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PÉPITEST, a software to establish the cognitive profile of the students in elementary algebra.

Stéphanie Jean, Élisabeth Delozanne, Pierre Jacoboni
LIUM (Laboratoire d'Informatique de l'Université du Maine)
Avenue Olivier Messiaen
72085 LE MANS cedex 9, France
jean@lium.univ-lemans.fr

Brigitte Grugeon
DIDIREM - Paris VII
2 place Jussieu
75 251 PARIS Cedex 05, France

Abstract: The work presented here is part of a multidisciplinary project, called the PÉPITE project. Its aim is to set up a system to diagnose student profiles starting from a multidimensional analysis grid to evaluate their competences in elementary algebra. This article deals with the conception, the making and the evaluation of an interface in Computer Based Learning Environments. In it, we present the method adopted to set up a software which proposes tasks to the students and collects data for the diagnosis module.

We consider here the problems linked to using didactic know-how related to pencil & paper tasks and in particular how to transfer these tasks to a data processing system. These problems are considered from the interface conceptor's point of view. In an attempt to make this clear, we make a distinction between ergonomy problems connected with the functioning of the interface and problems connected to the field of application.

Keywords: diagnosis of a student's knowledge, interface conception, evaluation of interface, student's modelling, mathematics.

1. INTRODUCTION

Studies in relation with Human-Computer Interaction draw attention to the fact that the user of a technical device faces a double problem: first, transferring his knowledge of the task and second, learning how to use the system [SENACH, 1993]. In Computer Based Learning Environments, these meaning transfer problems for the students are called by the didacticians « computational transposition » [BALACHEFF, 1994] [ARTIGUE, 1995]: technical and physical limitations interfere with the student's knowledge both at the representation level and at the action level. These limitations thus modify the perception of the effects of the actions. In our work, we use a pedagogical material previously intended for a pencil & paper environment. This article deals with the problems encountered by the Intelligent Tutoring System interface conceptors during the transfer from pencil & paper tasks to computerised tasks.

In this article, we consider these problems referring to a software realised as part of the PÉPITE project, which aims to describe the student's functioning in algebra, in order to establish their cognitive profile. The emphasis is laid on the method of conception adopted and the defining of evaluation criteria of the software. First, we present an analysis of the pencil & paper tasks to transfer and the aims of the system (needs analysis and task analysis). Then, we present the conception of the computerised tasks referring to what we want to observe in the student's productions. Finally, we present the experimentation of the software by the users.

2. THE BASIS OF THE PÉPITE PROJECT

The aim of the PÉPITE[1] project is to build a computerised environment able to «modelise» the reasoning process of the 15 years old students of French secondary schools (the year before the GCSE) in elementary algebra at the beginning of the year. The LINGOT project which will follow the PÉPITE project will use this «modelisation» to give the students appropriate learning situations likely to help the evolution of their knowledge. The idea is to seek out, in the student's way of functioning, the « grains » of knowledge (in French, the « pépites ») to use as a basis to build some new knowledge.

According to [BARON & VIVET 1995], the general problem of automatic diagnosis in an ITS is to infer the information of the learner's model from what is noticed of his behaviour, which means making an analysis and an interpretation of the data collected during the interaction. In the PÉPITE project, we base our work on a rigorous didactic and cognitive study which has been validated [GRUGEON, 1995]. This study allows us to establish cognitive profiles for students applying a multidimensional analysis grid to the answers given by them to a series of pencil & paper exercises (the pencil & paper tasks). In this part, we describe the basis of the project: the didactical analysis and the pencil & paper diagnosis tools created by Brigitte GRUGEON. After, we present the general architecture of the PÉPITE project.

2.1. THE DIDACTICAL ANALYSIS

This research in the didactics of mathematics starts from the hypothesis of knowledge building: the students have built up pieces of knowledge sometimes different from the reference knowledge. Consequently, the productions of the students present coherences and regularities which correspond to their personal knowledge. One of the results of this study[2] is a tool enabling us to interpret the productions in order to find the starting points to modify their knowledge. This tool (Cf. figure 1) combines a series of pencil & paper tasks with a multidimensional analysis grid allowing us to interpret the student's production to establish their

[1] Involving, in computer science, Martial VIVET, Élisabeth DELOZANNE, Pierre JACOBONI and Stéphanie JEAN from the LIUM (Laboratoire d'Informatique de l'Université du Maine) and, in didactics of mathematics, Michèle ARTIGUE and Brigitte GRUGEON from the DIDIREM laboratory of Paris VII.

