRE-AWP to eight-year-old users capabilities, modifying the system. For example, in order to facilitate the system learnability, we chose to replace the tutorial with a demonstration explaining the

AMBRE principle and showing how to use the interface during the first session; to reduce cognitive load, we modified the examples presentation. Moreover, we deleted the adaptation sub-step which was not appropriate to learners of this age.

Learning evaluation

After the pre-experiment, we are now evaluating the utility of the modified system: we measure the AMBRE-AWP effect on method learning for additive word problems.

In this aim, we use experimental method [0]. Thus, we are comparing AMBRE-AWP use with the use of two control prototypes during six sessions in classroom. We measure outcomes learning by different ways and we complete these data with a qualitative approach.

Specific questions to answer: During this experiment, we want to evaluate the AMBRE-AWP impact on method learning.

More precisely, we would like to know if the AMBRE-AWP has an impact on the learner ability to identify the class of a problem (i.e. problem type and unknown place) and to establish the equation corresponding to the problem class.

We state that

- AMBRE-AWP enables to identify that two problems have the same type.
- AMBRE-AWP enables to recognize problem type and unknown place, whatever surface features and difficulty of the problem.
- AMBRE-AWP might enable the learner to find the equation corresponding to the problem class.
- The identification of problem class might help pupils to solve difficult problems.

Moreover, we want to know if the AMBRE-AWP impact is due to CBR approach or if it is only due to problem reformulation with diagram.

Furthermore, we would like to understand learning processes implied in the system use. And eventually we want to observe how learners appropriate AMBRE-AWP during a repeated use.

Situation of evaluation: We designed AMBRE-AWP to be used in classroom. Thus, the experiment was conducted in classroom with 76 eight-year-old pupils divided in six groups in order to reproduce actual use conditions. During six weeks, each group work in computer classroom and use the software during half an hour. Each child uses the software individually.

Evaluation paradigm: We use a comparison design between three systems: the AMBRE-AWP ITS and two control systems (Fig. 6).

The whole system, AMBRE-AWP, guides the solving toward the CBR cycle according to the AMBRE principle.

The first control system, the “reformulation and solving system” presents worked-out examples and guides the learner to solve the problem. The learner reformulates the problem and then redacts the solution. Finally, he can read the problem report. In contrast with AMBRE-AWP, this system does not propose to retrieve and use a prototypical example. The aim of this control system is to verify the impact of reformulation with diagrams on learning.

The second control system, the “simple solving system”, proposes to find the problem solution directly. The system presents worked-out examples. Then, after the problem

presentation, the learner redacts the solution. Finally, he can read the problem report. Contrary to the AMBRE-AWP ITS, there is no reformulation and retrieval steps. As this system has fewer steps than the others, learners have to make another task after problem solving. This task consists in finding pertinent information in a text to answer a question so that all groups solve an equivalent number of problems.

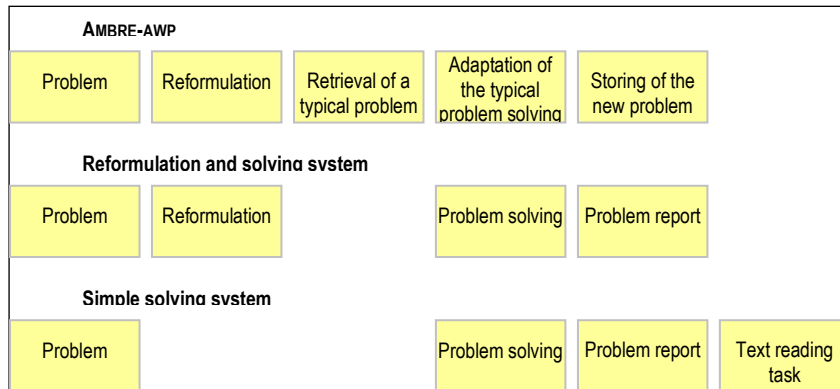


Fig. 6. The three systems used in the experiment

In each of the three pupils classes one group uses AMBRE-AWP and the other uses one of both control systems. Learners are assigned to groups according to their mathematical level so that groups are equivalents. In order to measure the learning outcomes, we use a “structure features detection task”, a problem solving task and an “equation writing task”.

“Structure features detection task” consists in reading a first problem, and then choosing between two problems the one that is solve like the same solution than the first problem. To choose problems for this task, we manipulate unknown place, problem type and surface features. This task enables to evaluate learner ability to identify two problems that have the same structure features.

Problem solving task consists in solving six problems, two problems close to problems presented by the system (“easy problems”), two problems that content non pertinent data for the resolution (“difficult problems”) and two “transfer problems” (problems with non pertinent data and surface feature not presented by the system).

