Constraint-Based Tutors: a Success Story

Tanja Mitrovic

Intelligent Computer Tutoring Group
Computer Science Department
University of Canterbury
Christchurch, New Zealand

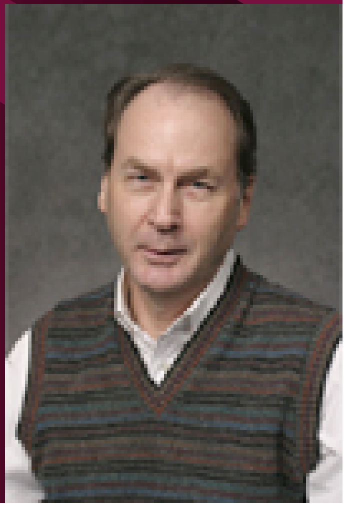
Student modeling

Problem:

- To describe what a student knows is not sufficient;
- To specify student’s misconceptions is too complicated.

Learning from performance errors

- Declarative/procedural knowledge
- Learning phases:
  - Error detection
  - Error correction
- CBM: domain and student modeling



Constraint-based Modeling

- Ohlsson, 1994
- The space of incorrect knowledge is vast
- Therefore: abstractions are needed
- Represent only basic domain principles
- Group the states into equivalence classes according to their pedagogical importance

Constraint-Based Modeling

- Domain knowledge represented by a set of constraints
- A constraint is a pattern of form <Cr, Cs>
- If a solution matches the Cr then it must also match the Cs, else something is wrong
- “Innocent until proven guilty” approach

Example constraints

- If you are driving in New Zealand, you better be on the left side of the road.
- If the current problem is a/b + c/d, and the student's solution is (a+c)/n, then it had better be the case that n=b=d.

Advantages of CBM

- Very efficient computationally
- No need for an expert module
- No need for a bug library
- Insensitive to the radical strategy variability phenomenon
- Neutral with respect to pedagogy

SQL-Tutor

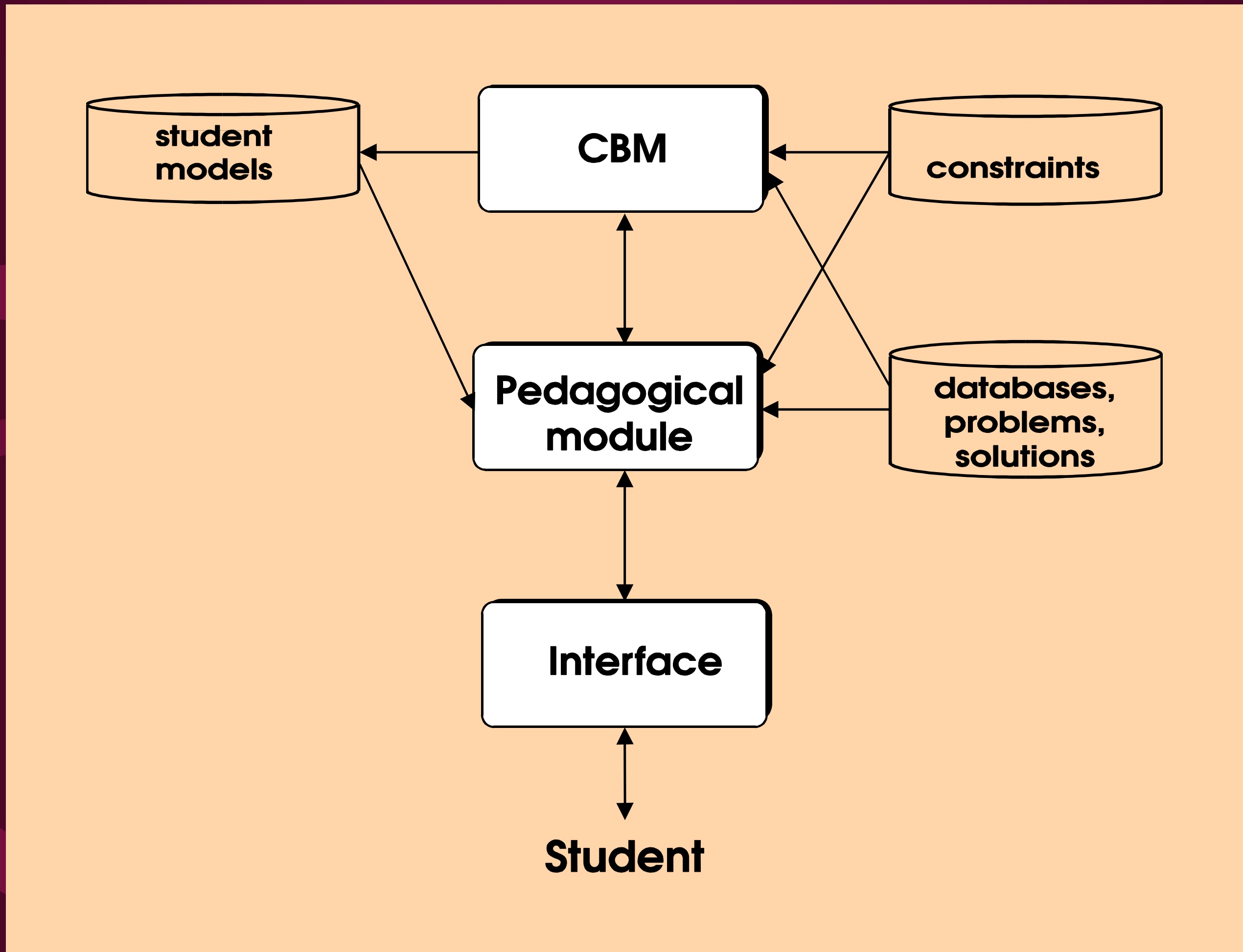
Research began in 1995

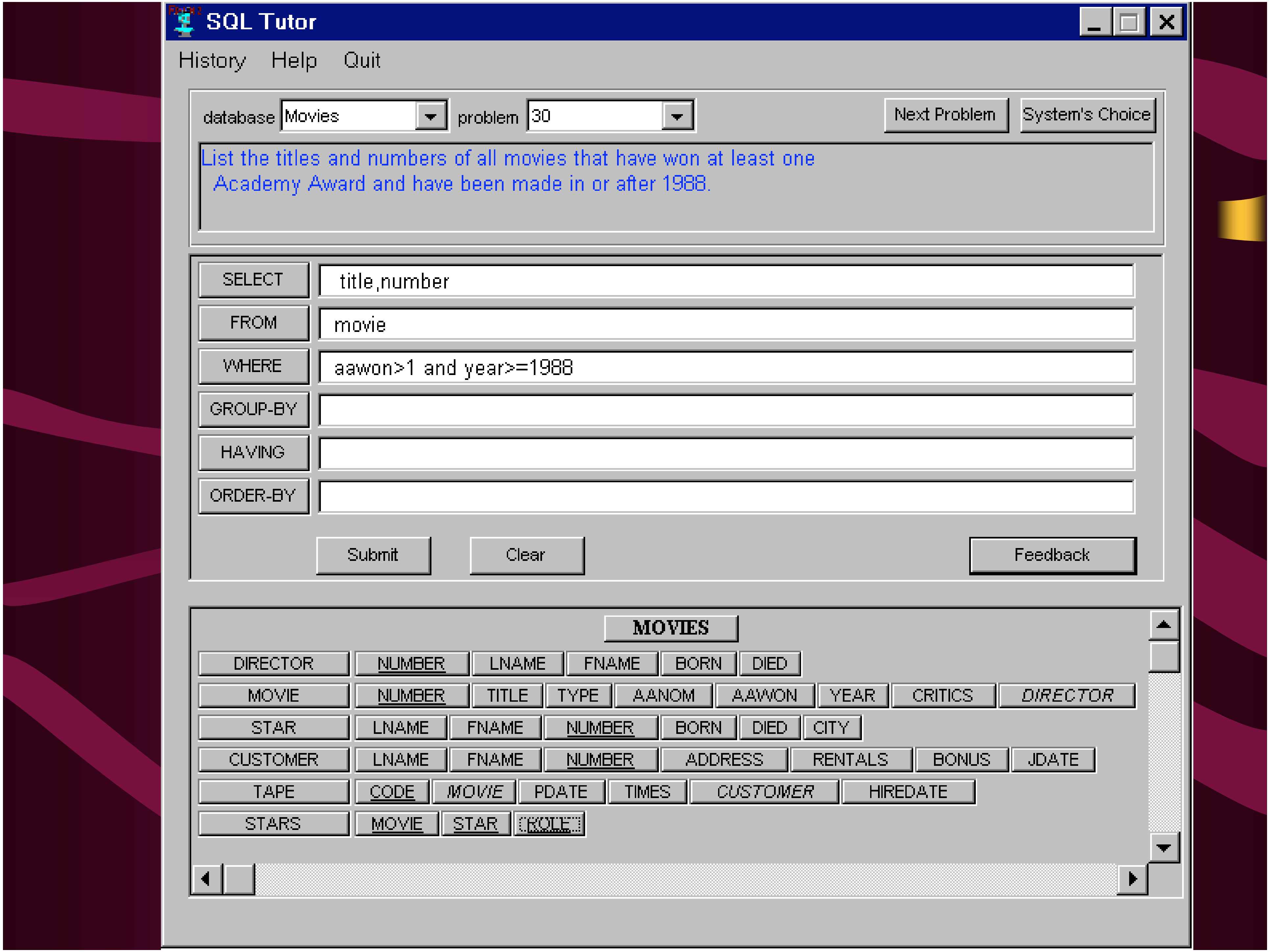
- Solaris version
  - Developed in 1997
  - Used in COSC313 in 1998
- MS Windows version (1998)
  - downloaded by **1186** people
    (May 1999 – 2001)
- Web version (1999)

