ICT-mediated science inquiry: the Remote Access Microscopy Project (RAMP)

This article was first published in the conference proceedings of ACEC2006 www.acec2006.info/acec2006

JOHN HUNT

University of the Sunshine Coast

Why ICT mediated science? Why new pedagogies?

The calls for the transformation of how science is taught (and what is taught) are numerous and show no sign of abating. Common amongst these calls is the need to shift from the traditional teaching and learning (focussed on preparing learners for careers in science and driven by tertiary institutions and science experts) towards a model that represents the social constructivist epistemology (Brooks & Brooks, 1993; Osborne & Freyberg, 1985; Yager 1991). These calls have coincided with the Internet revolution. Through the Internet, learners are able to access many and varied sources of information: a new era of information access has begun and continues at a rapid pace. Delivery of synchronous Scanning Electron Microscope (SEM) images to learners, who can be thousands of kilometres from the microscope, the focus of this study, is now possible using standard data lines, the Internet and data projectors: this is an adjunct to other information sources and exploits developing communication technology. Learners are able to access the knowledge and expertise of the remote science experts, usually a scientist in the specialist field and a science educator.

The challenges

The challenges cluster around two broad questions. The questions asked:

> ***Research Question 1:*** *Which pedagogies are promoted by innovations like RAMP (i.e. pedagogies that promote higher order thinking and understanding for learners)?*
>
> ***Research Question 2:*** *In what ways can ICT be used to enhance learner inquiry in science?*

RAMP explored and characterised these pedagogies and information and communication technologies that lead to enhanced learning in science, as well as enhanced attitude and perception towards science. The study investigated links between existing and emerging communication technologies and pedagogical practices and the impact these have on learners.

What does the literature tell us?

RAMP enabled learners to access current information, knowledge and expertise through building partnerships between schools, learners, and science experts and their facilities. Key amongst the driving ideas were learning experiences that engaged the learner, challenged the learner's current beliefs, encouraged the sharing of ideas between groups and individuals and engaged learners with ICT in a media rich, distributed network environment

This sit comfortably with commentary from Fensham (2004) that the context and emphasis of science should be designed so that it provides motivated learning and persistent engagement, features expectation and success and creates a sense of wonder and creativity.

Constructivism in science learning

Fensham's comments resonate with other views of constructivist learning in science. Tobin (1991) suggested that there was a need to connect with other persons, as they are a part of our experiential world. This reinforces the constructivist view that collaboration and cooperation are important teaching strategies. Tobin further tells us that the constructivist epistemology suggests that it is through the senses and interaction between learners and the environment occurs that learners make sense of their world.

When teachers use constructivist approaches to teaching science, it moves closer to the science that scientists do, as opposed to traditional science as a search for a set of universal truths. Scientists engage in science that is an active and social process (they collaborate and cooperate, increasingly across distance), a goal of reform-based science and contemporary curriculum. Contemporary and reform-based science supports the view that learning occurs best when the classroom has a focus on collaborative learning, activity is authentic and learner-centric and the roles of learner and teacher are blended (Brooks & Brooks, 1991; UNESCO, n.d.). Osborne and Freyberg (1985, p. 1) reinforce these views, suggesting that learners need to make sense of how and why things behave as they do rather than just finding out about their world.

The challenge for RAMP was to operationalise these ideas by developing a suite of pedagogies that created an environment rich in ICT use and that was pedagogically challenging for learners.

In Technology-Supported Learning Environments (Thomas & Knezek, 2002, p.3) suggest that '… real-world connections, primary source material, and sophisticated data-gathering and analysis tools are only a few of the resources that enable teachers to provide rich and powerful opportunities for conceptual understanding'. Thomas and Knezek further suggested that '… as technology becomes a supportive resource for teaching and learning in the classroom, teachers move from traditional teaching strategies to strategies proven by research to promote more effective learning'.

Linn (2004), describes how ICT in the contexts of various projects she has been involved in, made science accessible and thinking visible, a step towards 'pedagogical advantage' for learners. Linn's principles are summarised in Table 1 below.

