AN INTELLIGENT TUTORING SYSTEM FOR DATABASE TRANSACTION PROCESSING

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Abstract: We describe an intelligent tutoring system that may be used to assist university-level students to learn key aspects of database transaction processing. The tutorial aid is based on a well defined theory of learning, and is implemented using PROLOG and Java. Some results of the evaluation of the learning tool are presented to demonstrate its effectiveness as a tutorial aid in an e-learning environment.

1 INTRODUCTION

We describe an item of educational software that we have developed and have used to help University-level students to learn certain key notions in database transaction processing. We call this piece of software ITSTP (*viz.* an *I*ntelligent *T*utoring *S*ystem for (Database) *T*ransaction *P*rocessing).

ITSTP is an item of educational software that is intended to "intelligently" assist computer science students in developing their understanding of the *CRAS properties* (Barker, 1998). The term "intelligently" is interpreted by us as the capability of responding to a student's self-selected input by detecting, diagnosing and explaining his/her errors or confirming that his/her understanding is correct.

ITSTP is a learning aid that is able to respond to questions about CRAS property satisfaction in the same way that an "expert tutor" might and provides students with a tool for constructing their own learning experience, an attractive feature that textbooks do not provide. More specifically, ITSTP encourages students to learn about the CRAS properties by making and testing hypotheses. This approach appears to us to be the approach that students naturally adopt to learn about the CRAS properties. The traditional, text-based method that we have previously used to teach the CRAS properties does not adequately support learning by hypothesis formulation and testing.

Although ITSTP has thus far been used to help students to learn about CRAS property satisfaction, ITSTP may be modified to provide support for students learning any part of the Computer Science curriculum that involves reasoning about the consequences of the occurrences of events.

The rest of the paper is organized thus. Section 2 introduces the CRAS properties. In Section 3, the development of ITSTP is discussed and a sample of a user session is given. Section 4 gives details of the implementation. In Section 5, some results, produced from our evaluations of ITSTP, are described and discussed. In Section 6, conclusions are drawn, and suggestions are made for further work.

2 THE CRAS PROPERTIES

Conventionally, the performance of a read (write) operation by transaction t_i (where i stands for a natural number that identifies a particular transaction in a schedule) on a database item x is denoted in the literature by $r_i(x)$ ($w_i(x)$). That is, when an item x of data (e.g. a record, a set of records, the value of a field of a record, ...) is read from a database on behalf of a transaction t_i the performance of that operation is denoted by $r_i(x)$. Reading a data item x causes a copy of x to be transferred from the stable database and into main memory; x can then be updated. The writing back to stable storage of a value of x that is updated by transaction t_i is denoted by $w_i(x)$.

In addition to read and write operations, a schedule may also contain operations to signal the successful completion of a transaction (its commit point) or its

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failure (and, thus, abortion). The commit (abort) of a transaction t_i is denoted by c_i (a_i).

It follows from this discussion that a schedule is some sequence of read, write, abort and commit operations. For example, the schedule, $s = \langle r_1(x), w_2(x), w_1(x), c_1, a_2 \rangle$ denotes that after transaction t_1's read operation on data item x is performed, transaction t_2 writes x before t_1 writes x, and then commits. Finally, t_2 aborts.

The four CRAS properties (Kumar, 1996) are: *Conflict Serialisability (CS)*, *Recoverability (RC)*, *Avoids Cascading Aborts (ACA)*, and *Strictness (ST)*. As previously mentioned, the satisfaction of these properties is tested for by a DBMS to enable it to decide whether a schedule is guaranteed to correctly update a database, and whether efficient recovery techniques may be employed to deal with failures.

