PATHWAYS TO SPACE

Final report

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1. Executive Summary

Our shared vision for *Pathways to Space* was to create and test a single idea: bring research and education together in a public space using the inspirational context of Mars exploration to encourage high school students to consider space related courses and careers.

The four partners - the University of New South Wales (lead), the University of Sydney, the Powerhouse Museum, Sydney, and Cisco Australia - believed we could create a platform in a public space from which sustainability and multiple other opportunities would arise in the space research and space education spaces.

At the heart of the project is what has proven to be a highly successful resource – the creation of a 140 square metre Mars Yard, which is a scientifically accurate diorama of Mars with an adjacent robotics laboratory, located at the Powerhouse Museum, Sydney.

The Mars Yard is the largest of its kind in a public space in the world as far as we are aware. Two rovers were built for *Pathways to Space*. Mawson, the larger rover was used mostly for research and Snickers was used solely for high school students. The Mars Yard attracts the attention of many of the museum visitors and has resulted in new on-floor presentations aimed at younger children. These presentations discuss robotics, space flight, Mars exploration and the evidence for life elsewhere in the universe.

Research undertaken by the Australian Centre for Astrobiology at the University of New South Wales showed that 26% of the high school students who participated in *Pathways to Space,* where a post as well as a pre-survey could be matched (n=151), said they were now interested in space related courses and careers as a result of participating in *Pathways to Space*.

This was after students already interested in space were discounted in the calculation. This is a key performance indicator of the project's success as its key objective, and is in excess of the number of 8% predicted on the basis of previous outreach projects undertaken by Oliver.

Unexpectedly, we also detected a significant increase in the student understanding of creativity in science (Fergusson et.al., 2012). This was an important finding that warranted publication in the professional international scientific journal *Astrobiology.* This is discussed later in the report.

The Mars Yard has also been used to repurpose a course in space engineering at the Australian Centre for Field Robotics at the University of Sydney. The course now has the highest Australian Tertiary Admissions Rank (ATAR) in the country.

There were also three doctoral programs (one UNSW and two University of Sydney), two completed Masters and one in progress, 68 undergraduate and other postgraduate research projects, and 1,615 high school students through the project.

A highly successful test of an international collaboration with the Mars Student Imaging Project (MSIP) at Arizona State University led to Australian high school students, for the purposes of their defined and refined remote sensing research question, accessing the $10m THEMIS (Thermal Imaging System) camera on board the $300m Odyssey spacecraft in orbit around Mars. The collaboration and the outcomes are discussed beginning on page 14.

There were 39 published conference papers, accepted abstracts, presentations and invited talks related to the *Pathways to Space* project. One journal paper is published and another has been offered for publication.

The $987,584 ASRP grant was matched by in-kind dollars, which came to $2.15m; a return on the Commonwealth's investment of 2.1.

The Mars Yard has also attracted a number of VIP visitors. These have included the head of NASA Administrator Charles Bolden, Microsoft founder Bill Gates and his son Rory, astronomy philanthropist Dill Faulkes, world renowned cosmologist and author Prof Paul Davies, movie maker James Cameron and Deputy Director of NASA's Engineering and Science Directorate at the Jet Propulsion Laboratory, Rene Fradet.

Last year three of the four partners (UNSW lead), University of Sydney, and the Powerhouse Museum) won another large grant in association with the Mars Yard. The $2.9m NBN-Enabled Education and Skills Services Program grant aims to use the Mars Yard in combination with the capabilities of the National Broadband Network to help transform the science classroom from a linear transmissive approach (teacher lectures, students take notes) to partnerships in which students are encouraged to explore and own learning in science and mathematics.

The new grant enables ten people to be employed in space research and space related science and mathematics education until March, 2015.

New postgraduate opportunities and robotics research have also arisen. Two new experimental rovers will be added to the *NBN Mars Lab* project. The first, under development now, has extendable legs and wheels instead of the rocker-bogey mechanism used in all previous Moon and Mars rover exploration. It weighs 70 kilograms (twice the weight of Mawson) and when fully extended stands waist high.

The project has not ended with the completion of the *Pathways to Space* grant. The Australian Space Research Program provided us with a beginning.

2. Description of project.

The aim of *Pathways to Space* was, as mentioned in the Executive Summary, is to encourage high school students to consider space-related courses and careers.

The high school program consisted of a three-hour interaction with Mars-related science and engineering at the Powerhouse including a visit to the Mars Yard. Four 30-minute experiences were preceded with a 30-minute introduction to the science and engineering associated with exploring Mars, and finishing with a wrap up and consideration of space-related courses and careers.

The introduction exposed students to the multidisciplinary nature of space science, how missions are planned and conducted, and the operation of remote sensing instruments and the analysis of the results from those instruments. The students were also introduced to the tension between landing a mission in the safest place against attempting a mission to land a rover at a scientifically more interesting but riskier site.

The introduction was followed by four student-focused experiences in a round robin of four groups of 6-8 students:

1. Understanding the geology of Mars including a hands-on rocks experience and handling a 3.42 billion year old stromatolite (microbially mediated layered rock) that has been on a trip to the space station. Students considered two sites in Western Australiad: the Pilbara where ancient stromatolites are found and Shark Bay where stromatolites continue to thrive today. The students used these analogues in relation to the search for past or present life on Mars.

