Matching Mental Models: The starting point for authentic assessment in robotics

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Abstract

This paper discusses the matches and mismatches that occur between the mental models held by the teacher and students undertaking a robotics activity in an Australian school. It proposes that an understanding of participants' mental models of learning and assessment plays an important role in planning for, and reporting, on authentic assessment of a technology-based activity.

The longitudinal project, over 20 months, was an empirical qualitative study centred within information processing theory and linked with the introspection mediating process tracing paradigm. It involved students and their teacher in a socio-economically diverse urban Australian primary school and aimed to establish how the identification of participants' mental models can assist in the authentic assessment of learning through a richer understanding of the cognitive development taking place in a technology-based learning experience.

Robotics, as a component of the Queensland Technology Years 1 to 10 Syllabus published in 2003, provides a rich, multi-disciplinary environment in which to engage middle years students in Australia. The syllabus document provides guidance on planning and assessment for design and technology activities and provides a specific module for robotics.

However, engagement is not enough to ensure learning. All participants, students or teachers, bring to such activities their own mental models of robotics, learning, and assessment. Can understanding the matches and mismatches of such mental models provide a greater understanding of the individual's learning journey and the suitable assessment practices required to map the journey? This paper explores the participants' mental models at the half-way point of the project.

Key words

mental models, design and technology, assessment, cognition, robotics, learning

Introduction

The use of the term 'matching' could be somewhat problematic when applied to the mental models held by teachers and students. The definition of the noun *match* in the Chambers Concise 20th Century Dictionary (1985:594) reveals a binary where it can mean either 'a condition of exact agreement, compatibility or close resemblance' or 'a formal contest or game'. The definition of the transitive verb, *match*, has a similar binary with meanings of 'to be equal to' or 'to be able to compete with; to pit or set against another in contest or as equal'. The use of *matching* in the title of this article is intended to describe how the mental models of teachers and students can be compatible and thereby promote authentic assessment in a design and technology project. The term 'mismatch' when used in this text will denote when mental models are not compatible. What is apparent is that the term 'match' could mean both compatibility and in contest. In any given classroom at any point in time, assessment practices can become a contest where competition for grades can set student against student. Similarly, a mismatch of teacher and student mental models can cause confusion where the requirements for assessment are not clearly defined and communicated. Therefore, the matching of mental models as a starting point for authentic assessment takes the compatibility definition. While exact agreement may never be possible, determining how closely the mental models of students resemble those of teachers can influence the design of assessment strategies that convey the individual student's learning journeys and promote productive pedagogies.

What are mental models?

The genealogy of mental models began when Craik (1943) proposed the theory as an explanation for human thought processes. The theory recognised the existence of users' mental models of a system's interface created by designers. Mental models are dynamic representations of the reality of a system held by users. Craik's work was taken up by others working in broader fields including Johnson-Laird

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(1983) whose experiments in formal deductive reasoning in text comprehension supported mental model theory. Others (Meiser, Klauer, and Naumer, 2001; Gentner 1998; Barker, van Schaik, and Hudson, 1998; Schwartz and Glack, 1996; Carroll and Olson, 1988) have confirmed that mental models exist in order to understand the phenomena they represent in the real world. Barker, van Schaik, Hudson, and Meng Tan (1998) believe they are important because they form the basis of all behaviour.

Definitions of mental models appear to be as idiosyncratic as mental models themselves. This lack of a definitive designation reflects not only the robustness of mental model theory and its application (Moray, 1998; Rowe and Cooke, 1995) but the diverse research contexts in which mental models underpin descriptions and predictions of outcomes and behaviour. While we can conclude that mental models are problematic to define (Norman, 1983), the multiplicity of their application is not. Mental models enable us to 'understand the world by constructing working models of it in our minds' (Henderson and Tallman, 2006: 22). They are cognitive representations, not scale models, that are created individually and reflect structures of our environment, the tasks we undertake, the problems we solve (Halford, 1993) and even abstractions such as truth (Newton, 1996) that we encounter on a daily basis.

Mental model theory captures 'within one framework, an account of the deductive competence, biases, and pragmatic effects' that we require to interact successfully in a multitude of environments (Evans, 1996:323). The theory recognises that our mental models are functional at an individual level as they are being constructed (Norman, 1983) and aid the investigation of alternatives when new problems or real world phenomena are encountered (Carley and Palmquist, 1992; Renk, Branch and Chang, 1994). Our motivations to interact with our environment are as individual as the mental models we create to guide these interactions. Mental models that are functional for one may be unworkable for another but this individuality does not distract from the power of mental models to inform learners of various actions that are possible during any interaction (Bibby, 1992). During these times, various mental models are being run (Johnson-Laird, Oakhill, and Bull, 1986; Norman; 1983; Payne, 1991) and it is this 'core defining characteristic' (Henderson and Tallman, 2006:32) of runnability as well as the matches and mismatches that occur that are of interest to practising teachers.

