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A Curriculum Innovation Framework for Science, Technology and Mathematics Education

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Abstract There is growing concern about falling levels of student engagement with school science, as evidenced by studies of student attitudes, and decreasing participation at the post compulsory level. One major response to this, the Australian School Innovation in Science, Technology and Mathematics (ASISTM) initiative, involves partnerships between schools and community and industry organisations in developing curriculum projects at the local level. This project fulfils many of the conditions advocated to engage students in learning in the sciences. ASISTM is underpinned by the notion of innovation. This paper describes the findings of case study research in which 16 ASISTM projects were selected as innovation exemplars. A definition of innovation and an innovation framework were developed, through which the case studies were analysed to make sense of the significance of the ideas and practices, participating actors, and outcomes of the projects. Through this analysis we argue that innovation is a powerful idea for framing curriculum development in the sciences at the local level that is generative for students and teachers, and that these ASISTM projects provide valuable models for engaging students, and for teacher professional learning.

Keywords Innovation · School-community links · Science education · Mathematics education · Technology education · Teacher professional learning

Introduction

There is abundant evidence that many students in Australia and other developed countries are becoming increasingly disengaged with school science. To a large extent they find school science irrelevant to their interests and concerns, the pedagogies authoritarian, and the content unrelated to contexts they would recognise as significant (Lindahl 2007; Lyons 2005, 2006; Osborne and Collins 2001). There is also evidence that traditional science teaching does not capture the nature of contemporary science practice, being overly focused on the development of canonical abstract ideas and not paying sufficient attention to the multi disciplinary nature of contemporary science, the ethical and social and personal settings of science, or the human aspects of scientists' work and passions (Tytler and Symington 2006; Tytler 2007). Tytler (2007) argues that the problem with student lack of

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engagement with school science relates to a failure of the content and practice of school science to reflect significant changes in contemporary society, in students' perspectives, and in the nature of science itself, and the lack of representation of contemporary science practices in the school curriculum.

There is a growing awareness in many places of the significance of this problem, although there is considerable diversity in the reasons for this concern. Some governments and professional associations (Engineering Working Group 2008; European Commission 2004; COSEPUP 2005) are primarily concerned about the future supply of scientists. Others (Goodrum et al. 2001) emphasise the responsibility to make science relevant for all students through a focus on scientific literacy. The driving notion of scientific literacy, that underpins much contemporary thinking about the purposes of science education, focuses attention on the use of science ideas by the public. Laugksch (2000) points out the diversity of the public and the lives of individuals, and argues that 'the notion of an absolute definition of scientific literacy is an impractical idea. For all intents and purposes, scientific literacy depends on the context in which it is intended to operate' (p.84).

This is a complex issue and there are many views on what are the understandings and skills that will enable a diverse citizenry to operate effectively in a science and technology based world, and on how to achieve these in ways which capture the interest of students. Research on the science knowledge needs of the public includes studies such as those of Duggan and Gott (2002) who investigated the science required by employees in a number of science based industries and by people in everyday life, and Tytler et al. (2001a, b) who investigated the science needed by the public to understand and pursue an environmental dispute. Emerging from such studies is the necessity for students to understand the way contemporary science operates and to develop the ability to analyse science based issues as they confront these in their lives. This includes developing an understanding of the way evidence is gathered and used in science, and its limitations. Thus, school science needs to expose students to a diversity of settings and practices of science.

A second challenge concerns how to enlist students' engagement with science ideas. A common response is to propose and introduce a curriculum reform that represents a more student centred, inquiry based pedagogy, and sets the science being learned in contexts that students see as meaningful. In Australia, examples of this approach can be found in two national programs, Primary Connections, and STELR, managed by the Australian Academy of Science (2005) and the Australian Academy of Technological Sciences and Engineering (2008). These initiatives involve non-traditional pedagogies and are supported by teacher professional development programs.

A recent Australian Government initiative is an attempt to address these concerns in a quite different way. It has offered clusters of schools resources to undertake innovative projects aimed at improving the quality of learning of science, technology or mathematics within a set of defined conditions. Through the Australian School Innovation in Science, Technology and Mathematics (ASISTM) program the Australian Government has funded over 350 projects involving partnerships between schools and outside agencies such as industries, government departments, community associations, and universities. ASISTM is significant in that it represents an attempt to open up classrooms and support teachers by introducing 'teacher associates' from universities and community, industrial and scientific organizations to engage teachers and students with contemporary practice and knowledge in these areas.

A major feature of the ASISTM initiative, which contrasts with many existing programs aimed at linking schools with science in the community, is that projects are locally conceived, planned and implemented—an example of devolution of curriculum innovation with accompanying accountability processes that has a strong recent history as a model of school system management. The ASISTM initiative is also of significance in that the project leaders define the players and their roles in each project. This enables a range of perspectives to be recognised in the planning and implementation of science programs for school students. This is a quite rare event, but is congruent with arguments that have been mounted for a greater range of voices to be heard in determining the purposes and focus of school science (Fensham 2002; Symington and Tytler 2004; Tytler and Symington 2006; Tytler 2007). ASISTM allows these voices to shape initiatives at a local level.

Innovation in Education

The cornerstone of the ASISTM program is the promotion of innovation, and in particular the propagation of an ongoing 'culture of innovation' in Australian schools, as the means to bring lasting improvements to science, technology and mathematics teaching and learning. Clarifying what innovation means is crucial to any study that wishes to investigate the propagation of a culture of innovation within schools. How, for example, can schools (or indeed researchers) differentiate innovation from other forms of change phenomena? What are they to evaluate? And without a sound conceptual understanding of innovation, how can schools which are trying to respond imaginatively to 'problems and challenges' be supported, either with appropriate resources, recognition or enabling policy settings?

Researchers (Cuttance and Stokes 2001; Hargreaves 1999) have linked innovation in schools with the need for students and teachers to develop more flexible and generative approaches to learning as a response to an increasingly diverse society which values knowledge generation over reproduction. The ASISTM project, as part of the Australian Government's Boosting Innovation, Science, Technology and Mathematics Teaching (BISTMT) Program defines 'innovation in schools' as

> the practical application of an idea or ideas, new for schools involved in the project, to improve educational experiences and, hence, the learning outcomes of students. (BISTMT Programme Guidelines: DEST 2005, p.6).