Problems with learning SQL

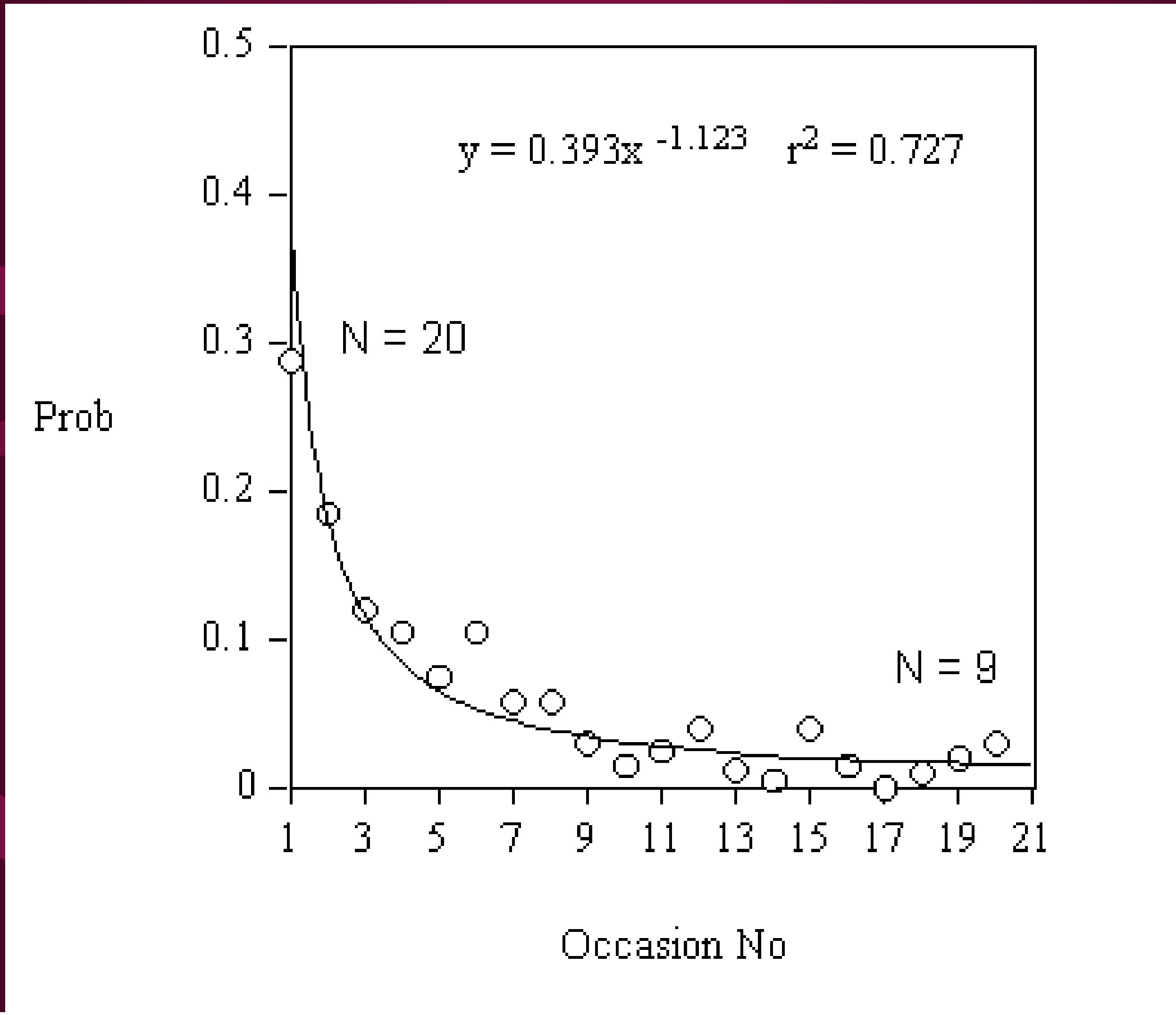
- Misconceptions about the relational data model
- Misconceptions about the SQL concepts
- The necessity to learn about DBMSs
- DBMS messages are difficult to understand
- DBMSs unable to deal with semantic errors

Architecture of SQL-Tutor




SQL Tutor
History
Help
Quit
database
Movies
problem
30
Next Problem
System's Choice
List the titles and numbers of all movies that have won at least one Academy Award and have been made in or after 1988.
SELECT
title,number
FROM
movie
WHERE
aawon>1 and year>=1988
GROUP-BY
HAVING
ORDER-BY
Submit
Clear
Feedback
MOVIES
DIRECTOR NUMBER LNAME FNAME BORN DIED
MOVIE NUMBER TITLE TYPE AANOM AAWON YEAR CRITICS DIRECTOR
STAR LNAME FNAME NUMBER BORN DIED CITY
CUSTOMER LNAME FNAME NUMBER ADDRESS RENTALS BONUS JDATE
TAPE CODE MOVIE PDATE TIMES CUSTOMER HIREDATE
STARS MOVIE STAR ROLE

Students did learn from it!



Comparison of competence (1998)

	Mean	StDev
Experimental group	82.75	8.90
Control group	71.23	17.55

History of ICTG

- SQL-Tutor
  - Solaris version (1997)
  - MS Windows version (1998)
  - Web version (1999)
- CAPIT (2000)
- KERMIT (2000)
  - Web version 2003
- WETAS (2002)
- LBITS (2002)
- NORMIT (2002)
- ERM-Tutor (2003)
- COLECT-UML (2005)

The goals of ICTG

- Enhancing CBM
- Testing the applicability and generality
- Development methodology
- Authoring system

Developing Constraint-based Tutors: Theoretical Underpinnings

1. How to represent the domain?
2. How to model the student?
3. What pedagogy?
   - When should the ITS take an initiative?
   - What to instruction to deliver?

Enhancing CBM

- Long-term student model
  - Overlay model
  - Probabilistic model
- Problem selection
- Problem generation
- Tailoring hints
- Animated pedagogical agents
- Open student models
- Supporting and modeling metacognitive skills