Conflict serialisability and recoverability are correctness criteria. For a schedule to be conflict serialisable, it is essential that no two transactions contain mutually conflicting operations (two operations, o_1 and o_2 (say), are said to *conflict* if they refer to a common data item and at least one of the operations is a write). If a schedule satisfies the conflict serialisability criterion then it is certain to avoid the *lost update problem* (Kumar, 1996). To satisfy the recoverability property, it is essential that the order in which transactions successfully terminate in a schedule is consistent with the order in which transactions read the updated values of data items that are written to the database. That is, if transaction t_i writes a data item x in a schedule s and a transaction t_j ($t_i \neq t_j$) subsequently reads this updated value in s (a *read from* by t_j from t_i) then t_i must commit before t_j in s. Satisfying recoverability ensures that a committed transaction is not subsequently aborted and, thus, that a commit point correctly signals the termination of a successful transaction.

The ACA and ST conditions are practical criteria that, if satisfied, reduce the amount of work that needs to be performed in order to recover from the effects of failed transactions and enable a particularly efficient method to be employed to manage aborted transactions. As the name suggests, satisfying the avoiding cascading aborts condition ensures that if a transaction aborts then it does not cause a chain (or cascade) of aborting transactions to arise. That is, the failure of one transaction, t_1 (say), does not cause another transaction, t_2 (say), to fail which causes another transaction t_3 (say) to fail and so on. For schedules that satisfy the property of strictness, a particularly efficient approach may be used to recover from the effects of failed transactions. If a schedule is strict then the value of any of the data items that are written by an aborted transaction in a schedule can be simply reset to the value they had prior to the transaction running (the *before image*).

We define the CRAS properties formally below. In these definitions, t_i and t_j denote arbitrary transactions, $T(\sigma)$ is an arbitrary schedule σ defined on a set of transactions T, r_i, w_i, a_i and c_i are respectively read, write, abort and commit operations by transaction t_i, $\rightarrow$ is "implication", $\wedge$ is 'and', $\vee$ is 'or', $\neg$ is negation, and $<$ denotes an "earlier than" relationship between operations. The meanings of the *read from* and *conflict* predicates are as explained above.

Definition 1 *A schedule σ on a set of transactions T is conflict serialisable iff the following holds:*

$$\forall t_i, t_j \in T(\sigma)\ conflict(t_i, t_j) \rightarrow \neg conflict(t_j, t_i)$$

where conflict is defined thus:

$$\begin{array}{l} \forall t_i, t_j \in T(\sigma)\ r_i(x) < w_j(x) \rightarrow\ conflict(t_i, t_j) \\ \forall t_i, t_j \in T(\sigma)\ w_j(x) < r_i(x) \rightarrow\ conflict(t_j, t_i) \\ \forall t_i, t_j \in T(\sigma)\ w_i(x) < w_j(x) \rightarrow\ conflict(t_i, t_j) \end{array}$$

Definition 2 *A schedule σ on a set of transactions T is recoverable iff the following holds:*

$$\forall t_i, t_j \in T(\sigma)\ read\_from(t_i, t_j) \rightarrow c_j \in \sigma\ \wedge\ c_j < c_i$$

Definition 3 *A schedule σ on a set of transactions T avoids cascading aborts iff the following holds:*

$$\forall t_i, t_j \in T(\sigma)\ read\_from(t_i, t_j) \rightarrow c_j < r_i(x) \vee a_j < r_i(x)$$

Definition 4 *A schedule σ on a set of transactions T is strict iff the following holds:*

$$\forall t_i, t_j \in T(\sigma)\ w_j(x) < r_i(x) \vee w_j(x) < w_i(x) \rightarrow a_j < r_i(x) \vee c_j < r_i(x) \vee a_j < w_i(x) \vee c_j < w_i(x)$$

Definition 5 *The auxiliary predicate read_from is defined thus:*

$$\begin{array}{l} \forall t_i, t_j \in T(\sigma)\ \exists x[read\_from(t_i, t_j) \\ \quad \leftarrow w_j(x) < r_i(x) \wedge \neg(a_j < r_i(x)) \\ \quad \wedge\ [\forall t_k \in T(\sigma)\ w_j(x) < w_k(x) < r_i(x) \\ \quad \rightarrow a_k < r_i(x)]]. \end{array}$$

3 ITSTP: AN OVERVIEW

ITSTP is a piece of software that enables students to test any syntactically correct schedule they choose as input to the system. Students also have complete freedom to choose to investigate the satisfaction of any of the CRAS properties by these schedules.

