# Developing Intelligent Tutoring Systems Using a Psychologically Motivated Authoring Environment

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**Abstract**

Although Intelligent Tutoring Systems (ITSs) have been shown to be effective in a number of domains, they are still rarely found outside the laboratory. We propose that to be truly effective, authoring environments for ITSs must be based on a psychologically plausible account of teaching. In this paper, we describe how the REDEEM tools exploit the existing psychological research to identify crucial instructional factors and effective default behavior. We argue that this will not only lead to improved ITSs, but also to better instructional theory.

## Introduction[1]

Using authoring environments for creating ITSs offers solutions to many of the well known problems facing real-world application of ITS. Course material developed for one ITS often can not be reused in another and the cost of developing new material is very high. Furthermore, instructional strategies offered by systems are rarely flexible enough to meet the varying requirements of both teachers and learners. However in order to benefit from the potential advantages of this approach to the creation of ITSs, the task of authoring must be simple enough that an instructor with no experience in artificial intelligence would be able to use the system easily and effectively. Existing evidence suggests that these demands are complex, even for experienced computer literate teachers (Major 1994).

The early authoring environments included the Instructional Design Environment (Russell *et al.* 1988), GTE (Van Marcke 1992), KAFITS (Murray and Woolf 1992) and COCA (Major 1995). These allowed appropriate domain material to be developed and gave teachers the ability teachers create their own teaching strategies. An evaluation of the authoring tools in COCA (Major, 1994) showed that despite offering considerable power to teachers, there remained a gap between the kinds of interfaces teachers would be prepared to use, and the AI-based representations required by the authoring tools. Therefore more recent authoring environments have recognized this problem and are based on more sophisticated models of human-computer interaction and teachers rarely have to write in pseudo-code. But this is not enough, interaction must not only be straightforward, it must be effective.

Psychological research has examined the factors that underpin effective instruction and it is precisely these factors, and these factors alone which must be employed in an effective authoring environment if it is to empower the author and the resulting ITS. Thus, the delivery component must teach using valid psychologically motivated defaults. In addition, it has long be known that no single instructional regime is appropriate for all situations (e.g. Ohlsson 1986). Consequently, an instructor should be given control over the critical factors which have been shown to affect learning outcomes. Identification of these crucial factors will generate a good model of the teaching process that should permit substantially different ITSs through a small set of configurations.

In this paper, we describe REDEEM, an authoring environment for creating effective ITSs. REDEEM focuses on authoring pedagogy rather than on helping instructors create domain material. We propose that such an approach offers an ideal compromise between Computer Based Training which has only limited expertise and ITSs that have significant intelligence but are costly and time consuming to develop.

We first briefly describe some of the research which motivated the design for REDEEM and then describe the authoring tools themselves.

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## Psychologically Motivated Instruction

Two important aspects in the design of an ITS are decisions about the subject material and the teaching sequence (i.e. what to teach) and the nature of instruction (i.e. how to teach).

### What to teach

One major issue for the REDEEM authoring tools and the resulting ITS is the decision about how to sequence instruction within a given learning domain. There is rarely a single fixed sequence of learning routes through a domain that will prove to be optimal for all learners (Resnick 1976). Investigations into aptitude x treatment interactions (ATIs) suggest that to maximize learning outcomes, authoring environments should provide for multiple ways of structuring course material.

A number of different aspects of REDEEM's model of teaching provide for this flexibility. Teachers can configure a wide variety of routes through a course. These may represent different pedagogical views. For example, teachers may suggest that the ITS first describe the theoretical framework before presenting specific examples or could on, other occasions, expose students to a number of relevant examples before introducing any general principles. While providing this flexibility, REDEEM monitors that the routes through the course remain sensible by allowing teachers to specify the pre-requisite knowledge necessary for a particular unit and ensure that it has been previously taught. Additionally, in certain circumstances, teachers may prefer to let students choose their own learning sequences. Hence, REDEEM provides for varying degrees of control to be given to the student.

### How to teach

There is a great deal of evidence that different types of students benefit from different instructional regimes (e.g. Cronbach and Snow 1977; Kyllonen and Shute 1989). Consequently authoring systems should be able to support a variety of instructional strategies. The different dimensions of instructional strategy provided in REDEEM allow different ITSs to be produced. This behavior is crucial for allowing teachers to achieve specific objectives. Differences in instructional variables can be accommodated when ITSs are capable of being configured to support different lessons and students. Particular categories of students (e.g. those high or low in incoming knowledge) could experience different instructional regimes. The same student could use the ITS for different purposes and hence would require alternative kinds of support, for example, first exposure to the material versus revision. In addition, REDEEM based ITSs can routinely apply a variety of teaching styles during a single lesson.