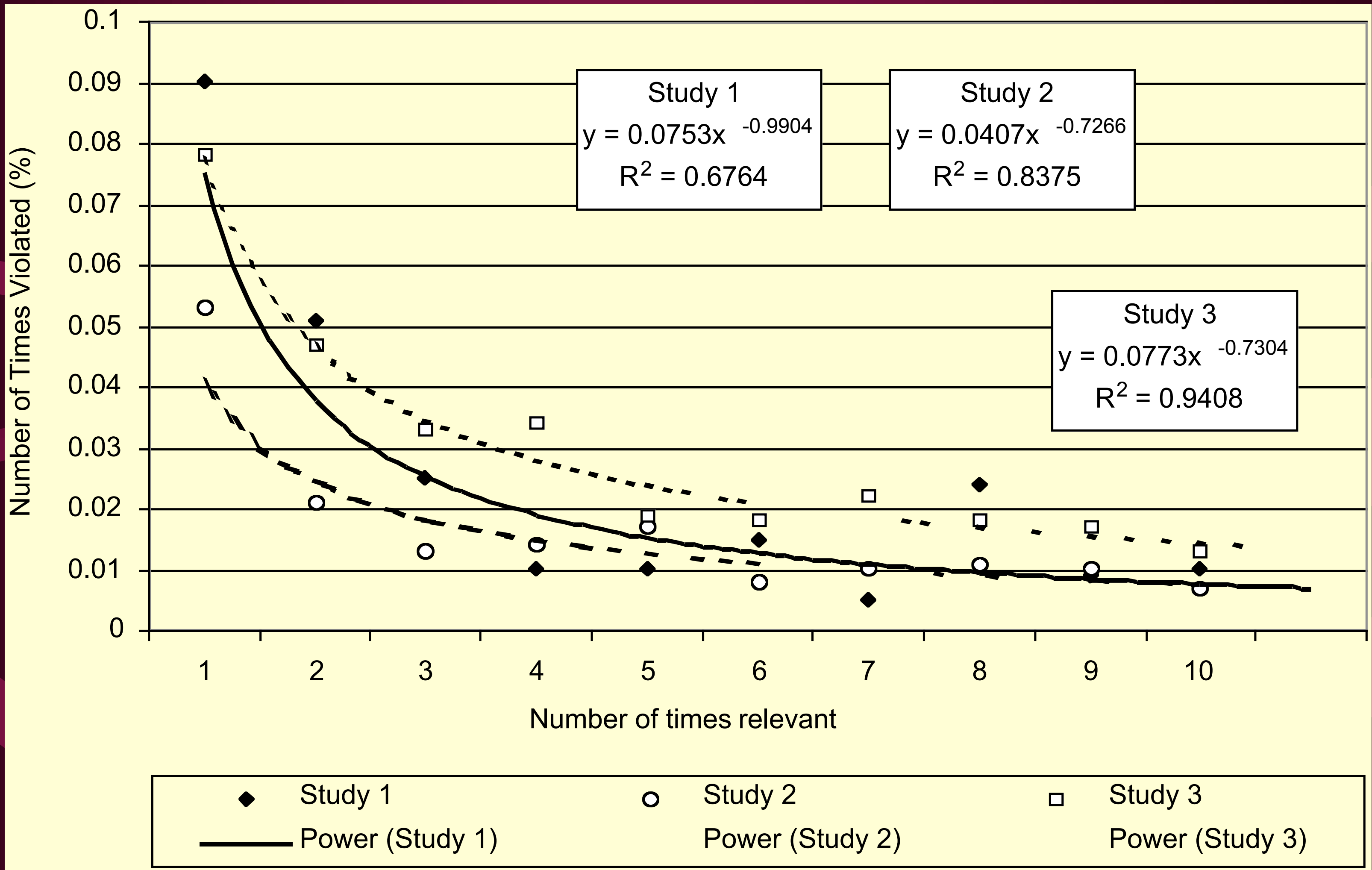
Evaluation

- Highest importance
- Always in authentic situations
  - Pre-post test performance
  - Log analysis
  - Subjective data
- Difficult to plan
- Hard to control
- Paper in Session 9b

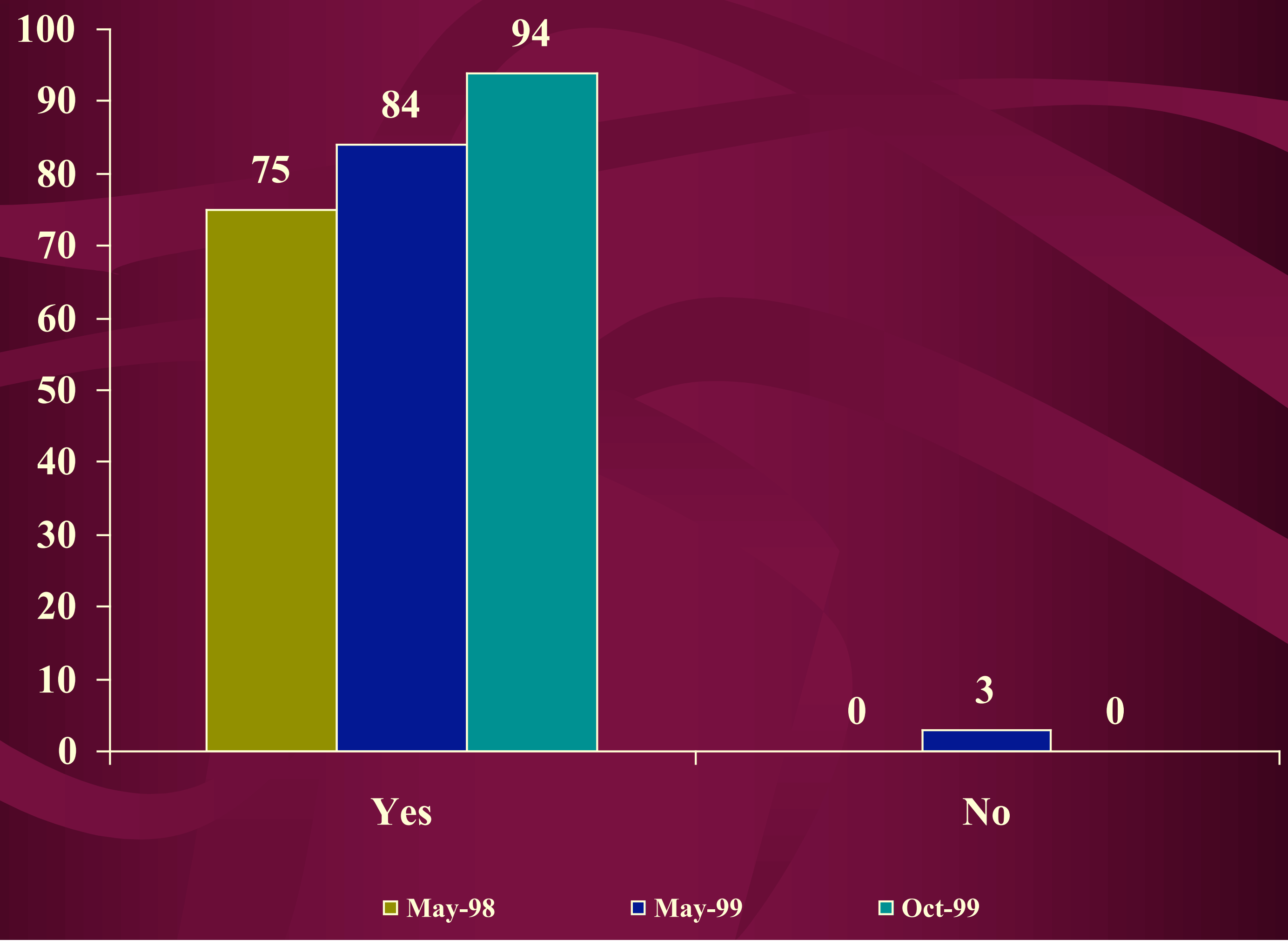
Evaluations of SQL-Tutor

- CBM and students' learning (1998 -)
- Effectiveness of feedback (May 1999)
- Probabilistic student model (October 1999)
- Animated pedagogical agent (October 1999)
- Self-assessment (2000)
- Open student models (2001)
- Teaching problem-selection (2002)
- Problem selection strategies (2003)
- Granularity of feedback (2004)