The software that implements ITSTP is written in PROLOG (Bratko, 2000). PROLOG has been widely used for implementing items of educational software

(see, for example, (Nichol et al., 1988)) and is appropriate for developing applications, like ITSTP, that require that a degree of "intelligence" be captured. The fact that the rules that define the CRAS properties can be directly translated into PROLOG was another reason for us choosing PROLOG to implement ITSTP.

3.1 Our Development Methodology

Our approach to developing ITSTP initially involved us adopting a *phenomenographic* method (Marton and Ramsden, 1988) for information gathering on students' understanding of concepts in transaction processing. By conducting 'dialogue' sessions with students we identified the strategies students used to understand the CRAS properties. From our review of the notes taken at the dialogue sessions, we were able to develop a prototype system for supporting students in learning about CRAS property satisfaction.

As our ITSTP tool evolved, we made increasing use of Gagne's *event-based model of instruction* (Gagne, 1970) to decide what material a user of ITSTP should be offered and the order in which information ought to be presented to a learner. Following (Gagne, 1970), when students use ITSTP they are reminded what the learning task to be performed is, and what it is they are supposed to be able to do once the learning task has been completed. Prominence is given to the distinctive features that need to be learned, different levels of learning guidance are supported for different types of learners, informative feedback is given, and learning takes place in a student-centred, interactive way, but with support available to students as and when they need it.

3.2 A Learning Session

After loading the home page for the system (which gives a brief overview of how to use the system), the user engages with ITSTP, by submitting a schedule to the system, via the page shown in Figure 1.

Each element of a schedule is represented by 3 data entry boxes, which correspond to 3 of the elements in an underlying 4-ary tuple, (o,t_j,i,t_s). Here, $o \in \{read, write, commit, abort\}$ denotes an operation, t_j denotes a transaction performing o, i denotes the data item acted upon by t_j, and t_s is a timestamp, the time at which o is performed. Timestamps are represented using a monotonically increasing sequence of natural numbers. For simplicity, a value for t_s is added automatically by the system (hence 3 data entry boxes are sufficient to represent the 4-tuple (o,t_j,i,t_s). The t_s values are based on the sequence in which the operations are entered by the user.[1] In the case where o is a commit or an abort, the data item is *null* as these

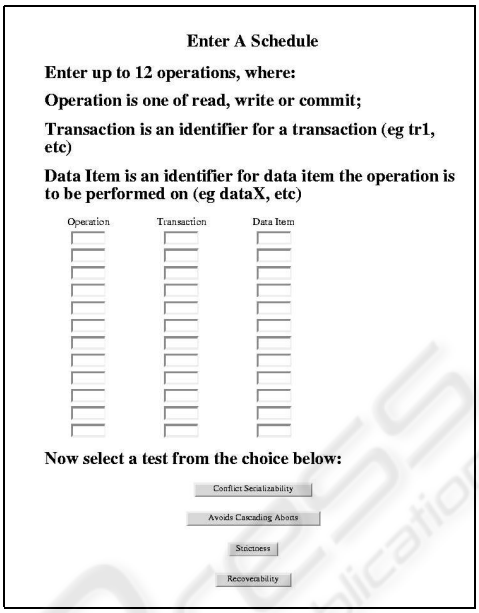
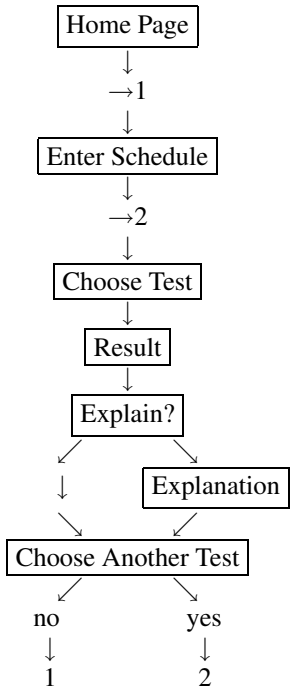


Figure 1: Schedule Entry Page

operations are not performed on a data item. Having entered a schedule σ, a user can select a CRAS property to evaluate with respect to σ.

