PROVIDING HELP AND ADVICE IN AN OPEN LEARNING ENVIRONMENT IN CHEMISTRY

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Abstract

Open learning environments allow users to work on a wide set of situations and explore by themselves the entire process of problem solving from definition to solution. Because it is not possible for the system to find a solution of every problem set by the user, coaching becomes more general, maybe less effective in terms of task achievement, but it can be supplemented by adaptive help depending on an analysis of the student's activity.

This paper presents a help system designed for Schnaps, an interactive learning environment in chemistry. Adaptation relies on a syntactic and semantic analysis of statements and expressions of relations written by the student. The results of this analysis based on heuristic classification are possible formulas with confidence value, hypotheses on quantities involved in formulas and, occasionally, implicit statements on properties like stoichiometry.

The help system is made of specific entities named *helpers*. A *helper* is in charge of all requests or initiatives that are linked by a common theme, style or pedagogical meaning. It aims at providing help with respect to a specific purpose. This framework facilitates design, maintenance and control.

Contents of help are made of pieces of text and graphics combined together to build *messages*. For the purpose of adaptation, most of them are templates fulfilled with contextual data drawn from the problem representation and the results of the analysis. The *determination rules* express the necessary conditions for sending a particular message. Helpers get their input from the *interaction history* that contains all the objects the student defined or introduced and a complete list of her actions with the results of the analysis for each of them.

Helpers that act under system's initiative concern the following themes : *working style, accuracy, conceptions,* and *meta*.

The purpose of the style helper is to comment the student's working style and give *methodical advice* on the best ways to use the available tools. The accuracy helper intervenes when the analysis fails to recognize the student's intentions in her expressions of relations or calculations ; its role is to point out one of the incriminated objects and to ask the student to confirm the interpretation, if there is one, or to indicate its origin, if not. The conceptions helper aims at explaining the object of difficulties in the student's writings and, above all, recalling her some details of concepts involved in the solving process. The role of the meta helper is to anticipate the questions students may ask about the environment capabilities and the embodied knowledge.

A preliminary evaluation conducted with high school students has shown that the messages provided by helpers are adapted to the context and often lead students to think about what is unclear in their work. Additional information about concepts was also found helpful in the general solving process. Thus, the help system based on helpers linked to a syntactic and semantic analysis of student activity, provides answers to interesting questions that arise during the problem-solving activity.

Keywords

Learning environments, help, interactions modeling, problem-solving, chemistry

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I. Introduction

Intelligent tutoring systems developed in the field of problem-solving are often based on detailed representations of the problem and of the solution that allow effective coaching [1], especially when these systems rely upon model-tracing techniques [2]. With these systems, students work only on a predefined set of problems, which have been previously analyzed by experts or tutors to produce an adequate representation of intelligent coaching knowledge.

In an *open* learning environment, the student defines all the problem characteristics within a delimited domain and the problem statement is not known by the system. These environments allow users to work on a wider set of situations and explore by themselves the entire process of problem solving from definition to solution.

In that case, coaching becomes more general, maybe less effective in terms of task achievement because it is not possible for the system to find a solution for every problem set by the user, but only of well-defined ones. In such situations, coaching can be supplemented by adaptive help depending on the student's activity.

In fact, when they are working with an open learning environment, students often ask questions on a wide range of subjects. Some of these questions that can be directly answered by the teacher in traditional classes, may be supported by an intelligent help system.

Research in this field initially stressed planning and dialogue modeling [3]. In distance learning, *epiphyte* advisors [4] dedicated to individual learning have been used to implement an advice system based on a hierarchical representation of the task, independent of the host system. Nevertheless, this kind of representation is only possible when the solutions require a limited number of steps.

Paolucci et al. [5] showed that advice-giving strategies based on syntactic analysis have been proved efficient in computer-supported inquiry in science. According to this direction, we developed a syntactic analysis combined with an appropriate representation of semantic knowledge, which has proved to be very useful in help generation.

The purpose of this paper is to present an advisor system that helps student in an open environment dedicated to problem solving in chemistry.

The first section presents the core of the environment and the tools offered to the student. In the next section, we discuss the varied forms of students' requests and tutor interaction. Then, we present the analyzer that performs identification of student's actions. The characteristics of helpers, entities in charge of specific help are detailed in the following section. The conclusion about the capabilities of coaching in open environments comes after a presentation of the results of a formative evaluation.