[2] This thesis also contains a study of institutional relations of the students to algebra which is outside matters here.

profile in elementary algebra.

2.1.1. The pencil & paper tasks

Three types of pencil & paper tasks are proposed to the students during a test:
– *technical exercises* whose aim is to determine numeric calculating and formal manipulating procedure,
– *recognition exercises* which aim to determine how students identify and interpret algebraic expressions in the algebraic writings frame or linked with other frames,
– *modelling exercises* whose aims are to identify if the students use the expected algebraic type of treatment, how they translate problems in the algebraic frame and how they use the tools adapted for the solving the problems.

The students' answers to the exercises are, in this didactical work, analysed « by hand » by the teacher with the multidimensional analysis grid.

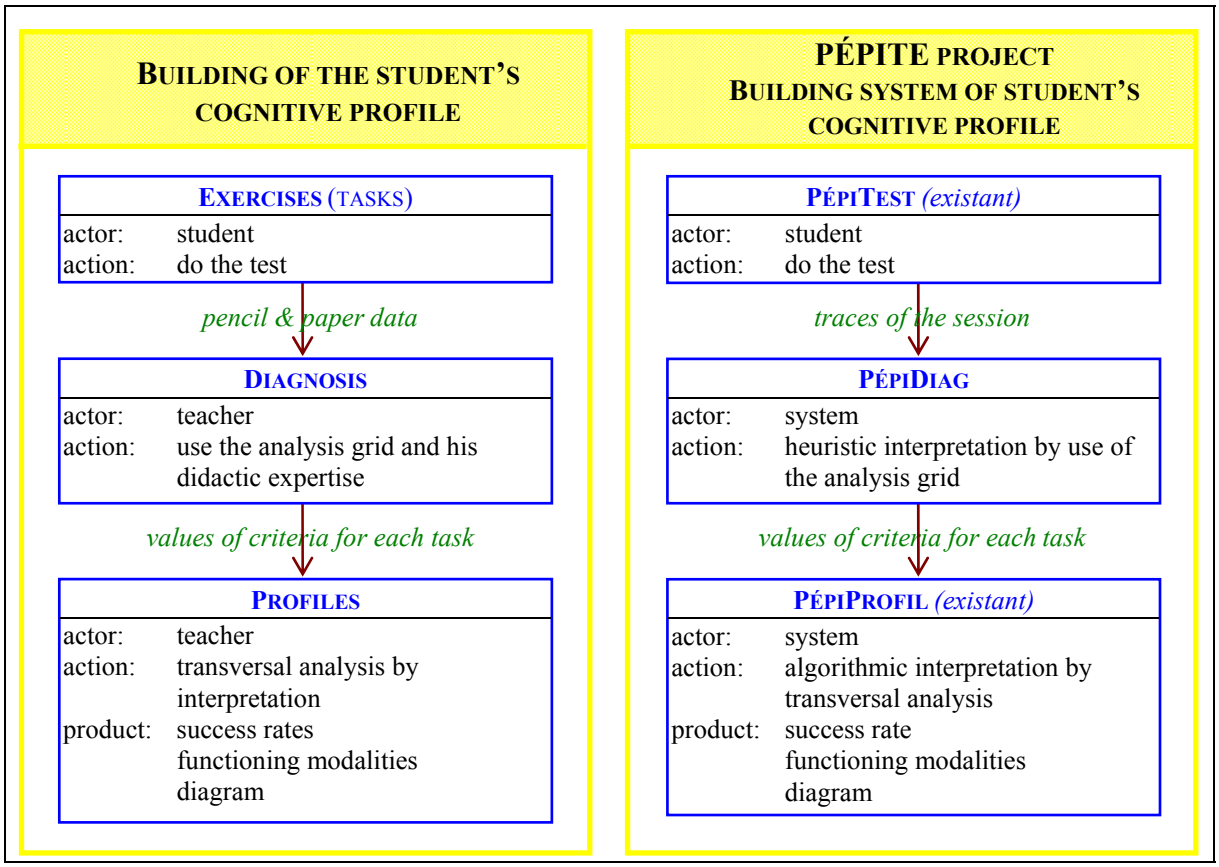


Figure 1: The pencil & paper diagnosis tool.

Figure 2: Architecture of the PÉPITE project.

2.1.2. The multidimensional analyse grid

This grid is made of five components [GRUGEON, 1995]:
– arithmetic / algebra relationship,
– operationality of formal manipulation of algebraic expressions,
– interpretation of semiotic representations in relation to algebra,
– production of semiotic representations in relation to algebra,
– role of algebra and rationality in algebra.