This definition of innovation is in line with current Government guidelines on how we should be thinking about innovation (i.e., "Innovation is about ideas, and the transformation of those ideas into value creating outcomes", National Innovation Council). While this is a useful place to start thinking about innovation in schools, it is silent on the other features that literally define innovation. For example, is innovation always and only aimed at improvement? Is the question of where the ideas come from important in understanding what innovation is? And, how are schools to differentiate innovation from other types of 'practical applications of new ideas'?

David Hargreaves (1999) convincingly argues for the importance of linking what 'innovation in education' is with where 'innovative' ideas originate. For Hargreaves, innovation is largely a process that begins with a certain type of thinking by local practitioners, in order to respond more effectively to the demands of their changing circumstances.

> For innovation is mostly 'bottom-up' and small-scale, it is what the imaginative and responsive school does when it encounters problems and challenges or when it thinks out a different and potentially better way of doing something that has become staled by custom or tradition. (Hargreaves 1999: 54)

Drawing on a range of different ways to conceptualise innovation (Angus et al. 2001; Cuttance and Stokes 2001; Hargreaves 1999; Latour 1996; Rogers 2003), and tested and refined through the course of field-based research with Victorian government schools (Smith et al. 2004; Smith 2005), we propose schools should think of innovation as:

> Innovation is the process of assembling and maintaining a novel alignment of ideas, practices and actors to respond to site specific issues and/or to pursue a vision. (Based on Smith 2005)

To expand on this definition of innovation; it incorporates four key features:

1. Innovation is a process of assembling and re-assembling. It is neither an invention nor an object per se, even if later it acquires an 'object-like' status.
2. Innovation involves a process of assembling and maintaining that is both dynamic and iterative. Throughout the life of an innovation, ideas are tested and refined, new actors are enrolled into a network of relationships.
3. Innovation is relative. The 'novel alignment of ideas, practices and actors' is novel only to a specific site (location, context and time) i.e., what is innovative at one school or school cluster is not necessarily innovative at another.
4. Innovation is purposeful. It is a response to a site-specific need and/or opportunity to make an improvement in some aspect of educational provision.

The significance of innovation in education, tested in the current research, is that it is a particular type of change process that knots together the production of new knowledge, creative solutions, new alliances and engagements into a multifaceted relationship—literally an interlocking 'network' of innovation.

The Research Questions

This paper explores 16 exemplars of innovative ASISTM projects. Through the interrogation of these projects we hoped to gain insight both into the projects' key characteristics and the factors that framed their success, and also how one might better understand the nature of innovation in an educational setting. We will use the data collected from multiple participants in the exemplar ASISTM projects to answer the following research questions:

1. To what extent is the definition of innovation developed above useful for supporting an analysis of the nature and effectiveness of exemplar ASISTM projects?
2. To what extent do these locally developed and implemented projects lead to worthwhile outcomes, and what are the factors that lead to successful outcomes?
3. To what extent do these projects represent a productive and coherent direction for curriculum innovation in science, technology and mathematics education?

Research Methods

We selected 16 sites from a cohort of 74 ASISTM projects, collated by the Curriculum Corporation (which managed the ASISTM initiative) and the relevant government department (DEST). These projects were suggested as suitable on the grounds that they were either completed or well advanced, and seemed to be on track to fulfilling their aims. From the 74 projects, we short listed sites of interest based on criteria that included a proportionate spread of sites from across the States and Territories, from Government and non-Government schools, and from metropolitan and regional or rural locations. In addition, we also looked to include a spread of characteristics of innovation such as disciplinary focus, variety of partner types, projects focused on indigenous issues, and a spread of locality type.

From our matrix, we initially identified 30 projects of possible interest. All 30 projects were contacted, with the research team conducting telephone interviews with the Project Coordinators and Critical Friends, plus reviewing the projects' interim and final term reports to DEST. Where available, the research team also looked at any additional material the site had produced (websites for example). From the 30 we chose 16 projects that best met our criteria of exemplary innovative projects, with a representative spread across the characteristics as described above. We could have included many of the remaining 14 projects in our list, as meeting our criteria (i.e. well advanced, seemingly successful in meeting targets, willing to participate, and broadly innovative).

In the paper we have used the real names of the projects and participants, having secured permission. Some of these projects have websites that can be accessed for further detail. They are intended to be 'innovation exemplars', and the study aimed to unpack the nature of this form of innovation and its potential as an educative process for schools. By charting the processes by which these exemplars anticipated or resolved challenges we can learn a lot about conceiving and managing innovation in school science, technology and mathematics.

Data Collection and Analysis

Alongside the initial interviews with project coordinators and critical friends, the team collected data from each site's initial ASISTM application, their milestone reports, face-to-face interviews with other key personnel (teachers, outside partners, students where applicable), and other relevant documentation that the site had produced. Where possible interviews were digitally recorded, otherwise the interviewer took notes. We focused our interviews on questions concerning: the context within which the innovation arose; the nature of the innovation in terms of the ideas being promoted, the practices being engaged with, the partners recruited and the resources involved; and the outcomes of the innovation.

Based on the understandings of innovation in education, described above, the research team developed an Innovation Framework based initially on previous experience with innovation projects. The nascent framework was used to build the interview protocol and then iteratively developed to underpin the analysis, first to frame the writing of project case studies (see Tytler et al. 2008), and second to identify major themes coming from these. The framework includes five basic dimensions:

1. The issues / vision underpinning the innovation
2. The ideas being explored/promoted
3. The practices being pursued
4. The actors recruited to the project
5. The outcomes of the innovation

Table 1 provides a more detailed presentation of the framework, demonstrating the way these dimensions were used to develop the questions explored in the interviews and then used to frame the analysis, and also the types of themes and examples that emerged under each dimension. During the interviews, detailed notes were taken from which case study descriptions were constructed (these are available in the full report by Tytler et al. 2008) which also included selected transcriptions to support key points made by the interviewees. Each research team member was responsible for constructing the case descriptions they had investigated, but each was looked over by other team members to ensure comparability and that each dimension of the framework was adequately represented. Two team members