Table 1: Linn's principles of pedagogical advantage

ICT can -

- **principle 1:** make science accessible
- **principle 2:** make thinking visible
- **principle 3:** help students learn from others
- **principle 4:** promote autonomy and lifelong learning

These pedagogical changes are part of the transformation that must be better understood and utilised, to bring about a broader reform in the teaching of science. These reforms are discussed in the following section.

What does ICT-mediated science look like?

It is broadly acknowledged that ICT has the potential to transform 'how learners learn', and learn and engage with science more specifically (Education Queensland, 2003, 2005; Linn, 2004).

Osborne and Hennessy (2003) mention the absence of the 'C' (communication) aspect of ICT, for example video-conferencing or email for the purpose of learning (as opposed to use for social exchanges) or synchronous linkage to the science of other schools/learners or scientists and their facilities and instrumentation. This does not appear to be well represented in many classrooms or education systems.

Atkins (1993) maps the communication dimensions of ICT connectivity, identifying three types of communication (or connectivity):

- people to people
- people to information
- people to facilities

He suggests that it is that interactions between these types of connectivity (or communication) that creates collaborations, and therefore enhanced learning opportunities; and that all three 'connections' are required for the generation of new knowledge.

The research questions described earlier emerged from the literature and focus on how ICTs are used and the pedagogies they are used with.

The methodology

The RAMP research is built around four phases of activity.

Phase 1: a scan of student-learner attitude to science. This was achieved using a modified Pell-Jarvis attitude scale (Pell & Jarvis, 2002) and the Draw a Scientist Test (Chambers, 1983). The use of an attitude scale provided environmental data to interpret the artefacts produced by the study, particularly the email conversations, presentations and interview transcripts.

Phase 2: the Pre-Intervention phase. Here learners participated in a semi-structured investigation of the anatomy of the imported red fire ant (IRFA). Learner research was supported by a weblog (fireants.blogspot.com) containing useful and safe information. This phase featured considerable email interaction between the learners and remote experts.

Phase 3: the Intervention phase. This is where learners engaged synchronously with remote experts (scientists and educators) and remote instrumentation, the SEM. This phase was termed the Intervention (a 45 – 60 minute live microscopy session). This element of RAMP was 'scripted' around what the learner research has revealed.

Phase 4: the post-Intervention phase: After the Intervention, learners completed their presentations (Week 6-7). This provided further data for analysis: learner work-samples. These artefacts were examined to identify evidence of enhanced leaning outcomes and understanding.

RAMP was particularly interested in demonstration of knowledge integration, higher order thinking and connectedness of ideas. In this same phase, learners completed a second attitude to science scan: a post-Intervention survey of student-learners. This data collection point was added to explore changes in attitude to science as a consequence of the experience. A post-Intervention interview was conducted with a sample of student-learners.

So what do we know now? What did the data tell us?

The data collected is analysed by source type and in pre- and post- Intervention situation. The discrete sets comprise:

- Attitude to science survey (pre- and post-)
- Draw a scientist test (pre- and post-)
- Email correspondence (co-researcher phase)
- The presentation (post Intervention)
- Review of pictures from the Intervention
- Individual Interviews (small sample)

The Attitude Survey comprised two parts, with Part A (Questions 1 – 22) probing attitudes to being at school, about science experiments and some broad questions about the conduct of scientific investigations. Tables 2 and 3 below show data significant to the study.

