Instructional Support For Teachers and Guided Feedback For Students In An Adaptive eLearning Environment

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Abstract

Adaptive Tutorials are Intelligent Tutoring Systems (ITS) in which students typically interact with a simulation towards a task-goal while being guided and remediated. Adaptive Tutorials can exhibit different kinds of feedback: students are given guidance based on their interaction, and teachers can also receive feedback on their own authoring choices to drive reflection and content adaptation. This paper will discuss different types of feedback which students are given within Adaptive Tutorials and their pedagogical utility. It will then look at providing teachers with timely support and feedback as well as post-hoc solution traces, to improve student learning. We suggest a refined ITS design and development lifecycle to better support teachers in the design of good pedagogy. We provide this in the form of the Adaptive eLearning Platform, which is a tool to support teachers in the adaptation of tutorials and the creation of customized student feedback. This in turn can result in an improved student experience, with more guidance and better learning.

Key Words: Adaptive Tutorials, Customized Student Feedback, Guided Instructions, Intelligent Tutors, Pedagogical Ownership

1. Introduction

eLearning systems vary in the degree to which they allow students to explore and provide guidance and feedback. We suggest that providing a tool to support guided learning is the best way of supporting student learning. Traditional Intelligent Tutoring Systems (ITS) typically support scaffolded and guided learning [1-2]. Kirshner, Sweller and Clark [3] provide strong support and empirical evidence for the benefits of avoiding cognitively overwhelming novice learners with lots of problems to solve in unfamiliar learning environments, as this type of unguided exploration can lead to cognitive overload. Students should be guided in their explorations using worked out examples and feedback. This is particularly important when teaching learning materials that are intellectually complex or high in element interactivity [4] Kirshner et al. [3] also make the point that practitioners of scientific disciplines often make the mistake of trying to use the procedures of the discipline to teach rather than first making students familiar with the facts, laws principles and theories of the discipline. So, for example, until students have understood the basic laws of physics, it is not a good idea to try and get them to discover physics principles by solving lots of physics problems. This sort of instructional design is very cognitively overwhelming. Learning will be impeded if the learning focus is on the application of the information, without allowing students to acquire basic knowledge. Rather, it is important to guide students in the acquisition of basic concepts and principles and then support them in their exploration and interaction within an unfamiliar environment.

If we can design eLearning content that has lots of individualized feedback tailored to students' specific misconceptions, the instructions will lead to more effective learning. Individualized feedback serves as a form of guidance. In order to create appropriate individualized feedback, teachers need access to system-based feedback regarding student mistakes, so learning content can be designed to address and alleviate the specific misconceptions of the students in the particular learning context. Such an approach represents the view that we cannot deduce the way students misunderstand a concept through an analysis of an expert's solution strategy. Students' misconceptions are contextualized, and must therefore be discovered [5, p. 62].

While there are many tools available to allow the creation of sophisticated online learning environments reported in the ITS research literature [6], what we suggest is needed most is a tool and development process that supports teachers in their pedagogical design and control of the learning environment. We should not necessarily expect teachers to become sophisticated technicians of the educational technology, but rather we want to give them control of the pedagogy and of student remediation. Such a tool and process was described in [7]. The model and concepts are further developed in [8].

What we are striving for is to give teachers *pedagogical ownership* of the educational technology content and process, where pedagogical ownership is defined as follows [9]:

> *Pedagogical ownership over instructional material means that the owner understands the content, the delivery mechanism and the pedagogy underpinning it. The owner is able to deliver the content to learners, to reflect on the effectiveness of that content and to adapt it to better suit the learning needs of students. It is therefore possible to conduct educational action research with such material.*

This suggests that the feedback the system provides the teacher, allows them to assess the success and utility of their pedagogical design and remediate their instructional design where needed.