II. The Schnaps environment

The domain of quantitative problems based on chemical reactions is of particular interest because of recurrent difficulties for high school and undergraduate students. First, solving these problems raises qualitative questions and involves high level concepts like *amount of substance* and *intensive and extensive variables*. Secondly, the complexity of the search is increased by the numerous relations that can be expressed between all quantities in the problem.

A. Architecture

The core of Schnaps is made of three main components :

a *solver* using a domain representation based on plans and relations used to generate constraints,
an *interaction module* which includes interface objects and control functions,
a *database* of chemical compounds and reactions, used for problem definition.

The present implementation of Schnaps is based on a client-server architecture. On the client side resides the interface presentation and the low level control of interaction. The solver, databases, and high level control of interaction remain on the server side. This architecture allows deployability of software over networks and enhances incremental development and components reusability [6].

Since Schnaps does not work on a predefined set of problems, the student has to *declare* the characteristics of the situation (*chemical reaction*) and the specific data (*extensive variables*).

Typically, the student's work with Schnaps is divided into two phases : problem definition and solution search.

B. Definition and solving tools

During the first phase, the student is provided with tools to introduce the compounds, set the chemical reaction, balance the chemical equation and define the properties of the *chemical system* (which compound is in which state of matter, which compounds are in the same *containers*).

During the second phase, Schnaps provides the student with a chemical calculator, an algebraic solver and a structured editor.

The interface looks like a worksheet made of lines. The user may insert and delete lines at every point in the worksheet . Each line is entered by the user through specific functions. These functions and their options, available through dialog boxes, can be divided into two groups :

Statements and definitions : these functions allow to set the initial data, declare the question from the problem terms, name a quantity, define a variable, declare stoichiometry, or add a line of comment.

Relations and calculations : these two functions behave like a chemical and algebraic calculator and solver. It allows definition of a relation, calculation and assignment to a variable or simple calculation. All calculations can be made on variables and numbers with units.

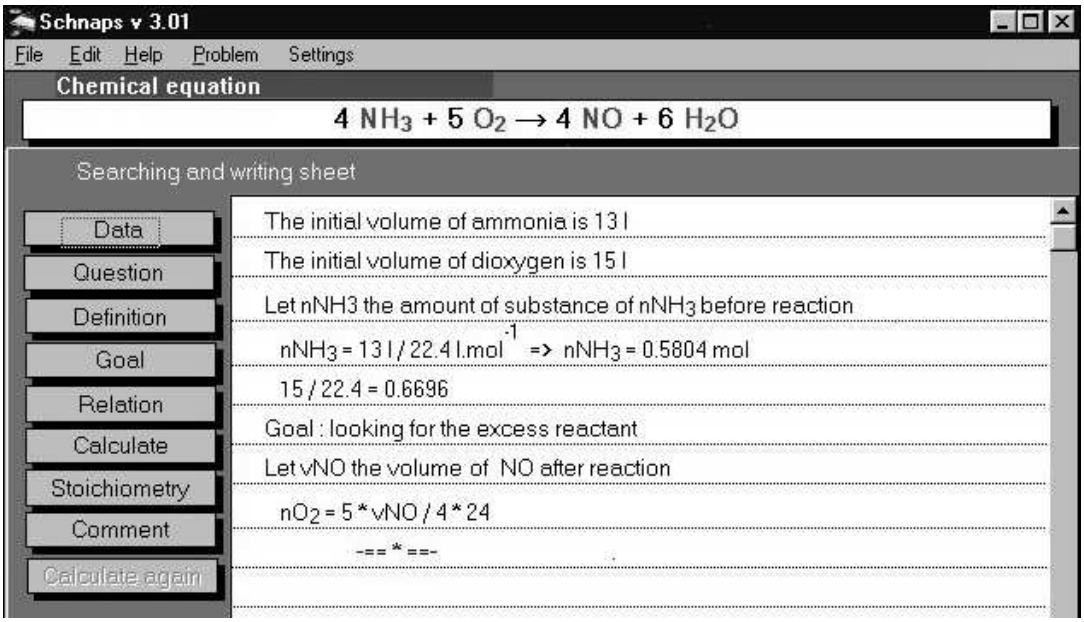

Figure 1. *The Schnaps problem solving interface*

In order to extend the advising capabilities of this minimal environment, two additional components were designed and implemented : an Analyzer of student actions, and a set of Helpers.