Table 2: Attitude Survey - Part A Pre-Intervention

	Questions about being at school						**Questions about science experiments**						
Question Number	**4**	**7**	**10**	**11**	**12**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**22**
	Drawing	Using the computer	Working by yourself	Working with your friends	Coming to school	Working out what to do yourself	Teacher telling you what to do	Choosing your own equipment	Finding out what happens yourself	Working by yourself	Working with friends	Finding out why experiments work	Telling friends what you have done
Female Average (PRE) n=24	4	3.5	2.4	4.8	3.1	2.3	2.3	3.1	2.8	2.5	4.7	2.2	2.6
Male Average (PRE) n=15	4.4	4.5	2.6	4.5	2.7	3	2.7	3.6	3.7	2.1	4.7	3.5	3.5

These data (Table 2) show that the learners generally had a high preference for communicating graphically (drawing), with the boys showing a significant preference for using computers. This is important, as the project was ICT based and built around an ICT-delivered Intervention, the use of email and a 'blog' during the co-researcher phase. Both gender groups expressed a desire to work with friends (collaboration) as opposed to working alone.

Table 3: Attitude survey Part A - Post-Intervention

	Questions about being at school						**Questions about science experiments**						
Question Number	**4**	**7**	**10**	**11**	**12**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**22**
	Drawing	Using the computer	Working by yourself	Working with your friends	Coming to school	Working out what to do yourself	Teacher telling you what to do	Choosing your own equipment	Finding out what happens yourself	Working by yourself	Working with friends	Finding out why experiments work	Telling friends what you have done
Female Average (POST) n=24	4.1	3.6	2.7	4.9	3.2	3	2.8	3.3	3	2.6	4.4	2.7	3.5
Male Average (POST) n=15	4.3	4.7	2.4	4.7	2.4	3.1	2.8	3.9	3.9	2.1	4.8	3.5	3.7

Learners also expressed a strong desire to design their own experiments as opposed to watching a teacher demonstration. In the Post-Intervention Attitude survey (Table 3), the questions flagged previously as 'of interest' show remarkable consistency, particularly given that raw data is being used.

Part B comprised Questions 23-42 (a 1-3 Likert scale was used) and focused on 'what I think about science', or 'science in a social context'. Table 4 below shows comparative data from the Pre- and Post- attitude survey. This was measured using a 3-point scale.

Table 4: Part B of Pre- and Post- Intervention Attitude Survey

		Female ***PRE*** ***n=18***	**Male** ***PRE*** ***n=22***	**Female** ***POST*** ***n=19***	**Male** ***POST*** ***n=14***
23.	I would like to be a scientist	1.55	1.72	1.68	1.64
24.	Science is good for everybody	2.16	1.95	2.21	1.92
26.	You have to be clever to do science	2.16	1.81	1.78	1.92
29.	Science is just too difficult	1.94	1.68	1.63	2.07
34.	We have to do too much work in science	2.11	1.63	1.84	2.14

There are considerable matters of interest in these data, particularly those areas shaded. For Item 23, the female learners appear to indicate an increased interest in science as a consequence of the experience, whereas there appears to have been a slight decline in male interest. A similar pattern is evident for Item 24. Item 26 presents a similar reversal, where females realise that science is not just for clever people. In a similar vein, this reversal continues for Item 29 where females suggest that science is not as difficult as they thought as a result of the experience, whereas the males have suggested it is difficult. Item 34 continues this trend.

Pell and Jarvis' (2002) identified strong links between attitude and practical work. They found 'strong correlation amongst pupils between a liking for independent investigation and science in a social context and positive attitudes to the subject'. These data tend to support this view.

The data from the Draw a scientist surveys were analysed against the frame used by Chambers (1983), although only significant data is shown in Table 5 below. Symbols of Research and Signs of Technology have been chosen to discuss here, as the project was research-focused and technology-mediated. Items 1 and 2 show a significant change in thinking about what a research environment looks like, where the post-Intervention results show that test tubes and flasks have less significance in the environment they interacted with. RAMP provided learner vision of the microscope laboratory via a remote control camera. Such items could not be seen when interrogated by the camera. Item 5 presents an interesting female perspective in that in both pre- and post – surveys, some learners believed that animals needed to be evident in a laboratory environment. This was in fact the case as the specimens in the microscope were Fire Ants. For some students at least, ants are viewed as animals and not just insects: a common misconception.

