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ABSTRACT

In the context of higher education, the development of students' problem solving skills continues to be an area of much ongoing research. Effective teaching of problem solving requires the adoption of process-based approaches that reveal to students the ways that experts solve problems, and the coaching of students in higher order and metacognitive skills that lead them away from a preoccupation with finding solutions and towards building up a repertoire of problem solving strategies. It is suggested that online environments and computer resources can scaffold the acquisition of domain knowledge and systematic problem solving skills. This article acknowledges that there are multiple ways to support complex problem solving, and that online environments hold great promise in creating effective instructional interactions. This study focuses on the metacognitive aspects of problem solving and more particularly on those aspects of technology-based scaffolding that support reflection, process support, and the anchoring of skills to domain knowledge. (Contains 20 references and 4 tables.) (Author)

Bridge over troubled water: Creating effective online support for the metacognitive aspects of problem solving

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Abstract: In the context of higher education, the development of students' problem solving skills continues to be an area of much ongoing research. Effective teaching of problem solving requires the adoption of process-based approaches that reveal to students the ways that experts solve problems, and the coaching of students in higher order and metacognitive skills that lead them away from a preoccupation with finding solutions and towards building up a repertoire of problem solving strategies. It is suggested that online environments and computer resources can scaffold the acquisition of domain knowledge and systematic problem solving skills. This article acknowledges that there are multiple ways to support complex problem solving, and that online environments hold great promise in creating effective instructional interactions. This study focuses on the metacognitive aspects of problem solving and more particularly on those aspects of technology-based scaffolding that support reflection, process support, and the anchoring of skills to domain knowledge.

Problem solving skills as central to learning

In tertiary education, there is an urgent need for professionals who can solve real problems, anticipate and predict problems and find realistic solutions. To meet this need effectively tertiary educators must now reexamine methods of teaching problem solving. In discussing pedagogical approaches, Hobden (1998; 223) states that:

> *"It (problem solving) is a routine activity occupying a large proportion of curriculum time and plays a central role in student's experience of classroom life. From the first days of science instruction, sets of routine problem tasks assigned by the teacher have been part of classroom life. As a teaching strategy, they have largely been used uncritically. It would appear that nearly all physical science education, and especially the physics component, seems to be based on the optimistic assumption that success with numerical problems breeds an implicit conceptual understanding of science."*

These comments apply to the way problem solving has been taught in the past, and to approaches that rely on traditional 'show and tell' where students do not engage actively with the problem or context. The traditional method of showing examples of solutions to problems followed by student practice represents a rather primitive approach in contrast to the teaching of acting, music or a sport, where the skills required for competent performance are taught in context, often in real world scenarios, and integrated so that expert performance results. Taconis et al (2001) have recently analyzed articles appearing in international journals between 1985 and 1995 on the effectiveness of teaching strategies for science problem solving. Very briefly, this analysis showed that in student performance and achievement, knowledge of strategy and practice of problem solving turned out to have little effect, whereas accounts of effective teaching of problem solving all give attention to contextualised strategies related to mastery of domain knowledge. The learning conditions recognised by Taconis et al (2001) as significant for building problem solving skills were those which provide learners with guidelines and criteria they can use in judging their own problem solving processes and products. The provision of immediate feedback to learners is also essential. These conclusions are congruent with earlier research carried out by Alexander & Judy (1988), Clarke (1992) and Lajoie (1993).

The learning paradox

A number of contemporary designs for learning environments require student self-direction and high-level metacognitive control. Exploratory and open-ended learning environments enable students to generate knowledge and engage in critical thinking. Similarly, project based approaches assume that students are able to generate questions and produce a final product that represent knowledge integration. Many students however lack essential metacognitive skills and a repertoire of learning strategies to enable them to maximise their learning in innovative learning environments. Table 1 shows how a range of contemporary learning designs assume metacognitive knowledge.

Example	Learning scenarios	Metacognitive skill needed
Anchored instruction	Narratives, stories, real life anchors	Capacity to define problems and abstract from case
Open ended learning environment	Multiple scenarios and viewpoints	Self-direction and self management
Project based learning	Collaborative, task based learning environments	Management of information, self and others
Problem based learning	Presentation of cases and events that present potential problems	Capacity to identify the problem and select resources to solve it

Table 1 : Metacognitive requirements of contemporary student –centered learning environments

These learning environments though highly successful, assume that students are goal driven and self-directed. Yet, these expectations bring with them a range of assumptions, primarily that students have metacognitive skills to enable them to cope with self-direction learning. Other research has shown that the processing demands of these environments are problematic and need to be investigated. One of the issues of most concern is that of the learning paradox noted by Schank & Cleave (1995) *"How can students learn by doing what they do, when they do not know how to do what they have to do to learn?"*. Stated quite simply, project and problem based learning assumes that students can access and apply knowledge and metacognitive strategies and engage in self-regulated learning. It is well established that in order to learn effectively, a repertoire of learning strategies and the capacity to manage one's own learning are fundamental (Boekaerts, 2000; De Corte et al, 2000). It is this range of skills that we refer to as metacognition.