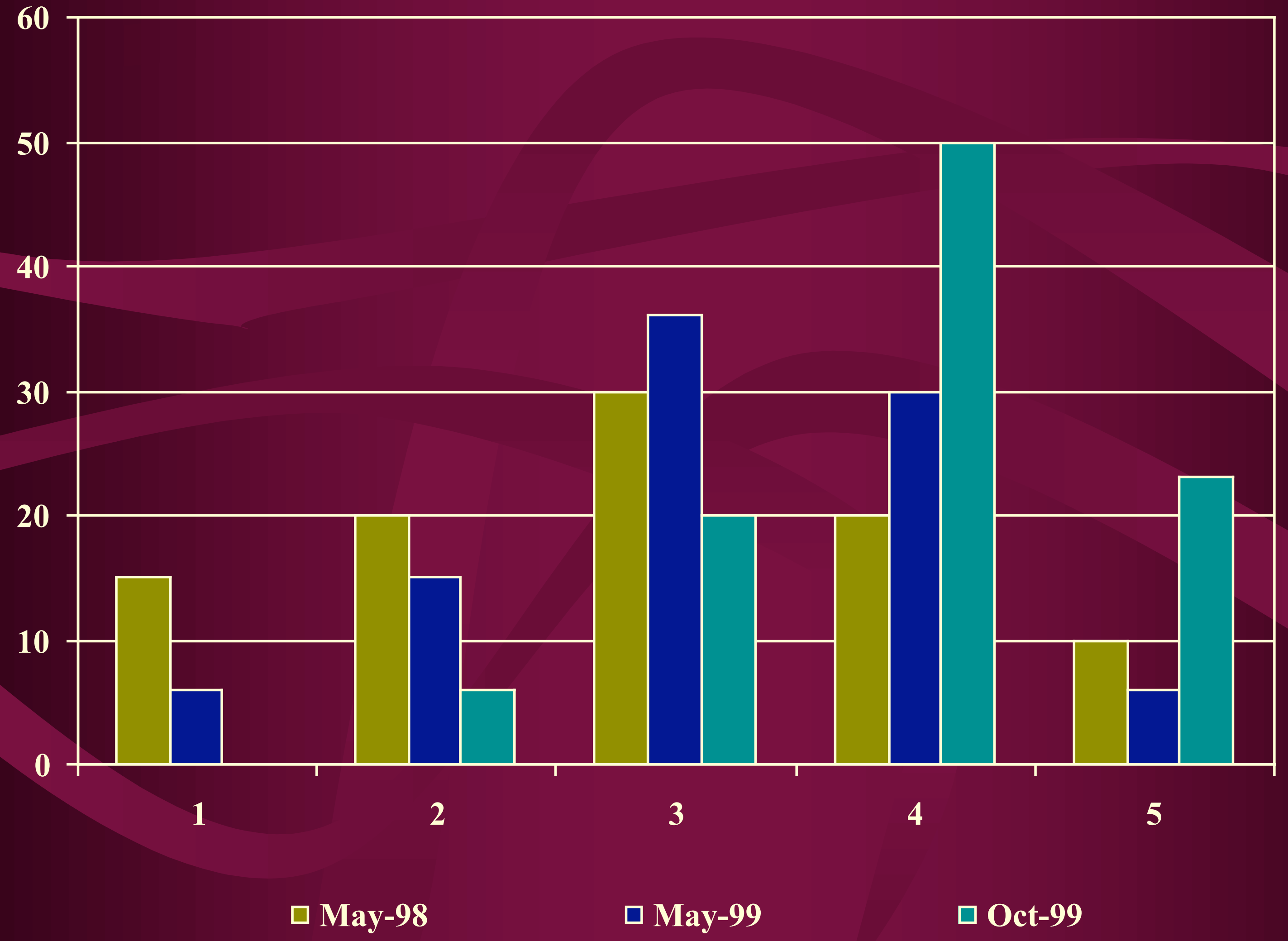
Mastery of constraints



Would you recommend SQL-Tutor to other students?



How much did you learn about SQL from the system?

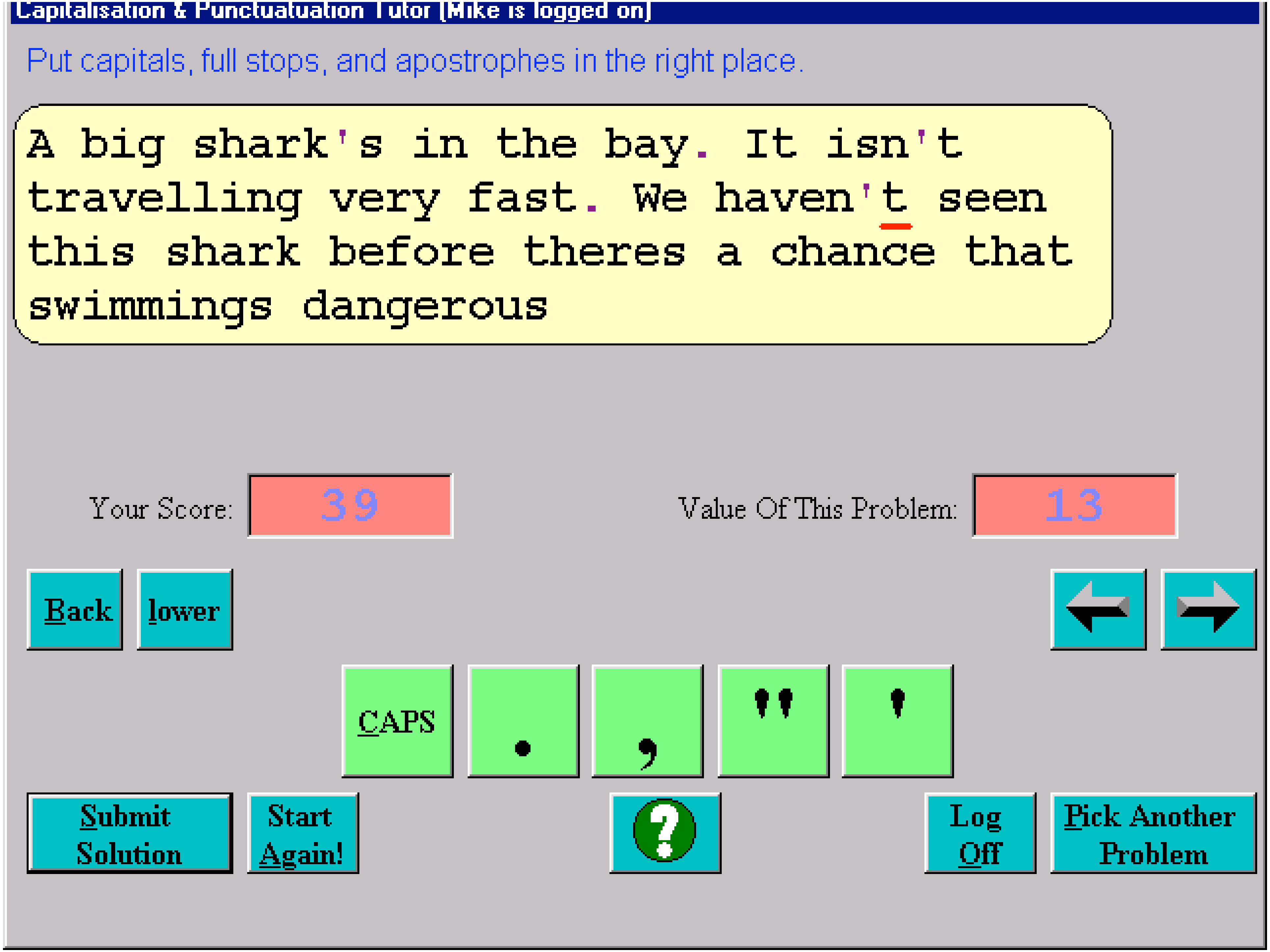


Generality of the approach

- Design tasks
  - SQL
  - Database design (EER model)
  - Software design (UML)
- Declarative tasks (CAPIT)
- Procedural tasks
  - Data normalization (NORMIT)
  - ER-to-relational mapping (ERM-Tutor)

CAPIT: Capitalisation and Punctuation Intelligent Tutor

- English punctuation and capitalisation for school children (9-11 years)
- Basic usages of capitals, commas, full-stops, quotation marks
- Completion exercise: student must punctuate and capitalise an unpunctuated, uncapitalised piece of text


Capitalisation & Punctualuation Tutor [Mike is logged on]
Put capitals, full stops, and apostrophes in the right place.
A big shark's in the bay. It isn't travelling very fast. We haven't seen this shark before theres a chance that swimmings dangerous
Your Score:
39
Value Of This Problem:
13
Back
lower
CAPS
.
,
"
'
Submit Solution
Start Again!
?
Log Off
Pick Another Problem

Evaluation of CAPIT

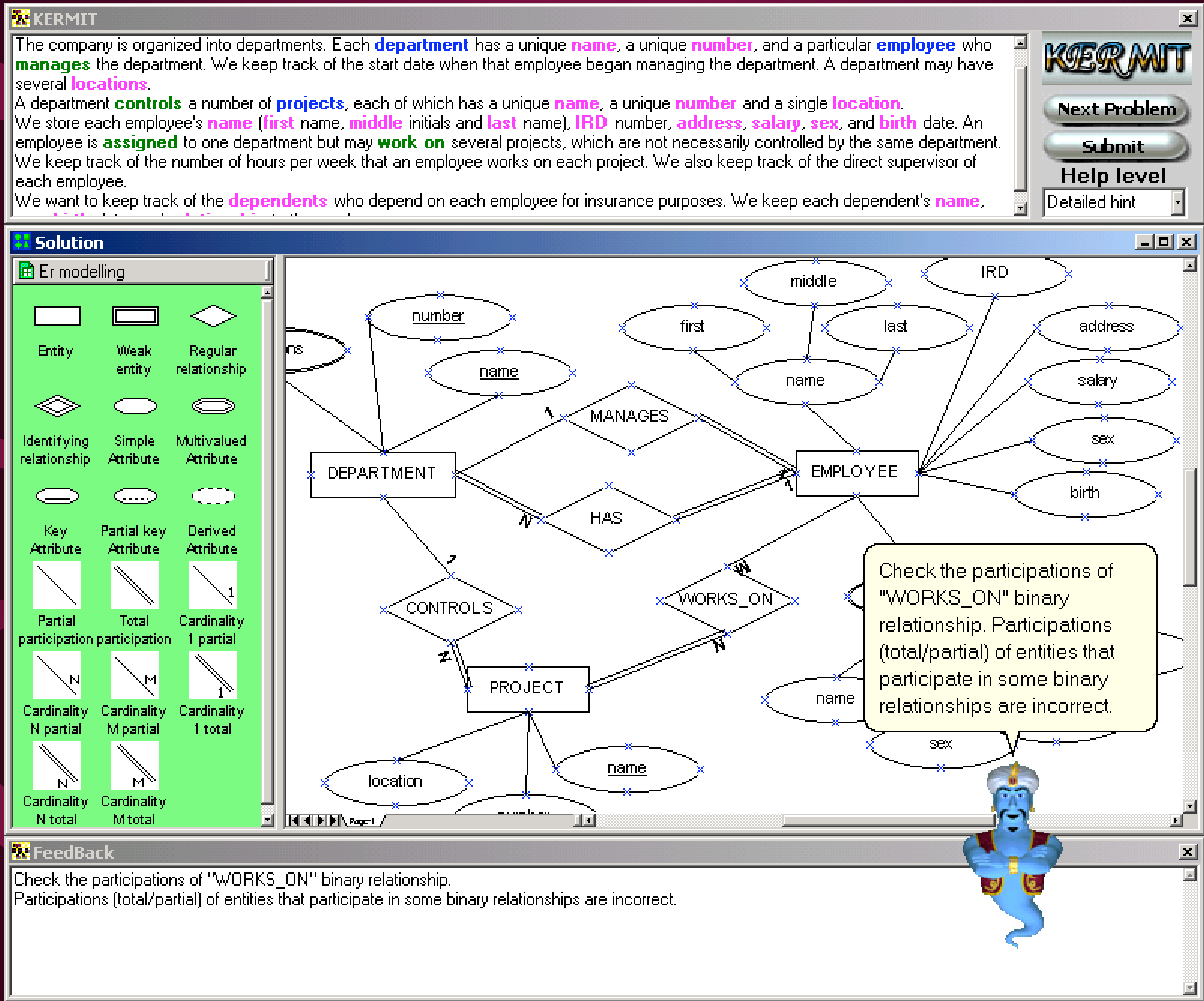
- One 45 min session over 4 weeks
- 3 classes of 9-10 year olds
  - Group A: no CAPIT
  - Group B: no student model
  - Group C: probabilistic student model