A set of criteria is associated to each of these components. For each answer given by the student the teachers award global values defined by the different criteria of the analysis grid.

Certain global values are specified by local values linked to the exercise.

2.1.3. The student's profiles

Applying the analysis grid to the productions of a pupil on the pencil & paper tasks produces for each pupil a set of values for each task. This result needs an important didactic analysis. This very fine description of the behaviour is too detailed to be used « as it is » by the teachers (or by a computer). A transversal analysis of the grid's results enables us to establish a higher level description: the « cognitive profiles » of the students. These profiles can be use to understand and modify the student's functioning and so to act against the pupil under-achievement.

These profiles have three levels of description:

– a *quantitative description* of algebraic competence in terms of success rates for the technical exercises and the modelling exercises,

– a *qualitative description* of functioning coherences, component by component, in terms of functioning modalities obtained by cross checking of values of certain criteria on the whole set of exercises,

– a description of flexibility between frames, represented by a *diagram*.

This diagnosis tool based on pencil & paper tasks has been tested several times. It has in particular been tested in June 1996 on 600 students of a third form class (14 years old students).

2.2. THE DIAGNOSIS IN PÉPITE

The PÉPITE project aims to automate the pencil & paper diagnosis tool invented by Brigitte GRUGEON. The architecture of PÉPITE contains three modules (Cf. figure 2):

– PÉPITEST which gives the students an adaptation of the pencil & paper tasks to the computer and which collects their answers. The difficulty resides more precisely in the transfer of the pencil & paper tasks to the computer platform. This software has been completed, this is the work which will be presented and discussed in this article.

– PÉPIDIAG which interprets and codes the students' productions, from the data furnished by PÉPITEST according to the multidimensional analysis grid, while awarding values to criteria tested by the exercise.

– PÉPIPROFIL which, from the preceding code, establishes the students' profiles and presents them to the users (teachers or researchers). This last module has been developed but it is not detailed here.

3. CONCEPTION OF PÉPITEST

In this paragraph, we present the conception procedure used to perfect PÉPITEST. We specify the dimensions, objectives and evaluation methods of the software. Secondly, we separate the ergonomic problems of usage, from those linked to the transfer of the tasks from the pencil & paper environment to the data processing environment[3].

3.1. CONCEPTION PROCESS

Many books about the Human-Computer Interface ergonomy recommend that evaluation be considered as a « state of mind » [KOLSKI, 1993] which must express itself throughout the design of a system. This preoccupation with validating design choices and detecting problems of usage as early as possible often translates itself into the adoption of an iterative design process founded on the producing of prototypes that are evaluated then eventually modified.

[3] This distinction is introduced for the convenience of the presentation, the ergonomy is also concerned with the problems of tasks and not only with the superficial aspect of the interface.

Using prototypes enables us to attain the objectives of the user - centered design: creating a system easy to learn and to use [PREECE et al., 1994]. Another benefit from using prototypes is to ease communication with the customers and within the multidisciplinary conception team [SENACH, 1993], [KRIEF, 1992], [KOLSKI, 1993], [VAN-HEYLEN & HIRACLIDES, 1996] for example.

This process demands an early examination of the criteria and evaluation methods. SENACH distinguishes two principal dimensions for the evaluation, the utility of the product and its usability [SENACH, 1993]. The *utility* deals with the adequacy of the software to the high level objectives of the *customer*. The *usability* concerns the capacity of the software to allow the *user* to attain his objectives easily.

Where PÉPITEST is concerned, the user is the student whose objective is to solve the exercises. The « customer » is the person or the system in charge of carrying out the diagnosis on the student's productions. The usability of the software concerns the quality of the interface with regard to the ergonomic recommendations [BASTIEN & SCAPIN, 1993]. Utility concerns the capacity of the software to give an account of the behaviour of the student in order to establish the diagnosis. From the conceptor's point of view, the problem consists of defining machine tasks that give equivalent data to the pencil & paper ones. The evaluation consists of specifying this equivalence.

The evaluation methods that we have selected for the usability dimension are the classical methods used for the Human-Computer Interfaces design. For the utility dimension, we rely more on didactics of mathematics methods [ROBERT, 1992] [ARTIGUE, 1990]. During conception, the validation consists of checking by a case-studies that the students' productions on the PÉPITEST tasks allow the didacticians to apply the analysis grid to draw up the students' cognitive profiles by hand.