Mental models are created and manipulated in working or short-term memory then stored in long-term memory (Gentner and Stevens, 1983; Henderson and Tallman, 2006; Johnson-Laird, 1983). The ability to retrieve mental models for manipulation is important for making inferences and relating propositions in problem situations. The effectiveness of running a mental model can be influenced by several factors such as a learner's meta-ability (Anderson, Howe and Tolmie, 1996; Haycock and Fowler, 1996; Johnson-Laird et al., 1986) and their ability to utilise their working memory effectively (Anderson et al., 1996; Johnson-Laird et al., 1986; Newton, 1996). Of interest to practising teachers are the limitations that learners may have in retrieving the necessary long-term memories where mental models are stored in order for their manipulation in problem-solving situations. While mental models need to be accessed, once retrieved they help to reduce the mental load created when interacting with problem situations and also help the development of metacognitive skills (Haycock and Fowler, 1996: 5).

When a learner is faced with a novel situation for which a problem must be solved, they retrieve the mental models that will steer and modify the actions they take. In this way, mental models are processes and products (Henderson and Tallman, 2006) because they are mechanisms that enable us to understand as well as act. Mental models function to mediate between what we can perceive and the actions required. In this way they are purposeful and act like tools (Henderson and Tallman, 2006) because they enable conceptualisation, memory, interpretation, prediction, communication, and performance control. Barker et al (1998:201) contend that the 'richer a student's mental models, the better will be his/her performance' within any domain. Having the opportunity to develop and subsequently run mental models in a challenging environment improves cognition which in turn becomes more effective through running and moderating mental models.

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Mental models are created for a purpose and this is of particular importance when studying their effectiveness in design and technology lessons. Because mental models provide an 'explanatory function for understanding the complexities in teaching and learning interactions' (Henderson and Tallman, 2006:25) they may assist in the facilitation of assessment practices that both enlighten and guide teaching, learning, and assessing in design and technology. While mental models are internal structures (Johnson-Laird, 1983; Norman, 1983; Renk et al., 1994), particular to the user (Greca and Moreira, 2000) they can be 'exteriorised' (Barker et al., 1998) when triggered by some stimuli or through interaction with a domain system (Norman, 1983; Carroll and Olson, 1988; van der Veer, 1990) such as robotics or computer software. This interaction results in some physical action or performance (Jonassen, 1995) which can be observed.

This study determined how the mental models of the participants guided them through the learning experiences with the robotics program and subsequently provided an explanatory function for forming opinions about relevant assessment practices and techniques that would best describe the learning journey. For a teacher, mental models continuously activate reflection of our pedagogical practice and this can be a liberating or stultifying experience (Fischbien, Tirosh, Stavy, and Oster, 1990). For students, such continual reflection of practice through running mental models can be equally liberating if they are given the opportunity to understand their thoughts and actions.

Robotics in Design and Technology

The Queensland Technology Years 1 to 10 Syllabus (QSA, 2003) provides guidance to teachers on the development and assessment of the learning area without mandating particular content. It promotes cross-curricula priorities and the engagement of students in life-long experiences including reflective practice and responsive creativity. "Introducing Robotics" (QSA, 2003) is a supplementary, discretionary module designed to engage students in learning outcomes from Level 6 (Lower Secondary – Middle Years). It provides teachers with sequential activities for students to build and program robotic devices using Lego™ Dacta equipment and Robolab™ software. The activities are organised into introductory, developmental, and culminating phases as shown in Figure 1.

Examples of assessment strategies included in the module and provide guidance to the teacher on how they may assess the demonstration of outcomes. The module reflects the pedagogical characteristics of the syllabus by suggesting negotiated assessment practices that include opportunities to reflect with the students on the evidence collected. The predominant source of evidence is the student technology project folio, templates for which are provided in the module. Templates for design proposals and briefs, product specification sheets and project management plans are also provided. It is suggested that the students work collaboratively to generate, create, and implement their designs before undertaking personal and team performance evaluations. In summary, the module provides useful guidance for teachers to implement and assess a robotics program using constructivist pedagogy.

