Computer-based Metacognitive Training: Improving the Diagnostic Expertise of Novice Graduates

Hiba Mustafa, Elizabeth Kemp, Ray Kemp

Computer-based Metacognitive Training: Improving the Diagnostic Expertise of Novice Graduates

H. Mustafa, E. A. Kemp, R. H. Kemp

Massey University

Key words: *Metacognitive training, diagnosis, problem solving, complex domains*

Abstract:

The diagnosis problem-solving task can be complex in many professions for which it is central, for example medical diagnosis, farm-management consultancy, etc. This is because often the expert must solve problems and make decisions in complex situations and while under time pressures. The complex nature of the problem situations and the novices' lack of advanced metacognitive skills also make it difficult for novices to gain expertise and successfully solve problems in their fields. From the literature it can be concluded that strong metacognitive skills lead to an improved performance and greater ability to solve problems in complex and time critical settings. We propose metacognitive training using a computer-based teaching system for novice university graduates who will work in complex diagnosis domains.

1 Introduction

Diagnosis is central to many important professions for example, medical diagnosis, plant pathology, vet science, and farm-management consultancy. It is a complex task in these professions firstly because: often the expert needs to solve problems and make decisions under time pressures, and secondly because there are various factors present in these settings which can make the problem situations complex and therefore difficult to solve. Three main factors contribute to this complexity, the problem situations are: information rich, knowledge intensive, and time critical [1]. It is difficult for novices to gain expertise in the types of professions considered in this research because these factors cause a high cognitive load [2]. Furthermore, novices lack the required advanced metacognitive skills to deal with these factors and to master the techniques used to deal with them. For these reasons, the novice to expert transition is very time consuming in these domains. For example, in farm-management consultancy it typically takes about 10 years for a novice farm-consultant to exhibit expert performance [2]. This research will consider the category of diagnosis domains that are less understood in terms of completeness and certainty (e.g. medical diagnosis) than other diagnosis domains (e.g. device fault diagnosis).

Experts require advanced thinking skills to support them when dealing with the types of problems presented in the category of diagnosis domains this research is concerned with. They use advanced metacognitive skills when problem-solving and decision making in complex domains. Metacognitive skills are important for successful diagnosis in these professions. From the literature, it can be concluded that strong metacognitive skills have positive impacts on life-long learning [3], knowledge transfer [3], and problem-solving [3, 4, 5, 6, 7, 8], thus leading to improved performance and a greater ability to solve problems in complex and time critical settings. According to [6], metacognitive monitoring is one of the three essential skills that distinguish an expert problem-solver from a novice.

University graduates are not provided with extensive explicit metacognitive training during their university degrees. The literature stresses that learners should be explicitly trained to perform metacognition, for example [6], and there is evidence that this metacognitive training is effective for significantly improving problem-solving performance [6, 7, 9, 10]. Attempts to provide metacognitive support in computer-based tools have been made in a variety of domains, and there are numerous successful examples especially for mathematics problem-solving for example [11] and [12]. These results are encouraging, and the need for further research has been clearly expressed in the literature for example [3], [8], and [13]. Furthermore, in the literature it is apparent that diagnosis has not enjoyed much research in the area of metacognitive training using computer-based systems. Filling this gap for diagnosis (in domains that are less understood) can help fast-track the novice to expert transition in a number of domains. The targeted learners are university graduates or near graduates (in the category of diagnosis domains this research is concerned with). These students have completed university programmes that provided them with practical knowledge for example by solving real-world problems in their field, etc. However, they have not yet acquired years of practical experience in their fields. After comparing the feasibility and potential effectiveness of a computer-based solution for this problem with other possible (non computer-based) solutions, a computer-based solution was found to be the most suitable approach.

The aim of this research is to design a complete educational computer-based metacognitive training component that will be part of a complete computer-based teaching system, and to prototype and test a subset of the approaches and techniques applied in this complete design. This software component is intended for use with a problem-based domain specific computer-based teaching system that supports learning for a domain in the category of diagnosis domains that is considered in this research. The authors first intend to develop a metacognitive training prototype that can be integrated with a stand alone domain specific system. The next step would be to develop a prototype that can be integrated with a web-based domain specific system.