The property to test is chosen by a simple choice of buttons on the Schedule Entry page. All further navigation is achieved following this convention, based on the following menu plan:



[1]This removes the possibility of the user reordering the operations by simply changing the timestamps. The test process revealed that users generally preferred the simplicity of the approach that we have adopted.

which we finalized after the testing process in the light of student feedback.

Once a test has been chosen, the system responds with a page showing the schedule entered by the user (now with the system-allocated timestamps), and an indication of whether the schedule is correct with respect to the chosen CRAS property. An example of the type of page that is generated as output is shown in Figure 2.

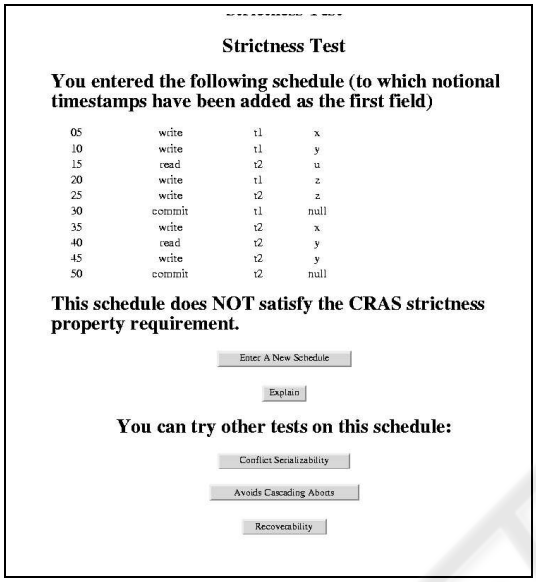


Figure 2: Initial Results Page

Having tested a schedule property, a user can ask for an explanation of the results obtained by selecting the *Explain?* option button; if the explanation is insufficient for the user, an option is provided for a further level of explanation, together with a summary of the chosen property.[2] A sample explanation page is shown in Figure 3.

4 THE IMPLEMENTATION

The main program is written in PROLOG. The input to this program consists of (i) a set of 4-ary tuples (see above) that represents a schedule σ, and (ii) a specific goal clause (corresponding to one of the CRAS properties). The program evaluates the goal clause with respect to σ, and returns either "true" or "false". Further goal clauses allow testing of the other CRAS properties, or can be used to produce an explanation of why a "false" result has been returned.

[2]This opens in an additional browser window, and has been omitted from the menu outline above.

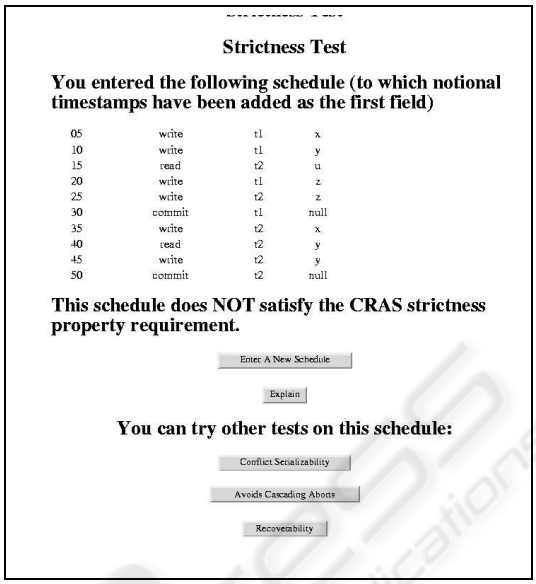


Figure 3: Explanation Page

We used XSB (Sagonas et al., 1999) to implement this program. XSB offers excellent performance that has been demonstrated to be far superior to that of traditional Prolog-based systems (Sagonas et al., 1994). It is also widely used for Prolog system development, and offers a wide range of interface packages and libraries, making it easy to combine with other applications.