2. Adaptive Tutorials and the Adaptive eLearning Platform

Adaptive Tutorials have been developed and fielded at the University of New South Wales (UNSW), in Sydney, Australia, since 2006. The Adaptive Tutorials were developed using the Adaptive eLearning Platform, which is a web-based system for the authoring, management and analysis of Adaptive Tutorials. From a pedagogical point of view, Adaptive Tutorials are analogous to real world teaching laboratory activities and are similar to the concept of Tutorial Simulations as described by [5]. They can essentially support any type of instructional design ranging from heavily guided to more explorative environments, with the focus being on teachers having control of the *type* of learning environment they want to create. The Adaptive Tutorials that we developed, were typically guided, featuring a detailed explanation that leads students through the interaction, whilst offering adaptive, remedial feedback in response to their misconceptions. Adaptive Tutorials are also interactive, typically featuring a simulation, enabling students to investigate a phenomenon, or a relationship between parameters of a problem in a hands-on manner, thereby encouraging the understanding of complex interactions between variables.

Adaptive Tutorials exhibit three different types of adaptivity. Firstly students receive feedback that is adapted to their specific misconceptions. Secondly, sub-activities including questions and tasks can be set-up to be sequenced adaptively depending on student performance. Lastly, teachers can adapt and modify the Adaptive Tutorials themselves, using feedback from the system to guide their reflection and analysis of the student's behavior in the tutorials.

The third level of adaptivity is what distinguishes the work on Adaptive Tutorials from other ITS systems and is of most relevance to this paper: the idea that the domain expert assumes pedagogical ownership over the content, and is able to adapt pedagogical aspects of the content, based on detailed reflection on the degree to which it supported students' learning. The approach comes as a reaction to the expressed need within the Intelligent Tutoring Systems community to improve the overall impact of ITS's within mainstream education. In particular, Woolf asks: "Given the large potential for improving education through new technology, why aren't thousands of effective education resources available for teachers in various disciplines? Where are the repositories of intelligent tutors?" [10, p:394]. We suggest that this is because the teacher has not been made an integral part of the ITS development lifecycle. Advanced educational technology such as ITS have been developed with a focus on students as content consumers and software developers and researchers as content developers. It is well known within the Human Computer Interaction literature [11-12] that if we ignore an important group of users they are unlikely to embrace or use the technology. There is therefore no surprise that teachers have little incentive to adopt ITS technology, as their role within its lifecycle process is unclear. If teachers are also included as primary users of the system in the initial design, we believe this situation can be remedied. Teachers should make the decision about format of instructional presentation, and if we want them to use the technology as part of their instruction, they need to have control over the pedagogy. The educational technology needs to be designed focusing on teachers' as well as students' needs.

3. Instructional Support for Teachers

According to Laurillard [5], when we approach the problem of pedagogical design, the crucial element in the design of any educational technology, let alone intelligent or exploratory learning environments, is the ability for the pedagogical designer (teacher or educational researcher) to be able to evaluate hypotheses regarding the validity of their instructional strategies in a systematic manner, and then to be able to adapt the instructional strategy in light of the evidence (or lack thereof). This type of reflective practice is captured in the notion of teachers as educational action researchers [13].

It follows that a central requirement imposed on developers of educational systems is that they should provide support for a continual cycle of reflection and adaptation by the pedagogical designer to drive their development [8]. This high-level "business" requirement tends to resonate all the way down to software architecture considerations. For example, developers of the MiGen system developed a software architecture that uses abstraction layers in order to be able to isolate feedback strategies in their system so that different evaluation studies could be performed [14]. The Adaptive eLearning Platform provides this support in the form of Solution Trace Graphs (STGs) [Figure 1], which are a visual representation of students' solution traces through a problem's state-space. These show how many students got a question correct and what mistakes were made by those who got it wrong, as well as how many attempts were made until a correct state was reached.

When students work towards completing a task that requires interaction in an Adaptive Tutorial they continuously change the "state" of the learning environment. A correct answer to a task is defined as a "correct" environment state, which is a set of conditions that must be satisfied. Additionally, error states are also defined, to which adaptive feedback is attached. A student's solution trace within a particular task is therefore the set of transitions made between the various states in the environment. Therefore, for any individual students, there will be a particular solution path and the set of solution traces for a student cohort can be visualized and analyzed using the Solution Trace Graph.