2. A Mars simulation competitive game in which students learned to drive a rover on Mars, understanding the opportunities and limitations. The students also undertook science and engineering missions within the game including rock identification, spectroscopy, and moving through the Martian landscape in an effective manner.

3. A team exercise driving a rover on the Mars Yard surface to effectively undertake a short mission in competition between the four teams to collect data that the students regarded as relevant to seeking evidence for the habitability of Mars. Students also engaged with Australian Centre for Field Robotics researchers developing robotic platform space sensors in situ – the living laboratory of the Mars Yard.

4. A visit to the space exhibition. For older students we offered an opportunity to learn some basic Arduino computer programming (open source and used in the Mars Yard robotics research).

We deliberately aimed at keeping the students engaged by not spending more than 30 minutes on any one task. It was interesting to observe that engagement across all participating groups was high, and instances of poor behaviour almost non-existent – including among the school that brought an entire Year group of 60. For the Mars simulation game, which incorporates science and engineering missions, all but a very few students were totally engaged with the game for the entire period.

We originally aimed the project at Year 10-12 students, but we modified this to Years 9 and 10 in line with demand.

Year 10 is where students make the critical decision on whether to take senior science in Years 11 and 12. The choice affects their ability to successfully go onto space-related courses and careers, and therefore the most optimal year group to concentrate on in a last ditch way. There is evidence in the literature that suggests decisions are made about science much earlier, but students in the extensive University of New England report *Choosing Science* (Lyons and Quinn, 2010) reported the choice was made in Years 9 and 10. The Years 9 and10 groups were also the groups mostly chosen by the schools to come to the project, although some Year 11 and 12 groups also participated.

We also had requests from some schools for Year 7 and 8 students to attend the project.

This was an opportunity to assess their ability to understand complex ideas in planetary exploration. These students had no difficulty undertaking *Pathways to Space* and this encouraged us to also trial at upper primary level with a few schools, which was also successful with a modification in introducing space robotics in a fun and challenging way with Mindstorm lego robotics.

Pathways to Space also included an ongoing study of the effectiveness of the project based on evidence and publication of those results. The results of both the main project and the follow-on MSIP project are reported below under analysis of the project.

3. Analysis of the project

The purpose of the Australian Space Research Program (ASRP) funding of $40m was to develop Australia's niche space capabilities by supporting space-related research, innovation and skills in areas of national significance or excellence. Fourteen ASRP grants were awarded of which four, including *Pathways to Space*, were for educational purposes.

Two grants of close to $1m were given to two high school projects and two to the higher education field. *Pathways to Space* was the only education project awarded in the first round. All four rounds were merit-based and competitive. The education grants were intended to support student projects and space education activities, including international education opportunities and the establishment of national space education programs and centres of expertise for space education.

Our project was designed as both a pilot and a showcase. From the outset we aimed to achieve a student-focused space education program with a strong element of evaluation so that we could understand the elements of what works and what does not. As we demonstrated the evidence on which to base such projects is disturbingly thin (Sless and Shrensky, 2001; Oliver, 2009), driven in part by funding for projects and funding for evaluation being usually two different types of grant (education project funding and research funding).

In addition to mixing what seems obvious – a strong project with strong evaluation – we undertook the space education project in tandem with space science and space robotics research, and in a public space. This approach provided strong struts to sustainability. The Mars Yard serves as a popular exhibit as well as a test bed and an education resource.

As we progressed with *Pathways to Space* we found success not only in our approach to the high school education program but also that the resource at the heart of the project – the Mars Yard – was a springboard for greater higher education interaction than we had imagined.

The education research was revealing. The three-hour interactions with the Mars Yard should have done no more than open high school students to the possibility of space related courses and careers.

We were more than surprised to find that in just a short interaction with scientists and engineers in using the Mars Yard, students had significantly increased their understanding of creativity in science (Fergusson et.al., 2012).

The pre-survey figure revealed how understanding creativity in science is low even

among the best high school students and is a matter worthy of further research as to why this is so.

The limitations of our research were that (with the exception of a low Socio Economic Scale school) almost all the students were selected to come to the project by their teachers. Our research showed, as mentioned, that participants were not normal population students – instead they were mostly above average students. Another limitation was the short interaction with *Pathways to Space* – just three hours, but this will change to sometimes much longer experiences in the NBN Mars Lab project, in at least one case among our test schools half a term for a whole year group (Year 10).

No control group was used because of the difficulty of getting two homogenous groups, but more importantly that the measure was from the baseline provided by pre-experience surveys compared to the post surveys and measuring that specific change (e.g. in measuring the understanding of creativity in science). We also employed non-parametric as well as parametric analysis of the data for robustness of the results given the non-random nature of the sample. This robustness was particularly mentioned by reviewers for the resulting scientific journal paper (Fergusson et.al., 2012).

If good students have an already low understanding of creativity in science, it may be safe to assume students not as good at science as the *Pathways to Space* students have an even lower understanding. We indeed found this in analysing the students' pre-experience survey from an entire year group from the low Socio Economic Scale school and compared it to the other student groups. Within the entire year group we found exposure to *Pathways to Space* closed the gap between the lower level understanding of creativity in science and that attained by the selected student groups. In other words the low Socio Economic Scale school students raised their level of understanding creativity in science to a greater degree.

