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Barnes, A. and Loong, E. Y. K. 2003, Teaching mathematics and the web : a task-object approach, in *Mathematics, making waves : proceedings of the Nineteenth Biennial Conference of the Australian Association of Mathematics Teachers, University of Queensland, Brisbane*, Australian Association of Mathematics Teachers, Adelaide, S. Aust..

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Teaching mathematics and the Web: A task-object approach*

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Some of the key learning areas such as SOSE and English have had long standing pedagogies that have taken educational advantage of the increasing resources on the World Wide Web. This paper explores the possibilities for similar congruencies between traditional mathematics teacher practices and mathematics resources on the Web. It looks at a range of existing teacher practices and analyses them in relation to a typology of mathematically relevant Web resources. A 'task-object' methodology is proposed where specific teacher practices or student tasks in existing curricula (and textbooks) are replaced or enhanced by the use of Web objects of relevant mathematics functionality. Examples are given and possible advantages for student learning discussed. The paper will describe a math learning object database project, which aims to provide 'curriculum- or task-driven' access to web objects.

Key learning areas, learning technologies and the Web

While there are many case studies of use of the World Wide Web in teaching there is little data on the broader picture of use of the Web across subjects and teacher specialisations in schools. The Australian *Real Time* study (Meredyth et al., 1999) did examine the use of information technologies across key learning areas in a survey of some 1258 teachers in 1998. The key learning areas (KLAs) were ranked in terms of information technology usage from the highest as: English, Society and the Environment, Science, Mathematics, and Technology and Enterprise. Other KLAs such as Languages other than English (LOTE), the Arts, and Physical and Health Education made little use of computers in the classroom. In 1998, Mathematics rated highest among KLAs for the use of educational software/games but lower for informational and creative uses and much lower for use in communication. Overall, Mathematics was rated fourth of the eight KLAs for information technology use.

In Australia since the *Real Time* study there has been a surge in expenditure on school information technology and a dramatic increase in access to the Internet in schools.

* This paper has been subject to peer review.

More recent Australian data from the South Australian 'Discovery Schools' (Filsell & Barnes, 2002; Barnes & DETE, 2002) shows the increased uptake of Internet-related technologies.

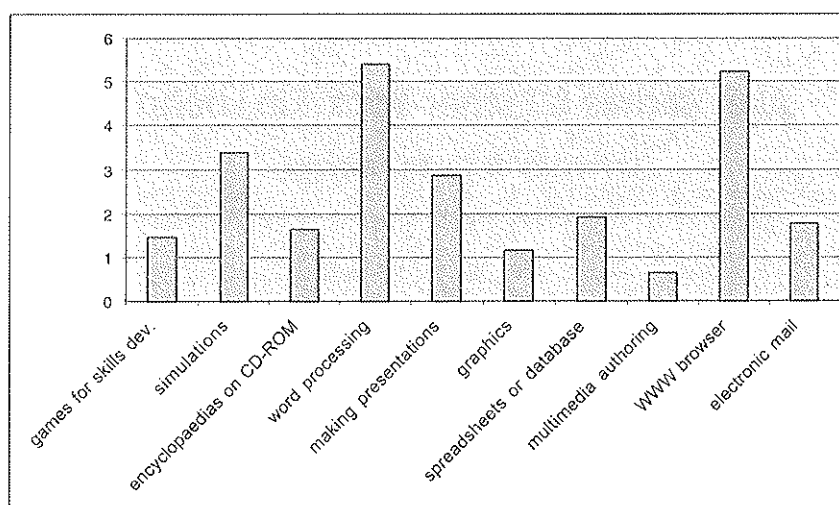


Figure 1. Mean usage of types of learning technologies in 2001 in the two discovery high schools, for 118 staff. The vertical axis shows the number of lessons in a term.

The data in Figure 1 shows the planned usage in lessons per term for learning technologies in two high schools in the discovery program. The data comes from a detailed staff survey, carried out by one of the authors in conjunction with the South Australian Department of Education, Training and Employment (DETE) over the three years of the discovery program (Barnes & DETE, 2002). The survey asked staff a number of questions in relation to their use of the Web, their priorities and confidence. Staff also indicated key learning areas taught. The following charts show individual responses to these variables for staff who indicate they teach mathematics and/or other learning areas (LAs). The data does not relate to class teaching in a specific learning area — a more complex survey task beyond the scope of the initial research. It is about mathematics teachers rather than mathematics teaching. Many teachers teach more than one learning area and while the data is useful for ranking purposes, it should be used with care when making ratio comparisons between different learning area indices.