The role of metacognition in learning and problem solving

Metacognition is a learner's knowledge about his or her processes of cognition and the ability to control and monitor those processes as a function of the feedback the learner receives via outcomes of learning (cf. Metcalfe & Shimamura, 1994; Schraw 1998b). Metacognitive knowledge refers to what the learner understands and believes about a subject matter or a task, and the judgments s/he makes in allocating cognitive resources as a result of that knowledge. Metacognitive control refers to the strategies the learner uses to achieve specific learning goals - strategies like planning and organizing, allocating attention to relevant and irrelevant factors, looking for relationships and patterns, monitoring comprehension, identifying and testing procedures, evaluating outcomes, and reflecting on learning (cf. Jacobs & Paris, 1987). Schraw (1998a) explains that attentional resources, existing cognitive strategies, and awareness of breakdowns in comprehension, are all enhanced by training in metacognitive knowledge and skills. While there are examples of successful metacognitive instruction in the literature, the most effective ones involve providing the learner with both knowledge of cognitive processes and strategies, and experience or practice in using them. Simply providing knowledge without experience or vice versa does not seem to be sufficient for the development of metacognitive control (Volet, 1991). It is also essential that learners have an opportunity to evaluate the outcome of their efforts, to reflect and self-assess their own approaches to learning.

Four categories of metacognitive knowledge are recognised as important and affect task performance and achievement of distance learners (White, 1999). These are as follows:

- **Self-knowledge:** Self-knowledge entails individual capacity to recognise their strengths and weaknesses and to evaluate themselves.
- **Task-knowledge**: This involves understanding the demands of tasks and what they require.
- **Strategic knowledge**: This refers to the knowledge of usefulness of strategies available for achieving learning goals.
- **Knowledge of plans and goals:** This refers to learner's capacity to set and maintain goals and to record what they intend to do through their learning.

Design of learning environments for metacognitive support

In response to a perceived need to support problem solving, an on-line tutorial designed in WebCT, called metAHEAD, has been created for first year science students in Biology, Biophysics and Chemistry. The aim of the tutorial is to help students explicitly develop their metacognitive skills in science problem solving. The tutorial comprises four modules - an introduction to thinking and learning, knowledge maps, explanations and descriptions, problem solving. In developing the resource, instructional design was guided by current research on constructive learning, and metacognitive skills development. Lin et al (1999) in considering the technological design of learning environments have noted that four features are important for effective scaffolding of reflective thinking by students. These are *process displays, process prompts, process models* and *reflective social discourse*. The first module of metAHEAD introduces students to key aspects of learning and problem solving and allows them to rate their own problem solving skills on a standard metacognitive inventory test. The second module helps them to build concept maps for topics in their subject areas. The last two modules concentrate on the sorts of skills needed for explanations and descriptions (as most often needed in Biology) and quantitative problems (more often needed in Biophysics and Chemistry).

As students tackle problems in the modules they are asked to engage in a number of the following activities: predict their own expected success on problems; discuss their success with other students during and after attempting the problem; explicitly consider strategies for use with particular problems; examine other students' answers and comments on them; listen to audio clips, view video clips or read transcripts of other students as they worked on problems and comment on these; rate other students' answers; post their answers to a bulletin board for discussion with other students; view lecturer's model answers and comment on them.

Students maintain an on-line logbook to record their responses to the various prompts throughout the tutorial and to record their answers to problems. In metAHEAD particular attention has been paid to supporting the four categories of knowledge identified as essential for development of metacognitive skills (White, 1999). Process prompts and process models are in evidence in the learning activities, which precede the solution of example problems, and in the many worked answers of students and lecturers and comments thereon. Bulletin board discussion of strategies and problem solving skills together with the creation of collaborative teams provide opportunities for reflective social discourse.

Evaluation of *metAHEAD*

It was intended to carry out a formative, integrative evaluation of metAHEAD in order to improve the design and to refine various aspects of the resource. Oliver (2000) has remarked that while a range of methodologies exists, each may be restricted in its use and in the range of situations it can be applied to.