It is worth noting that post surveys were taken at least two weeks after students visited to the project (so not on the day when enthusiasm would have been highest). This applied as much to a low Socio Economic Scale school that sent 60 students to the project as it did to the participating selective and private school students.

While it is recognised school science bears little relation to real science (e.g. Wong and Hodson, 2009), there has been no good evidence understanding real science is necessary to taking senior science or not or having an interest in science. However there are some data to suggest this is at least helpful in changing attitudes towards science (Dawes and Rasmussan, 2006; Oliver, 2008).

The *Choosing Science* report demonstrated that among the students in the survey electing not to take senior science, two-thirds said they did so because they could not imagine themselves as scientists. An interesting piece of research might be to understand how exposure to research and/or good career information affects the perception of students not being able to see themselves as scientists. An extension to that might be in providing evidence that understanding real science and engineering research is a key factor in changing attitudes towards science and engineering as career choices.

From the museum perspective in engaging with *Pathways to Space*, the Powerhouse has recognised for some time that the traditional exhibition medium presents problems when it comes to talking about contemporary science and technology. The technology is expensive, complicated, and prone to very rapid obsolescence. Meaning is often lost

when the artefacts of science are displayed in showcases.

An approach that the museum is testing is the idea of a 'living laboratory' where real researchers are provided with space in which to undertake their research and allow visitors to witness the development of new technologies and even allow the visitors to be part of the research. The *Pathways to Space* project has been the exemplar for this idea.

Three of the four partners in the *Pathways to Space* consortium have expertise in aspects of space research and education. While not specifically an objective of the project, partners have collaborated to the extent of developing a common centre of expertise in space education at the Powerhouse Museum as envisaged in the funding of the four education projects by the ASRP.

3.1 Student numbers

While our student numbers were in line with revised expectations at 1,615 students in total, they should have exceeded those expectations (based on the reaction we see from students using the Mars Yard). Getting schools to come to the project was challenging throughout, even with the help of the Powerhouse's schools program. Our best strategy was direct marketing to schools to let them know about the project and at an early stage before teachers have planned their school year. We found a number of instances where science teachers had just one opportunity a year to take their students on a science excursion.

We were faced with another challenge – teachers (in New South Wales at least) have much paperwork to complete for an excursion and, although the project itself was free, the cost of transport of one class is at least $300 for a bus or to take the train. $10 per student in a class of 30 is simply too high in some areas, particularly for low Socio Economic Scale schools. We experienced one school cancelling because students could not bring in the $6 each required for train fare. The Powerhouse Museum overall is also seeing a drop in school excursions, so *Pathways to Space* is not specifically affected – it is more general. Going online and taking projects to the schools appears to be a solution, at least in part.

In addition, the research in this project was limited by the response rate on post surveys – we received only 151 post surveys – about 10% of the total number of students participating. This number was sufficient for us to draw out results of the project, but the greater the rate of return the more accurate the results. Poor rates of return for post surveys among schools is a common problem for outreach projects that must rely on busy teachers to fit this task into their already over-crowded days. Fergusson, for example, found similar issues with comparison testing at the Victorian Space Science Education Centre. We are testing an online approach for our current project.

4. Evidence the project has been completed

As Project Manager of *Pathways to Space* I confirm the project has been completed. These lines of evidence are present to support that statement:

1. Presence of Mars Yard in the public space of the Powerhouse Museum together with iPads for public interaction with the Mars Yard

2. Presence of rovers

3. Presence of the Mars simulation app now accessible by the public at www.nbnmarslab.com

4. Pictures of multiple schools participating in the project

5. Research into the effectiveness of the project (Fergusson et.al., 2012)

6. A doctorate completed using data from project (Fergusson)

7. Three month extension to project successfully applied for to accommodate more than 400 students wishing to participate in the Pathways to Space program

5. Extent to which project achieved outcomes

The primary objective of this project was simple. If Australia is to increase its capability in space, the nation must have capacity to do so – and especially in having appropriate skills available in the workforce.

We approached this by:

1. Bringing together partners from diverse areas – space robotics, astrobiology, public and student engagement in space exploration, and technology in education to create the basis for building experience and expertise in space related education.
2. Engaging high school students sufficiently well that at least 8% not already interested in space would self-identify as being interested in space-related courses and careers as a direct result of participating in the project.
3. Building the framework for sustainability beyond the ASRP funding.

The results were:

1. The process of creating of the Mars Yard and adjacent space robotics lab in the public space of the Powerhouse Museum brought together with a space science education program has created the working relationship between partners needed to build experience and expertise in space-related education.
2. As mentioned earlier, among the students from whom we obtained both pre and post surveys 26% of students not already interested in space-related courses and careers self-identified as being interested in space related courses and careers as a direct result of participating in the project.
3. The framework for sustainability was built around the resource of the Mars Yard – sustainability comes through its attractiveness to researchers as a laboratory, and to the museum as a popular exhibit, but in addition the needs of the project to some extent also changed the needs and business model of Thinkspace offerings outside of the project but that draw in a connection to the Mars Yard such as Arduino, Mindcraft, electronics, and video making.