The main program is called via a Java program that provides the main interface. Java is a suitable language for this type of application because of its comprehensive internet application support. In addition, it is easy to access applications written in a variety of other languages (through the *Java Native Interface (JNI)* mechanism).

Calls to XSB from the Java interface program are handled by the YAJXB (Decker,) package. YAJXB makes use of Java's JNI mechanism to invoke methods in the C interface library package supplied by XSB. It also handles all of the data type conversions that are needed when passing data between C and Prolog-based applications. YAJXB effectively provides all the functionality of the C package within a Java environment. The C library allows the full functionality of XSB to be used. A variety of methods for passing Prolog-style goal clauses to XSB exists. However, we generally found that the string method worked well. This method involves constructing a string S in a Java String type variable, and using the $xsb\_command\_string$ function (or similar) to pass S to XSB. This approach allows any string that could be entered as a command when using XSB interactively to be passed to XSB by the Java interface pro-

gram. YAJXB creates an interface object; the precise method of doing this is a call like

```
i=core.xsb_command_string
  (command.toString());
```

where the assignment, as one would expect, handles the returned error code. In the case of the *explanation* goals, variations on this method allow for the return of data too, though this is not necessary where conformity (to a CRAS property) is merely confirmed or denied.

All of our development was done on a Sun Sparc/Solaris system. We used Apache's Tomcat (APACHE,) web server, partly because it was convenient to do so (it is installed on the University system we used for testing the software), and partly because of its simple, threads-based session management. Java and XSB are well supported on the Solaris platform and YAJXB, though primarily configured for Linux, compiles easily on Solaris.

5 EVALUATING ITSTP

We have adopted a two-phase approach to evaluate ITSTP. That is, we used a formative evaluation of ITSTP during the development of the learning tool. Thereafter, we conducted a summative evaluation of a prototype version of ITSTP.

5.1 The Formative Evaluation

For the formative evaluation, comments on the software were sought from: three members of the teaching staff at the University of Westminster (the "expert reviewers" (Tessmer, 1993)); a volunteer student from the university's MSc course in Database Systems (the one-to-one study); and a group of six volunteer students from the same course (the small-group testing). The volunteer students were randomly allocated to either the one-to-one or small-group testing (but not both). These students were learning about the CRAS properties at the time at which the formative evaluation of ITSTP was being conducted.

Initial demonstrations to the three expert reviewers provided some suggestions on how ITSTP could be improved. In particular, a number of recommendations were made on improving the user interface. The suggested improvements were made to ITSTP prior to us conducting the one-to-one evaluation.

The one-to-one evaluation took place over a period of two weeks and involved approximately 3 hours of contact time with the student volunteer. At the first of the one-to-one sessions, the student was introduced to ITSTP using a 10 minute presentation. He was provided with a quick reference guide to remind him of the basic functions supported in the version of ITSTP he was to use.

In the one-to-one testing, our data were gathered using observation and informal "interviews". This involved one of the authors sitting alongside the subject and encouraging him to articulate his feelings about the learning package as he was using it. The student reported that ITSTP was useful in terms of helping to develop his understanding of CRAS property satisfaction. He emphasized that ITSTP was motivating to use, and he repeatedly suggested that the scope ITSTP provided, to enable him to investigate schedules of his own choosing, was important in developing understanding. The student also suggested some useful modifications to ITSTP. We chose to make several of the suggested changes before starting our small-group testing.

The small–group testing was performed over a four week period (approximately 8 hours of contact time spread over six sessions) with a set of six student volunteers (three males and three females). The methods employed to gather data were the same as those used for the one-to-one sessions.

