The STEM Ecosystem: building cross-disciplinary leadership capacity in science, technology, engineering and mathematics.

Final Report 2016

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List of acronyms used

ALTC	Australian Learning and Teaching Council
AQF	Australian Qualification Framework
ATN	Australian Technology Network
BEAN	Biosciences Education Australia Network
CES	Course Evaluation Survey
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CUBENET	Collaborative Universities Biomedical Education Network
DVC	Deputy Vice Chancellor
ELA	Educational Leadership in Action
Go8	Group of Eight
GDS	Graduate Destination Survey
HERDSA	Higher Education Research and Development Society of Australasia
ICE	International Conference on Education
IMPEL	Impact Management Planning and Evaluation Ladder
NGO	Non-Government Organisation
MSA	Manufacturing Skills Australia
OLT	Office for Learning and Teaching
PVC	Pro Vice Chancellor
STEM	Science, Technology, Engineering and Mathematics
UES	Urban Ecology Symposium
USQ	University of Southern Queensland
VC	Vice Chancellor
VE	Vocational Education
VRQA	Victorian Registration and Qualifications Authority
WIC	Water Innovation Challenge

Executive summary

The disciplines of Science, Technology, Engineering and Mathematics (STEM) are critical for national productivity and global competitiveness. Demand for tertiary graduates with cross-disciplinary STEM skills will continue to exponentially exceed supply in Australia in the next 25 years (McLaughlin & Reid, 2012). Leadership in the promotion of STEM cross-disciplinary learning and teaching is critical to the development of future graduates. With these identified skills shortages across the STEM professions, there is a growing need for academic staff to impart knowledge from their own disciplines across new STEM learning boundaries and build skills in providing cross-disciplinary STEM opportunities for future graduates. This project, through the connection of industry, STEM academics and students created these opportunities and demonstrated the emerging potential in cross-disciplinary learning and teaching. The project also forged new patterns of learning opportunities in STEM tertiary education across Australia and crossed discipline and Australian Qualifications Framework (AQF) boundaries.

Based on an ecosystem model of distributed leadership (Harris et al 2007) the project drew together existing STEM academics and single discipline learning. Building upon the experience, examples of STEM cross-disciplinary teaching and learning at The University of Queensland, expanded opportunities for students across disciplines and contexts. This project created a STEM Ecosystem that transformed the learning experiences of over 200 students and provided direction and leadership opportunities for 50 core STEM staff at The University Sydney, RMIT University and University of Southern Queensland and over 140 other STEM staff across the wider sector. Through the ecosystem framework, senior STEM academics supported other staff including early career academics and encouraged the exploration of non-traditional ways of teaching STEM disciplines. In addition, the trialling and testing of new methods of educational delivery and engaged learning was undertaken. Using workshops, existing teaching modules, industry challenges, new courses and innovative delivery modes, the STEM Ecosystem expanded cross-disciplinary learning opportunities and connected industry, staff and students in emerging future-focused STEM initiatives.

By invigorating and encouraging a range of new cross-disciplinary projects in STEM disciplines this project advanced current work-integrated learning projects, their delivery modes and leadership. Through industry role modelling, it empowered and nurtured capacity in tertiary staff and provided opportunities for advancement of the scholarship of learning and teaching in STEM, evidenced by the invitations to showcase the work both nationally (Perth, WorldSkills event) and internationally (Singapore, Water Innovation Challenge). By invigorating and encouraging collaboration across disciplines, this project provided students with valuable lifelong learning skills and future employability skills.

The project utilised STEM industry leaders from Engineers Australia, Office of the Chief Scientist and Manufacturing Skills Australia. The project created an environment of cross-disciplinary scholarship in learning and teaching that nurtured, modelled, developed, showcased and disseminated cross-disciplinary projects. The 2016 STEM Ecosystem Showcase and Expo has been structured to illustrate industry involvement, national STEM academic staff involvement and cross-disciplinary activity. The participating STEM academic staff and students will be afforded

opportunities to hear of, and engage with, models of STEM cross-disciplinary learning and teaching.