This paper first introduces the diagnosis problem-solving task. The areas in the diagnosis process that require metacognitive support are then identified, and the metacognitive support provided by educational computer-based systems in the literature and in existing educational computer-based systems is discussed. This is followed by a high level description of the authors proposed solution, an outline of the metacognitive activities that will be supported during the diagnosis process, and the high level architecture of the proposed solution.

2 The issues in the diagnosis domain

2.1 What is diagnosis?

Diagnosis is one of various problem-solving tasks used in knowledge intensive domains. A complete set of problem solving tasks that can be used in knowledge intensive domains has been identified by [14]. The problem-solving tasks in the hierarchy can be divided into sub-tasks of analytic tasks and sub-tasks of synthetic tasks. Analytic tasks (e.g. classification, assessment, prediction, etc) operate on objects/artefacts that exist but are usually not completely understood, while synthetic tasks (e.g. design, assignment, scheduling, etc) operate on objects/artefacts that do not yet exist. Diagnosis is one of the analytic tasks.

Diagnosis has been defined by [15] as "the task of identifying the cause of a fault that is manifested by some observed behaviour". The fault could be a malfunction or disease. Diagnosis consists of the following three sub-tasks:

- Firstly, symptom detection is used, which involves checking whether the complaints are actually symptoms by comparing observations with expectations to see if there is a difference.
- The second sub-task is hypothesis generation which involves building up a set of possible diagnoses based on the initial and additional observations.
- Finally, hypothesis discrimination is used, where hypothesis are left or removed from the hypothesis set after testing each hypothesis using additional observations.

2.2 The diagnosis process

A simplified diagram of the diagnosis process called the ST-Model was first developed by [16] for clinical diagnosis in medicine; it is shown on the right side of Figure 2. This research will focus on the outer loop only because it is not concerned with induction (since it is not of great relevance to novices). First the evidence which is either seen or provided by the client/patient is used to form a set of hypotheses by *abduction*. Then the decision maker might prioritise the hypotheses in the hypotheses set. Next, he/she will make *deductions* to create expectations using his/her domain knowledge and test their hypotheses to check that the test results match with the expected results. The expert can either run their own tests or use further observations to check the correctness of the hypothesis. Deduction is therefore used to strengthen or reject the hypothesis in the hypotheses set. New hypotheses may also be generated from test results and new observations. This process continues until the decision maker has enough evidence to confirm a hypothesis. If this simplified process is further abstracted from, it appears that the decision maker is carrying out numerous loops of a hypothesise and test cycle. Many other processes are happening during diagnosis which have been abstracted out of the ST-Model.

2.3 The difficulties of the diagnosis process in several complex domains

There are a number of areas in the diagnosis process that require metacognitive support. These difficulties apply to a variety of diagnosis domains for example farm-management consultancy, medical diagnosis, and vet science. These are also examples of the types of domains this research is concerned with. The difficulties involved in diagnosis and a comprehensive set of techniques used by experts to deal with them have been identified by [17]. The main difficulties are: obtaining full co-operation and information, the large number of cues and time pressures, and the integration of available data with domain knowledge. Only a subset of the techniques used to deal with the first two issues will be supported. These are discussed below.

It is important to obtain the required accurate information from the client/patient. In order to get the right information, it is often important to ask the right questions at the right time. A large proportion of the information is obtained from what is seen or heard and therefore may be inaccurate. Verification or triangulation can be applied if necessary. Verification can be performed by asking the client to confirm or refute a particular fact. Triangulation requires redundant cues to check the correctness of information.

Data overload and time pressures can cause a burden on working memory. This can be problematic when a large amount of information is required by the decision maker. The decision maker weights and prioritises important information based on his/her perception of the situation. The remaining information is tagged for easy retrieval in case the decision maker later realises they need it. Framing is known as case base reasoning in Artificial Intelligence. It occurs when familiar features are used to access similar situations from memory. There is a risk of making premature conclusions especially when exposed to exceeding time pressures. This is called misframing. To avoid this, the expert must ensure he/she has collected enough information and that the diagnosis fully explains a sensible number of observations.