Table 1 The innovation framework

Major dimension	Questions framing the interviews and analysis	Emerging themes and examples
The issues / vision underpinning the innovation	What are the concerns underpinning these projects, and what do they have in common?	Perceived problems relating to student engagement with learning, and the limitations of school practices
	Is there a common thread in the vision expressed by these projects?	Common views about productive approaches to interest and engage students
The ideas being explored/promoted	What is the scope of the ideas being pursued?	Change in the purposes of school science
	How commensurable and/or effective are these ideas in helping the site achieve the innovation's aims?	Change in teaching and learning— • Teachers' practice • Changes to students' experiences • Changes to course content
	What is the educational significance of the ideas?	Different exposure of students to the nature of the discipline and its practices
The practices being pursued	How is the innovation operationalised?	Science/technology disciplinary practices
	What are the key elements—new scientific and technological practices, changed teaching and learning practices, changed relations between participants, a developed management structure?	Teaching and/or learning practices that are commensurable with the new ideas/actors being tried/recruited
		Development of management structures capable of supporting the innovation
		Communication across the participants (e.g., website, meetings)
The actors recruited in support of the project	What is the range of teacher associates and significant partners in the innovation? Are they actively involved? Do they have a natural interest in the innovation? What resources are important to the innovation?	Partners such as teachers, school clusters, organisations, non-school personnel
		Resources such as local or global installations, resource centres, or features of local sites.
Outcomes	What are the patterns of outcomes for the various players and how do these interrelate?	Intended and actual outcomes for: • students • teachers • non-school partners • community

independently read the case study descriptions to identify major themes, and these were refined through a process of discussion and iterative checking of the data until the major themes were agreed. These are presented in the findings section.

The aim of the analysis was to identify the major themes that arise from the case studies, particularly in relation to the concept of innovation, and to come to a broader understanding of the significance of these in educational terms. Specifically, the analysis was concerned to provide insights into the nature of innovation, its potential role in supporting broad educational change, and the way in which innovation can be encouraged and sustained at a system level. The innovation framework represented in Table 1 has been central to this research. We see it as being potentially valuable not only as a research tool but also as a framework for planning, implementing and evaluating innovations, and for helping create policy to support the development of a culture of innovation in schools.

Findings

The nature of the ASISTM program with its focus on local innovation poses problems for the preparation of this paper in that the projects were extremely varied and it is not possible to provide in the available space a detailed description of all of the projects. We have included brief overviews of selected projects in the paper to give a sense of the nature of what was achieved and to illustrate the points made in the analysis. Detail on all of the projects analysed can be found in the full research report (Tytler et al. 2008). In this section we describe the themes that emerged from the case studies, under the dimensions of the Innovation Framework, with a particular focus on the educational significance of the ASISTM initiative.

The Issues and Visions Underpinning These Projects

While the individual projects vary considerably in the details of their focus, the partnerships set up, and the specific science, technology and mathematics ideas pursued, a common issue and a common vision underpins all of the projects. The issue is the engagement of students with school science, technology or mathematics; the vision is to capture the interest of students in these subjects. There were certain features of the projects that were common. The pursuit of this vision of engagement commonly involved students actively engaged with exploring, often out of the classroom, designing and /or investigating, communicating with practising scientists and technologists, and linking their work with wider purposes and practices for science, technology or mathematics. A number of interviewees explicitly articulated this opening up of classrooms. For Glenn in the Serendip project, (see Box 1) the traditional school was a bubble, an artificial world in which teachers and students lived, separate from the 'real' world. Educators involved in this project wanted to burst the bubble, to open schools and communities up to each other.

Box 1

> *BioTech Units at Serendip Sanctuary*: The BioTech project in this Geelong satellite area was devised in response to a felt need to strengthen the community engagement of youth in the local schools. The cluster of schools agreed to develop a four year plan with sustainability as the theme whilst allowing diversity amongst the schools in their curriculum development within this agreed theme. Meg, the coordinator, managed a complex web of initiatives involving visiting scientists and other community members, environmental projects, excursion programs and project based learning initiatives. In the secondary school *Connections* is a one day a week program focused on connecting students with themselves, the community and the environment. In the primary schools the theme of sustainability is reflected in a range of activities involving local science-based services. The projects led to public outcomes such as a reclaimed piece of river, or reduced water use at the school.

The extent to which this vision of connections outside the classroom involved linking students directly with teacher associates varied according to the details of the project aims. Some projects had a strong sense that students needed to be connected to real practitioners.

> Just being around scientists, doing scientist stuff, it's really important… Spend some time with a park ranger—kids love them. (Glenn, Serendip project)

In these projects, overwhelmingly the vision of student interest and engagement was linked to exposing students to contemporary real world practice. For many, this implied access to expert practitioners of science, technology and mathematics.

The Nature of the Innovation

This section will present the themes identified under the 'nature of the innovation' aspect of the Framework, including new ideas and practices, actors, and the 'novel alignment' of these.

The Ideas Pursued in the Innovation

The ideas pursued in the case studies are incredibly varied and highly contextual. The knowledge and skills represented in the 16 projects include astronomy knowledge and the use of simulation software and telescopes, fish trapping and identification and monitoring, exploration of science careers in the local area, renewable energy design, 3D design and application, studies of endangered animals in urban settings, indigenous plants, and sustainability studies. Further, the knowledge pursued varied considerably not only in content but also in the way it was delivered and the purposes for which it was developed. A strong strand running through these projects is that of knowledge pursued for purposes intrinsic to local needs. Thus, at Kangaroo Island (see Box 2) the study of fish and the collection of data related directly to the need to develop a database and understanding of the local environment. In Science in the Aqua Zone (see also Box 2) students studied the indigenous plants and hence came to a better understanding of the lives of earlier users of the land. The focus for these projects, taken overall, is less on formal, structured knowledge, and much more on knowledge 'in action' and 'in context'. This is not to say that formal knowledge is not important in these projects, but the projects offer a challenge to the manner and context in which it is developed, and also a challenge to the narrow conception of knowledge that is the traditional focus of many past curricula in these subjects.