Results

Group	Pre-test (%)	Post-test (%)
A	54.5	47.8
B	58.1	62.7
C	51.0	61.3

KERMIT

- ER is a widely used conceptual data model
- Requires extensive practice to excel in it
- Developed as a problem solving environment
- Student modelling using CBM
- Implemented in Microsoft Visual Basic


KERMIT
The company is organized into departments. Each department has a unique name, a unique number, and a particular employee who manages the department. We keep track of the start date when that employee began managing the department. A department may have several locations.
A department controls a number of projects, each of which has a unique name, a unique number and a single location.
We store each employee's name (first name, middle initials and last name), IRD number, address, salary, sex, and birth date. An employee is assigned to one department but may work on several projects, which are not necessarily controlled by the same department.
We keep track of the number of hours per week that an employee works on each project. We also keep track of the direct supervisor of each employee.
We want to keep track of the dependents who depend on each employee for insurance purposes. We keep each dependent's name,
KERMIT
Next Problem
Submit
Help level
Detailed hint
Solution
Er modelling
Entity
Weak entity
Regular relationship
Identifying relationship
Simple Attribute
Multivalued Attribute
Key Attribute
Partial key Attribute
Derived Attribute
Partial participation
Total participation
Cardinality 1 partial
Cardinality N partial
Cardinality M partial
Cardinality 1 total
Cardinality N total
Cardinality M total
number
name
middle
IRD
first
last
address
name
salary
sex
birth
MANAGES
DEPARTMENT
EMPLOYEE
HAS
CONTROLS
WORKS_ON
PROJECT
location
name
sex
Check the participations of "WORKS_ON" binary relationship. Participations (total/partial) of entities that participate in some binary relationships are incorrect.
FeedBack
Check the participations of "WORKS_ON" binary relationship.
Participations (total/partial) of entities that participate in some binary relationships are incorrect.

KERMIT's Knowledge Base

- 88 constraints
- Syntactic constraints
  - All entity names must be in upper case
  - The weak entity participating in an identifying relationship should have a total participation
- Semantic constraints
  - The student′s solution should consist of all the entities present in the ideal solution

KERMIT - evaluation

- Evaluation performed 24-27 July 2001
- COSC226 (Introduction to databases)
- 57 students in two groups
  – Control group: no feedback (only full solution)
  – Experimental group had all levels of feedback
- Pre/post test + questionnaire

Pre/post Test Results

Group	Students	Pre-test	Post-test
Experimental	26	16.16 (1.82)	17.77 (1.45)
Control	31	16.58 (2.86)	16.48 (3.08)

Effect size: 0.57

Power 0.75

Average session length: 66 min

Problem-solving support via the interface

- Reducing the working memory load
  - Visualizes the goal structure
  - Providing domain-specific information
  - Structures students' thinking
- Enforcing good practices in the chosen instructional domain
- Provide a learning environment close to the real-world environment

Problem-solving support via the feedback

- Based on intelligent analysis of students’ solutions
- Various levels of detail
  - Correct?
  - Error flag
  - Hint
  - Detailed hint
  - All errors
  - Full solution
- Wording of feedback
  - Common-sense vs theory-based feedback

Wording of feedback

- Use the underlying learning theory!
- An effective feedback message should tell the student:
  - Where the error is
  - What constitutes the error
  - Reiterate the corresponding domain concept
- Theory-based feedback more effective than intuitive feedback
- Paper in session 5a

Supporting problem solving via self-explanation

- Inspired by Conati & VanLehn, Koedinger
- Supported in KERMIT (database design) and NORMIT (data normalization)
- Student required to explain during problem solving
- Results: SE increases
  - declarative knowledge
  - procedural knowledge
  - motivation

Self-explanation in NORMIT

- Explanation required for every action performed for the first time, or when there is an error
- Explanations selected from given options
- If the explanation is wrong, the student is asked to define the underlying domain concept


NORMIT - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Links
Normit
Change problem
Show history
Show model
Help
Logout
R (A, B, C, D, E)
{A,B} --> {D,E}
{C} --> {E}
{D} --> {C}
{E} --> {A}
You have chosen A as your candidate key.
This attribute (set of attributes) is a candidate key because:
Its closure contains all attributes of the table
All attributes are keys
It is a minimal set of attributes
It determines the values of all other attributes
It is a minimal set of attributes that determine all other attributes in the table
Every value is unique
Feedback
Help
In this task, you need to determine all the candidate keys for the given relation.
To add a key, type the attributes in the given space, and then click the Add button. The new candidate key will appear on the page, together with a Delete button that you
Done
Local intranet

NORMIT - give a reason - Microsoft Internet Explorer

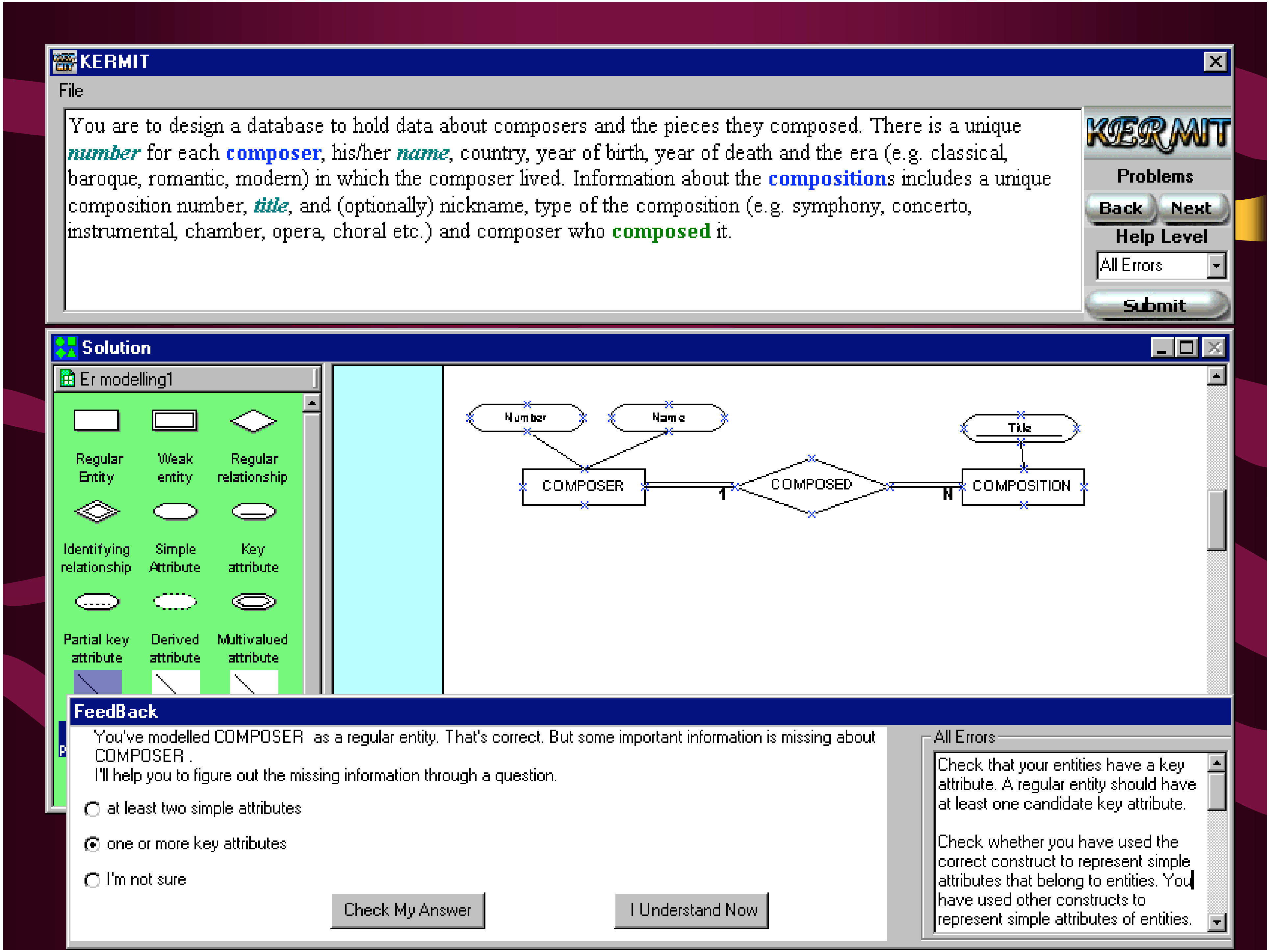
File Edit View Favorites Tools Help Links