3 Computer-based metacognitive training

3.1 What is metacognition?

Metacognitive thinking occurs when you think about your cognitive level thinking. The term metacognition refers to thinking about:

- how you will perform a task or how you are performing a task, and
- the knowledge that you have to perform it, then

monitoring and regulating those thinking processes and that knowledge while you perform the task [7]. This description shows that metacognition has two main components which are knowledge about cognition and regulation of cognition. Knowledge about cognition is referred to as metacognitive awareness, while regulation of cognition is referred to as self-management or self-regulation. The metacognitive process is illustrated in Figure 1. Metacognitive thinking can be applied when learning something, performing an activity, or solving a problem. Examples of metacognitive activities are planning, monitoring, regulation, reflection, and self-assessment.

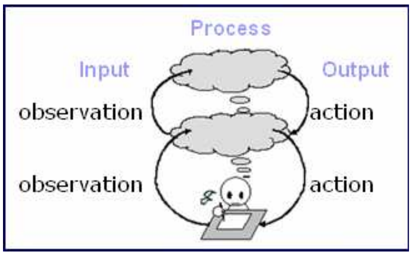

Figure 1. The metacognitive process [18, p. 2]

To clarify the distinction between metacognition and cognition, it is useful to remember that metacognitive strategies are used to *ensure* the achievement of a goal (by controlling the cognitive level thinking). In contrast, the cognitive strategies (e.g. calculating, reasoning, etc) help the learner *achieve* a goal.

3.2 Supporting metacognitive development

A variety of ways to support metacognition are covered in the literature and applied in existing computer-based systems. There are implicit and explicit ways of supporting metacognition. Implicit metacognitive support does not make the support for metacognition apparent, and *encourages* (but does not induce) the learner to practise metacognition. Examples of learning paradigms that support this include exploratory/discovery learning, constructivism, and collaborative learning. Examples of techniques that support it include cognitive scaffolding and simulations. Explicit metacognitive support makes the support for metacognition apparent, and *induces* the learner to practise metacognition, examples of techniques that can support this include metacognitive prompts/questions and displaying graphs of the learner's metacognitive performance. The likelihood that a learner will practise metacognitive thinking when implicit support is used depends on the learner, and the quality of experience or use of learning paradigms. Learners with low metacognitive awareness might not exercise their metacognitive skills if implicit support is used because they are not forced to do so [3, 19]. Therefore, implicit metacognitive support might not be as effective as explicit metacognitive support for this category of learners. Research has also shown that low achievers benefit more than high achievers from explicit metacognitive support [20, 21]. However, implicit metacognitive support still presents many benefits (and some advantages over explicit support) for supporting the development of metacognition, particularly for learners with an average or high level of metacognitive awareness.

Many methods have been used in education and experimental studies to support metacognitive development. A comprehensive description of these is provided in [8].

3.3 The suitability of a computer-based solution

Graduates who are beginners are likely to have a greater diversity of metacognitive skill levels compared to their cognitive skill levels. A computer-based system has the potential to provide an effective and feasible solution. Although a computer-based component/system has some drawbacks over other possible solutions, it also has many advantages that make it a more effective and feasible method. The other possible methods include a paper-based learning approach (e.g. a book), teacher aided learning, or a personal human tutor.

A comprehensive discussion about using computer-based learning environments to support metacognitive development in conceptually rich domains is provided by [22]. [23] also provide a discussion about how self-regulated learning (SRL) can be supported by a computer-based learning environment. Attempts to provide metacognitive support in computer-based tools have been made in a variety of domains including ecology [24], medicine [25], maths [11, 26, 27], biology [28], thermodynamics [29], inquiry support [30], programming [31], etc. Many of these systems have proven successful particularly those for mathematics problem-solving. These results are encouraging, and the need for further research in this area has been clearly expressed in the literature for example [3, 8, 13]. However, systems that provide extensive metacognitive support are very rare, and there is still room for improvement to make the metacognitive support they provide more extensive. Many approaches and techniques that are currently employed in computer-based systems to support metacognition can be improved to enhance the learning experience and better support metacognitive development. New approaches and techniques can also be designed to support metacognitive skills that are currently being neglected by computer-based teaching systems. It is also apparent in the literature that diagnosis has not enjoyed much research in this area. There are computer-based systems for diagnosis that provide some metacognitive support, however none of these provide extensive metacognitive support for novices. Therefore, this research would provide a novel research contribution.

3.4 Supporting metacognitive development using computer-based systems

A large number of methods are used in interactive learning environments to provide metacognitive training. A comprehensive description of these is provided by [8] and [32].

A set of learning paradigms which offer various benefits for metacognitive skill development have been explored in this research. These include exploratory/discovery learning, constructionism, collaborative learning, and problem-based learning.