To consider just one dimension from REDEEM's strategy authoring, the amount of learner control has been somewhat contentious in the design of ITSs with existing systems varying between high learner control (free discovery environments, Logo) and heavily directed instruction (e.g. model-tracing tutors such as Anderson's Lisp tutor, Anderson and Reiser 1985). Yet the relationship between learner control and learning outcomes is not a simple one. The success of high learner control depends on factors such as prior knowledge, motivation, instructional goals and cognitive skills (Steinberg 1989). One of the more robust findings from the research on ATIs is that learners with lower aptitude should be given less control over how they learn.

Furthermore, REDEEM's course material authoring allows teachers to make statements about the perceived level of difficulty of each page in the domain. The shell would aim to offer pages that fall within the ideal level of difficulty: i.e. in the learner's zone of proximal development, (Vygotsky, 1978). This is the region of activity in which learners can perform successfully given the aid of supporting context. Allowing the ITS to choose material at different levels of difficulty allows us to cater for a wider range of understanding.

Our approach allows one ITS to employ multiple teaching styles. This allows for much greater flexibility of teaching than is traditionally the case in ITSs. In REDEEM, teachers are allowed to configure different teaching strategies directly and describe, using a simple interview tool, when they would change some aspect of their strategy in response to a learner's performance. The resulting ITS can adapt both the form of (macro-adaptation) and the content of (micro-adaptation) teaching. Such behavior has been proposed as necessary for successful teaching by both artificial and human teachers (Wood *et al.* 1976; Ohlsson 1986).

## The REDEEM Software Tools

The REDEEM tools consist of three main pieces of software: the courseware catalogues; the authoring tools and the instructional shell. This software has been developed in Asymetrix Multimedia ToolBook and runs on Windows 3.1 or higher. An instructor uses the authoring tools to describe courses, construct teaching strategies and identify students. The shell uses this knowledge, together within its own default teaching knowledge, to interpret the courseware in such a way as to deliver intelligent instruction.

### Courseware Catalogues

The domain material in REDEEM is provided by a courseware catalogue. Courseware consists of pages from computer-based training developed in a standard authoring package, Asymetrix Multimedia ToolBook. These are not built within REDEEM but are used to provide the basic pre-prepared subject content. Consequently, this limits the flexibility of the resulting ITS to some extent, but it does allow greater reusability. The ideal courseware for REDEEM presents discrete pages of material showing the