A candidate key is:

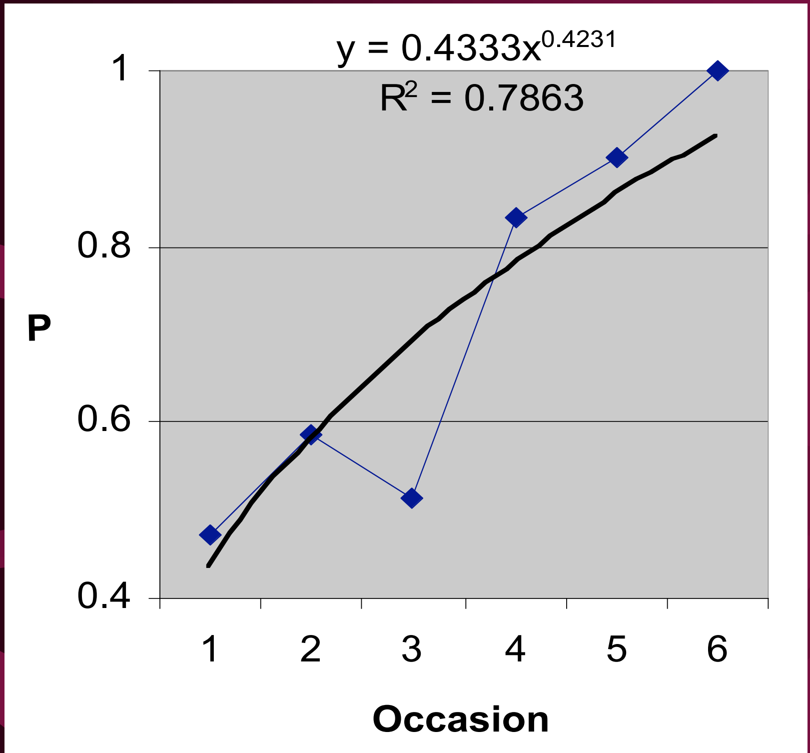
- an attribute or a set of attributes that determines the values of all other attributes
- a minimal set of attributes that determine all other attributes in the table
- a set of attributes the closure of which contains all attributes of the table
- a key other than the primary key
- a superkey
- an attribute with unique values
- a minimal superkey

Ok

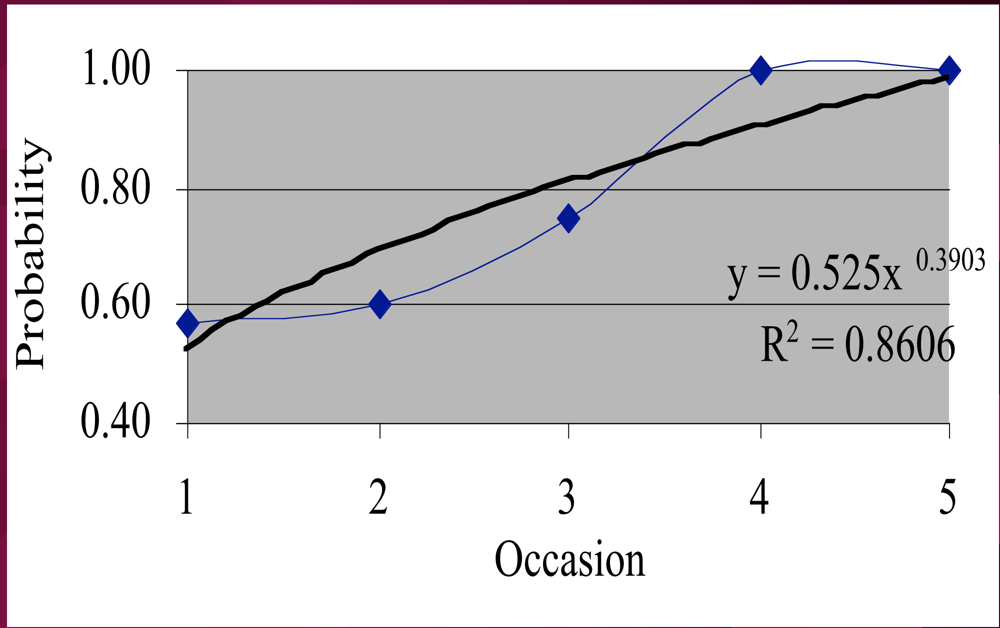
Done Local intranet


KERMIT
File
You are to design a database to hold data about composers and the pieces they composed. There is a unique number for each composer, his/her name, country, year of birth, year of death and the era (e.g. classical, baroque, romantic, modern) in which the composer lived. Information about the compositions includes a unique composition number, title, and (optionally) nickname, type of the composition (e.g. symphony, concerto, instrumental, chamber, opera, choral etc.) and composer who composed it.
KERMIT
Problems
Back
Next
Help Level
All Errors
Submit
Solution
Er modelling1
Regular Entity
Weak entity
Regular relationship
Identifying relationship
Simple Attribute
Key attribute
Partial key attribute
Derived attribute
Multivalued attribute
Number
Name
Title
COMPOSER
1
COMPOSED
N
COMPOSITION
FeedBack
You've modelled COMPOSER as a regular entity. That's correct. But some important information is missing about COMPOSER .
I'll help you to figure out the missing information through a question.
at least two simple attributes
one or more key attributes
I'm not sure
Check My Answer
I Understand Now
All Errors
Check that your entities have a key attribute. A regular entity should have at least one candidate key attribute.
Check whether you have used the correct construct to represent simple attributes that belong to entities. You have used other constructs to represent simple attributes of entities.

Defining domain concepts



NORMIT



KERMIT

WETAS

- Web-Enabled Tutor Authoring Shell
- ITS web server
- All tutoring functions taken care of:
  - Student Modelling
  - Problem Selection/Generation
  - Feedback
- Three types of interface support:
  - Text-based (WETAS controls interface)
  - HTML (Total user control)
  - Applet (mixed)

Tutors built in WETAS

- SQL-Tutor (reimplemented)
- LBITS
- Radiology Tutor
- EER-Tutor (KERMIT)
- COLLECT-UML

New project: ASPIRE

- WETAS does not support authoring of domain models
- eCDF grant
- Authoring-System for developing Intelligent Learning Environments
- Web-enabled (both authoring and delivery)