3.2. USABILITY OF PÉPITEST

The quality of a Human-Computer Interface is not guaranteed by the simple fact that it respects in the best possible way a certain guide of style or a certain set of recommendations [SENACH, 1993]. Nevertheless ergonomic criteria gather experience in these domains and constitute a guide for conceptors. We took in account this ergonomic criteria in PÉPITE while referring to [BASTIEN & SCAPIN, 1993], but we did not forget the specificity of PÉPITE, as a evaluation environment.

The validation consists of submitting our prototypes to the judgement of experts (experts in ergonomy and experts of the domain: didacticians and mathematics teachers), to informal tests by users, and finally to controlled experimentation in a high school class.

3.3. UTILITY OF PÉPITEST

The activity of the student on the PÉPITE tasks must furnish data allowing a didactician (and later software PÉPIDIAG) to apply the multidimensional grid of analysis.

In the conception phase of PÉPITEST, we keep as validation criterion the possibility for the didacticians to carry out coding of the data obtained during the experimentation in the classroom and thus to obtain profiles confirmed by the teacher of the class.

At first sight, pencil & paper tasks such as Multiple Choice Questions do not give any transfer problems. However, tasks that necessitate the production of sentences or of mathematical expressions (in particular the modelling exercises) give problems. We can fear that the users will simplify their syntax while typing sentences with the keyboard. With regard to mathematical expressions, different authors [of which ARTIGUE 1995] have noticed that the transition for fractions or square roots from spatial writing (pencil & paper) to linear writing (the keyboard have only a fraction bar) disturbs the students.

We expect the experimentation to provide us with corpora to study to what extent these expression constraints modify the data and change the diagnosis.

Indeed, each task gives special difficulties linked to the nature of the cognitive activities in

play and specified in the analysis grid. The detailed study of each of these tasks is not our purpose here [JEAN 1996]. Here we will simply present an example.

3.4. AN EXAMPLE OF TRANSFER TASK

Complete the table by writing a sentence translating each step of the calculation program opposite the corresponding algebraic expression.

step 1	Be a number of departure designated by x	x
step 2	.....	- x + 3
step 3	.....	$(-x+3)^2$
step 4	.....	$\frac{1}{(-x+3)^2+4}$

Figure 3: task example pencil & paper.

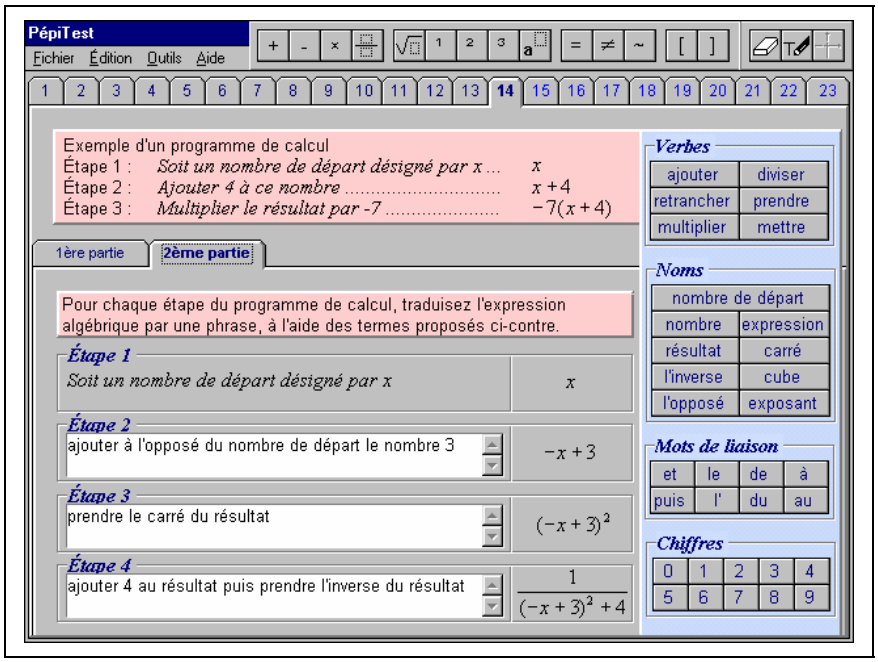


Figure 4: The same task example in PÉPITE

This exercise (Cf. figure 3) tries to identify in the student's work the conversion rules used to pass from the algebraic frame to the natural language frame. In the pencil & paper corpus, we raised only two cases: either the students did not treat the question at all, or they used a very limited number of terms, of which we established the exhaustive list. We have chosen to transfer this exercise proposing a set of terms to construct the sentences (Cf. figure 4). The list of these terms is wide enough to construct correct sentences, but allows also a number of errors expected or not. This tool modifies the proposed activity: this is undoubtedly an aid provided to the students which does not however give any indication to the answer. The exercise set up like this can help some students to begin their work without preventing them from giving erroneous answers.