Introductory	**Developmental**	**Culminating**
Formulate plans for gathering information and acquiring relevant skills. Research and discuss robotics. Follow instructions to build robots and use sample programs.	Analyse the design challenge and prepare project proposals and design briefs. Devise project management plans. Prepare product specifications. Construct and program a robot.	Trial and refine robotic devices. Evaluate robotic devices. Evaluate personal and team performances.

Figure 1. Synopsis of Activities from "Introducing Robotics" (QSA, 2003).

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Papert (1980) in his seminal text *Mindstorms* discussed the transformation of learning when children learn to program. Their learning becomes 'more active and self-directed' (Paper, 1980:21) when the knowledge they acquire is for a recognisable, personal purpose. This is the central tenet of constructivist pedagogy where purposeful learning occurs when information and procedures are delivered but knowledge is constructed by the learner (Duffy and Jonassen, 1992). Papert's (1980) research supports this pedagogical shift from one that is behaviourist to one that is process or constructivist oriented (Bilotta and Pantano, 2000; Conway, 1997). Several other studies (Barchi, Cagliari and Giacopini, 2002; Kiesler and Goetz, 2002; Resnick, 1989; 1994) have aimed to establish the cognitive development and mental model construction by children who learn within contexts that involve technological objects, such as robots.

The methodology of building, testing, evaluating, and altering a robot's behaviour requires an 'experimentally driven design' (Bilotta and Pantano, 2000: iii) approach by the students. This approach enables the retrieval and manipulation of the students' mental models to enable the accomplishment of the set goal for the robot. Resnick (1989; 1994) discovered that different solutions, in programming the robot to accomplish a goal, were created by the students particularly where the tasks the robots were to accomplish were complex. Mental models that were not viable needed improvement in order for the robot to be programmed to achieve the required goals (Norman, 1983; Seel, 2001). Students can 're-launch' mental models (Henderson and Tallman, 2006:.27) and critique their reliability in order to determine whether they should be kept or discarded.

The study of robotics offers a problem-based, learner-centred, and purposeful learning environment where the students can construct their own meanings (Jonassen, 1995) develop functional mental models (Norman, 1983) that inform the student of sensible actions during the interaction (Bibby, 1992). The students should learn how a complex system operates by being better able to provide causal explanations (Milrad, 2002) for the robot's behaviour and being able to anticipate actions and explain the changes in programming or construction that are required for the desired action.

Context of this study

The school involved in the project is in an urban area in Queensland, Australia. The campus has 550 students from preschool to Year Seven. Behaviour management has been a strong focus of the school and the predominant role of the deputy principal is to support staff and parents with student behaviour. Robotics was newly introduced to the Year Six students when the project commenced. The teacher participant, Pamela, established a small robotics laboratory with six stand-alone computer terminals and three robotics kits.

When the project began, Pamela had been a practising teacher for eight years. She had undertaken some professional development in robotics and decided to implement a program in order to engage behaviourally-challenged students in the school. She worked with a teaching partner in an open-plan classroom. The robotics laboratory was situated next to the classroom which contained six internet-linked computers. Students were divided into four groups and then partnered for the activities. Some early orientation lessons were conducted with the students to familiarise them with the robotics equipment and software. This paper picks up their journey eight months into the project.

Collecting the data

Data were collected from the teacher, Pamela, and her students, aged 10 to 11 years, over a 20-month period from semi-structured and stimulated recall interviews, questionnaires, teach back episodes, forums, and journals. Data from questionnaires and journals were collected from twenty-five student participants. Four students were anonymously drawn from the total group of twenty-five participants and these four students participated in the interviews, teach-back episodes and forum. Mental models were categorised as espoused, in-action, and reflective (Henderson & Tallman, 2006; Henderson, Putt, & Coombs, 2002; Strauss, 1993; Senge, 1992). Figure 2 outlines how the data contributed to this categorisation.

Espoused	In-Action	Reflective
Pre-Experience Semi-structured Interviews. Likert Scale Questionnaires.	Stimulated Recall Interviews. Journals. Teach Back Episodes. Forum Interview.	Post- Experience Semi-structured Interviews. Likert Scale Questionnaires. **Longitudinal** Semi-structured and Paired Interviews.