Item 7 (machines) shows a significant shift towards recognising that machines can be present in scientific laboratories. This is likely a consequence of the vision and conversations learners had around the electron microscope during the Intervention.

Table 5: Sample data from the Draw-a-scientist Test (DAST)

		Male			**Female**		
				Pre= 20 *Post= 15*			*Pre= 25* *Post= 24*
Item		**No Indication**	**Some Indication**	**Great Indication**	**No Indication**	**Some Indication**	**Great Indication**
Symbols of Research							
1. test tubes	Pre	7 (35%)	2 (10%)	11 (55%)	12 (48%)	0 (0%)	13 (52%)
	Post	9 (60%)	1 (6.3%)	5 (33.3%)	19 (79.1%)	0 (0%)	5 (20.8%)
2. flasks	Pre	10 (50%)	2 (10%)	8 (40%)	16 (64%)	0 (0%)	9 (36%)
	Post	8 (53.3%)	1 (6.6%)	6 (39.9%)	19 (79.1%)	0 (0%)	5 (20.8%)
3. microscope	Pre	20 (100%)	0 (0%)	0 (0%)	24 (96%)	0 (0%)	1 (4%)
	Post	11 (73.3%)	0 (0%)	4 (26.6%)	20 (80%)	0 (0%)	5 (20%)
4. bunsen burner	Pre	17 (85%)	1 (5%)	2 (10%)	24 (96%)	1 (4%)	0 (0%)
	Post	15 (100%)	0 (0%)	0 (0%)	24 (100%)	0 (0%)	0 (0%)
5. animals	Pre	20 (100%)	0 (0%)	0 (0%)	23 (92%)	0 (0%)	2 (8%)
	Post	15 (100%)	0 (0%)	0 (0%)	22 (91.6%)	0 (0%)	2 (8.3%)
Signs of Technology							
6. solutions in glass	Pre	14 (70%)	1 (5%)	5 (25%)	19 (76%)	2 (8%)	4 (16%)
	Post	13 (86.6%)	0 (0%)	2 (13.3%)	18 (75%)	0 (0%)	6 (25%)
7. machines	Pre	19 (95%)	0 (0%)	1 (5%)	23 (92%)	1 (4%)	1 (4%)
	Post	9 (60%)	0 (0%)	6 (40%)	16 (66.6%)	0 (0%)	8 (33.3%)
8. captions	Pre	20 (100%)	0 (0%)	0 (0%)	25 (100%)	0 (0%)	0 (0%)
	Post	15 (100%)	0 (0%)	0 (0%)	24 (100%)	0 (0%)	0 (0%)
9. male	Pre	10 (50%)	1 (5%)	9 (45%)	13 (52%)	1 (4%)	11 (44%)
	Post	7 (46.6%)	0 (0%)	8 (53.3%)	13 (54.1%)	0 (0%)	11 (45.8%)
10. signs/labels	Pre	14 (70%)	1 (5%)	5 (25%)	24 (96%)	0 (0%)	1 (4%)
	Post	15 (100%)	0 (0%)	0 (0%)	24 (100%)	0 (0%)	0 (0%)
11. pencils in pocket	Pre	16 (80%)	0 (0%)	4 (*20%)	23 (92%)	1 (4%)	1 (4%)
	Post	15 (100%)	0 (0%)	0 (0%)	24 (100%)	0 (0%)	0 (0%)

From these surveys and tests, it has been possible to build a view of how the Intervention has impacted on learner thinking.