The project's six key objectives and outcomes have been achieved:

1. *The provision of operational and strategic leadership and interdisciplinary connection for the existing and developing communities of practice in STEM disciplines across the four project universities and further spreading to the wider sector.* This was achieved through:

- Six project newsletters
- The website, detailing teaching resources and artefacts
- The case study monograph
- The case study videos
- The STEM Ecosystem Showcase and Expo

2. *The provision of opportunities for current STEM staff to demonstrate, lead and collaborate by utilising existing STEM courses in cross-disciplinary projects that drew together the commonality of STEM discipline skills.* This was achieved through:

- The case studies at three universities
- The case study videos
- Peer reviews of leadership capacity
- The two conference presentation and two journal articles
- The case study monograph

3. *The connection of STEM academic staff with current industry leaders.* This was achieved through:

- Staff/industry mentoring
- Vivid 2015, Sydney, 2015
- Industry-based projects at Katherine Communities
- The Urban Ecology Symposium, 2015
- WorldSkills demonstration event Perth, 2014
- The industry roundtable, 2014
- The STEM Ecosystem Showcase and Expo, 2016

4. *The enabling of confidence and capacity-building in STEM academics, including early career academics.* This was achieved through:

- The five case studies at three universities
- The student engagement and qualitative feedback data
- The course evaluation (CES) data
- Industry employment invitations to students
- The STEM Ecosystem monograph

5. *The creation and links into, existing learning and teaching repositories of best practice approaches to integrated cross-disciplinary courses and projects.* This was achieved through:

- The project website uploads and downloads
- The case study videos
- Links with CUBNET/BEAN

6. *The creation of national leadership recognition of cross-disciplinary STEM learning and teaching.* This was achieved through:

- The STEM Ecosystem Showcase and Expo event
- The STEM industry roundtables
- The STEM Ecosystem monograph
- The conference and journal papers
- The WorldSkills Expo demonstration in Perth
- The Water Innovation Challenge, (WIC) Expo in Singapore
- Commendations from the Vice Chancellor and Deputy Vice Chancellors at The Sydney University

The STEM Ecosystem project team has identified a range of potential opportunities for the continued building of future STEM cross-disciplinary capacity in academic staff, the development of cross-disciplinary skills in STEM graduates and the involvement of industry in cross-disciplinary STEM learning. These opportunities and recommendations are:

- The effectiveness of partnerships between school, vocational education and training providers, research agencies, universities, STEM professionals and businesses be further explored and evaluated through:
    - The trialling of STEM cross-disciplinary work-integrated models of learning and teaching at non-partner universities; and
    - The continuation of existing cross-disciplinary courses, workshops and learning innovations at the lead and partner universities.
- The National Innovation and Science Agenda (2015) be advanced through:
    - The compulsory inclusion of a cross-disciplinary work-integrated unit/courses in all undergraduate STEM degrees in Australian universities.
- To meet the demand of today's STEM careers and professions of the future, the skills of STEM graduates should be further explored through annual industry roundtables sponsored by DVCs Academic/Education and PVCs Learning and Teaching in each of the lead and, partner universities. The roundtable be focussed upon:
    - Reports of Graduate Destination Survey's (GDS) and other employability data on STEM graduates;
    - Discussion and promotion of STEM cross-disciplinary initiatives across tertiary education;

- Presentations from key STEM leaders around cross-disciplinary learning opportunities and
- Presentation of a policy paper to government on the relevance and future employability opportunities in cross-disciplinary STEM learning.

- The STEM pipeline and the involvement of non-STEM discipline students in cross-disciplinary projects and learning approaches be enhanced through:
    - The assignment of academic credit to cross-disciplinary learning innovations, workshops and courses for non-STEM students.
- The repository of project artefacts and STEM resources on the project website be maintained through ongoing funding from the lead university.

STEM is an important part of our nation's development. This project has expanded the reach of STEM in universities and across tertiary staff. A thorough STEM strategy is about far more than simply igniting a passion for a particular STEM discipline in our classrooms. It is about applying STEM cross-disciplinary skills to enhance our capacity, which will translate into direct benefits for our society through improvements in our economy, new opportunities for our industries and advances in our standard of living. The changes we need to make demand commitment and a collaborative effort.