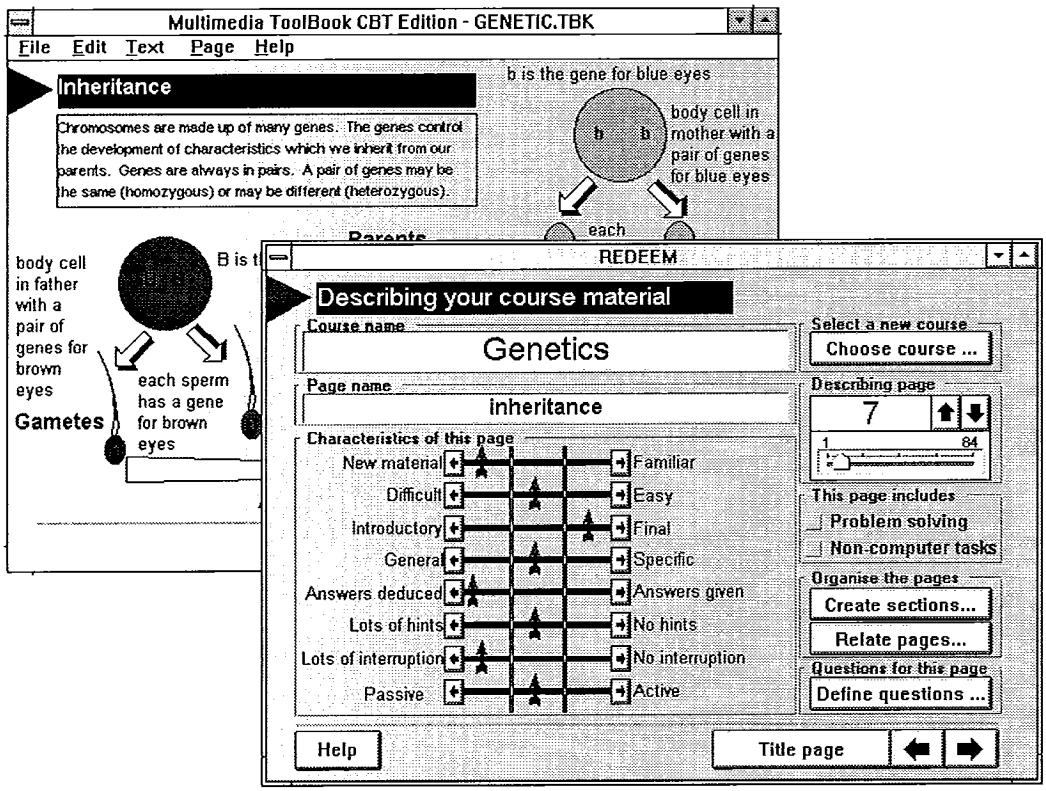


Figure 1. Describing a page of course material using

different aspects of the domain at varying levels of difficulty. We are currently testing REDEEM using a genetics course for 15 year old high school students, built with the assistance of a their biology teacher. The material covers around 12 hours of teaching time and includes a full range of multimedia presentations, with still photographs, text, graphics, sound, animation and simulation.

## Authoring Tools

REDEEM's authoring environment consists of five main tools. These allow the teacher to describe the different courses, to construct teaching strategies, to categorize students, to assign different strategies to different student categories and to describe how teaching should be refined during a lesson.

**Describing Course Material.** To begin the authoring process, course material must be described. This is the most time-consuming aspect of the authoring task, but need only be done once and could be shared amongst different teachers. For each domain page, the teaching material is classified upon a number of dimensional ratings. Hence, each page is rated as to whether it is likely to be familiar to the students, new or introductory. These dimensions were developed in consultation with teachers and in reference to the research literature. In addition, teachers can associate non-computer based tasks which they have developed with appropriate pages in the material. Rapid elicitation of course features is ensured by graphical manipulation of sliders (see figure 1 for a page of course material and the authoring tool).

In addition to any interactive problem solving tasks already present in the course material, teachers can prescribe appropriate questions. Question templates allow teachers to define questions and specify answers and give up to five hints for each question that follow the principle of contingent instruction. The shell will monitor the student's performance on these questions to help inform the student model.

Pages can also be combined into sections. Material which addresses similar topics can be grouped into one block for delivery even if the relevant pages are distant within the courseware catalogue. Relations between individual pages can also be specified. Thus, pages which are analogous can be related and pre-requisite knowledge can be described. All of this information is used to construct a semantic network of the domain. This description is used by the shell to implement teachers' preferred routes through material and to make default decisions about adapting content.

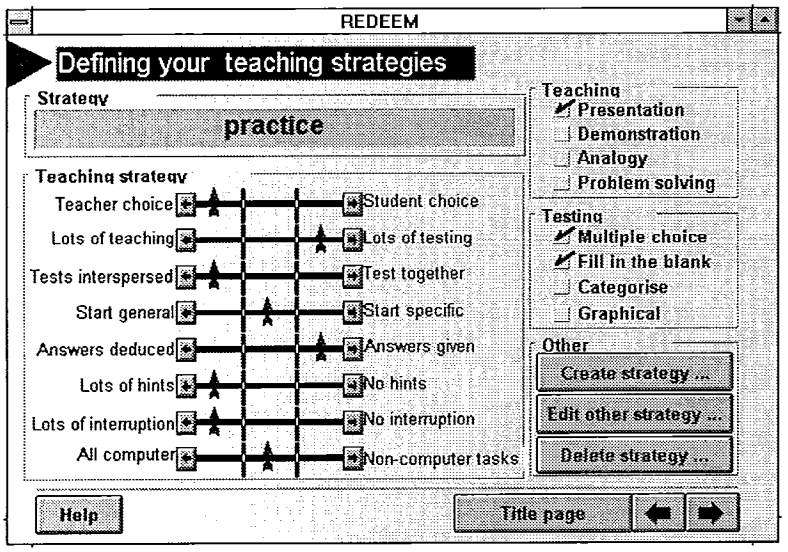


Figure 2. Screen showing teaching strategy authoring

**Developing Teaching Strategies**. The second important component of the authoring task is the definition of a number of teaching strategies to provide the basic repertoire of the teaching shell. Figure 2 shows the definition of a strategy that has been called *practice*
Different instructional principles can be embodied in various strategies by manipulating the sliders. Each slider in Figure 2 has three discrete positions that result in a different style of teaching. For example, moving a slider from having tests interspersed to having tests together will mean that the positioning of questions changes from after every page, to after every section or at the end of the course. Similarly, selecting high teacher choice ensures that the shell will choose what it considers to be the most appropriate page for the student, selecting high student control leaves this decision completely to the learner and at an intermediate stage the shell offers the student a selection of its most preferred pages. A number of different teaching strategies have been developed for REDEEM. Teachers are free to use these, edit strategies or develop completely new ones of their own using the specified dimensions.