Phase 2: the *Pre-Intervention* phase, was supported by a weblog (fireants.blogspot.com). This phase of the study required learners to act as co-researchers and they engaged in email conversations with the scientists and science educators. To ensure that students interacted with their research findings, they were asked to present this work as a question and answer set. Learners demonstrated in several ways that they were building an understanding and knowledge of the anatomy, form and function of their specimens. Evidence of this was found in the quality of email communication. This use of Ryan's Question Key (1992, 2005) ensures engagement with information and that students are not just copying/pasting data found from another source

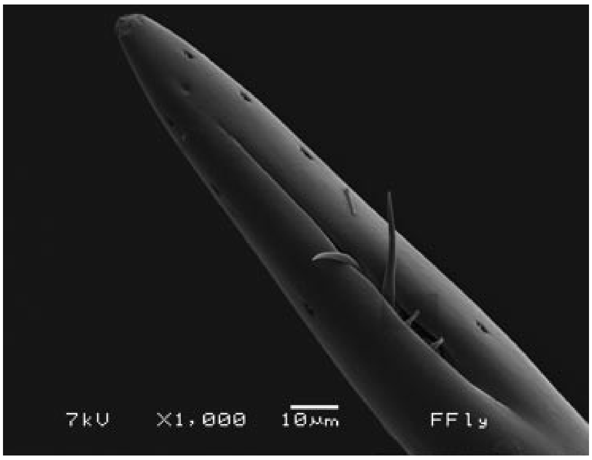
Building an understanding and knowledge of the anatomy form and function of specimens

Table 6: Question and answer set provided by Cara, Jason and Maria

Q.	Is it possible for us to have a look at the egg-laying organ located on the tip of the fruit fly's abdomen please?
A.	This organ is inserted into fruit and the eggs are then laid. Fruit fly's also have hair at the tip of this organ that allows them to taste the fruit before it lays any eggs. (See Picture 1 below)
Q.	What is the size of a red imported fire ant?
A.	They range from a quarter to half an inch.
Q.	What do the nests look like?
A.	They are dome shaped and usually don't have clear entry or exits.

Phase 3: The *Intervention* comprised an hour-long, live image based-presentation from the University of Queensland's Centre for Microscopy and Microanalysis (CMM). The email communications (Table 6 above) were used to 'script' the intervention. Question and answer sets from emails were used to develop the storyline of the Intervention, identifying the sequence and choice of specimens for the SEM chamber. Learners were amazed at the clarity and size of their specimens, over 250 kilometres away. (The teacher reported 'dropped jaw' syndrome when the first images arrived.)

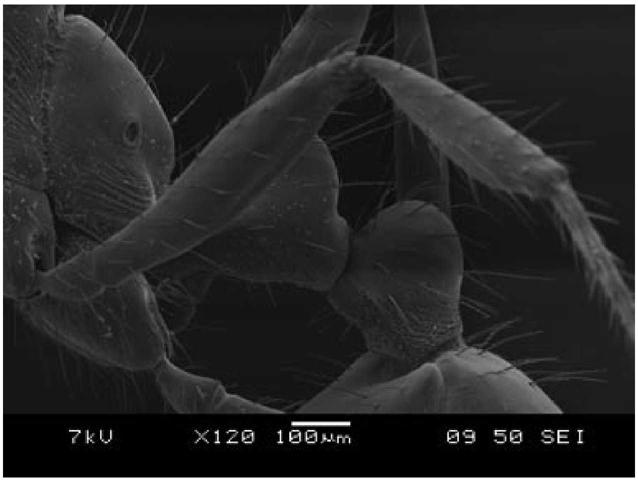
Phase 4: On completion of the Intervention, learners completed their presentations. These comprised 15 group data sets, ranging from 3D models to Power Point Presentations and from a DVD with soundtrack to a video News Report. It was rewarding to see that most groups avoided the use of Power Point as the tool of presentation.