Staff who report teaching mathematics are ranked eighth out of the ten learning areas above in their adoption of learning technologies in their classes. As in the *Real Time* study, teachers of English and SOSE are the biggest users of learning technologies but mathematics and science teachers have also fallen behind Arts and LOTE in this particular survey. Comparison of learning technologies across learning areas suggests teachers of mathematics are above mean only for 'making presentations' or 'spreadsheets and database'. Mathematics teachers rank highest in terms of spreadsheet and database usage followed by computing and science.

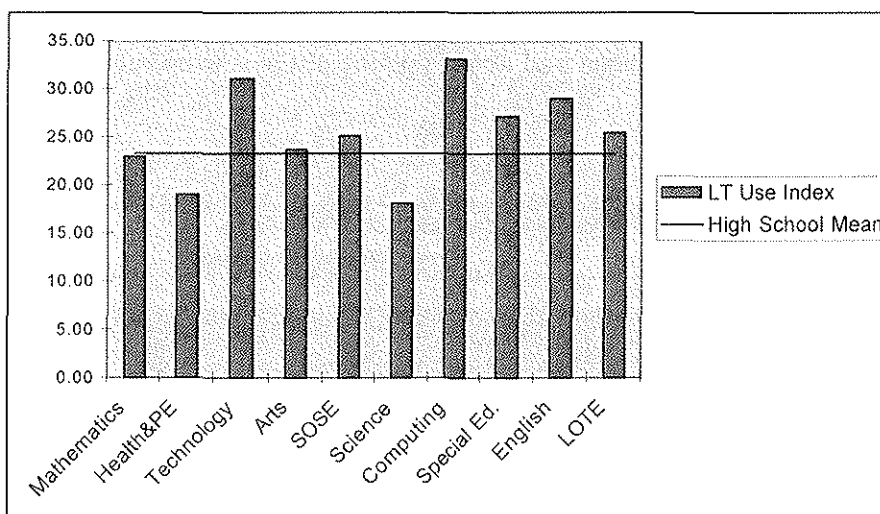


Figure 2. Reportage of lessons using learning technologies (LT) per term of staff claiming teaching in particular learning areas. The LT Use index is an aggregate of the learning area uses in Figure 1 above.

In relation to the Internet, Figure 3 shows that for the World Wide Web, mathematics teachers lag behind teachers of LOTE, Special Education, English, Computing, SOSE and Technology. Mathematics teachers provide less than the mean number of lessons using the World Wide Web. Use of e-mail shows a similar picture.

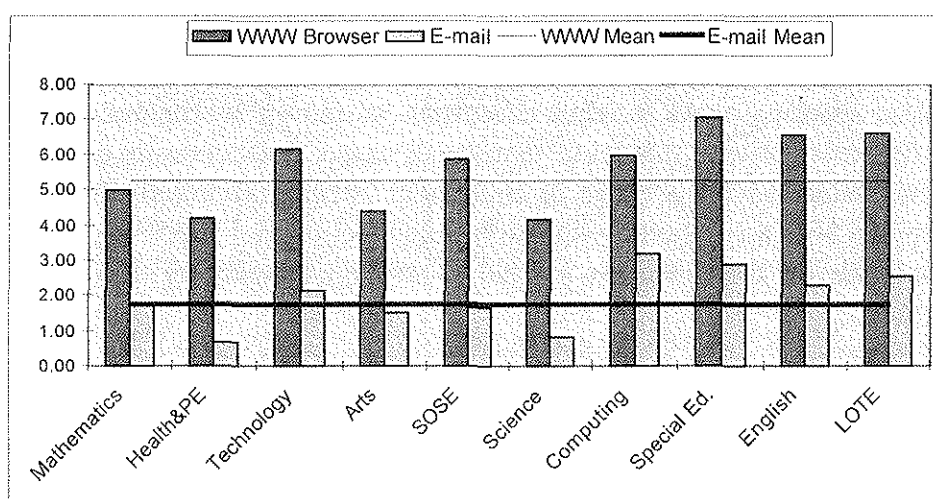


Figure 3. Reportage of lessons involving the World Wide Web and e-mail by teachers citing various learning areas.