Box 2

Marine and Environmental Education: The Kangaroo Island marine and environmental education project is a complex project involving three schools and a number of initiatives built around the marine and aquatic waterways of the island. The key aspects of the innovation are the use of scientists to work with teachers and students in monitoring fish and other animal populations and environmental conditions, to build up a substantial data base of scientific interest, the involvement of the community in these projects, and the interlocking and expanding funding base that has seen these grow to include a number of marine environment research and intervention projects.

Leading Edge Marine and Environmental Science Development (Science in the Aqua Zone): In this project, 34 teachers in 16 schools, numerous scientists and educators from Flinders University, the Australian Science and Mathematics School (ASMS), and local industry involved in ecotourism, were linked in three clusters across South Australia. The project used the local environment and resources to engage students with relevant science and mathematics. While the schools in the clusters worked collegially they also acted independently to address local issues and opportunities. The clusters focussed respectively on Marine Science and Aquaculture, Marine Ecology and Ecotourism, and Bio-remediation. While the schools were individually responsible for various components, the project leadership facilitated these schools working as a cooperative in both teacher professional development and resource development. Each cluster had a project manager, an action research facilitator, and teacher associates. The schools within each cluster used an action research model of teacher professional learning to support the development of curriculum resources.

A point often made about engaging students in science is the need to situate content in contexts that are relevant to students' lives and interests. This is often interpreted as building on students' hobbies and everyday worlds, for instance by studying force and motion using sports examples such as skateboarding, or amusement park rides. It is interesting that engagement of students in these projects did not go down this path, but rather built engagement and interest through interaction with contemporary settings, and with authentic practices and practitioners who were both expert and enthusiastic in representing the subject's ideas and practices. What worked for the students in these projects was involvement in genuine and contemporary ideas and practices, in a local setting.

The ideas driving these projects were locally determined, dependent on the local context and the enthusiasms of the teachers and/or teacher associates. Thus, we can argue, through these case studies, that a central aspect of student engagement in the sciences is the situating of ideas and practices in local and authentic settings. This poses a challenge for system wide curriculum policy as will be discussed later in the paper.

Another characteristic of a number of these projects concerns the use to which the knowledge is put. In a number of these projects knowledge is linked strongly to community or related purposes. For instance:

- The Serendip Sanctuary project involved regeneration of the local environment; and
- The Kangaroo Island project was aimed at producing scientifically valid knowledge and the construction of a data base.

A number of the projects focused explicitly on students' knowledge of the way science, technology and mathematics are practised in the local community. The following quote taken from the Kids' Design Challenge case study (see Box 3) makes the point.

> The process that they go through is real…. …the Council actually accepted the kids' plans, modified them slightly and began work on redesigning the median strips that they had picked as their area. …Real purposeful learning (is) going on. There is a purpose to doing it. Not that tasks in class have no purpose, they do, but when other people are coming in as well, giving them input with the architects that visit and the engineers that visit, they see that it is real world.

Thus, engagement with science or technology not only involved applying established content knowledge to authentic local settings, but included the production of knowledge for use in these settings.

Box 3

The Kids' Design Challenge (KDC) project was about more outward looking conceptions of science education, in effect seeing science as a living activity rather than a sharing of historical information. The central activity of the project was combined planning of science and technology units with a particular focus on two design challenges involving, respectively, go-karts and the local environment. The children in the participating primary schools undertook these challenges with the assistance of professionals in the field – engineers and architects. The project built on an existing network, where a group of teachers were actively promoting hands-on science activity. The ASISTM funding provided the means to develop this activity. Teachers from various schools met at the planning meetings and developed resource materials that enabled them to return to their schools to deploy the two challenges.

The Practices Represented in the Innovations

These projects involved a range of practices, determined again by local contexts including the existence of enthusiasts and experts. The practices are of two types:

- practices in science, technology and mathematics that form the content focus for activities; and
- pedagogical practices and wider school and cluster practices associated with the innovation.

In the first type, students were often exposed to cutting edge contemporary practices. Thus, at Kangaroo Island some students achieved considerable expertise at trapping and tagging fish, and predicting their distribution. In the Wildflowers in the Sky project (see Box 4) the project coordinator Rob Hollow told of indigenous students who took pride in achieving competence and exercising responsibility for setting up and aligning the telescope. In the Waste Busters and Wind Gusters project (see Box 4) primary school students became most adept at not only producing efficient blades for their model wind turbines, but also in applying a scientific methodology to explore and verify competing claims i.e., the 'why' of one design being more efficient than another.

Box 4

Wildflowers in the sky: In this project, scientists and educators from the CSIRO Australia Telescope, inspired by Australia's bid for a major international radio astronomy facility, worked to link remote schools in mid-Western Australia with the astronomy research community to support the teaching and learning of astronomy.

Waste Busters and Wind Gusters: *Reality Science in Schools:* This project, involving a cluster of very small rural schools, capitalised on local science based developments through the proposal for a wind farm and the existence of a bio-reactor. Using the big ideas behind these, the Collector cluster decided to design and implement a series of integrated studies (which still sat within the curriculum framework), to investigate with their students the science behind biodegradable waste and the harnessing of wind-generated power. The project supported teacher professional development both in the science and in the use of IT knowledge in pedagogically effective ways.

In the second type, a number of these projects involved a focus on pedagogies that offer more agency to students, provide more meaningful contexts that encourage student engagement, and change the relationship between teacher and learner through engagement in a shared task. Thus, for the fish-monitoring program at Kangaroo Island some older students became expert at trapping and tagging, and helped other students and teachers.

This presumption of more student centred pedagogies was in some cases a challenge to teachers, sometimes affecting their involvement in the innovation. In other cases it led to significant change and professional satisfaction. For example teachers interviewed with the Gladstone Learning and Assessment Tasks project (see Box 5) spoke about how their involvement in the project had led to a more 'hands-off' approach by teaching staff and a deeper sense of confidence to teach 'real' science well.