“Equation writing task” consists in writing the equation corresponding to a proposed diagram. This task allows us to test the learner ability to associate the corresponding equation with the problem class (represented by diagrams). This task is realized only by groups that made the reformulation step (the AMBRE-AWP group and the “Reformulation and solving system” group).

The experimental design we adopt was an *interrupted-time series design* (Fig. 7): we present the problem solving task as pre-test, after the fourth system use, as post-test and differed post-test. The “structure features detection task” is presented after each system use; the “equation writing task” is presented after the fifth system use and as post-test.

At the end of this experiment, we expect that the use of the AMBRE-AWP system improves learning outcomes and facilitates the acquisition of problem classes:

- With the “structure features detection task”, we expect that, in post-test, the AMBRE-AWP group chooses more often the problem which has the same structure features than the group that use the “simple solving system”.
- With the problem solving task, performances in post-test may be better than in pre-test in all groups and with all problems. Moreover we might observe significant differences between the AMBRE-AWP group and the group that use the “simple solving system” for difficult problems and transfer problems solving performances.
- With the “equation writing task”, we expect that learners are able to write the right equation corresponding to a diagram.
- The comparison between the results of the “AMBRE-AWP” group and the “reformulation and solving system” group will inform us about the impact of the reformulation using diagram on learning outcomes.

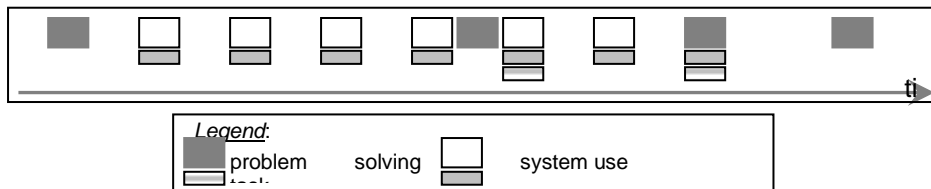


Fig. 7. Experiment design

Qualitative approach: The experimental method enables us to evaluate learning outcomes, but it does not allow us to take into consideration others aspects:

- We would like to understand strategies learners use to solve problems with AMBRE-AWP.
- We want to identify difficulties encounter by learners. More precisely, do these difficulties disappear during a repeated use of the system or do they persist?
- We want to take into account the complexity of the situation. Thus, we notice interactions between persons that supervise the sessions and learners and interactions between learners.

Therefore we complete our analyses using qualitative methods [0] [0].

Before the experiment, we made an “a priori” analysis in order to highlight the various strategies usable by learners who solve problems with AMBRE-AWP. During the system use, we notice all questions asked. Moreover, we observe the difficulties encountered by learners, the interactions between learners and the interactions between learners and persons that supervise the sessions. In post-test, the learners will fill up a questionnaire in order to take into account their satisfaction and remarks. Finally, we will analyse the use traces in order to identify the strategies used by learners, to highlight the most frequent errors and to identify the steps that cause 1 difficulties to earners.

For the moment, the experiment has begun, and we have no results yet. The experiment finishes in April. We will go to present results and discussion in the final version of the paper.

Conclusions and perspectives

The framework of the study described in this paper is the AMBRE project. This project relies on the CBR solving cycle to have the learner acquire a problem solving method based on a classification of problems. We implemented a system based on the AMBRE principle for additive word problems solving (AMBRE-AWP). Then we evaluated it with eight years old pupils. In the first experiment, we observed five children in laboratory, in order to identify some usability problems and to verify the adequacy of the system with this type of users. Then, we have set up an experiment in classroom with 76 pupils. We are comparing the system with two control systems to assess the impact of the AMBRE principle on method learning.

The experiment is not finished yet; we will present the results and discuss in the final version of the paper.

Future works on the AMBRE-AWP ITS concerns three main points.

We first want to design new activities on the links between the wording of the problem, its reformulation and its solving: how a modification on the wording acts on its reformulation, how a modification on the reformulation acts on its wording, and what are the consequences of these modifications on the solving.

We secondly plan to adapt AMBRE-AWP for other types of learners. The simplest change consists in adapting it for ten years old pupils, restoring the sub-step of solving that was not appropriate for height-year-old pupils, and proposing a new activity allowing to reorganise the groups of problems: what are the groups that look similar, what are their differences, etc. We also study the possibility to propose AMBRE-AWP to adults within a literacy context, using new story types in the problems wordings.

Thirdly, we are designing an environment for teachers enabling them to customize AMBRE-AWP environment and to generate the problems they wish their pupils to work on with the system.

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