In another series of questions teachers were asked to indicate how often they use technologies for preparation, or reporting. The scale ranged from never to always with 'never = 0', 'rarely = 1', 'occasionally = 2', 'frequently = 3', 'always = 4'. Figure 4 below

shows two Internet related activities about getting information from the Internet (usually the Web) for use in lessons and about posting student work, and resources on the web.

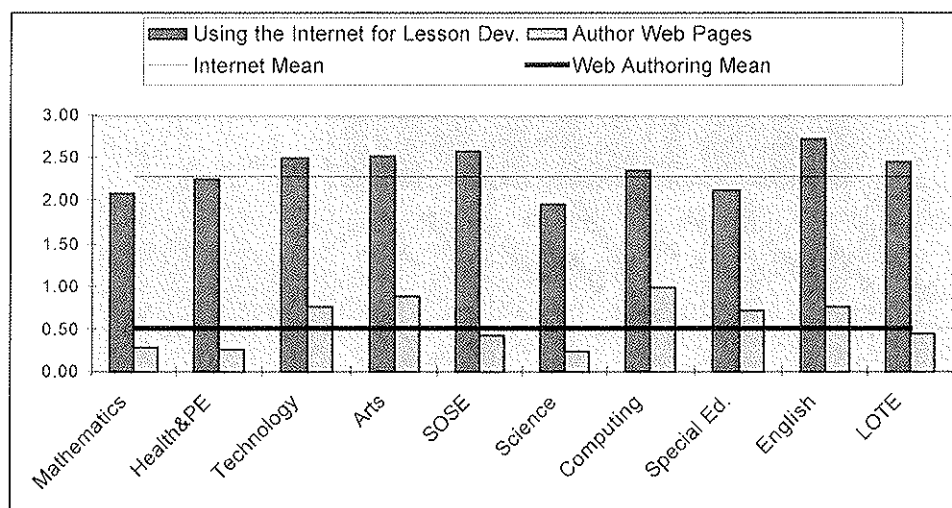


Figure 4. Reportage of the frequency of two teaching preparation tasks by teachers

The data suggests that mathematics teachers are less inclined to use the World Wide Web in their preparation and hardly ever use the Web as an authoring environment.

The data does not suggest teachers of mathematics do not use the World Wide Web. Indeed web usage increases for all categories of teachers across the three years of the discovery program. Mathematics teachers tend to take up the Web less than their peers in many other learning areas (science excepted). Moreover, mathematics teachers' priorities are consistent with this lower than mean usage. Teachers were also asked to indicate their valuation for a range of equipment options. Generally mathematics teachers thought both a computer with Internet connection and WWW access in class would be valuable for their own use but not as strongly as teachers citing any other learning area.

A final set of questions in the staff survey asked about confidence in various areas. Mathematics teachers in fact showed higher than average confidence with search engines and with Web authoring for 2001. Further detail on the use of learning technologies by teachers in the discovery schools will be available in a forthcoming paper.

A picture emerges of mathematics teachers confident in their use of the World Wide Web but less likely than many other learning areas to utilise the Web in either direct teaching or in preparation. None of the above in any way suggests that such teachers are not effective in their current teaching practices, however they do seem less likely to take up the new opportunities offered by the World Wide Web compared to many of their peers.

What is at issue here is not mere usage of the Web in teaching and learning, but the adoption of effective teaching and learning practices that make use of the technology. Some of the learning areas above have had long standing pedagogies that can work effectively with Web materials. The well-developed pedagogy of 'resource'-based learning for example was widely used in SOSE and English prior to the web, but the advent of the Web made accessible a huge array of useful resources and saw a considerable expansion in this approach to learning.

In the following we seek just such congruence between traditional mathematics teaching practices and Web materials. To do this, we encourage a different view of Web materials and examine their relevance to mathematics teaching.

Teaching strategies and Web objects

A typology of mathematical Web objects

There is on the World Wide Web an array of 'materials' of varying relevance to mathematics education. These materials might be websites, collections of web pages or web objects within the pages. Some materials may have embedded within them sophisticated mathematical algorithms that govern their interaction with the users. In an attempt to bring some order to thinking about these materials, Loong (2001) chose to consider the materials as being composed of 'learning objects' and made an initial attempt to categorise them in relation to their functionality and characteristics. The approach further extends that of the Learning Object Model promoted by the Learning Standards Committee of the IEEE (Suthers, 1999) and that of the Learning Federation Australia (2002) in its role in developing Australian educational content for the web.