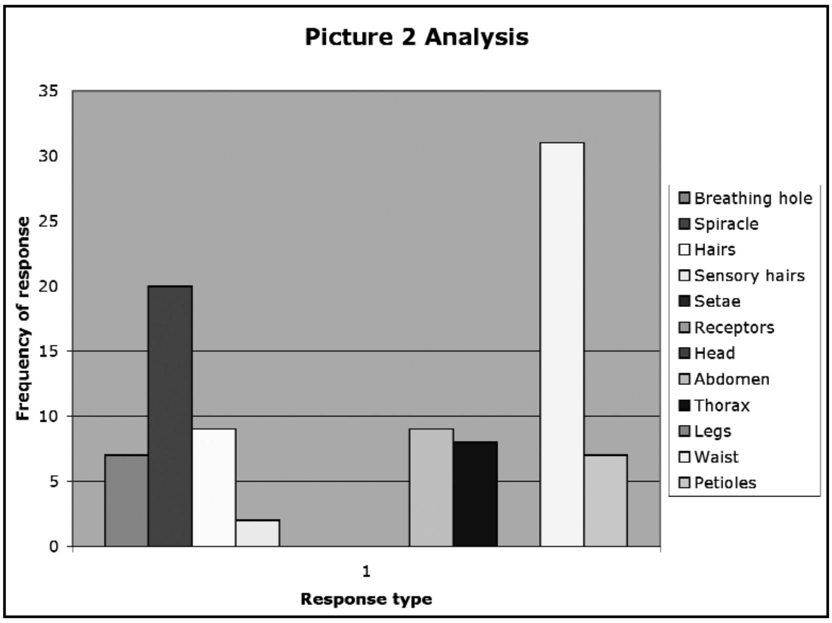
Picture 1: the ovipositor discussed in Table 6 above and viewed during the Intervention.

Pictures 2 and 3: The students (pictures 2) above created a 3D model of an ant and inside its thorax placed a selection of their research questions. Other students (picture 3) explored a film genre, producing a movie poster and DVD.

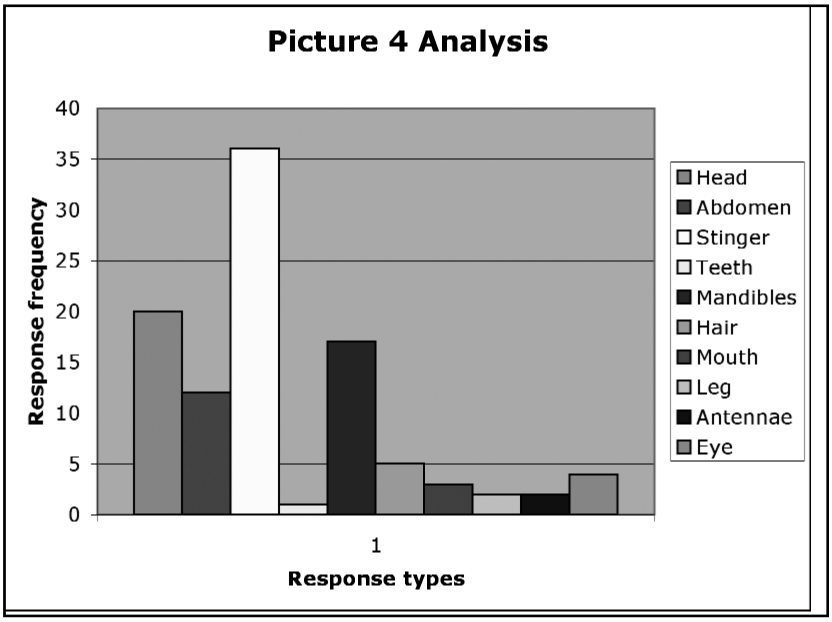
Four weeks after the Intervention and on completion of the presentation/project, learners were asked to repeat the Attitude and DAST surveys. The results of this have been discussed previously. Additionally, learners completed a Picture Quiz using selected images from the Intervention. Six images were used to represent the major anatomical features seen. Picture 6 on the next page is an image of the 'petioles' of the fire ant, used during the Picture Quiz. The fire-ant is unique in that it has two petioles (pre- and post-), making identification easier. This was discussed with learners during the Intervention. At the same time, a 'spiracle' can be seen together with leg segments and joints, setae and sections of the abdomen and thorax.



Picture 6: The petioles of the fire ant



In analysing learner responses describing what they could see, it is evident that 'spiracle' and 'waist' were dominant recalled features. Learners often used both scientific and generic terminology in the same sentence/conversation. Picture 4 analysis below show similar patterns of use.