Again, the power that ITSTP provides to enable students to investigate any schedule and CRAS property was reported to be an attraction of the learning tool, and important in helping students to develop their understanding of schedule properties. The students also commented positively on the internet availability of the software: although our small-group testing was limited to that described above, all of the students involved in the formative evaluation of ITSTP reported that they had used the learning tool, via the web, on several additional occasions outside of the test sessions.

The feedback collected from students engaging in the small–group testing was used by us to develop ITSTP further and prior to its summative evaluation.

5.2 Summative Evaluation of ITSTP

The field test of ITSTP was conducted with the cohort of 29 students at the University of Westminster who were taking the Database Administration (DBA) module as part of their part-time BSc Computer Science degree programme in the Second Semester of the 2002/2003 academic year.

Students were introduced to the version of the ITSTP software to be summatively evaluated during a 2 hour tutorial session; the introduction was presented identically to that used in the one-to-one and small-group testing. Following the introductory session, ITSTP was used for the next three weeks during the part-time students' tutorial time.

In overview, there were two parts to the summative evaluation of ITSTP. Firstly, a t-test was performed on the results of a phase test that included questions on

the CRAS properties. The t-test was intended to compare the performance of the part-time students (the experimental group) with that of the 47 full-time DBA students (the control group) who had used the standard module text (Bernstein et al., 1987), henceforth denoted by $\mathcal{B}$, but not ITSTP. The full-time students had taken the same test in the semester before the experimental group. Secondly, a 5-point Likert scale was used to produce data on the perceptions the part-time students had of ITSTP and $\mathcal{B}$, as methods for facilitating understanding of the CRAS properties, and their attractiveness as learning instruments. A t-test was again used to analyse the data produced and was based on a comparison of the matched pairs of scores produced by each respondent for ITSTP and $\mathcal{B}$.

Mean test scores for the part-time and full-time students for the phase test were calculated for both the CRAS and non-CRAS related questions to compare the performance of the two sets of students. Because we felt that ITSTP might have had an effect in encouraging learning gains, we chose to test the alternative (directional) hypothesis that: the part-time students performed better on the test of CRAS property understanding than the full-time students. The corresponding null hypothesis was that there was no difference in the phase test scores produced by the two sets of students.

The analysis of our data showed that the mean test scores (out of 12) for the full-time and part-time students on the questions on CRAS properties were 6.52 and 8.38 respectively (the corresponding standard deviations were 9.65 and 6.97, respectively). The computed t-statistic was 0.81 for 27 degrees of freedom. Hence, the directional hypothesis had to be rejected in favour of the null hypothesis.

A comparison of the mean scores (out of 28) achieved by the students on that part of the phase test that did not directly relate to the CRAS properties revealed that the average mark for full-time students was 16.96 whereas the average mark for part-time students was 17.58. As such, whereas the average score for the full-time students on the phase test questions relating to the CRAS properties was 29% lower than the part-time students, the average mark for the full-timers on questions not related to the CRAS properties was only 4% lower. Although these figures do not prove anything, they offer some *suggestive* evidence that ITSTP might have helped students to understanding the CRAS properties.

The combination of the statistically non-significant analysis of the phase test scores and the fact that a number of potentially confounding variables applied in our study meant that we were not able to draw any firm conclusions on whether ITSTP had been of value in terms of helping students understand the CRAS properties.

The Likert scale included a total of 24 statements (with an equal number of positive and negative statements). These items were divided into three categories. Eight of the statements were intended to measure the extent to which ITSTP and $\mathcal{B}$ were perceived as being of value in facilitating student understanding of the CRAS properties, a further eight items were intended to help to decide the extent to which ITSTP and $\mathcal{B}$ were motivating to use, and the remaining eight statements were used to collect the students' opinions on the value of comparable features of ITSTP and $\mathcal{B}$ (i.e., their explanations, exercises and examples). Students were asked to indicate their strength of agreement/disagreement with each statement in the Likert scale. The five options were: strongly agree, agree, unsure, disagree and strongly disagree.