At first sight, we expect more answers to this exercise in its PÉPITE version than in its pencil & paper version.

4. EXPERIMENTATION

PÉPITEST was the object of an experimentation whose objective were:

– to validate the interface from its usability point of view,
– to collect a corpus on the test software and to compare them to the pencil & paper corpus, in particular for the modelling exercises and some exercises for which the PÉPITE version is very different from the pencil & paper version,
– to check by case-studies that the productions of the students on the PÉPITE tasks allow the didacticians to construct the students' profiles « by hand ».

4.1. ORGANISATION OF THE EXPERIMENTATION

The experimentation took place in October 1996 in a fifth form class of thirty-two students of a high school in the suburbs of Paris. The test lasted 1H 45 on the usual timetable of the mathematics class. The students were divided up in two rooms and each student had access to a post.

These students were supposed to be accustomed to using a computer through technology classes at high school. It was impossible to organise a preliminary session with the software and of its tools.

We collected the traces of the session, that record the answers of the students to the exercises (equivalent to the information collected in the pencil & paper test) as well as information on the usage of tools and the timing, a questionnaire filled in by each student, the sheets of notes taken by the observers during the experimentation (three didacticians, two computer scientists and the teacher of the class) and the rough copies of the students (if any).

4.2. RESULTS

We present here the results obtained concerning the three objectives that we fixed for this experimentation: usability of the interface, differences between the two types of corpora for the exercises and possibility of constructing the cognitive profiles from the students' productions.

4.2.1. Usability of the software

After the first half-hour, the questions concerning the usage of software disappeared. The questions asked by the students during this period concerned the use of a computer (keyboard, return to the line, drag and drop, selection of fields), the use of PÉPITEST tools (the eraser), mathematics (use of brackets, calculation, terminology) and the mathematics with PÉPITE (typing mathematical expressions). For the two last points, difficulties naturally lasted longer for certain students.

Handling the software through solving the exercises therefore took less than half an hour. Globally, the guidance set up (structure of the screen, cursors, help balloons) worked well. We plan nevertheless to reduce the learning time by proposing two or three screens presenting the few basic manipulations necessary to the use of PÉPITEST.

Finally, we noticed, as other experimentations have already shown [DELOZANNE, 1994] [SCHNEIDERMAN, 1992] that the sophisticated tools invented by the conceptors are under-used.

4.2.2. Differences between the corpus and « manual » building of profiles

We noted, while observing the students during the test and while studying the traces of the sessions, that the students behave globally in a similar manner during the PÉPITE test and during the pencil & paper test.

As we had foreseen, the typing of algebraic expressions gave problems to the students without however preventing them from writing them. Certain exercises which were not much attempted in pencil & paper test are more attempted on PÉPITEST, in particular the exercise presented in figure 4. We did not note the opposite phenomenon.

Case-studies indicate that the productions on the modelling exercises are similar and that in the unusual exercises PÉPITEST accentuates the difficulties of certain students which sheds more light on the behaviours that we are trying to identify.

Finally and especially, on the first analysed productions, the didactician was able to apply the analysis grid and obtain cognitive profiles confirmed by the class teacher. This is undoubtedly the most interesting result from our conceptor point view.

5. CONCLUSION

In this paper, we have presented the software PÉPITEST which collects data to diagnose the capacities of students in algebra. We have insisted on the conception problems and on evaluating the interface relying on works in Computer Based Learning Environments and in ergonomy of the interfaces. PÉPITEST has been completed and successfully underwent the test of experimentation in class. This concludes the first prototypage cycle for the iterative conception process [DELOZANNE 1994] [VAN-HEYLEN & HIRACLIDES 1996]. In our conception method, we laid great importance on defining the evaluation criteria of PÉPITEST which means specifying the equivalence between the data determined from the pencil & paper tasks and those of PÉPITEST. Our validation criterion of PÉPITEST consists of verifying that the data obtained from the software permits us to build equivalent profiles to the pencil & paper profiles. The validation of the whole PÉPITE project consists of demonstrating that the profile built by the machine with the data obtained by the software is equivalent to the profile built by a didactician with the same data.

The first results presented here and in particular the achievement of a corpus from PÉPITEST tasks, make it possible to envisage the didactic study necessary for the conception of PÉPITE's module of diagnosis. Only this second phase will allow us through case-studies and a statistic study, to validate the automatic diagnosis by comparing it to the manual diagnosis established from the pencil & paper corpus.

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