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Chapter 1 A STEM future

Setting the context

The importance of STEM disciplines for the future economic and social well-being of all Australians cannot be under-estimated: 75% of the fastest growing occupations require STEM skills and knowledge (Becker & Park, 2011). Increased participation in STEM-related tertiary education is fundamental to the economic and social well-being of the individual and the nation, yet the number and capacity of STEM graduates Australia produces from tertiary institutions is inadequate (OECD, 2011).

This demand for a well-qualified cross-disciplinary workforce in STEM disciplines is escalating. The Organisation for Economic Co-operation and Development (OECD, 2011) has highlighted the supply of skilled cross-disciplinary professionals in STEM, as an urgent global problem. This increasing global demand for cross-disciplinary STEM graduates is the result of a number of factors:

- The growing use and impact of information and communications technologies inter-woven across all STEM disciplines;
- The high rate of innovation fuelling rapid application of scientific advances in cross-disciplinary products and processes;
- The growth in more complex global interacting problems (climate change, global security etc); and
- The shift to more knowledge-intensive industries and services, not reliant upon single discipline responses.

STEM academics are central to meeting this increasing demand. The Australian Council of Deans of Science (2012) have highlighted that universities have a major role in meeting this demand. Threshold learning outcomes in STEM disciplines reflect a high degree of skills and knowledge commonality that complements and demands cross-disciplinary approaches. Expanding student options and providing work-relevant cross-disciplinary learning and teaching in STEM is fundamental to meeting Australia's needs. The interconnection between relevant cross-disciplinary STEM learning and teaching and the future skills and knowledge requirements of industry must be enhanced. More than ever before, STEM academics have a crucial role to play in preparing students for the global economy and the workforce of the future. Building and expanding STEM cross-disciplinary capacity in academic staff is integral to this preparation.

Global educational trends in the learning and teaching of STEM disciplines increasingly focus upon the need for cross-disciplinary industry-related approaches to student learning, that maximise opportunities for future employment and lifelong learning (Kuenzi, 2008). However in the Australian tertiary sector, STEM learning and teaching remains, for the most part, discipline-content entrenched. Rice (2011) noted that STEM disciplines in tertiary education are taught through "paradigmatic discipline-based examples" which are not practical, or reflective of real-life industry problems.

STEM disciplines are seen as opportunities to induct students into the content of the discipline, not as opportunities to develop cross-disciplinary skills or develop solutions to complex cross-

disciplinary problems. Efforts by STEM academics to undertake cross-disciplinary industry-related projects are rare and often not sustained. Silos of best practice cross-disciplinary projects remain and are not capitalised upon at the institutional level for the benefit of other tertiary STEM staff.

The ability of STEM academic staff to engage in ongoing cross-disciplinary learning and teaching practice is often compromised by skill shortages, lack of confidence, rapid technological change, lack of role-modelling by experienced academics and the discipline-specific learning and teaching demands of tertiary structures (Tytler, 2007). This results in STEM academics and their work-integrated projects in tertiary institutions offered in isolation of each other with STEM cross-disciplinary learning and teaching ad-hoc and not formally organised or embedded at the institutional level.

The needs of employers and future work opportunities do not recognise boundaries of discipline-specific education. Australian industries require individuals with skills and knowledge across a range of STEM disciplines. Threshold learning outcomes for STEM disciplines reveal commonality in these skills, yet leadership that nurtures and creates collaboration across STEM disciplines and fosters and grows confidence amongst STEM academic staff in promoting these common skills in cross-disciplinary work-integrated projects is often limited.

This project provided cross-disciplinary STEM leadership. It created a STEM Ecosystem for cross-disciplinary collaborative courses, workshops or innovations. It was led by RMIT University, and utilised STEM industry leaders from the CSIRO, Sunrise Health, Engineers Australia, Health Habitat, Vivid, WorldSkills, Amalgamated Metal Workers Union and Manufacturing Skills Australia. It drew together the STEM communities of practice at the partner universities and current ALTC/OLT project leaders. It created an environment of cross-disciplinary scholarship in learning and teaching that nurtures, models, develops, showcases and disseminates cross-disciplinary projects. This environment functioned as an Ecosystem, where best practice was exchanged and promoted, and relied upon collaboration and innovation. Based upon the skills ecosystem model (Finegold, 1999) it created opportunities for developing staff capacity across the STEM disciplines and leadership opportunities to demonstrate these capacities. The ecosystem, through the STEM Ecosystem industry roundtable and Showcase and Expo (April 2016) will bring together local and national leaders in STEM cross-disciplinary activity.