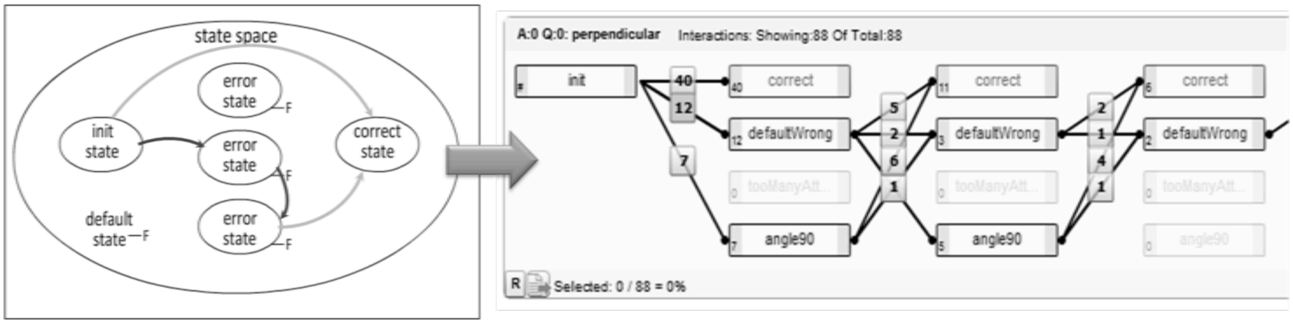


Figure 1: Students' transitions between environment's states (left) are visualized and analyzed in the Solution Trace Graph (right). Some students land straight in the correct state, while others transition between various error states before correctly completing the task.

This visual representation is used by teachers to reveal students' real misconceptions as they were working within an Adaptive Tutorial. This process is called 'reflection'. In tandem with reflection, the teacher refines the adaptive feedback in the Adaptive Tutorial, which is an 'adaptation' phase. As described in the definition of *pedagogical ownership*, the ability to perform reflection and adaptation is paramount to the teacher's sense of having control over the instructional material, and we suggest that enabling this should increase the adoption of ITS in general, and Adaptive Tutorials in particular.

This is the approach that has been taken at UNSW: we seek to promote pedagogical ownership of Adaptive Tutorials as a means of increasing adoption of them by teachers. We believe that this endeavor has been a success and to-date over 40 Adaptive Tutorials have been integrated into the syllabi of 10 major courses (each with 50–700 students), with over 3000 students a year now using Adaptive Tutorials [8, 15-16].

As a means to promote pedagogical ownership, teachers play a central role in the development process of Adaptive Tutorials. As already mentioned, from a pedagogical point of view Adaptive Tutorials resemble teaching laboratory activities. This analogy goes deeper, however, and the premise is that teachers should be able to develop Adaptive Tutorials in a way that is analogous to how they develop laboratory activities. In other words, they need not be concerned about building the software or understanding exactly how it works, but rather they should be able to import prefabricated "apparatus" into a learning environment, and then author lesson-plans that guide students through interaction with the apparatus. The conceptual framework for developing Adaptive Tutorials is called Virtual Apparatus Framework (VAF) [17] and its basic building blocks are virtual equivalents to real-world laboratory equipment.

The Adaptive eLearning Platform is used to build Adaptive Tutorials and is a software implementation of VAF. Pre-fabricated Virtual Apparatuses are created that can then be customized to specific teachers and students needs and context of use. We are in the process of creating a repository of online tutorials that are gradually refined each semester and can be used by different teachers who teach similar concepts and principles, but in different courses and contexts.