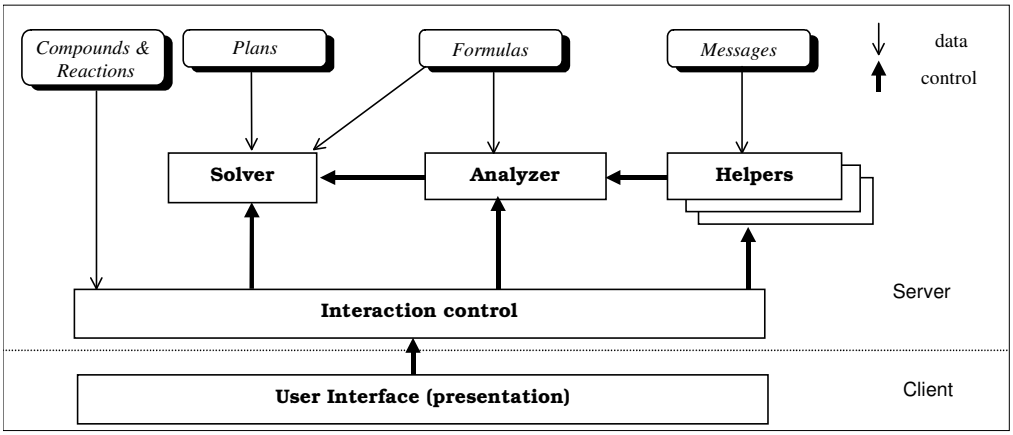

Figure 2. *General architecture of Schnaps*

III. Students requests and tutoring interaction

In order to specify the kinds of help system students might need, we conducted an observational study of student/tutor interactions during problem-solving. Students worked with the Schnaps environment without any available help. The human tutor answered to their requests and made interventions when necessary. Notes were taken during 10 sessions of interaction (5 students solving 4 problems in 2 sessions).

The student's questions can be classified in five different categories :

questions about the use of the tools
"How can I write the molar mass on the worksheet ?
questions about facts and notions
"I need the formula of the black powder .. because it says that it is a mixture....
request for explanation of results
"I wonder why it [Schnaps] *finds a different value, since it made the calculation ?*
request for feedback
"May I get a check on that [a calculation] *before going further ?*
questions about what the system knows and does
"All that, it [Schnaps] *knows what it is ?*

These results can be compared with an analysis of students requests performed by Van Lehn prior to Andes development [1]. He reports the following categories, ordered by decreasing occurrence : *what to do next , immediate feedback, how to achieve a specific goal, conceptual misunderstanding*. The main difference resides in the fact that students in our observation did not often ask what to do next. This difference is not the effect of a better comprehension or capability. It can be explained by the attitude of the tutor who anticipated the student's interrogation by giving hints or comments before she gets stuck. In addition, Van Lehn notices that human tutors often interrupt problem solving with discussions of basic principles and concepts of the task domain, which we observed also.

During these recorded sessions, we observed that the human tutor :

1) explains the operation of the tools,
2) comments some specific properties of the situation or characteristics of a concept,
3) gives advice about a better way to achieve a goal,
4) explains particular results when they differ from what the student expects to see,
5) discusses the purpose of the activity and comments the system capability in return.

Starting from these findings, we identified several topics of help whether it is passive (under learner's request) or active (under system initiative) : tools, procedures, methods, concepts and *meta* (about the system itself). Moreover, we noticed that these topics generally correspond to specific roles : describe, explain, counsel, advise, and justify. This correspondence between topics and roles was used to design consistent entities, which can take charge of one kind of help.

Nevertheless, the adaptation of help to the learner's needs depends on the system's capability to analyze and interpret her activity.

IV. Analysis and interpretation of the student activity

When looking at the traces of the students' interactions with Schnaps, we first consider two levels for the analysis : 1- elementary actions, and, 2- strategies and plans. Because students, who do not completely master the solving process, use very local strategies and often consider actions one after another, it was difficult to develop an efficient plan recognition method. In fact, students express most of their skills by applying "hypothetical" relations and making calculations on values and quantities. Therefore, we paid more attention on the analysis of the elementary actions.