Figure 2. Data collection instruments and mental model categories

Data were triangulated to ensure confidence that "the data generated are not simply artefacts of one specific method of collection" (Burns, 2000:419). The use of a variety of methods was necessary as the determination of mental models held by participants can be difficult to ascertain due to their internal, personal nature, and to the indirect and problematic nature of measuring internal models (Norman, 1983; Renk et al., 1994; Staggers and Norcio, 1993). However, mental models are said to be able to be inferred by some form of performance (Jonassen, 1995). This performance may include a user's explanations of a system and its components, and their predictions about its performance (Henderson and Tallman, 2006; Sasse, 1991).

Mental models of learning: matches and mismatches

Eight months after starting the project, the student participants had conducted a teach-back session with students of the same age who had not been involved with the robotics program. They had five minutes to design a thirty minute lesson after which they were interviewed. Three weeks after these sessions, the four student participants were required to design an assessment activity for each other, conduct the session and then provide feedback as a group in a forum interview. The forum interview was organised in such a way that the semi-structured exchange would reveal their mental models and the distributed cognition (Hutchins, 1995) or sharing of those mental models through discussion and debate (Henderson and Tallman, 2006). The session was video-taped and played back to the teacher, Pamela, for her thoughts and reactions. All participants kept a journal of their activities where they wrote about their robotic experiences and how they felt about their learning journey. Pamela's journal recorded the organisational, pedagogical, and assessment perceptions and problems associated with the project.

This triangulated data revealed that the students had a matching mental model of learning with robotics. The matching mental model was the mental model of linear learning of building and programming the robot. This match was not surprising because the students found that following this sequence was time-efficient given the necessity to share equipment. Their mental models of making use of available resources to solve problems were mismatched, evidenced by their actions when encountering problems with either building or programming. This mental model was dominated by other, more developed, mental models that the students used successfully in other learning areas or with other teachers. An example of this would be a mental model of teacher as expert being run by a student who responded to problems with raised hand. Figure 3 displays the students' in-action mental models of learning with robotics.

The teach-back sessions demonstrated mismatches for two of the students between their mental model of learning with robotics and their mental model of teaching robotics. While all participants had compatible, if not matching, mental models of learning with robotics there were obvious mismatches with the mental models of teaching. Teaching is complex even for trained adults and the students' teaching experience had been limited to peer tutoring

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Student	Mental model	Mental Model Examples
Ellen	Learning with robotics.	Build the robot then go on to the programming. Having a robot built before you started is easier than having the computer like at one screen and you take forever to build it.
Jayne		Doing it by computer and by looking through all of the steps because it tells you what to do.
Bree		First we got the robot and then you get the instruction kit. Then you get the Lego to build the robot and you just follow the steps through. Doing it yourself.
Sam		I was taught with two big tasks. Build the robot, program it and watch it run.

Figure 3. Mental models of learning with robotics

other students. In this instance, they were being asked to design and teach a lesson. Figure 4 shows the teaching methods used by each student and their reasons for using this strategy.

When the students were asked if they would alter their teaching methods to teach robotics in the future, both Ellen and Bree agreed that they felt comfortable with the method they had adopted. Their mental models for teaching matched their mental models for learning; to involve hands-on learning in a sequential format. Jayne, who described the steps to take to build and program the robot but did most of the tasks herself, reflected that she would show more things

Student	Observed teaching method	Reason for using this method
Ellen	Guided. Student had total hands-on experience. Sequential steps explained. *Outcome: Success.*	It was because that was how I learnt to do it.
Jayne	Demonstrated. Student had little hands-on experience. Steps missed. *Outcome: No success.*	So she could see what buttons to press and how to get into it and what it does on the computer. She didn't click on the computer because I was teaching. I did it because she wouldn't know what to do.
Bree	Guided. Student had hands-on experience. Sequential steps explained. *Outcome: No success but shared problem solving with student.*	Because that's the way Pamela taught us. So she could figure it out for herself.
Sam	Demonstrated. Minimal student hands-on experience. Sequential steps not explained. *Outcome: Success.*	I thought it was easiest for both of us. I guess I was experimenting a bit.

Figure 4. Observed teaching methods and explanations from Teach-back episodes

next time such as plugging in the infra-red (IR), using the instruction booklet and the robotics kits. Sam, who demonstrated the building and programming of the robot, reflected that his student should probably have the opportunity to handle the equipment and that he had taught in a manner that was different to how he was taught. He thought this method was easier because he 'didn't have to go through and explain everything' to his student. His mental model of learning dominated his mental model of teaching. Jayne and Sam had a mismatch between their mental models for learning and those for teaching. They held themselves as experts who had all of the 'knowledge in their heads' (Norman, 1988; Jonassen & Henning, 1999) and excluded their students from constructing their own knowledge by having a hands-on learning experience and running their own mental models for problem solving.