This notion of 'learning objects' is crucial in setting a new paradigm of use for mathematics teachers. Whereas in many learning areas such as SOSE, Geography and Language Studies, web materials are often considered and pointed to in terms of whole sites or collections of web pages, we are proposing a 'learning object' approach for the teaching of mathematics. This approach seeks to identify objects of mathematical relevance and signifies their value to specific teacher or student tasks.

Web pages can be considered as composed of objects that can be described as either 'resources' or 'communication'. Consistent with the Learning Object Model, resource groups have been categorised as either 'interactive' or 'non-interactive'.

Interactive resources were categorised as having functions that give feedback to the user or support explorations. Interactive objects engage with learners or teachers in some way and respond based on their programming or functionality. Learning objects commonly found with feedback functionalities include objects like exercises, games, and calculators. In certain instances, the feedback given is a closed one, for example, 'Incorrect. Please try again', or it could provide a link to an explanation. Exploratory objects found on the Web are those with capabilities that support student manipulation through changing parameters or settings, or sometimes following various commands and rules to construct mathematical representations. Objects categorised as *Non-animated investigations* are those which when manipulated respond directly with a change in representation. *Animated investigations* are objects that respond to user

changes by presenting an animation, for example a rotation, flyby or locus. Interactive objects all contain some mathematical functionality; some objects exhibit a simple numeric function; others may exhibit considerable symbolic manipulation or mathematical computation. Such functionality is sometimes generated by the user's computer through Javascript or Java applets, or may be generated by a server with specific mathematical software.

Non-interactive resources have been grouped as materials that are 'text-rich' or 'graphic-rich'. Text-rich materials, as the name implies, are materials that are rich in information and are predominantly in text form (with some in symbolic form). These materials have been grouped into the respective learning objects:

- research articles;
- expositions of concepts and mathematical ideas;
- teaching documents such as lesson plans, worksheets or databases, etc.;
- material with authentic life applications such as narrative text about banks or businesses;
- mathematics related jokes; and
- non-interactive pages of exercises and problems sets.

The other group of non-interactive materials are those that are presented in the graphic form. This category of materials can further be grouped as *general images* with mathematical relevance, for example, a picture of a geodesic dome, mathematical *diagrams* such as 2 or 3-dimensional shapes, graphs, charts or tables, or images of mathematics-related *cartoons*.

The number of people who use the Internet for electronic communication has grown considerably. Besides such direct communication with one another, the communication opportunities afforded by the Internet includes those on the World Wide Web where the user can participate in online discussions or threaded discussions made available from websites. There are numerous teacher forums and open forums that are educational, as well as those set up specifically for students. Since the mid-1990s several question and answer panels that specifically cater to mathematics have been established. Panel members are drawn from school mathematics teachers, mathematics educators and university students. Where responses have been overwhelming, the questions and answers have been archived but the facilities for such communication still exists.

This paper looks at this typology from a teacher practice perspective. Careful study of the characteristics and functionalities found in the learning objects lead to a consideration of the types of teaching strategies that can be used with them. Four main categories of teaching strategies have thus far been identified. They are: expositive strategies, active strategies, collaborative strategies and consolidation strategies. This mapping of the typology to teacher practice is not meant to be prescriptive but merely to demonstrate the possibilities for mathematics teacher usage of the Web. The mapping is presented in a graphical form in Figure 5.