4. Customized Student Feedback

Within Adaptive Tutorials we provide many different types of guidance and feedback. Depending on the context and type of activity, students can be given the following types of feedback:

1) Technical help – e.g., explaining how to work a piece of apparatus;

2) **Informative help** – e.g., explaining a difficult concept that a student is struggling to get correct by providing further information to the learner;

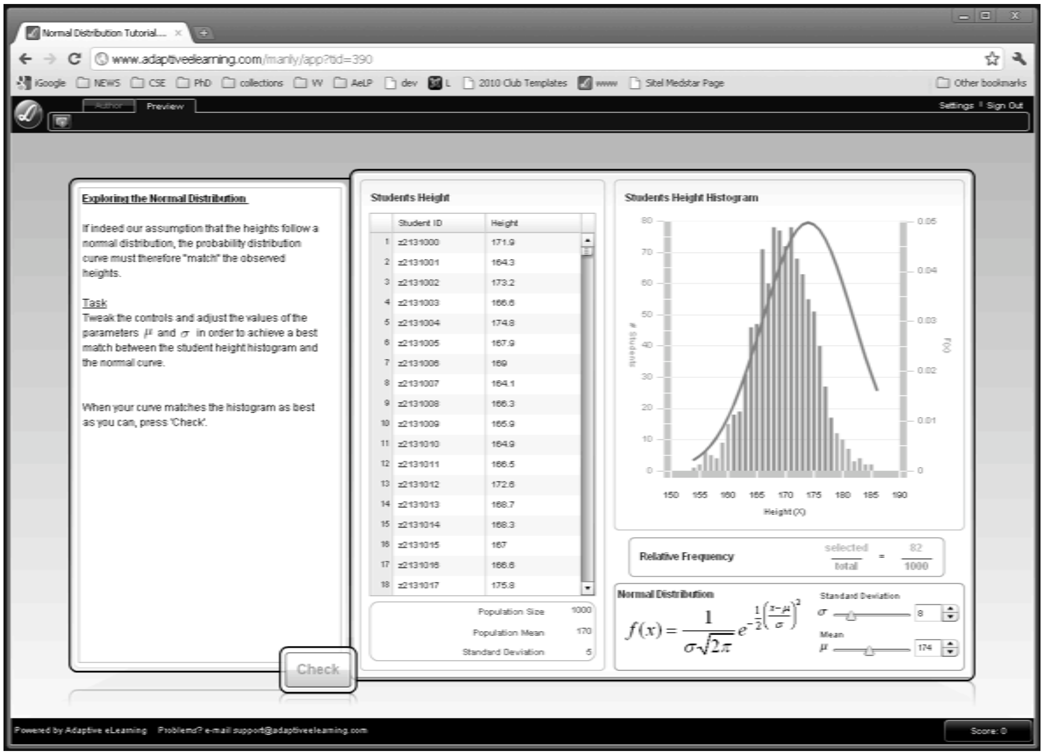
3) **Sub-topic teaching** – if students don't appear to have understood a certain topic the virtual tutor can choose to initiate a short teaching session, for example through following a dialectic discourse or by giving a sub-task designed to help the student grasp the concept;
4) **Intrinsic feedback on an action** – through the interactive manipulation of the apparatus with the goal of achieving an outcome, the students receives intrinsic feedback on their action [5, p.56]. It is a type of feedback that is the natural consequence of the action.
5) **Extrinsic Feedback on an action** – the 'tutor' who tracks students work can offer feedback that is extrinsic to their action and carries some judgmental element [5, p 56]. For example in response to a student's answer, the teacher provides feedback such as "this is correct" or "you should try to reconsider your assumptions".
6) **Intervention feedback** – in contrast to purely informative feedback, the 'tutor' can provide feedback that includes practical intervention and steps towards the solution. Such feedback involves intervening in the students' experimental setup or setting up a parameter for them (for example, correctly setting up the oscilloscope for the students after a number of failed attempts). Although informative feedback may also constitute hints and information that include steps towards the solution, we distinguish intervention feedback as it involves changing something in the students' physical or virtual environment, in this case, the state of the apparatus.