Summary of milestones, date achieved, and outcomes

Milestone	Date achieved	Outcomes
1. Production of Education project	June, 2011	• Three part-time staff hired (the three positions = 1.4 full time staff) • Mars simulation developer hired • Education program developed • Evaluation tool developed and validated • Ethics approvals obtained for study, permission notes prepared for students
2. Mars Yard and rovers	March, 2011	• Mars Yard designed and built with adjacent robotics lab • Two rovers designed and built • Two space engineering doctoral students acquired • One education doctoral student acquired • Telepresence installed in Thinkspace • Museum connected to AARNet
3. Inauguration and first students arrive	March to December, 2011	• Inauguration event in Mars Yard opened by Senator the Hon Kim Carr, Minister for Innovation and Science • First students arrive • Follow on research project devised for Pathways students • First data collected • Bill Gates and son Rory spend time in Mars Yard (December 2011)
4. Paper published on results and extension project for Pathways students	February 2012 to December 2012	• NASA student research project offered to follow on Pathways students (MSIP) • NASA Administrator Charles Bolden visits project (April, 2012) • Paper published in a professional peer-reviewed journal on results of the project • Pathways follow-on project students achieve refereed conference proceedings paper
5. Sustainability frameworks for ongoing student research, ongoing Mars Yard, and engagement of others, especially overseas space agencies	Ongoing throughout but in place January, 2013	• New $2.9m grant to take project Australia-wide • Mars Yard sustainability attained by making the exhibit a well visited one with three iPads outside of the Yard for students and their parents to participate in Mars Yard virtually • An international collaboration with NASA's Mars Student Imaging Project

5.1 Unexpected outcomes

There were three unexpected outcomes of *Pathways to Space* apart from those already mentioned:

1. *Pathways to Space* proved to be an agent of technological change in the Powerhouse's digital learning studios, Thinkspace.
2. *Pathways to Space* also changed the way of doing business with schools to also include engagement via video conferencing.
3. The success of the Mars Student Imaging Project.

Thinkspace and technological change

The presence of *Pathways to Space* has proven to be an agent for technological change in the Thinkspace digital studio area, prompting introduction of these offerings:

1. Mars simulation game – was not conceived in the grant application but proved to be a popular and important strut in the delivery of the education program
2. Arduino (programming language for driving rovers in Mars Yard) introduced into Thinkspace offerings to schools and the Thinkspace holiday program
3. Electronics and development of the Thinker 1 board designed to provide easy access to electronics for students
4. Mars simulation game converted to Google's Liquid Galaxy technology
5. Augmented reality exhibition
6. Week long video course themed on Mars Yard
7. Spurred physical redevelopment of Thinkspace

Video conferencing

TelePresence ™ was installed at lower than normal cost in Thinkspace as part of the *Pathways to Space* project as Cisco's contribution to the project. This connection was used regularly for connecting the Mars Yard on the ground floor to Thinkspace where several of the activities took place and is now used extensively for connecting to classrooms.

As a result *Pathways to Space* has helped the Powerhouse move to the forefront of museum-based education and learning at a time when museums are being looked to for help in the introduction of new national curricula and the new pedagogies that it is hoped will follow

Pathways to Space has also transformed the Powerhouse's digital learning facilities into first class video conferencing facilities, creating a new emphasis for Science, Technology, Engineering and Mathematics education to complement the work done with visual arts and media.

In addition, education and curatorial staff have, through the *Pathways to Space* project found new approaches to video conferencing, finding ways to utilise the interactive potential of this new medium.

Mars Student Imaging Project

We formed a partnership with NASA's Mars Education Team at Arizona State University

to open their Mars Student Imaging Project to *Pathways to Space* students who wanted to undertake a space-related research project.

Around 30 of the self-identifying students from *Pathways to Space* expressed interest in undertaking the NASA student research project, but the requirement was they would need to come into the Powerhouse for around four months. Saturday jobs, Saturday sport, and distance reduced the number to 16 and then to 13 Years 10 and 11 students, who came from four Sydney high schools (Casula, St George Girls, Riverview and Cranbrook Boys).

The Powerhouse group, facilitated by Jeff Stanger, head science teacher at St George Girls, worked on their research question and presented to a team of NASA scientists and educators at ASU to get the right to obtain their own THEMIS image, research the image and report back to the NASA team at ASU on their results. Their efforts attracted a visit from the NASA Administrator and four times in space astronaut Charles Bolden who spent 1.5 hours with the students and visiting *Pathways to Space*.

Around half the group elected to continue research for another four months beyond the final report on their research to NASA scientists and educators at Arizona State University. This extra work resulted in:

- Abstract accepted for the planetary science session of the 12th Australian Space Science Conference
- The award of outstanding presentation to the students at the conference
- The acceptance of a refereed conference proceedings paper

5.2 Undergraduate and postgraduate students as an outcome

PhD Students from USYD:

We have two PhD students (not graduated yet) at the ACFR who used the Experimental Mars Rover (EMR)-Mawson and Mars Yard.