Pamela's mental model of learning is based on the collaborative cognitive approaches of constructivism (Piaget, 1972; Rogoff, 1998) and social-constructivism (Vygotsky, 1978). It is student-centred and process- rather than product-oriented. Her espoused mental model of learning did not include her role as expert and she encouraged the students to use other resources to solve the problems they encountered. After initial orientation sessions with the students, she left them to work through the pilot programs on their own. If they encountered a problem, they were encouraged to back-track through the steps to find where they had made an error. She also encouraged the use the help facility within the program to trouble-shoot problems. This strategy often met with frustration on the students' part due to their mental models of learning which included reliance on teacher assistance when difficulties were encountered.

Her mental models of learning were consistent throughout the project and matched her espoused mental models which positioned her as guide for the students through problem-based, learner-centred, and purposeful learning experiences. Her espoused mental model defines this approach:

> *"I think that the students of today are able to work with a lot of different information on different levels and combine that information. They also like to have hands-on where they're actually doing something. It's got a real-world application and so to make those connections with the wider world they need to be able to see how the things they're doing in the classroom actually link further out."*

Her mental model of learning included teacher, peers or help facilities as guide-on-the-side where students' learning was facilitated within their own Zone of Proximal Development (Vygotsky, 1978).

The students adapted their mental models to include her social-constructivist mental model and most developed the problem solving skills required to work their way through difficult building and programming episodes. Jayne, however, continued to use a mental model of retention of declarative knowledge. Remembering facts and following 'recipes' had been a successful strategy for her in her classroom work and, even when faced with obvious error, as she was in her teach-back session, she continued to run this unhelpful mental model and so failed to seek information from other sources to find the way around problems. Sam's mental model of showing his student how to build and program also mismatched his mental model of learning. While acknowledging that you learn best by doing it yourself, he provided no such opportunity for his student.

Mental models of assessment: matches and mismatches

Pamela's in-action mental models of assessment contained an understanding of how the students perceive assessment practices:

> *"we make presumptions about what these kids know about assessment and how it should all go together and who makes the decisions and you can really see from these kids that they're quite aware what needs to go in and what doesn't need to go in and that as a learner they can make the decisions about what needs to be assessed."*

She was responding to a video of a group interview, or forum, conducted with the four student participants which discussed, amongst other matters, their views of assessment in general, and robotics specifically.

The teacher had continuous discussions with the students throughout the project which preceded each activity and resulted in the students writing in their journals. At the beginning of each session they

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reviewed their last journal entry before writing the goal for the session after which they recorded what they had achieved and their feelings about the session. Pamela's mental model of learning included developing the students' metacognition and the journals were a regular part of this process. Her mental model of assessment contained three fundamental strategies including:

- conversing – discussions with students about what they know;
- chowing – physical construction and programming of the robot; and
- recording – ongoing record that students control through journal or video.

The students' mental models of assessment matched those of their teacher in many areas but also contained some mismatches with each other and with Pamela. Figure 5 shows the participants' mental models of assessment strategies and content. While all of them contained a 'showing' element where a student would be required to build and program a robot, several students included a preference for writing tasks or tests.

Ellen is the student whose mental model of assessment strategies and content most closely matches the teacher's mental model. She included an additional multi-media package to show through pictures and words the learning that has occurred and this closely resembles the journal entries done during the project. Jayne is the only student whose mental model of assessment specifically contains the need to retain knowledge. She refers to the role memory plays in retaining declarative and procedural knowledge and proposes that you can show you have learned if you have 'remembered it' and that going into the program 'straight away' is an indication of learning. Jayne was the one participant whose mental model of learning did not include using problem solving skills and she did not refer to available resources to help her through difficult problems. Her mental model of retaining knowledge dominated her activities and limited her ability to move through the programs.

Bree's mental model of assessment strategies contains 'written assessment' which is differentiated from 'writing in our journals…shows the teacher… we're you're up to'. This matches Sam's mental model, but mismatches the other participants. Her mental model of assessment did have some matches with the other participants when, during the forum she states that a good assessment would be to 'build a robot and try to be able to do it'. Sam's mental model of assessment contained 'creativity' and doing assessment that shows something individual about the learner. His mental model of assessment content matches Pamela's whose reference to being self reflective indicates this personal learning journey of the student. His mental model also included testing as a strategy which is almost a mismatch with his own mental model of assessment given the other significant strategies such as 'that's themselves' and 'not in the book' that recognise individuality and creativity.