The interpretation by the Analyzer of the statements and definitions available through the interface is rather straightforward. All these declarations are directly compared with the internal representation of the problem and the solution, if there is one.

The main question of the analysis comes from relations that can be expressed in many different surface forms. Since the problem statement entered by the student may be incorrect or incomplete, the analysis cannot only rely on the expert solution of the problem. The core of the Analyzer consists of a match between a student expression and a set of formulas in order to show possible syntactic (algebraic) and semantic (chemical) discrepancies.

The knowledge base of formulas contains both correct and incorrect relations between quantities expressed in a canonical form. Incorrect relations were elicited from students' writings during a previous analysis of students' difficulties in chemistry problem solving. This knowledge base comprises 51 canonical formulas representing 20 correct and 31 erroneous ones.

```
 (form      (= (/ (Volume ?Compound1 ?Instant1)
         (Coefficient ?Compound1))
        (/ (Volume ?Compound2 ?Instant2)
         (Coefficient ?Compound2))))
(conditions (Initial ?Instant1)
      (Final  ?Instant2))
      (Gas ?Compound1)
      (Gas ?Compound2)
      (Stoichiometry))
```

Figure 3. *Example of a canonical form with one set of applying conditions*

Finding the most likely match between the student's expression (e.g. $nO_2 = 5 * vNO / 4 * 24$) and all derived expressions from the canonical forms that contain the same quantities is performed through a four steps process :

1- Recognize the quantities involved in expressions, which gives hypotheses for the operands,
2- Generate all possible patterns with the hypotheses for operands,
3- Identify the expression by pattern matching, which gives hypotheses of formulas,
4- Evaluate these hypotheses, and, if necessary, search for other formulas.

The results of the Analyzer are : possible formulas with confidence value, hypotheses on quantities involved in the formula and, occasionally, implicit statements on properties like stoichiometry.

V. Helpers, a framework for answers and interventions

Considering the various kinds of help that should be developed to match the students needs, the help system has been designed with specific and independent entities named *helpers*. A *helper* is in charge of all requests or initiatives that are linked by a common theme, style or pedagogical meaning. It aims at providing help with respect to a specific purpose.

The control of helpers is made in the interaction module that solicits possible ones and then selected the most adapted.

Among helpers which are under learner's control, which we do not describe in this paper, the most advanced one is the Conceptual Helper that provides all useful information about the characteristics of reaction, the quantities and all possible relations between quantities involved in a chemical reaction. The Conceptual Helper, described in [7], contains about 180 different concepts. The information displayed for one concept is generated from text elements and interactive graphics. It depends on student's known difficult concepts and on previous requests.

Helpers that act under system's initiative concern the following themes : *working style, accuracy, conceptions,* and *meta*. These four helpers are constructed with the same scheme : messages, rules of determination.

Contents of help are made of pieces of text and graphics combined together to build *messages* sent to the student. For the purpose of adaptation, most of them are templates fulfilled with contextual data drawn from the problem representation or the results of the Analyzer. The *determination rules* express the necessary conditions for sending a particular message to the student. If there is more than one possible message at a given time, a precedence value attributed to each message is used to choose the most appropriate one.

Helpers get their input from the *student history* that contains 1) all the objects she defined or introduced, and 2) a complete list of her actions with the results of the Analyzer for each of them.

A. Working style helper

The purpose of this helper is to comment the student's working style and give *methodical advice* on the best ways to use the available tools and particularly to express relations or calculations. In some sense, it reproduces the *methodical part* in human tutoring.

The rules of "good use" are derived from similar advice made by teachers. The data necessary for firing the rules are given by the analysis of the student's use of the tools along sessions. When it notices some confusion in the student actions, this helper suggests a "better" way to use tools or to achieve a goal.

These rather short messages are not numerous and cannot be repeated during the same session. For instance :

> Please name quantities before using them.
> You should add units to numbers that represent values of quantities.