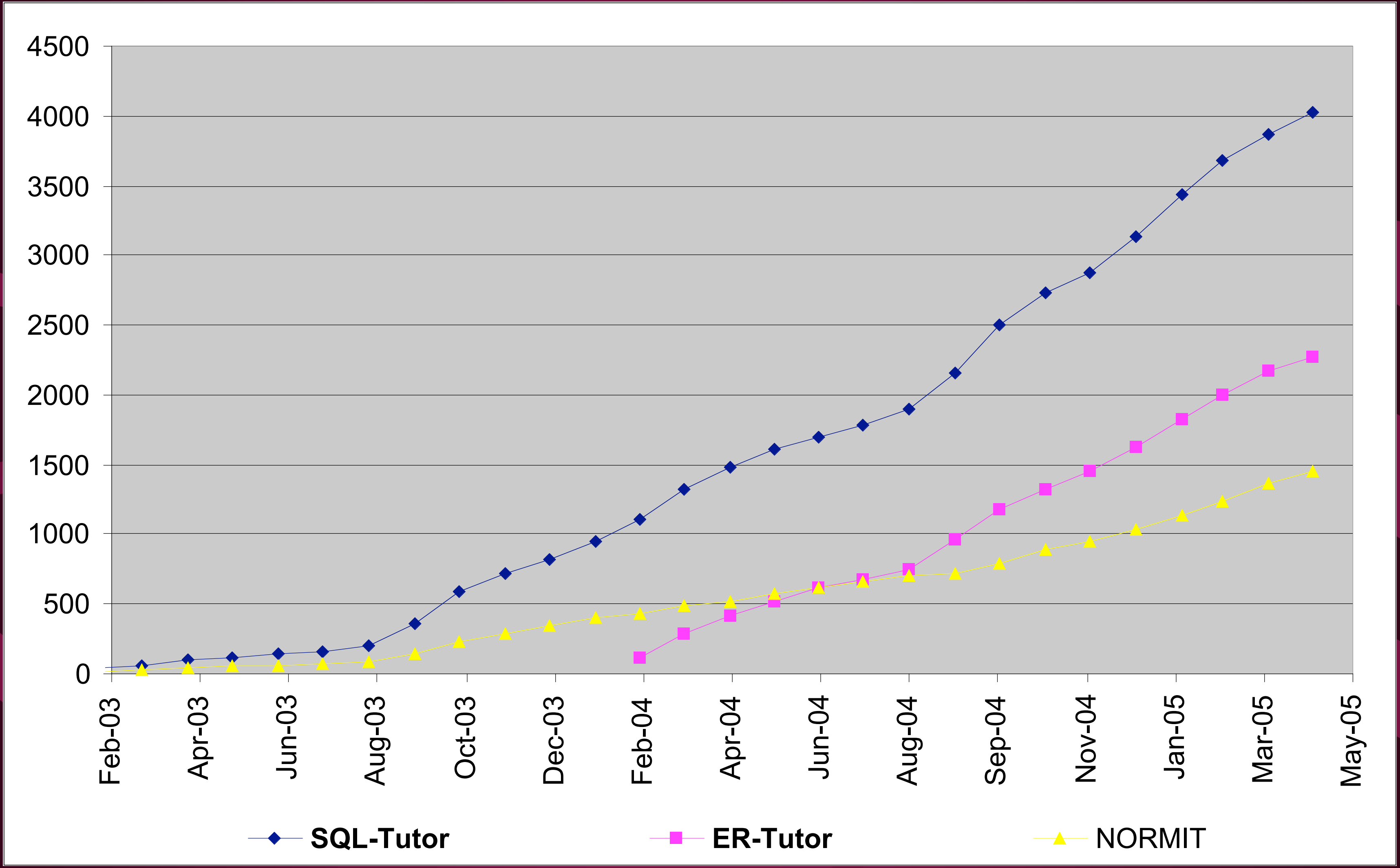
ASPIRE

- The author describes the domain in terms of an ontology
- Syntax constraints are induced automatically from the ontology
- Semantic constraints induced with the author's help
- Interactive demo on Thursday
- Paper in Session 6b

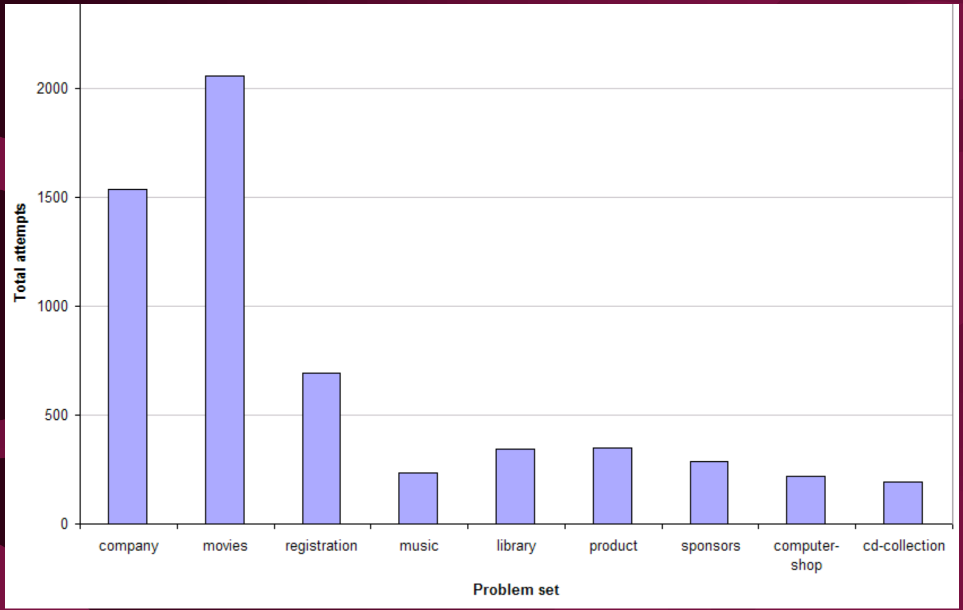
Commercializing efforts

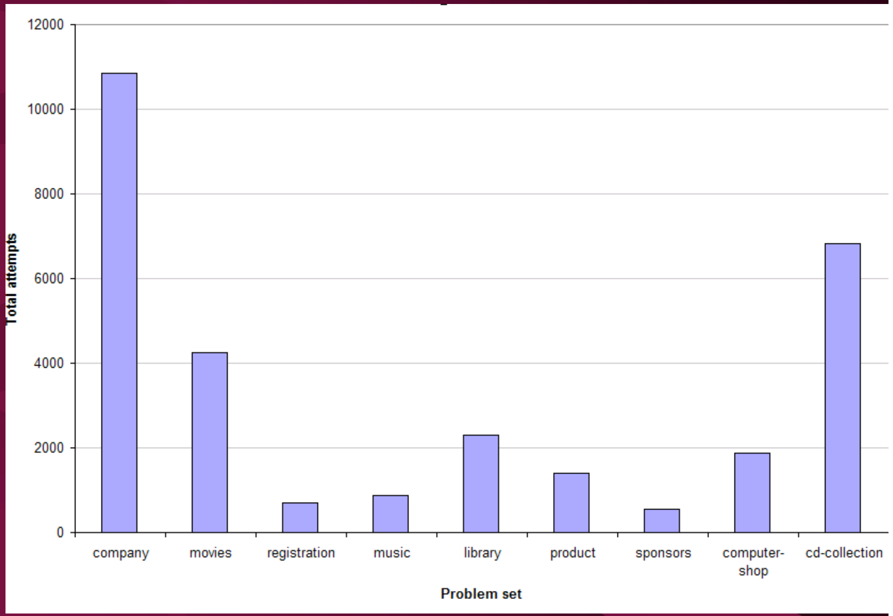
- DatabasePlace Web portal (Addison-Wesley)
- www.databaseplace.com
- Access to the portal sold with AW books
- February 2003 (SQL-Tutor & NORMIT)
- February 2004 (ER-Tutor)