The following set of instructional approaches which have the potential for supporting metacognitive development in learners has been explored in this research. The application of each technique to cognition, problem-solving, and metacognition was considered because all of these dimensions offer benefits for metacognitive development.

Scaffolding is providing just enough support to allow the learner to perform tasks on their own [33]. This can be a very effective way of providing individualized support. By definition, scaffolding should be faded by the instructor. However, scaffolds which can be faded by the learner were also considered in this research for example, optional tools available to the learner which can facilitate problem-solving.

If advanced scaffolding using either a learner model or human is not provided, other methods can be used to try to provide an adaptive/individualized experience for the learner for example guided exploration, intelligent/interactive agents, and adaptive feedback.

Other techniques were also considered which are not used for scaffolding or adaptive support however still support the learning experience, for example:

- Problem-solving reification allows aspects of the problem-solving process (like abstract concepts or actions) which are implicit or unexpressed during problem-solving to become explicit [8]. This facilitates the understanding of the problem-solving process. For example, worksheet problems can be used to make the underlying problem structure of algebra word problems visible [32].
- Graphical problem transformations support the construction of a graphical representation of the problem. For example, The Geometry Tutor [34] and ANGLE [35] provide a high level representation of a problem-solution/problem space.
- Metacognitive prompts and questions are often used to encourage the learner to reflect on his/her learning experience [8, 19]. For example, while the learner is solving a problem, he/she can be asked whether they think their problem-solving process requires improvement.

4 A computer-based metacognitive training component for diagnosis

4.1 Metacognitive support points for the diagnosis process

This research project aims to enhance some existing approaches and techniques (and design new ones) that can be used by computer-based systems to support metacognitive development. The next major step of this research is to propose a computer-based teaching component for diagnosis that can provide extensive metacognitive support, and to test some of the new/enhanced approaches or techniques applied in this proposed component. Two initial objectives to support the accomplishment of this aim involve finding out which metacognitive skills are currently being neglected, and where the current systems are lacking in terms of providing extensive metacognitive support. The goal of this project is to devise a computer-based teaching component that provides an effective and efficient learning experience for the learner in terms of developing his/her metacognitive skills. The support will focus on developing the metacognitive skills required for diagnostic problem-solving (in the category of diagnosis domains this research is concerned with). The intention is also to provide the learner with an “all-rounded” experience in terms of developing a broad range of the metacognitive skills they need.

The proposed computer-based component should cater for a variety of cognitive and metacognitive abilities and provide an effective and enjoyable experience. The simulation of a realistic problem-solving environment (with realistic conditions and constraints) can help the learner exercise the various skills they will require for solving real world problems in their feild. The authors plan to design a generic computer-based component that will be suitable for:

- Supporting a variety of diagnosis domains (in the category of domains this research is considering), and
- Integration with a variety of computer-based learning environments that take a problem-based learning approach and provide cognitive support (for the category of diagnosis domains this research is considering).

The metacognitive activities proposed by the authors for the diagnosis process are shown in Figure 2. They focus on supporting a subset of the key areas in the diagnosis process that were identified as requiring metacognitive support in complex diagnosis domains. In summary, they are concerned with deciding on the likelihood of the current diagnosis, information weighting and verification, and checking whether enough information has been collected. The proposed solution also supports pre and post reflection, planning, monitoring, and self-assessment as these skills are crucial when problem-solving in complex settings. Their focus is as follows:

- Pre-reflection – Previous cases he/she has come accross that had similar symptoms
- Post-reflection – The correctness of his/her of initial abduction and final diagnosis, and how he/she could have improved them
- Planning – The constraints and how he/she will deal with them
- Monitoring – How well he/she is performing and what he/she needs to do in order to correctly modify his/her behaviour e.g. speed alteration, change of strategies, etc
- Self-assessment – How sure he/she is of his/her initial hypothesis set and final diagnosis