1. Ken Ho (Expected completion: March 2014)
    - Research Title: "*Traversability Estimation for a Planetary Rover in Deformable Terrain*"
    - Supervisors: Thierry Peynot and Salah Sukkarieh
2. Angele Lui (Expected completion: August 2014)
    - Research Title: "*Learning a Stochastic Mobility Prediction Model for Planning with Control Uncertainty on Unstructured Terrain*"
    - Supervisors: Thierry Peynot , Robert Fitch and Salah Sukkarieh

Master Students from USYD:

1. Rowen McAllister (Graduated in 2013)
    - Thesis Title: "*Motion Planning and Stochastic Control with Experimental Validation on a Planetary Rover*"
    - Degree: Masters of Philosophy, The School of Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney
    - The School of Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney
    - Supervisors: Robert Fitch and Thierry Peynot

2. Mathew Vytrhlik (Graduated in Nov 2011)
    - Thesis Title: "*Development of a Localisation System for an Experimental Mars Rover Platform*"
    - Degree: Masters of Professional Engineering (Mechanical Engineering), The School of Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney
    - Supervisor: Ali Haydar Goktogan
3. William Reid (Expected completion is end of 2014)
    - Research Topic: *"Development of NBN-Rover01 and Motion Control of a Highly Mobile Martian Analog Rover"*
    - He started this research in 2013 and he is working for the development of the first NBN robot.
    - Supervisors: Salah Sukkarieh, Ali Haydar Goktogan

List of Undergraduate Courses Utilising the Mars Yard or/and the EMR:

Year	Unit of Study	Number of Students
2011	AERO2711, AERO3711 Space Engineering Project 1 and 2	6
2011	AMME4500, Guidance, Navigation and Control	19
2011	BABS 6741 Astrobiology third level	15
2012	AMME4500, Guidance, Navigation and Control	15
2012	BABS 6741 Astrobiology third level	10
2013	AERO2711 Space Engineering Project 1	2
2013	AERO5700, Space Engineering (Advanced)	1
	TOTAL	68

Undergraduate Thesis and Engineering Project Students from University of Sydney:

1. Suchet Bargoti (Graduated in 2011)
    - Thesis Title: "*Local Navigation of a Mars Rover Using a Depth Sensor*"
    - Supervisor: Salah Sukkarieh, Ali Haydar Goktogan
2. Phil Soo Park (Graduated in 2013)
    - Thesis Title: "*Low-Cost Vision-Based 3D Pose Estimation System*"
    - Supervisor: Ali Haydar Goktogan
3. Callum McCarter (Expected completion date: Oct 2013)
    - Research Topic: "*Development of a Pan/Tilt Mechanism for NBN-Rover1*"
    - Supervisor: Ali Haydar Goktogan
4. Steven Potiris (Expected completion date: Oct 2013)
    - Research Topic: "*Development of a Vision Based Auto-Docking System for the Experimental Mars Rover in Mars Yard*"
    - Supervisor: Ali Haydar Goktogan
5. Sue Ann Wong (Expected completion date: Oct 2013)
    - Research Topic: "Localisation of *the Experimental Mars Rover in Mars Yard Using Laser Scanner*"
    - Supervisor: Ali Haydar Goktogan

6. Allan Ross Dizon (Expected completion date: Oct 2013)
    - Research Topic: "*Development of a Manipulator for the Experimental Mars Rover*"
    - Supervisor: Ali Haydar Goktogan
7. James Abbottsmith (Expected completion date: Oct 2013)
    - Research Topic: "*NUI for Teleoperation of the Experimental Mars Rover*"
    - Supervisor: Ali Haydar Goktogan

Visiting Students:

1. Johanne Thibault (Research completed in 2011)
    - Thesis Title: "*A Manipulator Development for an Experimental Mars Rover* "
    - Mechatronic Engineering Diploma at Polytech Annecy-Chambéry, University of Savoie, France
    - Supervisor: Ali Haydar Goktogan
2. Benjamin Ohms (Research completed in 2012)
    - Thesis Title: "*Development of an Robotic Arm for the ACFR Mars Rover*"
    - Aerospace Engineering (Diploma)
    - University of Stuttgart, Germany
    - Supervisor: Ali Haydar Goktogan
3. Brieuc Mallet (6 months internship in 2012)
    - Subject: "Graphical User Interface for a Planetary Rover"
    - The University of Toulouse, France
    - Supervisor: Thierry Peynot
4. Rodney LI (Project completed in 2012)
    - Thesis Title: "Robot Astrobiologist: Automatic Detection of Stromatolites"
    - 4th Year student from The University of Sydney
    - Supervisor: Thierry Peynot
5. Lydia Drabsh (Project completed in 2012)
    - Thesis Title: "*Evaluation of the Performance of the Intersense IS-1200 localisation system*"
    - 2nd year student, University of Sydney, Aerospace Engineering Project
    - Supervisor: Thierry Peynot
6. Marco Manghisi (Research completed in 2012)
    - Thesis Title: "*Hardware in the loop simulator (HWIL) system development for Experimental Mars Rover (EMR)*"
    - Aerospace Systems
    - Politecnico Di Torino, Italy
    - Supervisor: Ali Haydar Goktogan
7. Aditya Mahajan (Research completed in 2012)
    - Post-Bachelor Degree Work Experience Project Title: "*Wheel Slippage Estimation for an Experimental Mars Rover*"
    - The School of Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney

- Supervisor: Ali Haydar Goktogan

8. Suchet Bargoti (Research completed in 2012)
    - Post-Bachelor Degree Work Experience Project Title: "*Wheel Slippage Estimation for an Experimental Mars Rover*"
    - The School of Aerospace, Mechanical and Mechatronic Engineering, The Universtiy of Sydney
    - Supervisor: Ali Haydar Goktogan
9. Pierre Rancony (Research completed in 2013)
    - Project Title: "*Modeling of Rocker-Bogie Mechanism of the Experimental Mars Rover*"
    - Mechatronic Engineering Diploma at Polytech Annecy-Chambéry, University of Savoie, France
    - Supervisor: Ali Haydar Goktogan
10. Anthony Tompkins (Expected completion date: Oct 2013)
    - Volunteer project title: "Development of a Low-Cost Vision-Based Localisation System for the Experimental Mars Rover"
    - The School of Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney
    - Supervisor: Ali Haydar Goktogan

PhD student, University of New South Wales

Jennifer Fergusson: Project title: *Engaging students in the nature and practice of science*
Supervisors: Carol Oliver, Malcolm Walter.

6. Highlights, breakthroughs, difficulties

Highlights of the project:

- Mars Yard built
- Two rovers built
- Powerhouse connected to AARNet
- Telepresence installed
- Pathways to Space project Ministerial opening March 31, 2011
- First students arrive May, 2011
- Media piece: Mars in Sydney aids rover research, Science Show, Robyn Williams May, 2011, http://www.abc.net.au/radionational/programs/scienceshow/mars-created-in-sydney-aids-rover-research/2947478
- First international conference paper July 2011
- Participation in Ultimo Science Festival
- Students camp all night on the Mars Yard as prize
- Development of the Mars simulation game February 2012
- Participation in Science Week with rovers at Martin Place, Sydney
- Bill Gates and his son Rory spend 30 minutes in Mars Yard (December, 2012)
- Mawson features on short video Christmas card for the Powerhouse Museum, December 2012 http://www.youtube.com/watch?v=I_DbymsPH9k
- Mars Student Imaging Project collaboration with the NASA Mars Education Team at Arizona State University

- Winning of new $2.9m grant with the NBN-Enabled Education and Skills Services program to take the Mars Yard experience to schools anywhere in Australia
- High school student research collaboration established with NASA's Mars Education team at Arizona State University
- Head of NASA, Administrator Charles Bolden visits *Pathways to Space*, April 2012.
- ABC 702 Radio, Linda Mottram's interview with Mathew Connell and with Dr. Ali Haydar Goktogan "*A piece of Mars in the middle of Sydney*", 23 April, 2013 1:23PM AEST, Accessible via: http://www.abc.net.au/local/stories/2013/04/23/3743387.htm
- Sarah Redfern High School student report on visit, May, 2012 http://www.sarahredfe-h.schools.nsw.edu.au/news/excursion-to-powerhouse-museum
- Achieved total of 39 published conference papers, abstracts, presentations and invited talks
- *Pathways to Space* MSIP students get abstract accepted in 12th Australian Space Science Conference
- *Pathways to Space* MSIP students get refereed conference proceedings paper published
- Stream of national and international VIP visitors and academics (MIT, Arizona State University, University of Connecticut and Curtin University, Western Australia)
- Rocket science takes off as universities battle for the brainy, Sydney Morning Herald (syndicated to major cities January, 2013) http://www.smh.com.au/national/tertiary-education/rocket-science-takes-off-as-universities-battle-for-the-brainy-20130116-2ctwl.html
- Lunabotics team uses Mars Yard, January, 2013, http://www.sydneylunabotics.com/index.php/outreach-activities/48-powerhouse-museum-visits
- Life on Mars for Cranbrook student, March 2013, http://www.cranbrook.nsw.edu.au/community/news/life-on-mars.aspx
- Three doctorates, one in final stages of award
- Two Masters complete, third Masters under way
- 68 undergraduate interactions with Mars Yard
- Telepresence used in NSW Connected Classrooms interactions

6.1 Difficulties

Pathways to Space, as seen throughout this project, has achieved its goals and is now moving onto the next phase of development with the resources and expertise that have resulted from the Australian Space Research Program funding.

Few projects run exactly to plan, and in fact change is required if a project is to exceed expected outcomes as this one has. Projects that are multi-organisation face the challenge of communication between the organisations and in particular interpretation of milestones, workflow patterns in and between the organisations and not assuming each organisation holds the same end vision in mind.

7. Governance

One of the main challenges of Pathways was to create trust between partners who had not worked together either institutionally or personally in the past. An Advisory Board

was established which met six times (twice a year). On reflection, this was not enough, especially in the early days of the project, when it could have been used more effectively to build the team.

However, the Board insisted on the creation of a risk register and some other basic tools of project management, which were of enormous help to the Project Director and to others with key responsibilities to deliver the project.

8. Lessons learned

1. Mars Yard

Space in the Powerhouse Museum enabled a much larger than anticipated Mars Yard, that was then delayed by such unavoidable occurrences such as needing to re-source rock and soil materials because of flooding in Queensland. While the delay caused us to need to revise numbers of students to 1,500, the strategic benefit was that we attained a world-class resource that will be available for many years to come. As a result, far more students than anticipated will eventually use the Mars Yard

2. Project management

In the commercial world a project manager is highly trained and highly paid for the role for good reasons. However, while project management guidance and support is essential for the grant holder, education environments are very different from the commercial world.