All these forms of feedback serve as some form of customized instructional guidance. The feedback the students receive is dependant of their personal trajectory through the lesson content, as well as the mistakes or misconceptions they have. What type of feedback to give when is decided by the instructional designer, based on their educational expertise.

Another very important type of feedback the system provides is *reflective feedback* to teachers – in order for teachers to exert pedagogical ownership over adaptive tutorials they must be able to conduct pedagogical action research. This entails being able to reflect and adapt the content to better suit the needs of students. We thus need to provide teachers with data mining or *analytics* tools to assess the effectiveness of their own authored feedback in the adaptive tutorial. As already mentioned, this is provided in the form of the Solution Trace Graph and the associated analysis tools in the Adaptive eLearning Platform. This is second order feedback, as it is feedback to the teacher about the effectiveness of their feedback to students, with the goal of reflecting on the effectiveness of their lesson content. It is this type of analytical and diagnostic feedback that separates our system from others by enabling teachers to drill down from a high-level overview into the details of student activities, which ultimately allows the refinement of instructions and feedback to suit students needs, thereby further enhancing pedagogical ownership.

5. Supporting the Teacher in Analyzing Students' Misconceptions in an Adaptive Tutorial

The following is a real-world example of how, through the process of reflection and adaptation, the teacher is able to better adapt lesson content to students' misconceptions and build appropriate feedback into the tutorial. An Adaptive Tutorial was developed for a statistical component in a Qualitative Methods course in the Economics program, for the Australian School of Business at UNSW. The activity was designed to assist students in learning how to correctly use statistical tables, set up null and alternative hypotheses, carry out tests,



Exploring the Normal Distribution

If indeed our assumption that the heights follow a normal distribution, the probability distribution curve must therefore "match" the observed heights.

Task
Tweak the controls and adjust the values of the parameters μ and σ in order to achieve a best match between the student height histogram and the normal curve.

When your curve matches the histogram as best as you can, press 'Check'.

Students Height

	Student ID	Height
1	z2131000	171.9
2	z2131001	164.3
3	z2131002	173.2
4	z2131003	166.6
5	z2131004	174.8
6	z2131005	167.9
7	z2131006	169
8	z2131007	164.1
9	z2131008	166.3
10	z2131009	165.9
11	z2131010	164.9
12	z2131011	166.5
13	z2131012	172.6
14	z2131013	168.7
15	z2131014	168.3
16	z2131015	167
17	z2131016	166.6
18	z2131017	175.8

Population Size 1000
Population Mean 170
Standard Deviation 5

Relative Frequency $\frac{\text{selected}}{\text{total}} = \frac{82}{1000}$

Normal Distribution

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

Standard Deviation σ 8
Mean μ 174

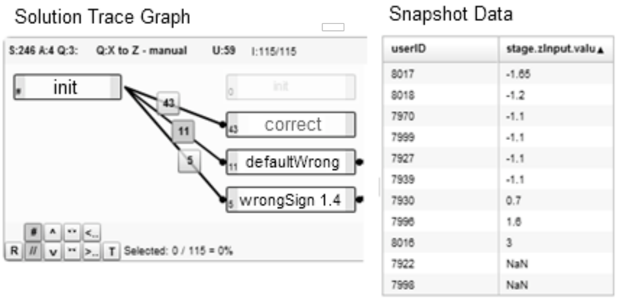
interpret computer generated *p*-values and reach conclusions (Figure 2). These are all areas where students commonly make mistakes and for which they commonly need extra support.

The Adaptive Tutorial featured 30 questions that were designed to gradually teach difficult concepts within the domain. In authoring the Adaptive Tutorial, the teacher prepared detailed adaptive feedback for a variety of anticipated misconceptions. These were encoded into the system as rules that represent incorrect student behavior, or answers, and feedback was then attached to each of these rules.