From our pragmatic perspective, we found the Open University model as described by Jones et al (1996) a useful framework. This approach focuses on three main themes: context, interaction and outcomes. This is outlined in table 2, and shows that range of data that was collected and analyzed. As practitioners, we sought an evaluation approach that was broad and flexible enough to suit our situation, which was the introduction of an innovative resource within a university context. From the outset, data has been gathered on the design and use of metAHEAD from pilot studies, practitioners' opinions, instructional designers who have used and developed the program and academic staff who have used sections in their teaching. It was important to include this data in our evaluation, as we needed a holistic picture of its benefits.

	Context	**Iuteractions**	**Outcomes**
Rationale	Need for metAHEAD at UNE; curriculum context	Need to look at student interactions with the resource.	Learning outcomes; problem solving outcomes; changes of perception and attitude must be considered
Data	Designers aim; principles underpinning design; pressing iterations	Records of students' interactions, student diaries, and online logs	Measures of effective problem solving, changes in attitude, strategy, perception of self.
Methods	interviews; written records;	Observations, videos, diaries, computer records, product data generated by students	Focus groups, tests and questionnaires

Table 2: Features of the evaluation approach adopted

As *metAHEAD* is embedded in Web CT, it allows for the gathering of the following types of data for the evaluation of metacognition, data collection was relatively standard self-rating quiz data taken at beginning and end of semester; students' self predictions of level of success with particular problems and reflection upon these on completion of the problem; on-line log book entries including students' notes on strategy use and actual problem solutions; bulletin board discussions. These data are complemented by further data gathered from small face-to-face focus group discussions. As a further elaboration of our evaluation approach, we collected a range of data relating to the interactive and scaffolding features of metAHEAD. These are summarised in table 3.

Data source	**Type of evidence**
Journal entries	Progress logs (process data)
Oral discussion	Online transactions (process data)
Learner's self assessment	Prediction of success (process data)
Solution logs	Solutions to problems (product data)

Table 3: Evaluating metacognition in online environments

Evaluation and data analysis

Data has been gathered from focus groups giving feedback on technical issues and development of problem solving skills. There are two main areas of feedback gained from this evaluation. Students have greatly appreciated the availability of other students' answers and particularly the comments on them. This has allowed them to put their own answers into a better perspective and to give a clearer idea of what the lecturer expects. (The fact that assessment and lecturers' expectations drive the majority of students cannot be escaped.) These do provide process models and support reflection by the students on many aspects of problem solving. Coincidentally, other student answers help some students to feel more of a part of a group and that they are "not so stupid after all", which can affect student motivation to succeed along with others. Students have identified that their motivation often parallels their success in the subject. Becoming part of a community of students working on a unit is particularly important for distance education students, who may be otherwise rather isolated. The ability to discuss issues on the bulletin board has been helpful for these students.

Students have also mentioned that planning and analysis of problems, whereby parts can be tackled step by step has been helpful to them. Becoming more aware of and practicing such skills has been beneficial for students who in the past may have been daunted by a problems and given up too soon when it seemed too difficult. While we have provided some models and coaching online, students appear to need a more staged approach, with step-by-step examples and support. This 'cognitive apprenticeship' approach is in tune with the constructivist principles underpinning the design of metAHEAD. Table 4 shows a summary of student comments gained from the evaluation.

Comments on what students gained from metAHEAD
Helps think about level of confidence and predict degree of success.
Helps motivation somewhat.
Helps with ways to understand the question better in order to tackle it successfully.
Helps with breaking up tasks – something they didn't commonly consider explicitly.
Talking to other students is helpful, hear other views.
Getting feedback from lecturer, hearing them explain and comment on lecturer's answers.
Appreciated other students' answers, so they could compare their own answers, and lecturer's "metacomments" on these were important.
Other students' answers also show other ways of solving problems.
Information about learning and thinking processes – eg chunking information.
Comments on limitations of metAHEAD
Can't replace face to face. Need personal tutor for motivation.
Notebook tool has great technical deficiencies particularly for science answers involving formulas and equations.
Needs to help students with more practice.
Needs more models and demonstrations of how to work through problems step by step.
Technical difficulties. Eg Plug-in for Quicktime movies.

Table 4: Summary of comments from evaluation data

Implications for instructional design

The aim of metAHEAD was to design a learning resource to offer students support in metacognition and problem solving and a learning experience that was different from traditional teaching in first year (freshman) study. The focus was on building student self-awareness of metacognition and strategy development infused into disciplinary content (chemistry, physics and biology). Our initial evaluation has shown both positive and negative aspects of the resource, and insights gained will be used to design the resources and improve its capacity to support problem solving. Our choice of evaluation approach has been effective and worthwhile, providing valuable data on context, interactions and outcomes of the resource. Continuing evaluation will assist in refining the resource, tailoring to student needs and improving its relatedness the context in which it is being used i.e. the support of metacognition at tertiary level.

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