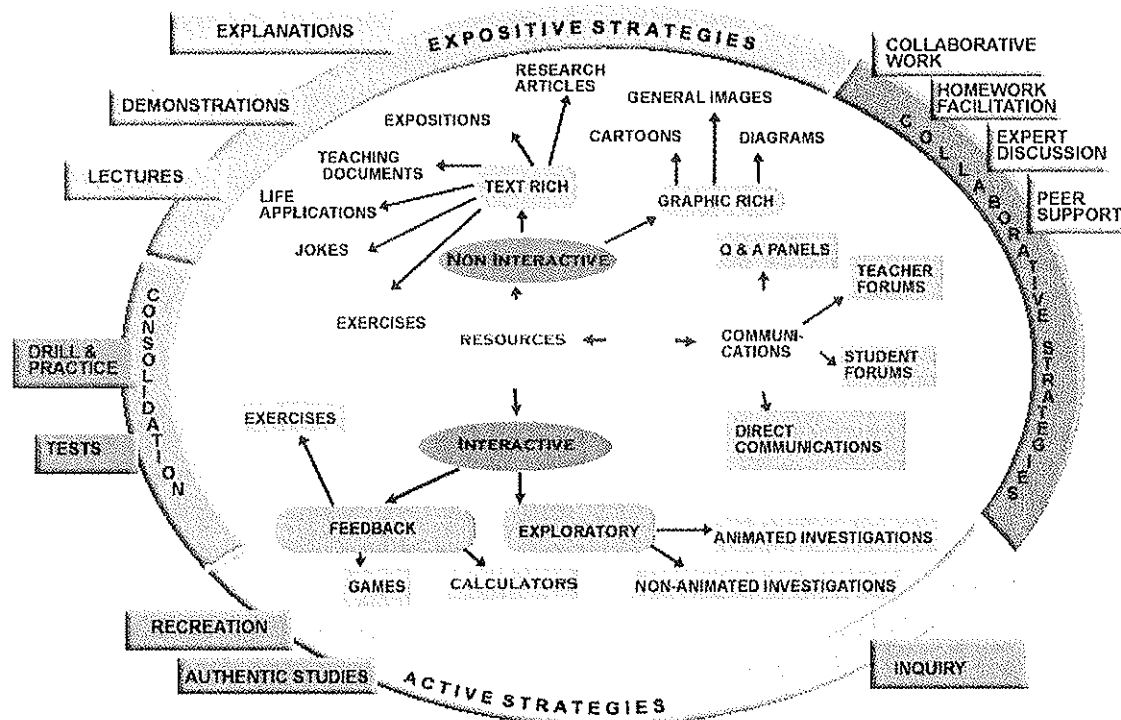


Figure 5. A typology of Web objects and the teacher practices they can facilitate.

Web-based teaching strategies

Mathematics has long been thought of as a domain for abstract or logical thinkers. As such, the teaching of mathematics has been dominated by practices that attempt to build on those abstract capabilities. However, as Gardner (1983) argues, there are other types of intelligence that may be involved in the learning process. In considering the World Wide Web as a resource for mathematics teaching and learning, one should consider how best to exploit the functionalities found on the Web so that it caters for the diverse learning differences found in our students. The following describes some groups of strategies that could be applied to a Web-based environment.

Expositive strategies

Expositive strategies such as lectures, demonstrations or explanations can be used with learning objects that are text-rich or graphic-rich. Materials from such learning objects can be used to enhance teacher preparations and presentations. Traditionally, this approach is used to transmit information from the teacher to the student, and if not carefully planned can be boring and poorly presented. This approach can be more effective if suitable web objects are used to stimulate or motivate students as well as to demonstrate key concepts. Interesting learning objects could be used at the beginning of lessons as attention grabbers and to establish motivation to follow through to the body of the lesson. Although in Figure 5 where expositive strategies are used with non-

interactive text-rich or graphic-rich material, a teacher could equally use interactive explorations as a springboard for classroom exposition. Many of the dynamic and interactive applets can be used to demonstrate key ideas or as set induction. This teacher-centred approach can be turned into one that is student-centred when students are directed to do a range of tasks with text-rich explanations or concepts found on the Web. Although expository strategies like these are better disposed to key learning areas like SOSE or Language Studies where text plays a vital role, their value in students' mathematics project work or search for historical progress of mathematical ideas should not be discounted.

Active strategies

Web objects that are high in their interactivity lend themselves well to being used in a constructivist way. The dynamic and interactive nature of these objects allows students to manipulate and change parameters, and view the resulting effect. Active (constructivist) strategies that utilise dynamic learning objects for explorations allow abstract concepts to be represented visually and interactively. These have the potential to cognitively and visually engage the learner in a way that is not possible through static symbolic forms. There are increasing numbers of such learning objects on the Web that mathematics teachers can utilise for their teaching. Inquiry methods of teaching and learning can be used with such exploratory learning objects. The teacher sets the problem or activity and students explore the situation; the teacher and students can then discuss the situation and draw their conclusions. Under such circumstances, the students sharpen their observation and inquiry skills and begin making conjectures and postulations rather than being passive receivers of knowledge. The teacher's role is more of a guide and questioner rather than a provider of knowledge. While broader inquiry activities are becoming an increasing feature of mathematics curriculums such as SACSAP (Department of Education, 2001), the object-based explorations above have value in focussed concept development. It is a characteristic of such broad investigations that they are lengthy and require considerable teaching resources in their implementation and evaluation. However in the crowded curriculum, the use of exploratory web objects that are specifically focussed around mathematics concepts can be less consuming of time and resources.