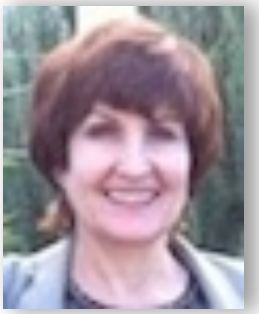
We learned about the complex organisation environment that transpires from multiple partners from multiple cultures that are beyond the realm of normal project management. This extended, too, to the participating schools.

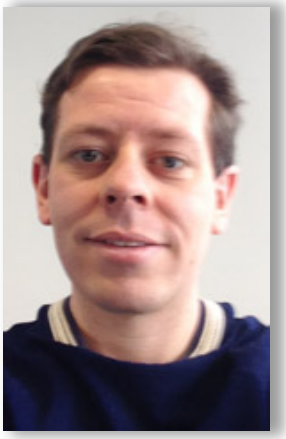
9. The team

The following 31 people all took a role in the making and success of the Pathways to Space project:

	**Dr Carol Oliver,** Project Manager and Project Director Dr Carol Oliver is Associate Director of the Australian Centre for Astrobiology at the University of New South Wales, Sydney. Her key research interest is in high school scientific literacy and how that translates into the public community when students pass into adulthood. She has a doctorate from the University of New South Wales and a research Masters from Central Queensland University, both in science communication. She also on the NASA Astrobiology teams at MIT and Arizona State University collaborating on the making of Virtual Field Trips to sites of astrobiological interest.

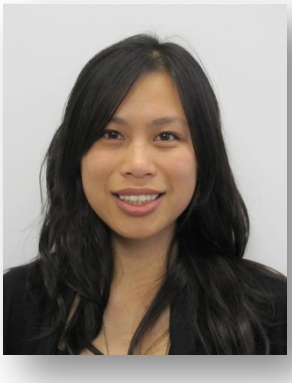
	She is a full member of the International Academy of Astronautics elected for her international outreach activities in space education.
	**Matthew Connell** is Principal Curator Physical Sciences and IT at the Powerhouse Museum. His specific curatorial expertise in is computing and mathematics. He has developed exhibitions and programs on computing technology, computing history, robotics, AI, human computer interaction mathematics, logic, new media and interaction art and design. He has also been researching new approaches to museum exhibitions especially for science and technology related subjects. Matthew is the Powerhouse Museum Lead on the *Pathways to Space* project seeing the project Mars Yard developed with the museums public gallery as a 'Living Laboratory'.
	**Professor Salah Sukkarieh** is an international expert in the research, development, operationalisation and commercialisation of field robotic systems as well as Lead for the *Pathways to Space* project. He has lead a number of robotics and intelligent systems R&D projects in logistics, commercial aviation, aerospace, education, environment monitoring, agriculture and mining, and has consulted to industry including Rio Tinto, BHP, Patrick Stevedores, Qantas, BAE Systems, QLD Biosecurity, Meat and Livestock Australia, and the NSW DPI amongst others. Salah is the Professor of Robotics and Intelligent Systems at the University of Sydney, and the Director of Research and Innovation at the Australian Centre for Field Robotics. He has supervised over 10 research fellows, and graduated over 25 PhDs, 5 Masters and 60 honours students. He has received over $30m in government and industry funding, national and international.

	**Peter Mahony,** is the Manager of Learning Technologies at the Powerhouse Museum. Peter is responsible for program direction and delivery across the Thinkspace digital learning centre, as well as being curriculum leader for special learning projects including NBN Mars Lab. Thinkspace offers experiences in which learning is amplified through technology. Courses include media production, gaming, programming and physical computing for children, families, school groups, teachers and people with a disability. His qualifications include a Masters of Teaching, Graduate Diploma in Music Therapy, Bachelor of Arts, and Cert IV Workplace Train and Assess. Peter has a background in music and performing, and sings tenor in Sydney's premiere soul and gospel Acapella group Cafe of the Gate of Salvation.
	**Dr. Ali Haydar Goktogan** is a Senior Research Fellow at the Australian Centre for Field Robotics (ACFR) of the School of Aerospace, Mechanical & Mechatronic Engineering (AMME), the University of Sydney, Australia. He received his B.S. degree in physics, M.S. degree in computer engineering from The Middle East Technical University (METU), Ankara, Turkey, and Ph.D. degree from the ACFR. His research interests include space robotics, unmanned aerial systems (UAS), and large-scale, fault-tolerant, real-time, distributed systems. He designed the Experimental Mars Rover (EMR) platform used on the *Pathways to Space* project
	**Jennifer Fergusson**, Education Lead, University of New South Wales. Jenny undertook a number of tasks in the education program including helping to map the project to the curriculum, to teach, and to assist in the creation of the education program. Jenny is also undertaking her doctorate in relation to *Pathways to Space,* and this is nearing submission for her doctoral award.