Box 5

The Gladstone based *Designing quality project based learning and assessment tasks* was an opportunity for a group of local educators to bring together under the one banner a number of recent state government initiatives such as the Queensland Curriculum, Assessment and Reporting (QCAR) Framework, previous relationships with industry groups and teacher initiated activities, such as the Teacher Generated Tasks. Involving over 900 students in Years 4, 6 and 9 from 12 schools, the project focused on exploring innovative approaches to the teaching of science, mathematics and technology through 'project-based learning tasks'. These tasks were developed primarily by teachers, in partnership with industry mentors, and would over time form the basis of a bank of 'authentic tasks', which align with the assessment, standards and descriptors of the Queensland mathematics, science and technology curricula. Other key actors who supported the development and implementation of these new tasks included university mentors, and critically, the Assessment and New Basics Branch of Education Queensland.

Taken as a set, these projects involved a number of pedagogical practices that differ from much traditional classroom practice, at least in science and mathematics:

- Project based or problem based learning;
- A strong skills focus involving scientific and related processes;
- More open pedagogies where students are given increased agency;
- The creation of knowledge by students rather than simply knowledge absorption;
- A wider set of knowledges including knowledge of processes, interdisciplinary links, knowledge about the contemporary and local use of STM, and knowledge of people using STM in employment;
- Significant learning experiences for teachers involved;
- A 'real' audience for students' work;
- Field trips and projects in the local environment;
- Working with scientists and with local community members; and
- Involvement of parents and the wider school community.

The practices described above were in almost all cases as significant for teachers as they were for students, if not more so. For many teachers in these projects, the interaction with scientists and technologists and other community personnel led to a steep but satisfying learning curve. Many teachers talked of renewed confidence and interest in their teaching, as a result of the experience. This was true of their experience with contemporary practices in their discipline, and the development of expertise (e.g., in fish monitoring, or night viewing with a telescope, or in measuring the velocity of billycarts) and also of their experience of new pedagogies. "I was a teacher who hated science. This project got me and I discovered how much the kids love science." These pedagogical practices, and the widened set of purposes described in the section on the ideas underpinning these innovations, are consistent with the scientific literacy aims that underpin contemporary thinking in science curriculum development in Australia and elsewhere (Goodrum et al. 2001; Rennie 2006; Tytler 2007). A curriculum focused on scientific literacy gives precedence to working and thinking scientifically, student autonomy and interest, and the capacity to engage with science in contemporary social and personal settings.

The Actors Recruited in Support of the Project

One requirement of the ASISTM program was for projects to form clusters comprising schools, industry partners, experts and so on. Hence it is unsurprising to find these types of human ‘actors’ present in one form or another in every case. These include:

- Teachers, students, school-based leadership and management groups (Principals);
- State-based officials from the respective Departments of Education;
- Local community members (e.g., Parents, local science professionals);
- Personnel from industry-based organisations (e.g., the Perth SciTech centre, the Royal Automobile Club of Victoria);
- Personnel from knowledge-based organisations (Universities, CSIRO); and
- Critical Friends.

Non human actors also actively shaped and enabled the project. For example:

- Installations such as the Square Kilometre Array, a major radio astronomy infrastructure bid, or the Remotely controlled Telescope at Charles Sturt University;
- The concentration of industrial plants and industries in Gladstone;
- Technologies such as a 3D printer in the Collaborative Interaction Design project; and
- Particular environmental conditions such as the native fish populations in Kangaroo Island, the clear skies in Western Australia that encouraged a suite of astronomy projects, or the indigenous plants on the Eyre Peninsula.

The actors represented in these projects were extremely varied, but what perhaps is of more interest than simply who was involved, is the question of how they were involved and the variation between roles, and how this affected the path of the project. The recruitment of a variety of actors enabled complex projects with a wide set of outcomes. For instance, the Designing the Teaching of Design and Technology (see Box 6) which was university-based, brought to schools high levels of expertise and ‘real world’ industry links.

Box 6

Designing the Teaching of Design and Technology: Year 11 and 12 design students at four public schools in Canberra were given an open-ended design brief by the School of Design and Architecture at the University of Canberra: If gravity did not exist but all the other dimensions of life were exactly the same, how would designers respond? And whilst the task set was interesting of-itself, what was exemplary, from an innovations perspective, was that this design task was as much about the processes involved in good design ‘in the real world’ as the final product.

A number of these projects achieved remarkable outcomes through the recruitment of powerful actors. For example, the Western Australian Department of Science, Technology and Information was committed to developing astronomy education in Western Australia and so was involved in the two astronomy projects studied. CSIRO has the resources and commitment to support the continuation in some form of the projects it has been involved with. At Kangaroo Island Tony Bartram had organised a complex web of partnerships with the local council, the University of South Australia, other academics, school clusters, and local fishermen and tour operators. The Gladstone project was advantaged by the close involvement of locally-based senior education departmental officers, representatives from the light-metal industries and Central Queensland University.

If the engagement of students involves exposure to contemporary ideas and applications, in local contexts, then this poses a serious challenge to teacher professional learning. How does a teacher keep abreast of new knowledge and practice and views of the subject? Implicit in ASISTM is the partnering of teachers with outside experts. This could be seen as a genuinely innovative and productive model of teacher professional learning in an environment where changes to the nature of the science, technology and mathematics curriculum are being canvassed. In these projects teachers gained knowledge of content and practices, and knowledge of the nature of contemporary application of the sciences in local settings. This was an enriching experience.

Teachers were not passive players in any of the projects. In many of the projects teachers drove the innovation, and where this was not true they were active partners in planning and implementing the project. In the Wildflowers in the Sky project the teachers at the local secondary school and the School of the Air were active in modifying the project materials and their developed units are now on the website. These projects generally involved genuine collaboration, and teachers sometimes expressed surprise at the interest in education shown by the non-school partners. Overwhelmingly, what motivated the outside partners, including those drawn from industry, was a concern for improving the knowledge, skills and commitment to mathematics, science, and technology of this younger generation from whom scientists and technologists of the future will be drawn, and a sense of 'corporate social responsibility' to put resources into worthwhile education processes as part of a community obligation. This motivation was very evident in the Gladstone case study. In Gladstone local industry has led the way on a number of civic projects leading to improved community resources. This would make sense in terms of an industry maintaining a positive profile in the community. However, questions can be raised about whether offers from industry to contribute to educational programs can always be accepted. For example, is it appropriate to have an industry heavily dependent on coal-fired electricity playing a role in the development of units dealing with energy policy?