Number of registered DatabasePlace users



Comparing local to distant students

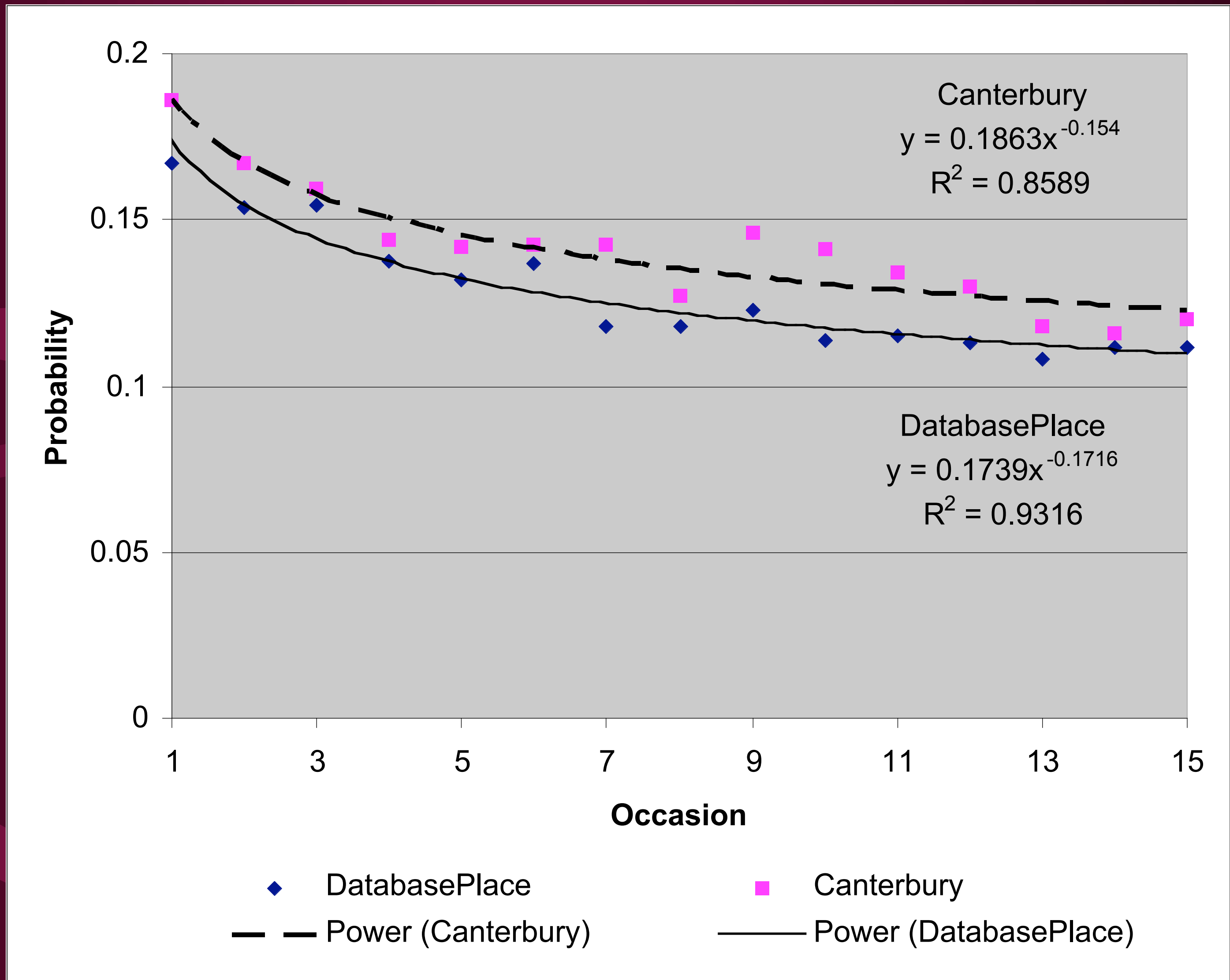




Comparing local to distant students

	Canterbury	DatabasePlace
No attempts	3-15%	30-45%
No solved problems	3-12%	12-40%

Comparing local to distant students



Current projects

- ML for constraint induction (Pramudi Suraweera)
- Adding support for collaboration
  UML-COLLECT (Nilufar Baghaei)
- Affective modeling
  (Konstantin Zakharov, Amali Weerasinghe)
- A constraint-based Java tutor (Jay Holland)
- Adding question asking facility to constraint-based tutors (Nancy Milik)

Come visit us!

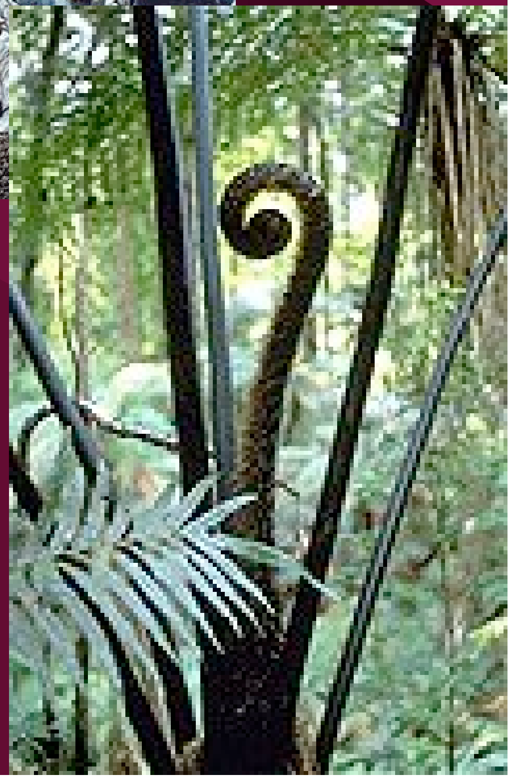
Some of our visitors

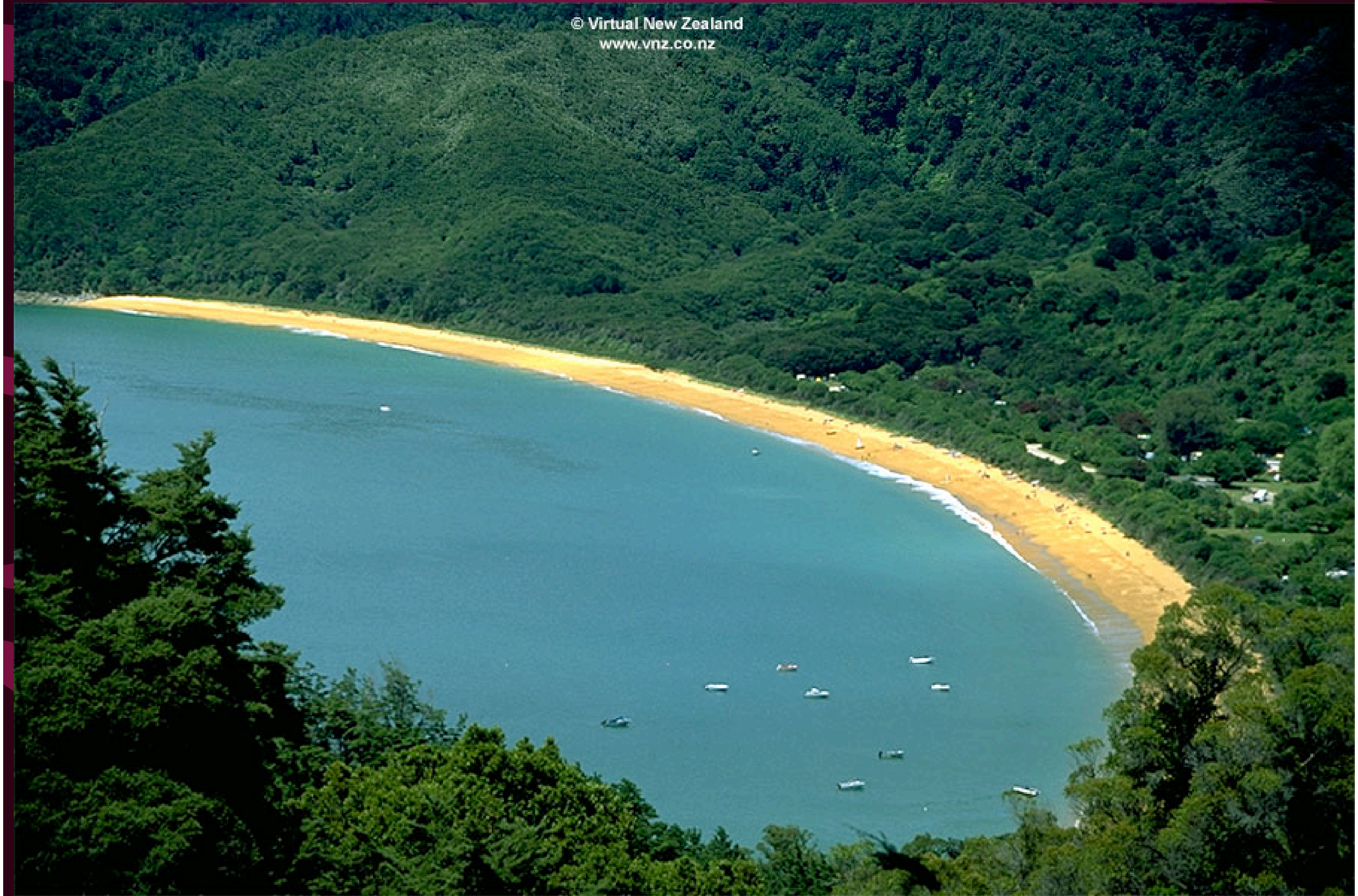
- Beverly Woolf (1999)
- Ken Koedinger (2000)
- Vladan Devedzic (2002)
- Stellan Ohlsson (2004)


South Pacific Ocean
Tasman Sea
Auckland
Hamilton
Tauranga
North Island
Gisborne
New Plymouth
Napier
Cook Strait
Palmerston North
WELLINGTON
Greymouth
South Island
Christchurch
South Pacific Ocean
Invercargill
Dunedin
Stewart Island
0 150 300 km
0 150 300 mi


© Virtual New Zealand
www.vnz.co.nz


© Virtual New Zealand
http://www.vnz.co.nz




© Virtual New Zealand
www.vnz.co.nz


copyright 1993 philg@mit.