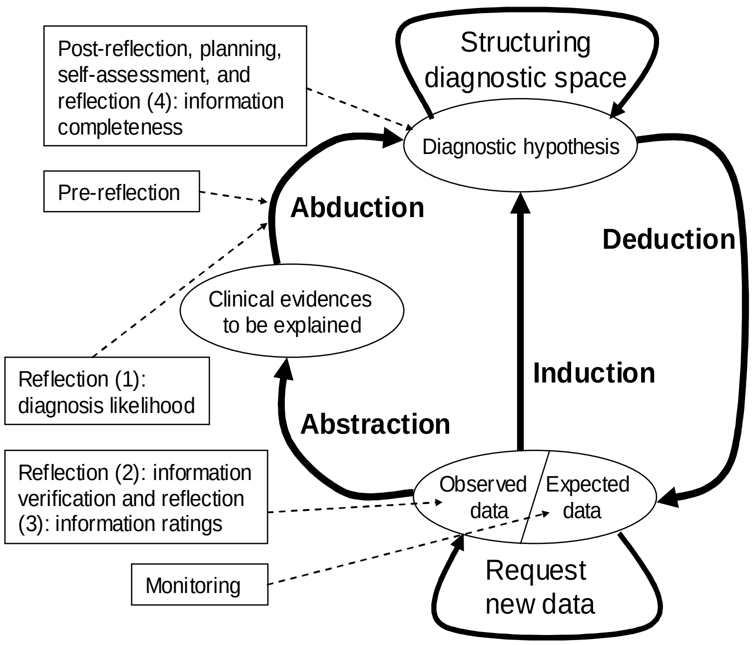

Figure 2. Proposed metacognitive activities for the diagnosis process annotating [16, p. 121] ST-Model

4.2 High level system architecture

A high level architecture of the proposed intelligent tutoring system has been defined by the authors; it is shown in Figure 3. Most of the modules and repositories are the same as those of a typical ITS, however a metacognitive student modeler module has been added as well as a metacognitive knowledge repository and a metacognitive student models repository. The authors hope to test out the metacognitive support provided in the metacognitive knowledge repository, the metacognitive student modeler module, the pedagogical module, and the interface module. The authors intention is to design and develop a generic metacognitive training component that can be used as part of an existing problem-based domain specific computer-based teaching system (for the category of diagnosis domains considered in this research).

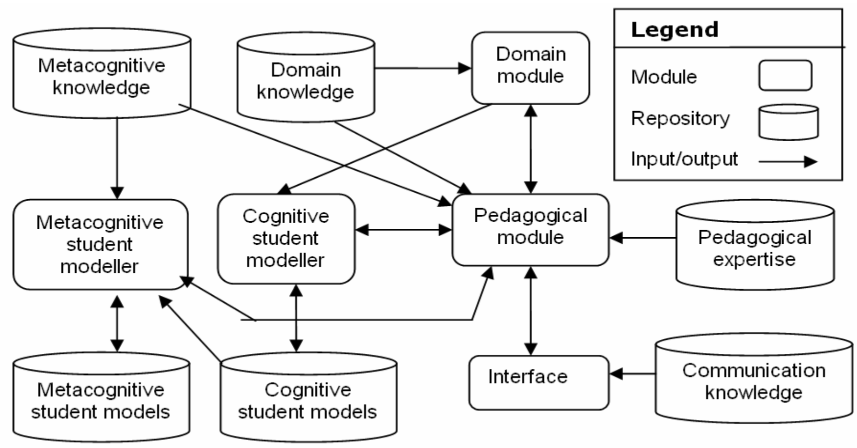

Figure 3. The high level system architecture

5 Conclusion and future directions

Diagnosis is central to many complex professions. Metacognitive training can help fast-track the long novice to expert transition in the category of diagnosis domains that are less understood in terms of completeness and certainty. There is a need for a computer-based system that provides metacognitive training for novice graduates in these types of diagnosis domains. This system would provide a novel research contribution. The issues and difficulties faced by novice graduates in the types of complex domains considered in this research have been determined. A literature review for metacognitive support in computer-based teaching systems has also been carried out. This was followed by the development of an initial framework for a metacognitive training component for the category of complex diagnosis domains considered in this research. The proposed component targets a number of points in the diagnosis process that require metacognitive support in complex domains. It also supports a set of metacognitive skills that are crucial when problem-solving in complex settings. The metacognitive training component proposed, is a generic component that can be used with a problem-based domain specific computer-based system that supports diagnosis in the category of domains this research is concerned with.

The next step of this research will be to devise new methods and techniques (and improve existing ones) that can be used in the proposed metacognitive training component. The authors plan to then develop and test a prototype that applies a subset of these approaches for particular complex diagnosis domains. This will enable the evaluation of some of the ideas proposed in this research.