Members of the local school communities were also significant actors in many of these projects. In fact, an assumption underlying a number of these projects was the education of the community through students. For example, the vision underpinning the Kangaroo Island project was one of educating the local community about the value of the local marine environment and the need to intervene before it was degraded.

A Novel Alignment

This section has dealt with the individual aspects of our definition of innovation, and argued that each of these—the issues and/or vision, the ideas, practices, and actors—represent new directions for these clusters of schools, and overall represent a fresh and compelling vision of worthwhile directions for science, technology and mathematics education. However, in terms of innovation, it is the way these elements interact and form a mutually supporting whole, that indicates the strength and quality of the innovation. The recruitment of actors who bring fresh and significant knowledge and practice in contemporary science, technology and mathematics, aligned with a recasting of the nature of knowledge in the curriculum, had implications for the wider purposes of science, technology and mathematics curricula, and this in turn implied changing practices, in particular changing pedagogical practices. As an example, astronomy units developed for the Western Australian Earth and Beyond project contained many activities that can be found in texts. However, the particular innovation lay in the bringing together of five exemplary teachers of astronomy to share their expertise, and to put them in touch with astronomy installations and a wider network of teachers, to enrich and diversify the approaches; all this in the context of a significant governmental drive towards a premium astronomy research installation. What is important for the success of individual projects, and the likelihood of their sustainability, is that these elements are mutually supportive. For each of the 16 projects this was the case. In fact, when asked to identify what was innovative about their project, informants were quick to point out the new partnerships that had been forged, together with the new practices and ideas that this had allowed. In talking about sustainability, again it was the strength of these connections that tended to be emphasised.

Thus, to understand the innovative nature of these projects, and how to select and support projects on the criterion of innovation, we must look to the interactions between these elements and the extent to which they are mutually supporting. It is important, for instance, that there be a mutuality of interest amongst the actors to develop and support coherent ideas and practices. A prior history of interaction is helpful in indicating likely success.

Outcomes of the Innovation

A Variety of Outcomes

The major, overt focus for the ASISTM initiative is learning and engagement of students. However, from the perspective of the Innovation Framework one could talk of outcomes in terms of the partnerships formed, the development of ideas, the changing cultures in schools in relation to new ideas and practices, or the changing processes in schools and networks, focused on supporting innovation. In this section we will discuss outcomes for the various actors involved; students, teachers, non-school partners and the community.

For Students

There were, for the students involved in these projects, examples of significant knowledge generation and the development of expertise. These would include the students on Kangaroo Island developing expertise in monitoring fish and associated knowledge about fish and their habitats, and students from the primary school cluster at Collector (NSW) developing a sound understanding of science and the world around them. For teachers and schools, the strong focus on student engagement, and on participation of students in contemporary ideas and practices, meant that only rarely was attention given to measuring outcomes in any quantifiable way. However, there was considerable informal evidence of learning in student work produced as part of these projects. Further, anecdotally, teachers talked of the high quality of student work encouraged by engagement in authentic processes. While these projects were evaluated at a number of levels concerning student and teacher attitudinal outcomes, there seemed to be a dearth of assessment instruments or strategies that could be used to probe the diverse range of outcomes implied by these projects, and teachers seemed to take the view that the quality of learning was self evidently embedded in the quality of the activities.

For a number of these projects there was a strong focus on future possible science or technology based careers. This was explicit in interactions with some teacher associates and project partners. The GrowSmart project in the Riverland area of South Australia provided an opportunity for pupils to learn about local horticulture and agriculture industries and professional career opportunities which exist where innovative, highly skilled science and technology concepts and processes are crucial to the longevity of the local industry. For many projects there was value in students being able to interact with teacher associates who were university students, close to their own age, with science and technology interests, acting as role models and giving them a picture of university life. However, data on student destinations following the project were not available.

For Teachers

For primary teachers, knowledge and confidence were significant in their response to the projects as might be expected from previous research. Renewed confidence was a major theme, however, also with secondary teachers for whom the particular contemporary knowledge was often new and challenging. In projects such as Wildflowers in the Sky teachers have gained both content knowledge and confidence with pedagogical content knowledge. Arguably, they have also gained a richer sense of the nature of science.

In most projects there has been a differential uptake of the innovation by teachers. In some projects (e.g., Kangaroo Island) the open way of working with students, and presumptions of negotiation of knowledge and processes, attracted some teachers more than others. Teachers willing to engage with a collaborative, field-based way of working, and having the beliefs and pedagogical skills, championed the project; others expressed scepticism. One teacher interviewed claimed her involvement in the project had changed the way she taught.

Researchers working in the field of teacher professional learning and teacher and school change have long questioned the effectiveness of short, one-off professional development in supporting significant learning. The ASISTM stories, of teachers working in partnership with practising scientists and technologists, and with peers with enthusiasm and expertise, around projects that deal with local and contemporary applications, raise the possibility that the ASISTM project has generated a very potent and successful form of professional learning for teachers.

> the model of teacher professional development promoted within this project is not a short sharp burst of activity, but an ongoing supported and sustained long term engagement that enables teachers to reflect on their practice and reconsider ideas within their given milieu (project leader)

For Non-school Partners

Scientists in most cases were enthusiastic about the projects and benefited from them in a number of ways including enjoyment of working with teachers and students, support from students for significant scientific projects, and a better understanding of how to communicate science effectively. There were a number of examples in the projects of Teacher Associates being attracted to consider teaching as a career.

For the Community

There is an implicit intention that the ASISTM projects will have an impact on the community through the students' engagement with socio-scientific issues and their exposure to careers with a scientific basis, and there is evidence that this occurred. Some projects have contributed to the community in quite direct material ways. For example, Little River Primary School, part of the Serendipity project cluster has been working on a biological control project. "The school will breed an insect that will eat the cactus that has infested Little River. It is hoped the insects will eradicate the cactus weed." At Kangaroo Island parents have become involved with a number of interconnected projects.

Discussion: Curriculum Implications

There are many ways in which the nature of the ASISTM program raises questions about the school science curriculum. In this section we will identify and discuss some of these and ask whether the program has given any pointers to future directions in curriculum.