In addition, the course material itself may support different teaching styles so that, if, for example, there are problem solving activities present in the course material, the shell will be directed to prefer units that contain them when the problem solving style is selected. Selecting teaching by analogy will ensure that the shell choice of the next page will take account of any analogous relations to the current page. The testing styles inform the shell that the teacher prefers questions to be asked in certain ways, such as multiple choice or fill in the blank.

**Categorizing Students**. Students can be categorized into a set of author-defined categories. The teachers can specify these at any degree of granularity ranging from the whole class to an individual child (see figure 3). These categories to determine the most appropriate strategy at any given moment during teaching. The categories can either be fixed through the session or if the teacher selects performance related categories, then the validity of categories can be evaluated against a student's performance. If so, the shell will automatically change the category as the overall standard of the student (as defined in the shell's student model) changes. If this occurs, a new teaching strategy will commonly result. Alternatively, these categories could be used to represent dimensions other than performance, such as learning styles or degree of literacy, numeracy. REDEEM uses these student categories, as well as information gained during a student's interaction with the shell, to modify its instructional behavior.

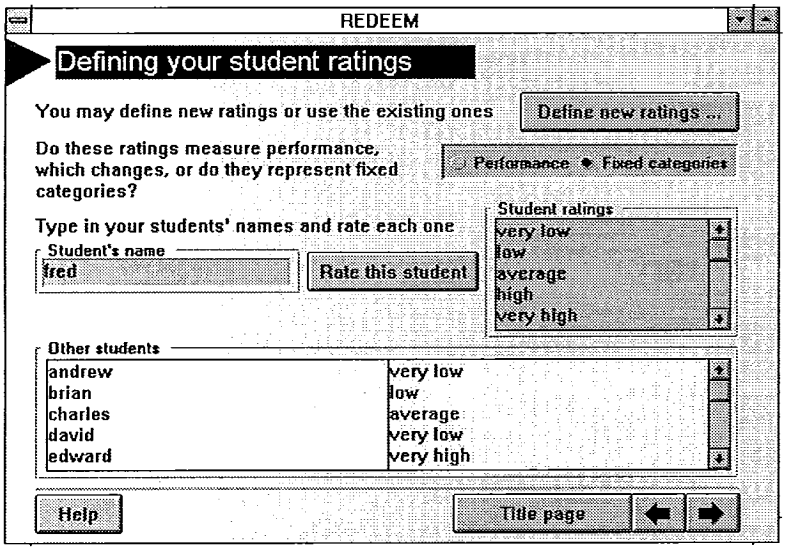


Figure 3. Screen showing describing students.

**Strategy Refinement**. Particular teaching strategies can be assigned to the student categories. Thus if a student changes category, the REDEEM shell may also change the way that it teachers that student. In addition to this facility, teachers can describe the circumstances under which they would prefer to see the shell's teaching behavior change. This tool leads the teacher through a number of multiple-choice questions, eliciting information about the circumstances in which particular aspects of the current strategy might change. The teacher can make decisions about when to increase learner control by specifying that when the student's performance improves to a certain level they may be given more control. They can also can describe preferences about when to change the amount of teaching and testing and what factors would influence their decision to change the topic that is being taught. All of these dimensions can be fixed in the shell or subject to change as the teacher chooses. Figure 4 shows one of the interview screens.