References:

[1] Kemp, E.A.; Kemp, R.H.; Gray, D.I.: Towards a Framework for Teaching Naturalistic Decision Making in Information Rich and Knowledge Intensive Environments. *International Conference on Computers in Education*, Hong Kong, 2003.

[2] Gray, D.I.; Kemp, E.A.; Gardner, J.: The Problem Solving Process used by Farm Management Consultants: Implications for training, *Primary Industry Management,* 3 (2000), pp. 31-37.

[3] Bransford, J.D.; Brown, A.L.; Cocking, R.R.: *How People Learn: Brain, Mind, Experience, and School*, National Academy Press, Washington, DC, 1999.

[4] Fortunato, I.; Hecht, D.; Tittle, C.K.; Alvarez, L.: Metacognition and problem solving, *Arithmetic Teacher*, 39 (1991), pp. 38–40.

[5] Pressley, M.; Ghatala, E.S.: Self-regulated learning: Monitoring learning from text, *Educational Psychologist*, 25 (1990), pp. 19–33.

[6] Schoenfeld, A.H.: *Mathematical Problem Solving*, Academic Press, New York, 1985.

[7] Hacker, D.J.: (Ed.) *Metacognition: Definitions and Empirical Foundations*, Lawrence Erlbaum Associates, Hillsdale, NJ, 1998.

[8] Gama, C.: Integrating Metacognition Instruction in Interactive Learning Environments, *Computer Science*, University of Sussex, Brighton, UK, 2005.

[9] Poyla, G.: *How to solve it*, Princeton University Press, NJ, 1957.

[10] Cardelle-Elawar, M.: Effects of teaching metacognitive skills to students with low mathematics ability, *Teaching and Teacher Education*, 8 (1995), pp. 109-121.

[11] Corbett, A.; Mclaughlin, M.; Scarpinatto, K.C.; Hadley, W.: Analyzing and Generating Mathematical Models: An Algebra II Cognitive Tutor Design Study. *Intelligent Tutoring Systems: 5th International Conference*, Montréal, Canada, 2000, pp. 314-323.

[12] Teong, S.K.: The effect of metacognitive training on mathematical word-problem solving, *Journal of Computer Assisted Learning,* 19 (2003), pp. 46-55.

[13] Dimitrova, V.: Maintaining Diagnostic Interactions that Promote Learners' Reflection. *11th International Conference on Artificial Intelligence in Education (AI-ED 2003)*, Sydney, Australia, 2003, pp. 228-238.

[14] Schreiber, G.; Akkermans, H.; Anjewierden, A.; De Hoog, R.; Shadbolt, N.; Van De Velde, W.; Wielinga, B.: *KNOWLEDGE ENGINEERING AND MANAGEMENT The CommonKADS Methodology*, MIT Press, Cambridge Mass, 2000.

[15] Benjamins, R.; Jansweijer, W.: Toward a Competence Theory of Diagnosis, *IEEE Expert*, 9 (1994), pp. 43-52.

[16] Magnani, L.: Basic Science Reasoning and Clinical Reasoning Intertwined: Epistemological Analysis and Consequences for Medical Education, *Advances in Health Sciences Education*, 2 (1997), pp. 115–130.

[17] Kemp, E.A.; Gray, D.I.; Kemp, R.H.: Supporting realistic decision making: a conceptual foundation for developing computer-based teaching systems. *Work in progress*, 2007.

[18] Kayashima, M.; Inaba, A.; Mizoguchi, R.: Towards Shared Understanding of Metacognitive Skill and Facilitating Its Development. *7th Conference on Intelligent Tutoring Systems*, Maceió, Alagoas, Brasil, 2004, pp. 251-261.

[19] Lin, X.D.; Lehman, J.D.: Supporting learning of variable control in a computer-based biology environment: Effects of prompting college students to reflect on their own thinking, *Journal of Research in Science Teaching*, 36 (1999), pp. 837–858.

[20] Kapa, E.: A Metacognitive Support During the Process of Problem Solving in a Computerized Environment, *Educational Studies in Mathematics*, 47 (2001), pp. 317–336.

[21] White, B.Y.; Frederiksen, J.R.: Inquiry, modeling, and metacognition: Making science accessible to all students, *Cognition and Instruction*, 16 (1998), pp. 3-188.