Of interest is the mismatch between the teacher's mental model of assessment strategies with those of the students in regard to one-to-one conferencing. Pamela had used one-to-one conferencing from the beginning of the project to ensure that students were making progress in their groups. However, not one student participant included this strategy in their mental model of assessment. This indicates that the use of this practice as an assessment tool had not been clearly communicated to students so it was not part of their mental model of assessment. The conversations were happening but the students were unaware of the significance of them for assessment purposes. So while Pamela is aware of the 'presumptions' made about what students know about assessment and how it should all go together, her own presumption excluded them from developing the mental models required to fully contribute to the 'decisions about what needs to be assessed' and how what they had learned would be communicated.

Pamela does express some understanding of the limitations of the students' mental models when she states that students know that there's a 'timeline' and 'they all need to be consistently moving together through that timeline'. She believes that this mental model of learning is 'ingrained' and that they feel that they are 'catching up as opposed to moving through at your own pace and doing your own learning'. This indicates that, regardless of exposure to constructivist pedagogy, mental models of learning and assessment

Participant	Mental Model	Mental Model Example
Ellen	Assessment Strategies.	• Show/tell. • Teaching someone else. • A chart or a PowerPoint presentation because you write and do pictures of what you learned. # • Build the robot and see if she could do that successfully. • Go on the computer and build a pilot and if she could do that successfully.
	Assessment Content.	• Outcomes for confidence. • How well they did it, technique.*(process of building robot) • How well they built it.*(product of building robot) • If they had trouble programming and building.
Jayne	Assessment Strategies.	• Build a robot, pick a program and download it. • Showing how you've done it. • Take a photo of the robot you built.
	Assessment Content.	• Confidence. • Remembered it.*(declarative and procedural memory) • She could go into it straight away. • She'd know how to do it.
Bree	Assessment Strategies.	• A written assessment. # • Write it in our journals. • Build a robot and try to be able to do it.
	Assessment Content.	• Confidence. • Technique used. • Achievement.
Sam	Assessment Strategies.	• Testing – doing robotics tests. # • Keep photos. • Write about it in your journal. • Teaching others. • Entering robot comps.* (competitions)
	Assessment Content.	• Creativity, that's themselves.*(individually created program) • Not in the book and hasn't been tried.* (new program) • Problem solve. • Skill and being independent.
Pamela	Assessment Strategies.	• One-to-one conferencing. # • Show what they have done. • Video tape what they're doing. • Writing in their journal. • Peer assessment on group function. #
	Assessment Content.	• Problem solving strategies. • Being self-reflective. # • Made their own progress and had some success.

Figure 5. Mental models of assessment: Strategies and Content
*# mismatches * (interpretation of response for reader comprehension)*

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that are product- as opposed to process-oriented may be ingrained by the time students are ten years old. If so, then it is a challenge to modify these mental models to include negotiated, authentic strategies that demonstrate individual learning journeys. The mental models students have established may be controlling how they learn and not just about how they understand assessment. Stripling (1995: 164) warned that teachers 'will not succeed in changing students' limited or incorrect mental models unless the mental models themselves are addressed'.

Concluding comments

Our mental models have a profound impact on the ways we teach, learn, and show what we can do (Henderson and Tallman, 2006). They help explain how we go about completing tasks and how we review our performance. For teachers and students working with Design and Technology they are pivotal in guiding the participants through the learning process. They provide the mechanism that enables action and understanding (Henderson and Tallman, 2006) of the outcomes of investigations into alternatives for real world solutions to problems (Carley and Palmquist, 1992; Renk et al., 1994) whether they be designing, building, and programming a robot or guiding learners through a hands-on learning experience. Their autonomy enables teachers to guide students through learning activities and their mediating characteristic enables teachers to modify interactions if required (Henderson and Tallman, 2006).

This study has shown that it is not enough to understand what students know before or indeed after a learning experience. It is important that the students themselves have a clearer understanding of what they know, what they have learned, and how to communicate this understanding clearly. Mental models cannot be taught. Nor can they be transferred into students' brains (Henderson and Tallman, 2006). Stripling (1995) clarified the necessity of addressing the mental models held by students in order to correct erroneous ones that may limit learning. A mental model that limits learning or the clear communication of that learning through assessment cannot be challenged unless it is exteriorised through some action. If 'thought models reality' (Craik, 1943:22) then mental models that include authentic assessment practices can be developed if the participants, teachers and students, share them in clear communication practices that are understood, and accessible to all.

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