In addition to completing the Picture Quiz, some students participated in a semi-structured interview. Two interesting stories are reported here.

Firstly, a group of female learners wanted to share their display with me rather than participate in an interview. This flexibility provided considerably richer information than the intended plan of a semi-structured interview. Lucille, Cara and Sonya decided that we should test their ant food and poison. Their research had determined that household ants are exterminated by blocking the 'spiracle' [sic] with fine powder. They reasoned that if this were the case, it would be possible to 'drown' them also. Their investigation developed a mixture of sweet things to attract ants and added this mixture to a solution of gelatine. The sweetness would attract them and the gelatine would drown them by blocking the spiracle. Now that's science.

Lastly, I relate a story from a group of 'underachieving' males [their teacher's comments, not mine]. These students asked to see other samples under the microscope. Why? To see if other insects and animals had similar features – comparative anatomy, a purpose of this study and indicative of the cognitive engagement sought.

The Research Questions and what this means

This study sought to inform the questions below.

Research Question 1: Which pedagogies are promoted by innovations like RAMP (i.e. pedagogies that promote higher order thinking and understanding for learners)?

Research Question 2: In what ways can ICTs be used to enhance learner inquiry?

Learners were engaged in a media-rich environment across a distributed network (Table 7: ICT used). This network connected learners to information sources (Internet and email), to external sources of expertise (scientists and science educators) and to the instrumentation used by scientists (scanning electron microscope). They demonstrated through their email communication that they were engaging at a higher level with the information they had researched, and in doing so, connected to remote expertise. The artefacts produced (presentations) crossed a range of genres and further demonstrated that the engagement with information and experts had been more than superficial. They had worked both at school and at home in their groups to complete these tasks (collaboration and cooperation).

Table 7: ICT and pedagogical approaches used in the RAMP model

RAMP phase	ICT used	RAMP pedagogical approach
Research	Email	Communication with experts
	Internet	Group research on topic of interest
	Internet and Video streaming	Synchronous delivery of imaging
	Teleconferencing	Communication between learners and scientists
Intervention	Scanning electron microscope	Instrumentation of the scientists
Presentation	Power Point	Each of these items are used to present
	Video camera	and share information from the research
	Digital camera	and Intervention: many genres were used

The learners who produced a video recording in a news report genre, spoke with confidence and knowledge of their work, while others made presentations and had searching questions to pursue further, for example, do other insects have similar features? After the Intervention, learners showed confidence in using both the generic and technical language of science: all indicated a desire to participate in future sessions, offering examples of what the subjects to be studied might be. Learners were keen to 'know more' and have 'more time to ask questions'. This points towards learners working in an environment illustrative of what contemporary classrooms and pedagogies should look like. Table 8 describes how RAMP has actioned both the call for reform in science education and the use of 'new' pedagogies in an ICT-mediated environment.

RAMP enabled an exploration of how developing technologies might be harnessed to make science more interesting for learners. It identified pedagogical practices that are suited to an ICT-mediated environment, accepting that these apply equally to other learning situations. RAMP has further demonstrated the benefits of showing learners 'how science works': the collaborations between people, information and places described by Atkins (1993).

Acknowledgments: *Thank you to those wonderful students and teachers who worked with me to collect the information reported here. You inspired me to complete this, with your enthusiasm and passion. In the latter phases of this study new video streaming technology was used. Thank you to Momentum Technology Group (www.momentumgroup.com.au) and Telstra for their support in making this technology available to me: m-View Broadcast server and NextG wireless broadband.*

Table 8: The RAMP pedagogical practices

1. Cooperative and collaborative practices were encouraged
2. The teacher role was that of both co-researcher and facilitator
3. The learner role was that of collaborator and co-researcher/expert
4. The expert role (scientist) was that of listener, co-researcher and collaborator
5. The instructional emphasis was on knowledge generation in an inquiry based environment
6. The conceptual emphasis was on the manipulation of facts: cognitive engagement
7. The demonstration of success was built around the presentation of new knowledge
8. Technology use was built around practices that required the use of new pedagogies: communication, collaboration, information access and expression