[22] Azevedo, R.: Computer Environments as Metacognitive Tools for Enhancing Learning, *Educational Psychologist*, 40 (2005), pp. 193–197.

[23] Shakya, J.; Kumar, V.: Capturing and Disseminating the Principles of Self-Regulated Learning in an Ontological Framework. *3rd International Workshop on Applications of Semantic Web Technologies for E-Learning at the 3rd International Conference on Knowledge Capture*, Banff, Canada, 2005, pp. 27-35.

[24] Luckin, R.; Boulay, B.D.; Yuill, N.; Kerawalla, C.; Pearce, D.; Harris, A.: Using Software Scaffolding to Increase Metacognitive Skills amongst Young Learners. *11th International Conference on Artificial Intelligence in Education*, Sydney, Australia, 2003, pp. 27-30.

[25] Crowley, R.; Legowski, E.; Medvedeva, O.; Tseytlin, E.; Roh, E.; Jukic, D.: An ITS for medical classification problem-solving: Effects of tutoring and representations. *12th International Conference on Artificial Intelligence in Education*, Amsterdam, 2005, pp. 555-562.

[26] Koedinger, K.R.: 2000. Intuitive Strategies and Learning Formal Representations. Retrieved 12 June, 2005, from http://pact.cs.cmu.edu/koedinger/koedingerResearch.html
[27] Koedinger, K.R.; Anderson, J.R.; Hadley, W.H.; Mark, M.A.: Intelligent Tutoring Goes to School in the Big City, *International Journal of Artificial Intelligence in Education*, 8 (1997), pp. 30-43.
[28] Lajoie, S.P.; Lavigne, N.C.; Guerrera, C.; Munsie, S.D.: Constructing knowledge in the context of BioWorld, *Instructional Science*, 29 (2001), pp. 155–186.
[29] Rosé, C.P.; Aleven, V.; Torrey, C.: CycleTalk: Supporting Reflection in Design Scenarios with Negotiation Dialogue. *CHI 2004 Workshop on Designing for Reflective Practitioners: Sharing and Assessing Progress by Diverse Communities*, Vienna, Austria, 2004.
[30] Kyza, E.A.; Edelson, D.C.: Reflective Inquiry: What it is and how can software scaffolds help. *Annual Meeting of the American Educational Research Association*, Chicago, IL, 2003.
[31] Kumar, V.; Winne, P.; Hadwin, A.; Nesbit, J.; Jamieson-Noel, D.; Calvert, T.; Samin, B.: Effects of self-regulated learning in programming. *Fifth IEEE International Conference on Advanced Learning Technologies (ICALT 2005)*, Kaohsiung, Taiwan, 2005, pp. 383-387.
[32] Jonassen, D.H.; Carr, C.; Yueh, H.: Computers as Mindtools for Engaging Learners in Critical Thinking, *TechTrends,* 43 (1998), pp. 24-32.
[33] Vygotsky, L.S.: *Mind and society: the development of higher mental processes*, Harvard University Press, Cambridge, MA, 1978.
[34] Anderson, J.R.; Boyle, C.F.; Yost, G.: The geometry tutor. *Proceedings of the Ninth International Joint Conference on Artificial Intelligence (IJCAI 85)*, Los Angeles, California, USA, 1985, pp. 1-7.
[35] Koedinger, K.R.; Anderson, J.R.: Reifying implicit planning in geometry: guidelines for model-based intelligent tutoring system design. In Lajoie, S. P. & Derry, S. J. (eds.) *Computers as Cognitive Tools*, Lawrence Erlbaum Associates, Inc, Hillsdale, New Jersey, 1993, pp. 15-46.

Author(s):

Hiba Mustafa, BE
Massey University
Institute of Information Sciences and Technology, Department of Computer Science
Turitea Valley, Palmerston North, New Zealand
h.mustafa@massey.ac.nz

Elizabeth Kemp, A/Prof.
Massey University
Institute of Information Sciences and Technology, Department of Computer Science
Turitea Valley, Palmerston North, New Zealand
e.kemp@massey.ac.nz

Ray Kemp, Dr.
Massey University
Institute of Information Sciences and Technology, Department of Computer Science
Turitea Valley, Palmerston North, New Zealand
r.kemp@massey.ac.nz