As part of the Adaptive Tutorial, the following question was posed to the students: *We discover that the heights of all male students in Australia are normally distributed with a mean of 175 cm and a standard deviation of 7.5 cm. Task 1: Calculate the Z value that relates to a height of 164.5 cm in this population.*

Following the question's text, an input box was placed on the screen, into which students were supposed to enter the answer (which is -1.4). To cater for possible mistakes, the teacher had to anticipate students' incorrect input, and then author feedback to cater for their misconceptions. On top of the correct rule (that tried to match the input the students entered to the correct solution of -1.4), two other rules were encoded, capturing incorrect student behavior. The first rule was called 'wrong sign' and targeted the case when the students entered 1.4. The feedback in that case would be: *"Wrong, but almost there. What about the sign of Z? Please try again"*. The second rule was the generic "default-wrong" that basically targeted any input that is not -1.4 and not 1.4. Students were encouraged to 'try again'.

On inspection of student's behavior after the tutorial ran, it appeared that 5 students landed in the anticipated 'wrong sign' (-1.4) and 11 students landed in the generic 'defaultWrong' state. The Solution Trace Graph enabled us to drill down and look at what values students had entered. Three of the students had made the same mistake and entered a solution value of -1.1. The teacher's role was to 'reflect' on why this sub-group of students had come to the same value and what their common mistake or misconception was. Appropriate remediation could then be created for this typical mistake. After much deliberation the teacher worked out that these students were using the wrong value for the mean. Instead of using 175 as was given in the current question, they used 170, which is a number that appeared in a previous question. While this particular misconception is numerical and specific to the particular lesson and context, other misconceptions could be more conceptual. The type of feedback provided to the teachers allows for all sorts of mistakes and misconceptions to be highlighted and customized feedback created for the students.



Snapshot Data

userID	stage.zInput.valu▲
8017	-1.65
8018	-1.2
7970	-1.1
7999	-1.1
7927	-1.1
7939	-1.1
7930	0.7
7996	1.6
8016	3
7922	NaN
7998	NaN

Figure 3. Sample data from the Solution Trace Graph for the Statistics lesson

6. Reflection on the Process

Just as in the Human Computer Interaction Design lifecycle, where iteration is a core component of good design [12] so continual refinement of the lesson design becomes an integral part of the educational process. Teachers become action researchers who can reflect upon and adapt their lesson content as needed. The Adaptive eLearning platform allows us to create an instructional design paradigm that gives teachers ultimate control of the pedagogy, without the need for them to become technological experts (we leave that job for the software engineers). The long-term aim is to create a design paradigm that is similar in its simplicity to that of PowerPoint - Microsoft's ubiquitous presentation software - that allows users to easily create sophisticated presentations without being sophisticated programmers. Similarly we would like teachers to be able to create sophisticated Adaptive Tutorials without the need for them to be technical experts.

Alan Cooper [11] advocates for software products with good interaction that are designed by interaction designers with the users' needs as a focus, rather than leaving the design to the programmers who are not trained in design. Such a design paradigm promotes development of technology that users can embrace and naturally know how to use and easily interact with. Similarly, we advocate the need to have education systems whose instructional design and content is authored and controlled by the teachers, and not by the software developers. This process allows teachers to assert pedagogical ownership over their lessons, just as they would with a lecture or worksheet based tutorial. Teachers can then embrace the technology and can create on-line tutorials that students will enjoy interacting with and be guided to learn from.

7. Conclusion

Different types of feedback can be created in learning environments, and the pedagogical designer must consider the different strategies available and their pedagogical impact. We have designed a learning platform that supports the teacher in the creation of sound instructional design with guided feedback for the students, and related feedback to the teachers for their reflection and lesson adaptation. Students' individual mistakes and misconceptions can be individually addressed, and feedback can be customized to support different students' needs.

We suggest a new educational technology design paradigm, with teachers being able to iteratively author and adapt lesson content and feedback to students, to suit individual learning needs. As part of this process, both teachers and students need to be recognized as primary users of ITS, with the teachers as educational action researchers in pursuit of constant improvement towards enhanced student learning outcomes.

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