The Rewards of Local Innovation

First, the program has allowed people not normally involved to influence what is being learned in school programs. Whereas normally it is teachers and textbook writers who determine the experienced curriculum, the ASISTM program has encouraged schools to bring in other perspectives. Through the involvement of a broad range of community members, students have been exposed to activities and ideas not normally encountered in the school program. For example, The Kids Design Challenge brought architects and engineers into the classroom activity as students grappled with real world issues. Second, the ASISTM program has drawn attention to the importance of enabling projects that address local issues or take advantage of local opportunities. For instance there are two projects in which there is a focus on employment opportunities in science based careers in the local (rural) areas. Third, the ASISTM projects also allowed the specific interests of teachers to impact on the curriculum experienced by the students. It is difficult to over-estimate the potential impact of having students working together with teachers in areas about which they are personally committed. In some sense these ASISTM projects can be seen as providing the opportunity and support to unlock the potential of local teacher expertise and enthusiasm. These case studies provide a compelling argument that system wide curricula need to allow for, and indeed explicitly encourage, local innovation of this sort.

The Relationship Between Innovation and the Formal Curriculum

It would be wrong to suggest, however, that currently school programs do not facilitate the type of activity that has been generated by ASISTM. In a number of Australian states there has been a substantial degree of devolution of curriculum responsibility to schools, and in a number of projects participants talked about the enabling nature of the current curriculum to support what they were doing. In some of the projects teachers talked of the impetus received from their state curricula. These encourage approaching science from a wider, more problem-based, and multi-disciplinary perspective than is traditionally the case.

While it might be thought that these locally driven and contextualised projects could only be possible in the relative curriculum freedom of the compulsory years of schooling, a number of projects involved senior students within an external examination environment. The Designing the Teaching of Design and Technology project actively sought the involvement of Year 11 and 12 students, to both improve the quality of these students' approach to design, and to offer perhaps a more meaningful experience of design as it is taught in a tertiary context. In the Gladstone project, the innovation was boosted by the fact that schools in that region are able to negotiate assessment that supports their innovations, whereas a more centralised examination system would have made the project more difficult to achieve and manage.

Some Implications of Local Curriculum Innovation

ASISTM, at least for these 16 projects, has done what was intended—it has opened up schools to the possibilities of innovation in accessing cutting edge technologies, grappling with contemporary science and technology processes and applications, seeing how scientists work and generate new knowledge, and considering contemporary issues. In many cases this has been exciting and engaging for students. In many cases it has been exciting, challenging and energising for teachers and has led to improved classroom processes for students. Questions are bound to arise concerning the implications and limits that might be considered if this opening up of the curriculum and of schools was to become more established as a curriculum generation model.

This type of curriculum innovation introduces complexities in knowledge and its applications beyond those attendant on more managed curriculum models. Community issues, industry imperatives and technological choices are potentially all part of the mix for innovation in school practice. This raises interesting questions for education systems and the community more broadly. The projects covered in this report reflect the fact that science and technology are not conducted in the community within a value-neutral environment and the choices of projects by teachers suggest the value stance that they hold. Some of these values, such as sustainability, or commitment to career relevance, are non-controversial and would be generally applauded. This may not be the case for all values represented by industry partnerships.

Conclusion

In this section we will consider the research questions that drove the study.

The Usefulness of the Innovation Framework

The definition of innovation, and the innovation framework that flows from that, has proven generative in making sense of the nature of these disparate projects as exemplars of innovation and in analysing the multiple outcomes of the innovations. Thus, we would argue that the framework allows us to go beyond simple formulations of innovation as process, or culture, and to identify the substructure of innovation that sets it apart from superficial change, and distinguishes between substantive innovations and those of less substance.

The Outcomes, and Factors Leading to Success

The study has identified a range of outcomes for these disparate projects, for students, teachers and the wider community, relating to disciplinary knowledge and practices and knowledge of the nature of science, mathematics and technology and their societal applications. From the viewpoint of participants generally these exemplar projects could be said to have successfully addressed their aims and fulfilled their potential.

One weakness that was identified by the study was the lack of clear data on student learning outcomes. Part of this related to the fact that the case studies were generated in many cases some time after the projects had run their course, but nevertheless we found a lack of clarity and a lack of evidence relating to these outcomes. Teachers generally were very positive about the quality of learning that had occurred, but looked to the quality of the learning environment for their evidence rather than student outcome data directly. We would argue that schools need support to develop instruments and approaches to assessment that are capable of capturing the wider set of learning outcomes evident in these projects, than is normally broached in formal curricula in science, technology and mathematics.

The study identified a range of factors that marked these projects as effective, and these aligned with the innovation framework; the quality of ideas, the freshness of new practices, the appropriateness of the actors driving the project, but above all the extent to which these were coherent and mutually supporting.

Innovation as a Productive Direction for Curriculum Change

The ASISTM initiative was devised as part of a Government response to the problem of lack of engagement of Australian students in STM, and the projects studied here addressed this question of engagement very directly. Students and teachers developed productive relationships with science, technology and mathematics professionals that led to new knowledge of contemporary practices in these disciplines and their operation in contemporary Australian society. For many teachers this was an opportunity for professional renewal. Thus, it seems that innovation, as defined within these projects, is capable of carrying the burden of increased teacher and student engagement with science, technology and mathematics. The projects led to new knowledge being created and a confidence to move beyond those pre-packaged forms of knowledge that often dominate centralised curricula. Students were exposed to models of human uses of these disciplines, and potential role models for their own career futures, a circumstance being given considerable emphasis in recent writing on student aspirations in STM (Tytler et al. 2008).

Just how this vision of the innovating school can be further worked through within a coherent curriculum model is still open to question. It is true, however, that these ASISTM projects involved the introduction of pedagogies that align closely with those recommended for middle years classrooms (Victorian Department of Education and Training 2003), and a wider conception of the nature and practice of science. One question that arises is: how can teachers develop the very particular knowledge of concepts and practices and social applications that inevitably accompany such innovations? These ASISTM projects seem to have been successful in their use of teacher associates and industry expertise to work alongside teachers to develop such knowledge, in a way that was respectful of both parties.