Why is leadership in STEM learning and teaching needed?

Current educational trends in the learning and teaching of STEM disciplines focus upon the need for cross-disciplinary approaches to student learning, that maximise the opportunities for future employment and lifelong learning (Kuenzi, 2008). Research shows that integrative and cross-disciplinary approaches improve students' interest, engagement and learning in STEM (Reiss & Holman, 2007). Cross-disciplinary approaches act as a motivator for teaching staff and provide cognitive benefits to students as well. However, the nature of tertiary STEM disciplines often mitigates cross-disciplinary approaches (Brown, 2010).

This project, by providing an ecosystem of senior STEM academics who were able to lead, encourage, demonstrate and mentor staff in best practice cross-disciplinary learning and teaching, was an inspiration for innovation and change within STEM disciplines. Academic staff were supported and encouraged to move away from "paradigmatic examples" of STEM teaching (Rice,

2011) and through the confidence gained by senior academic support, trial new approaches in their own institutions.

STEM academic staff were empowered by their involvement in the ecosystem and the industry mentoring opportunities. The ecosystem model was a mesh network of inter-connected individuals, who drew skills and knowledge from role-modelling and mentoring, and who trialled new approaches to effect change in their own teaching, and also inspire and motivate others to change. The project approach and industry-led reference group has been able to expand the ecosystem to future academic staff, to other universities and to industry bodies through its senior representation.

The project outcomes

The primary outcome of the STEM Ecosystem was to foster leadership potential for health, science and engineering staff at a range of levels, building staff capacity and confidence in STEM cross-disciplinary pedagogy. The project achieved the following outcomes:

1. Increased capacity of STEM academic staff to design, develop and lead industry-relevant cross-disciplinary courses;

2. The formalised engagement of STEM discipline learning and teaching staff with the ecosystem;

3. An increased number of STEM staff-initiated cross-disciplinary learning and teaching projects;

4. Improved understanding and awareness of specific learning and teaching strategies to maximise the outcomes for students engaging in STEM cross-disciplinary projects;

5. A teaching and learning repository of cross-disciplinary STEM resources;

6. Improved national and international connectivity and leadership for STEM learning and teaching academic staff; and

7. Embedding of cross-disciplinary learning and teaching strategies in discipline curriculum.

Chapter 2 Creating the ecosystem

Approach and methodology

The rationale for this project was based upon four key imperatives:

- The critical industry need for STEM graduates who can demonstrate cross-disciplinary application of their skills for future Australian and international workplaces;
- The significance and importance of providing a leadership structure (Ecosystem) for building capacity in STEM academics in cross-disciplinary teaching;
- The commonality of threshold learning outcomes across STEM disciplines; and
- The pedagogical need to encourage STEM academics to design and develop integrated, cross-disciplinary approaches to learning and teaching in industry-driven projects.

This project was built upon the concept of skills ecosystems as the basis for the approach (Buchanan, Baldwin & Wright, 2011). The concept of ecosystems as models for the mentoring of leadership projects and the promotion of skill networks is well grounded in the literature (Hargreaves, & Fink, 2004). Skills ecosystems act as leaders in their environment and provide leadership opportunities for those involved in them. Introduced by Finegold (1999) in his examination of knowledge and skill creation and transmission in the cluster of computer and biomedical firms in the Silicon Valley, USA, the concept has been used in and across various industries as a self-sustaining management model (Buchanan, 2006).

Further literature has developed the ecosystem concept to apply to environments that foster entrepreneurial skill development and those that foster regional, national and international networks of potential leaders (Hall & Lansbury, 2006; Schwalje, 2011). Over the last decade the concept of skills ecosystems as leadership catalysts has been recognised by Australian Governments, with funding in 2003 to a skills ecosystem national program of joint state-federal developments that tested new and dynamic frameworks for leadership. One outcome of the national program was partnership projects between tertiary institutions and industry that focussed upon improving staff capacity and the use of cross-disciplinary skills. A key finding of the nationally funded projects was their ability to highlight aspects of the ecosystem environment that influenced the development, application and replenishment of skills and leadership opportunities for staff working within the ecosystem (DETA, 2007).