26 responses to the Likert scale were returned. To produce the measures of student attitudes, a three-stage approach was adopted. The initial step involved "signing" the 24 items included in the Likert scale as being a positive or negative statement about ITSTP or $\mathcal{B}$. Next, the returns were analysed using the following system: for each positive statement a response of "strongly agree" was given a score of 5, an "agree" response was given a score of 4, a score of 3 corresponded to an "undecided" response, "disagree" was scored as a 2, and "strongly disagree" was scored as a 1. Conversely, for each negative statement, a "strongly agree" response was given a score of -5, "agree"was scored as -4, "undecided" was recorded as a -3, "disagree" was given a score of -2, and -1 corresponded to a "strongly agree" response. By summing the scores for each return, a figure corresponding to the respondent's attitude towards ITSTP and $\mathcal{B}$ was computed. In the final step, the $\mathcal{B}$ score for each respondent was subtracted from the score for ITSTP. This calculation gave a measure of a respondent's attitude to ITSTP that is relative to their attitude towards $\mathcal{B}$.[3]

To analyse the information produced from the Likert scale, t-statistics were computed to compare the mean scores for the perceptions students had of ITSTP and $\mathcal{B}$, overall and for each of the three categories of items included in the Likert scale.

In the overall measure of the two methods, the average difference in the ratings of ITSTP and $\mathcal{B}$ was 16.79 in favour of ITSTP, and no student reported that $\mathcal{B}$ was "better" than ITSTP. The t-statistic for the comparison of average differences was 2.25. This is statistically significant at the 2% level. Not surprisingly, given the overall results, ITSTP was also perceived to be "better" than $\mathcal{B}$ in all three of the sub-categories of Likert scale items.

In terms of facilitating understanding of the CRAS

[3] A positive score indicates a more favourable attitude towards ITSTP than $\mathcal{B}$; a negative score represents a more favourable attitude towards $\mathcal{B}$ than ITSTP.

properties, the average difference in scores between ITSTP and $\mathcal{B}$ was 2.07, in favour of ITSTP, and all but four of the students reported that ITST had been more valuable than $\mathcal{B}$ on this measure. In the t-test comparison of the average difference in the ratings of ITSTP and $\mathcal{B}$, the t-statistic was 2.18. This value is significant at the 5% level.

The average difference in the rating of ITSTP and $\mathcal{B}$ on motivational appeal was 10.85, and all but one student reported that ITSTP had been more motivating to use than $\mathcal{B}$. The t-value, of 2.51, for the comparison of average differences in ratings between ITSTP and $\mathcal{B}$ on motivational appeal is significant at the 2% level.

The average difference in scores on the value of the exercises, explanations and examples was 4.63 in favour of ITSTP. The t-statistic for the average difference was 3.21, which is significant at the 1% level.

6 CONCLUSIONS AND FURTHER WORK

We have described an intelligent tutorial aid, ITSTP, that may be used by undergraduate computer science students to learn about transaction schedule properties. The tutorial aid enables students to create their own learning environments. ITSTP can respond to student input in the way that an "expert tutor" might and provides extensive explanation facilities and online exercises. The results of our analysis of ITSTP suggest that the tool is perceived by its users to be of value in facilitating understanding of the CRAS properties, and ITSTP is reported by users to be motivating to use. A longitudinal study of the effectiveness of ITSTP as a learning tool is a matter for further work.

Although currently focussed on the CRAS properties, extended forms of ITSTP are possible to support students' learning other topics in the University-level Computer Science curriculum (e.g., database recovery techniques and *state machines* (Borger and Stark, 2003)). Being web-based, ITSTP is suitable for use by Computer Science students taking courses in distance learning mode; investigating the use of ITSTP in a distance learning environment is another matter for future work.

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