Teacher Professional Development

One of the most striking outcomes of so many of the ASISTM projects studied was the way in which the projects operated as teacher professional learning activities. In some of the projects the provision of teacher professional development was a key aspect of the planning. However, there were many others in which there was no initial expectation that teacher professional development would occur yet this had been a major outcome of the project. The development has been both in terms of the science or technology and also in terms of pedagogy.

There is no argument that teachers are the key to capturing the interest of students. Whilst these projects show that Teacher Associates are able to make a valuable contribution, the hope of programs such as ASISTM must be that teachers are able to take what has been learned from the project and to incorporate this into the ongoing program in the subject. This places teacher professional learning at the very centre of what can be gained from such programs.

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References

Angus, M., Chadbourne, R., & Olney, H. (2001). ‘Managing Innovation’ in P. Cuttance and the Innovation and Best Practice Consortium. *School Innovation: Pathway to the Knowledge Society*. Canberra: Department of Education, Training and Youth Affairs. Accessed Jan 2009 at: http://www.dest.gov.au/sectors/school_education/publications_resources/school_innovation/default.htm.

Australian Academy of Sciences (2005). Primary Connections: Linking science with literacy. Retrieved May, 2008, from http://www.science.org.au/primaryconnections/index.htm.

Australian Academy of Technological Sciences Engineering (2008). STELR project. Retrieved July, 2009 from http://www.stelr.org.au/.

COSEPUP. (2005). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Washington, DC: National Academies Committee on Science Engineering and Public Policy.

Cuttance, P., & Stokes, S. (2001). Innovation and Best Practice. In P. Cuttance and the Innovation and Best Practice Consortium. *School Innovation: Pathway to the Knowledge Society*. Canberra: Department of Education, Training and Youth Affairs. Accessed Jan 2009 at: http://www.dest.gov.au/sectors/school_education/publications_resources/school_innovation/preface.htm.

Department of Education, Science and Training (DEST). (2005). *Boosting Innovation in Science, Technology and Mathematics Teaching (BISTMT)*. Canberra: Department of Education, Science and Training.

Duggan, S., & Gott, R. (2002). What sort of science education do we really need? *International Journal of Science Education, 24*(7), 661–679.

Engineering Working Group (2008). Skills shortages in engineering. Retrieved 24 January, 2008, from http://www.skillsinitiative.gov.au/skills_shortages/engineering.htm.

European Commission. (2004). *Europe needs more scientists: report by the high level group on increasing human resources for science and technology in Europe*. Luxembourg: Office for Official Publications of the European Communities.

Fensham, P. (2002). Time to change drivers for scientific literacy. *Canadian Journal of Science, Mathematics and Technology Education, 2*, 9–24.

Goodrum, D., Hackling, M., & Rennie, L. (2001). *Research Report: The status and quality of teaching and learning of science in Australian schools*. Canberra; Department of Education, Training and Youth Affairs. Retrieved July, 2009 from http://www.detya.gov.au/schools/publications/index.htm.

Hargreaves, D. (1999). *Schools and the future: the key role of innovation in innovating schools*. Paris: OECD.

Latour, B. (1996). *Aramis*. Cambridge: Harvard University Press.

Laugksch, R. C. (2000). Scientific literacy: a conceptual overview. *Science Education, 84*, 71–94.

Lindahl, B. (2007). A longitudinal study of students' attitudes towards science and choice of career. Paper presented at the 80th NARST International Conference New Orleans, Louisiana.

Lyons, T. (2005). Different countries, same science classes: students’ experiences of school science in their own words. *International Journal of Science Education, 28*(6), 591–614.

Lyons, T. (2006). The puzzle of falling enrolments in physics and chemistry courses: Putting some pieces together. *Research in Science Education, 36*(3), 285–311.

Osborne, J., & Collins, S. (2001). Pupils’ views of the role and value of the science curriculum: A focus group study. *International Journal of Science Education, 23*(5), 441–467.

Rennie, L. (2006). The community’s contribution to science learning: Making it count. *Proceedings of the ACER Research Conference: Boosting Science Learning—what will it take?* (pp. 6–11). Melbourne: Australian Council for Educational Research.

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). New York: The Free.
Smith, C. (2005). 'What Sustains Innovation in Education? A Comparative Study in Victorian Government Schools'. Beyond the Pilot: Sustaining Innovation, unpublished report, Melbourne: DE&T.
Smith, S., Smith, C., & Ryan, M. (2004). *Survey report of innovative projects*. Melbourne: Victorian Schools Innovation Commission.
Symington, D., & Tytler, R. (2004). Community leaders' views of the purposes of science in the compulsory years of schooling. *International Journal of Science Education, 26*(11), 1403–1418.
Tytler, R (2007). Re-imagining science education: Engaging students in science for Australia's future. *Australian Education Review No. 51.* Australian Council for Education Research, ACER press.
Tytler, R., & Symington, D. (2006). Science in school and society. *Teaching Science, the Journal of the Australian Science Teachers Association, 52*(3), 10–15.
Tytler, R., Duggan, S., & Gott, R. (2001a). Dimensions of evidence, the public understanding of science and science education. *International Journal of Science Education, 23*(8), 815–832.
Tytler, R., Duggan, S., & Gott, R. (2001b). Public participation in an environmental dispute: implications for science education. *Public Understanding of Science, 10*, 343–364.
Tytler, R., Osborne, J., Williams, G., Tytler, K., & Cripps Clark, J. (2008). *Opening up pathways: Engagement in STEM across the Primary-Secondary school transition.* Canberra: Australian Department of Education, Employment and Workplace Relations. Report accessed July 2009 at: http://www.dest.gov.au/sectors/career_development/publications_resources/profiles/Opening_Up_Pathways.htm#authors.
Tytler, R., Symington, D., Smith, C., & Rodrigues, S. (2008). *An Innovation Framework based on best practice exemplars from the Australian School Innovation in Science, Technology and Mathematics (ASISTM) Project.* Canberra: Commonwealth of Australia. Report accessed July 2009 at: http://www.dest.gov.au/sectors/school_education/programmes_funding/programme_categories/key_priorities/asistm/.
Victorian Department of Education and Training (2003). *The Middle Years*. Accessed March 2009 at: http://www.sofweb.vic.edu.au/mys/docs/InnovationExcellence/SIEInnovationDiscussionPaper.doc.