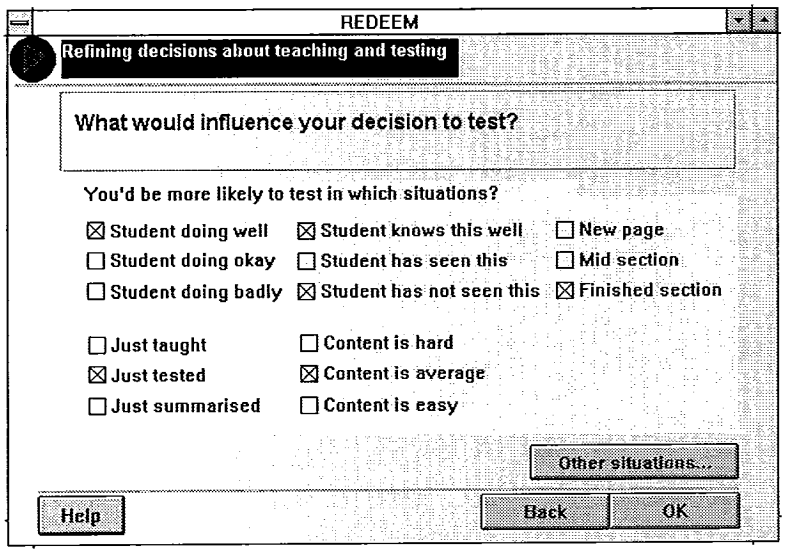


Figure 4. REDEEM eliciting knowledge about strategy refinement

## ITS Shell

The ITS shell runs the ITS by delivering the course material according to the information provided from the authoring tools in combination with its predetermined defaults.

**Delivering Adaptive Instruction**. Adaptive instruction is achieved in the shell using teacher's strategy description and the semantic network created from the teacher's descriptions of the course material. There are a number of tutorial actions available to the shell. The first is to choose appropriate domain material, for example should the next page be more general, less familiar, contain a problem solving task, and have any pre-requisites been mastered. The delivery of any non-computer based task is monitored. Students are told when to choose such an activity and cannot proceed until they have done so. The shell selects the next tutorial activity by choosing between presenting new material or by selecting an appropriate test by monitoring when the teacher has requested that testing should take place and how many questions they prefer this student to answer. The shell also monitors students performance on questions offering help when in a contingent fashion if the teacher has so requested. The shell also monitors whether it is appropriate to hand control over some of these decisions to the student.

**Default Tutorial Behavior**. The second way that adaptive teaching is achieved is through defaults in the shell. The rules that govern this behavior were generated from two sources - commonly held principles of instruction that were gathered from teacher's in interviews and experimental results on instructional design. Such rules include preferences for easy and for introductory material when a student is starting a new section, more difficult material when the student is judged to be performing well. Psychological principles include those generated from contingent instruction (Wood *et al.* 1976) which determine the help students receive. This states that when students are failing then offer more help, if they are succeeding, then offer less help.

**Student Model**. REDEEM employs a simple overlay model. The values of the model change over the course of a session as students see new material and as they answer questions. The basic course material unit being modeled is the page. Depending on the nature of the material, this basic unit could correspond to an individual declarative fact, or to a step of a procedure.

**Student History**. The shell maintains a student history in addition to the student model. It keeps a trace of all modules taken, including pages visited, questions that were asked and their answers, number of hints offered, scores and time on tasks. This history is sufficiently detailed that it is possible to recreate a student's session artificially. This information is used for two primary purposes - it serves as the basis of the report given to an instructor and provides information for research purposes.

**Strategy Refinement**. When necessary, meta-strategic knowledge is used to alter the rules for making these decisions about teaching. In order to achieve macro-level adaptation, the model of the teaching strategy used at each cycle of interaction with the student will not necessarily be the same as the models used in the previous or subsequent cycles. This is yet to be fully implemented, but it is proposed that the shell will use knowledge elicited in the authoring tools to offer more fine-grained changes of strategy during run-time instruction.

## Further Uses of REDEEM

We have discussed how psychological theories of instruction can form the basis of the development of authoring environments for ITSs. However, there is another connection that can be exploited between psychology and ITS. At present, we are still searching for a sufficiently general theory that can provide a basis for all the design decisions that have to be made to construct working systems.

By ensuring that the dimensions available in REDEEM are those which research has identified as important in producing effective teaching, we are in a position to confirm or falsify these claims. This is because authoring environments can easily keep domain material constant while at the same time changing instructional behavior so as to investigate its effects in relation to specific teaching objectives and specific types of students scientifically.

Thus, the relationship between psychology and reusable ITSs should be a symbiotic one. Current research can inform the design of ITSs, which can then be used to test the theories embedded within it, which in turn can inform developing theories of instruction and learning. Experiments using authoring environments should provide cleaner results than those found in the past as they allow different teaching styles to be applied consistently and to the same course material, thus eliminating other sources of variance. However, such research will always be time consuming and costly due to the time needed to run well controlled experiments. REDEEM does offer a partial solution to this problem by substantially reducing the time needed to implement different ITSs.

## Summary

This paper has described the REDEEM authoring environment. We have argued that by exploiting the relationship between psychological theories of learning and instruction and authoring environments more effective instructional tools result. Work conducted in schools will be able to show whether such an approach is justified by exploring whether including teachers in ITS design does result in more successful learning outcomes. In addition, we proposed that this relationship was not uni-directional but that theories of instruction could be enhanced by the results of theoretically motivated experiments performed with such an authoring environment.

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