B. Accuracy helper

This helper intervenes when the Analyzer fails to recognize the student's intentions in her expressions of relations or calculations. In general, these inaccuracies and ambiguities arise because of undefined variables or unknown (not yet declared) values. However, the failure may also occur when the student writes an unknown (possibly wrong) relation between values or quantities.

The purpose is to point out one of the incriminated values or variables and ask the student to confirm the interpretation given by the Analyzer, if there is one, or to indicate its origin, if not. In general, asking the student about the origin of a particular object raises indirect reflection about its meaning and usage in the problem. This can lead to a reflexive attitude of the learner whose benefit has been often claimed [8].

This helper makes large use of the results of the analysis of expressions and examines the discrepancies between the most likely formulas and the student expression. Interventions depend on confidence given to these elements and may be different among students. Most messages ask the learner to be more explicit or precise in her operations.

For instance, in a problem about the reaction $4\ NH_3 + 5\ O_2 \rightarrow 4\ NO + 6\ H_2O$, a student writes : $nO_2 = 5 * vNO / 4 * 24$. If nO_2 and vNO are easily recognized by the Analyzer, the following message can be displayed :

I can't understand / interpret / make sense of what you want to calculate with this expression. What is the origin of "24" ?

C. Conceptions helper

The purpose of this helper is to explain what could be the object of difficulties in the student's writings and, above all, to recall her some details of concepts involved in the solving process.

The rules of this helper make use of the hypotheses of erroneous formulas found by the Analyzer. If the erroneous formula is undoubtedly identified, the message content can be directly related to the misconception like the following one, given if the student inverts a relation between the amounts of reactants :

A relation like a/b = c/d rewrites as a*d = b*c but not as a*b = c*d.
In a chemical reaction, the amounts of substance are *directly*, but *not inversely*, proportional to the stoichiometric coefficients.

When the identification is not assured, the action of this helper may result in explaining a particular concept. If the results of the Analyzer show that the student has some difficulties with one formula, all the concepts related to this formula are recorded in the student profile with weights depending on their importance in the formula. The concept displayed by calling the Conceptual Helper is selected among those that get the highest weight.

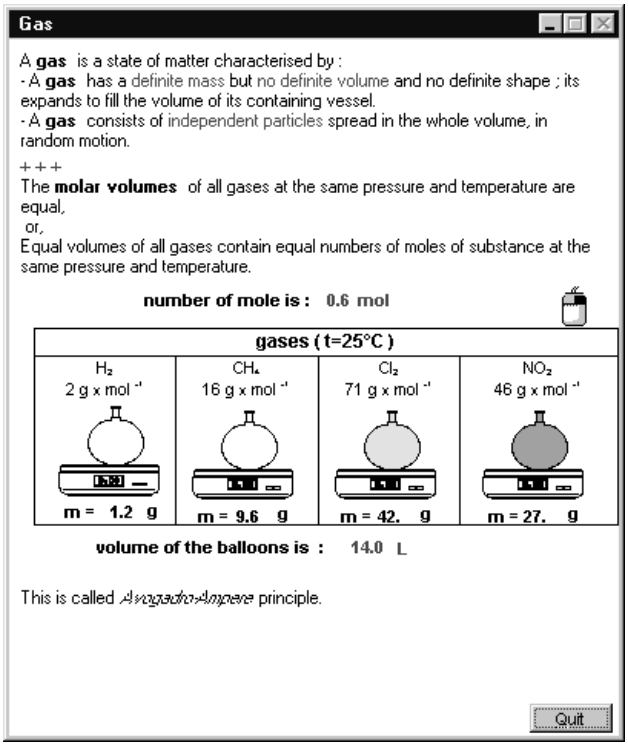

Figure 4. *The concept of gas displayed in the Conceptual Helper*

D. Meta helper

The role of these interventions, named *meta-interventions,* is to anticipate the questions students may ask about the environment capabilities and the embodied knowledge.

This helper can :

1) explain the *pedagogical situation* and the *general purpose* of the task and,
2) remind the student of the facilities of the system (tools utility, available help, interventions adjustment).

The determination rules rely on the average use of all available functions and the advice already given. Here is a general intervention for the beginning of the session :

Begin with all what you know about the problem. You will get more precise and efficient advice.

VI. Control of system interventions

The control of system interventions is distributed among helpers, the interaction module and users.