Feedback systems such as those found in some Web mathematics games enable students to learn mathematics in a recreational way, in addition to reinforcing certain mathematics concepts or capabilities, and can replace some dreary repetitive mathematics exercise in the textbook. Investigations with calculators such as those found in some bank websites or business websites can be used to replace exercises that hold little relevance to everyday life situations. By establishing certain scenarios, and using information found on the Web, mathematical modelling problems can be set. Instead of using exercises as a practice for recently learned procedures, students can construct a mathematical model based on a real life situation, solve the model for mathematical solutions, interpret these solutions in the context of the real situation, and refine the model to produce better solutions (Herrington, Sparrow et al., 1997)

Consolidation strategies

There are both interactive as well as non-interactive exercises on the Web. The non-interactive exercises are not different from those found in textbooks, and their value may be one of complementing textbook problems through increased difficulty levels or variety. On the other hand, interactive exercises have great value. Interactive feedback systems found in Web exercises have the potential to encourage independent self-monitoring and evaluation among students. Besides the drill and practice afforded by such objects, there is also motivational value in giving instant feedback on the student's progress. In some systems, hints are given and the student redirected to the section of the module that explains the concept.

Collaborative strategies

Collaborative work on the Web has been shown to increase students' awareness of the many and varied solutions to open-ended problems: because of the influence of other students' notes, by becoming aware of the general formula others use, and by having access to many mathematical views and conceptions (Nagai, Okabe et al. 2000). Peer support is clearly one of the advantages of Web communications. Online mathematics clubs on the Web allow individuals who share similar interests to feel they belong to a community instead of feeling isolated (Way & Beardon, 2001). The teacher can encourage the use of communications with peers and experts to facilitate homework: the excitement and fulfilment from getting into a discussion with experts from anywhere in the world can be an uplifting experience.

The task-web object approach

In mathematics, curriculum is usually structured and sequenced, and understanding is developed through mastery of first elementary and then more complex topics. Mathematics teachers will present expositions and methods but a large amount of student time is involved in the active doing of tasks in examining proofs and methods, and carrying out exercises from worksheets or textbooks. Web objects could be utilised in many of these tasks. Many of these web-based tasks could be carried out as homework.

The task-web object approach would see some of these tasks enhanced or substituted by the appropriate use of web objects.

Table 1: Possible task replacements or enhancements with appropriate web objects

Strategies	Replace/ Enhance	With
Consolidation	Textbook and worksheet exercises	Interactive games http://www.aplusmath.com/cgi-bin/games/geomatho Interactive exercise with feedback and clues http://www.mathcounts.org/GoFigure/Main.taf?function=Start&NewQuestion=True&LevelID=101&CategoryID=100
	Teacher Evaluation	Student self evaluation through web tests http://www.bbc.co.uk/apps/iff/schools/gigaquiz?infile=angles&path=gcsebiteize/maths/angles
Active	Explore a graph manually	Dynamic exploratory investigations http://www.univie.ac.at/future.media/moe/galerie/fun2/fun2.html#sincostan
	'Real-Life' Problems in textbook	Authentic case studies e.g. bank calculators, weather studies, real databases https://services1.anz.com/nola/application/hl/help/Information.asp
Expositive	A flat colourful diagram	Animated 3-dimensional diagrams http://www-sfb288.math.tu-berlin.de/vgp/content/curve/PaSurfCurve.html Dynamic investigations
	Expositions on concepts	Student initiated search for information on the Web http://library.thinkquest.org/3288/fractals.html Inquiry led investigations
Collaborative	Giving answer to a difficult homework question	Ask an expert, student forum http://www.nrich.maths.org/discus/messages/26/26.html?1035306537

The effectiveness of the task-web object approach will rely on teachers having direct access to objects that match particular task needs. To that end the authors have set up a prototype database that demonstrates how access to relevant web objects can be supported. This database can be accessed via the following web site <http://www.education.unisa.edu.au/elearn/w3mathsed/> under 'A search facility' in the 'Resources' webpage. In addition to 'key words' fields, other relevant fields that can be used to facilitate a search in the database include: branch of mathematics, key ideas, year level, skill level, interactivity type, object type, and targeted education system.

Conclusion

For mathematics education to effectively use the Web, appropriate pedagogies will have to be used. The task-web object approach is an attempt to suggest a feasible practice that can be used by mathematics teachers. By capitalising on students' enthusiasm for things on the Web, mathematics teachers could enhance student interest in mathematics through using the replacements or enhancement strategies suggested.

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