BIOGRAPHY

JOHN HUNT *is a primary teacher in Queensland, researching remote communication technologies at the University of the Sunshine Coast. He has held the position of principal, deputy head teacher, Head of Department (Science) and university lecturer at institutions in Queensland, the UK and Saudi Arabia. John is a trained operator of a scanning electron microscope and considers this work a 'hobby'. His workshops have been broadcast for the last four years across Queensland, to York University (UK), and international schools in Irian Jaya. Wireless broadband and low bandwidth streaming video technology has now given him the flexibility to conduct workshops 'in the field': flexible learning and flexible delivery. John can be contacted by email at jhunt102@eq.edu.au.*

REFERENCES

Atkins, D.E. (1993). *Overview of the Upper Atmospheric Research Collaboratory.* Paper presented at the Upper Atmospheric Research Collaboratory Workshop, Menlo Park, CA.

Brooks, J.G. & Brooks, M. G. (1999). *In Search of Understanding: The Case for Constructivist Classrooms,* Revised Edition. Association for Supervision and Curriculum Development. Alexandria: VA.

Chambers, D.W. (1983) Stereotypic images of the scientists: the draw-a-scientist test. *Science Education.* 67 (2): 255-265.

di Sessa, A.(2000). *Changing minds: Computers, learning and literacy.* Cambridge Mass: Massachusetts Institute of Technology

Education Queensland (2003). *Science state: smart state.* Publisher

Education Queensland (2005), *ICTs for learning: science and ICTs.* The State of Queensland (Department of Education and the Arts), Brisbane.

Fensham, P. (2004). *Science in the smart state.* An unpublished paper from the Bundaberg district science forum (August 15 2004), Central Queensland University.

Goodrum, D., Hackling, M., & Rennie, L. (2001). *The status and quality of teaching and learning of science in Australian schools.* Canberra: DEST.

Hunt, J. & Harrison, A. (2004). *ICT-mediated science inquiry: a pilot study*. Rockhampton: QLD.

Lederman, N.G., & Niess, M.L. (1997). The nature of science: Naturally? *School Science and Mathematics,* 97(1), 1-2.

Linn, M.C. (2004). Chapter 1.1 Using ICT to teach and learn science. In Holliman, R. & Scanlon, E. (Eds). *Mediating science learning through information and communications technology*. (pp.9-26). London: Routledge Falmer.

Osborne, R. & Freyberg, P. (1985). Learning in science: the implications of children's science, Heinemann, London.

Osborne, J. & Hennessy, S. (2003). Report 6 - Literature review in science education and the role of ICT: promise, problems and future directions. NESTA Futurelab: Bristol.

Pell, T. & Jarvis T. (2001). Developing attitude to science scales for use with children of ages from five to eleven years, *International Journal of Science Education,* 33(8), pp 847-862.

Ryan, T. (1991), *Thinking keys,* (out of print) available online at: <http://www.headfirst.com.au/freebooks.htm>

Soloway, E. (1994). 'Ways of Seeing'. *Communications of the Association for Computer Machinery,* 37, 15-20.

Thomas L.G. & Knezek, D.G. (2002). Standards for technology-supported learning environments. *The State Education Standard.* National Association of State Boards of Education. Alexandria, VA.

Tobin, K. (1991). *Constructivist perspectives on research in science education,* paper presented at the annual meeting of National Association for Research in Science Teaching (NARST), Lake Geneva, Wisconsin.

UNESCO (n.d.). *New Pedagogy: ICT in Primary and Secondary Education.* Online at <http://www.unescobkk.org/index.php?id=1571>

Yager, R. E. (1991). The constructivist learning model: towards real reform in science education. *The Science Teacher.* (reprinted 2003). National Science Teachers Association (NSTA). Washington: DC.