Possible messages are selected in each helper. At the highest level, in the interaction module, the question is to determine the more appropriate helper for the actual situation. To decide which helper is appropriate is performed in three steps. First, the list of possible helpers is established, second, the retained ones are solicited, and then the most appropriate message is selected for intervention. This process is achieved through a weighing system that attributes weights to helpers and messages.

The weight of a helper is principally determined by a factor indicating the student progression in the general solving task, which we name *pedagogical phase*. This notion comes from a cognitive analysis of student/tutor interactions showing that a tutor does not give the same kind of comment all along the task [9]. Even if it is not possible to follow all of the student's steps in the solving process, we have been able to identify four pedagogical phases : *definition*, *exploration*, *solution* and *evaluation*. For instance, *writing style* help is preferred during the *exploration phase* and *accuracy help* during the *solution phase*.

The second important factor used to determine which helpers can be solicited is the response delay. Messages that focus on the last action of the student (dealing with inaccuracy or misconceptions) can be displayed immediately after the end of the action (immediate feedback). On the other hand, general help (writing style, recall of available tools) is better accepted if it comes after a certain delay.

The other parameters are : the interaction history, in order to avoid repetition, and the student profile, indicating her preferences. Besides, the user is offered the possibility to set the frequency of the system interventions and the extension of the set of concepts that can be the object of help.

VII. Preliminary evaluation

A preliminary evaluation of Schnaps was carried out in the Spring of 1998 with twenty groups of high school students. Every group, including three students, solved five problems during two one-hour sessions of work with the environment. During these sessions, students could ask questions and get help from a tutor if they did not find accurate answers with the help system.

In most cases, the Analyzer was capable of finding adequate hypotheses for formulas and operands found in students expressions. The unrecognized expressions are the result of combinations of several relations or oversimplifications made by the students.

Students made moderate uses of Conceptual Help, mostly searching for precise information (e.g. the value of molar volume depending on conditions of pressure and temperature). They often found an appropriate answer but had some difficulties in finding an entry that closely matches their question.

While observing the students reactions to the system *interventions*, we found that they always appear in conformity with the context and do not contradict human interpretations of the students actions.

However, students showed certain indifference to general comments like working style messages. Even if they don't disagree, students did not seem to be concerned. In addition, it was not possible to notice any effect of these messages on their subsequent work.

Furthermore, they were amazed by some messages, especially those showing that the system has made a reasonable interpretation of their writing or intentions.

For instance, "*It is very smart !*" commented a student when the message "I presume that n22 is the initial amount of Cu_2O ?" occurred after she declared that the initial mass of Cu_2O is 200 g and then entered the expression : n22=200/143.08 (note that the molar mass of Cu_2O is 143.08 g/mol).

In general, we verified that students paid serious attention to interrogative messages even if the answer is not explicitly required. This attitude confirms the hypothesis of increased involvement of students when help is provided through questions about their work [10].

VIII. Conclusion

With the Schnaps environment, the learner has the opportunity to explore the entire process of problem-solving, from definition to solution, in the domain of quantitative chemistry. The system is capable of finding a solution of well-defined problems but cannot guide the student precisely in other cases.

Helping capabilities in such an open environment depend on a syntactic and semantic analysis of student activity. The Analyzer module of Schnaps provides hypotheses on the most significant elements of the student work : relations expressed in algebraic expressions, explicit or implicit statements about the situation, working style.

An observational study of student/tutor interactions during problem-solving was carried out to define the help system. Helpers have been designed to model the different forms of help requested by students or provided by tutors. Style, accuracy, conceptions, concepts and meta help may be taken in charge by such helpers.

Even if they are not intended to suggest the most suited actions to perform at every step in the solving process, the messages provided by helpers are adapted to the context and often lead students to think about what is unclear in their work. Additional information about concepts is also found helpful in the general solving process.

The indifference to general messages observed during a formative evaluation of the system suggests the need to develop more interrogative forms of help, resulting in short dialogue, which involves students in clarifying their choices. However, the help system provides many significant answers to the interesting questions that students ask during their problem-solving activity.

This framework based on entities in charge of one specific kind of help facilitates design, maintenance and control. Combined with the client-server architecture, it opens the perspective of deploying intelligent environments over networks and point the way to more adaptive help in distance learning.

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