	**Muhammad Esa Attia**, is a Senior Technical Officer at the Australian Centre for Field Robotics (ACFR) of the School of Aerospace, Mechanical & Mechatronic Engineering (AMME), the University of Sydney, Australia. He is responsible the electrical and electronic subsystems used on the Experimental Mars Rover (EMR) platform and the Snickers rover used on the *Pathways to Space* project.
	**Prof Malcolm Walter**, Science Advisor Malcolm Walter played a major role in the design of the Mars Yard and supplied the stromatolites that are used there. He attended many sessions with students to share his expertise on early life on Earth and the search for life on Mars.
	**Dan Collins** is the museum's Chief Technology Officer and manages both the ICT and digital/website functions for the Powerhouse Museum. For *Pathways to Space* Dan played a role in the co-ordination of the AARNet network link and also the video conferencing functionality between the project participants. At the Mars Yard, Dan worked closely with the University of Sydney team to deliver technical infrastructure that underpinned the remote rover operations now possible.
	**James Oliver** is involved in the creative development of interactive 3d game like educational software. He is a science educator and program producer. James is also the designer and programmer behind the Mars simulation game, which allows students to explore a part of Mars in the virtual environment and to undertake science and engineering missions.

	**Kerrie Dougherty** is Curator of Space Technology at the Powerhouse Museum. She is also a lecturer in Space and Society studies (including space education) at the International Space University and a member of the Space Education and Outreach Committee of the International Academy of Astronautics. Kerrie's initial role in *Pathways to Space* was to develop the public exhibit aspect of the Mars Yard within the Powerhouse Museum, using text, graphics, artefacts and audiovisual materials to interpret the activities in the Mars Yard for museum visitors. She also provided input into the initial development of the student program as well as the development of the Mars simulation interactive for the public. Kerrie had an ongoing role in promoting the project to the public, school groups and professional colleagues, and in bringing VIP visitors to the Mars Yard. She also had an ongoing research role, identifying educational research and the latest developments in Mars exploration that could contribute to the continual enhancement of the student program.
	**Dr. Thierry Peynot** is a Research Fellow at the Australian Centre for Field Robotics (ACFR), The University of Sydney. His main research interests include resilient perception for mobile robotics and planetary rovers. He was the leader of the robotics research of the project for ACFR and supervised all ACFR postgraduate students of the project, with Dr. Robert Fitch and Prof. Salah Sukkarieh. He also developed research on automatic stromatolite recognition in collaboration with David Flannery and Prof. Malcolm Walter of the Australian Centre for Astrobiology, at UNSW.
Thinkspace staff: Kusum Normoyle, Robbie Mudrazjia, Daniel Green, Joy Suliman	
Michael O'Brien, Cisco Lead	
Cisco staff: Jan Zanetis, Andrea West	

	**Greg Sawyer**, Manager Communication Services at the University of New South Wales responsible for the UNSW Data networks, PABX telephony system and infrastructure installation project management incorporating 160,000 networked devices, 1,500 network devices, 3,000 wireless access points, 13,000 extensions supporting 60,000 researchers, academics, staff and students across 25 sites. Greg assisted with negotiations in relation to the installation of AARNet into the Powerhouse Museum.
	**Dr. Robert Fitch** is a Research Fellow at the Australian Centre for Field Robotics (ACFR), The University of Sydney. His main research interests include motion planning and distributed robotics. He supervised the research of Angela Lui.
Brad Baker, Exhibition designer	
Powerhouse IT staff: Mitch Mitchell	
The Advisory Board	
	**Chair: Brett Biddington AM (and UNSW representative**) Brett helped to write the *Pathways to Space* grant application and served as Chair of the Pathways Advisory Board for the duration of the project. He owns a Canberra-based consulting company, which specialises in space and cyber security matters.
Anthony Rogers (Powerhouse)	
Hugh Durrant-Whyte (University of Sydney)	
Peter Elford (Cisco)	
Postgraduate students:	
Jennifer Fergusson (see entry	

above)	
	**Ken Ho** is a PhD student at the Australian Centre for Field Robotics (ACFR), The University of Sydney. His research aims at developing novel traversability estimation methods for a planetary rover in deformable terrain using 3-D perception and machine learning techniques. Ken also contributed to the development of the Experimental Mars Rover prototype of the project, now known as Mawson
	**Angela Lui** is a PhD student at the Australian Centre for Field Robotics (ACFR), The University of Sydney. Her research is concerned with stochastic mobility prediction models for planning with control uncertainty on unstructured terrain. Angela also contributed to the development of the Experimental Mars Rover prototype of the project now known as Mawson
	**Rowan McAllister** completed his M. Phil. at The University of Sydney in 2012 and graduated in 2013. His thesis, entitled "Motion Planning and Stochastic Control with Experimental Validation on a Planetary Rover" was part of the research program developed in the Pathways to Space. Rowan is now a PhD candidate at the University of Cambridge, UK.
External:	
Nick Cross, AARNet	

10. Conclusions and recommendations

This was a successful project. It achieved the stated aims in excess of 1,500 students and

longer-term benefit of the Mars Yard as an enduring legacy of the project attracting other investment in high school science education as well as producing a rich environment in which postgraduate research is flourishing.

This report makes two recommendations:

1. In future projects of this sort we recommend ensuring adequate provision is made for appropriate governance and project management to be built in as fundamental elements of the project.

2. Noting the success of this project and other ASRP projects we urge the consideration of setting aside a small amount of money for five years' hence to refurbish key infrastructure in those projects such as the Mars Yard for *Pathways to Space.*

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