The role of skills ecosystems and their success in sustained change by exposing individuals to new forms of work and leadership roles within a supportive workplace environment has been identified in Australia by Buchanan, Baldwin and Wright (2011). Building upon this literature and the previous learning and teaching innovations of the project team members, this project used the skills ecosystem model to bring together discipline academics to generate positive, mutually reinforcing dynamics to fuel ongoing knowledge creation and growth of personnel into leaders able to provide learning and teaching direction for STEM cross-disciplinary projects.

The four key features of an ecosystem that are necessary for successful innovation, development change and dissemination (Finegold, 1999), form the methodological stages of this project:

- A supportive host environment, where ideas and early career teaching and learning staff can be mentored and test new ideas;
- A catalyst for “being” and “remaining” through the cross-disciplinary courses;
- Continual nourishment or cross-fertilisation of ideas to encourage and stimulate change and development through the industry roundtable and STEM conference; and
- A high degree of independence, free from previous or existing discipline silos.

By adapting the ecosystem leadership concept to STEM staff, this project built upon existing research and provided learning and teaching leadership for STEM academics, the wider institutions and the tertiary sector. This project utilised the key features of skills ecosystems to engage STEM discipline staff as cross-disciplinary leaders and created an ecosystem of interdependent networks and collaborative leadership frameworks under the STEM banner.

A total of five case studies were completed and showcased in the project. The case studies were situated in diverse disciplines at three universities: RMIT University, The University of Sydney and University of Southern Queensland. Each university nominated within their case study particular programmes that were deemed cross-disciplinary learning models. As a result, five different programmes and cohorts emerged from the case studies: 3 models at RMIT University, one model at The University of Sydney and one model at the University of Southern Queensland. Each of the case studies has been further explained and detailed in the STEM monograph and the project website.

The 24-month project had four distinct phases. Several of the phases were overlapping and ongoing during the project. The project model (Ecosystem) also allowed for continuing development beyond the life of the project. The four detailed project phases were:

Phase 1- Catalyst (Seeding/planting the ecosystem)

In this phase, the project focussed upon the creation of a STEM Ecosystem and the creation of the STEM cross-disciplinary projects, workshops or courses. The formalisation of the ecosystem was undertaken through the establishment of the e-newsletter and the creation of the STEM learning and teaching website. The ecosystem instigated cross-disciplinary activity in Engineering, Health, Mathematics and Science at the lead university. In this phase the Water Innovation Challenge workshop at RMIT was the case study leader. The project was led by STEM academics and included mentoring by experienced STEM academics at The University of Queensland and role modelling by STEM industry members. The client was Health Habitat.

Phase 2 – Nourishing

This phase of the project nourished the ecosystem and built upon the experiences, knowledge and leadership of the STEM academics to sustain interest. STEM cross-disciplinary best practice was introduced into an existing course at the lead university - Sustainable Systems Engineering. The

case study - Katherine Project - was completed. Staff, including an early career academic used the course to test new ideas and refine learning and teaching experiences to enable dissemination and modelling for other STEM academics in other universities. The STEM academics were able to draw mentoring and senior support from the ecosystem. Mentoring was also used at this stage to ensure industry participation and follow-up. At the lead university, the courses were organised to count for course credit for STEM students. During this phase, the e-newsletter and the project video formed a vital link in communication and dissemination.

Phase 3 – Support (Growth phase)

This phase of the project was aimed at supporting the STEM academic leaders as they further developed and embedded industry advice and feedback about the cross-disciplinary projects. Two of the partner universities (The University of Sydney and University of Southern Queensland) trialled parts of the cross-disciplinary courses as appropriate to their contexts. A third leadership STEM model was introduced at the lead university, the Urban Ecology Symposium. This phase was also focussed upon the formal recognition of this leadership through academic publications and conference presentation (ACEN 2014, HERDSA 2015, ICE 2015). Throughout this phase further development of the STEM academics as leaders was continued through mentoring and their involvement in the e-newsletter and the conference publications.

Phase 4 - Independence (Diaspora)

This phase of the project was strongly focussed upon the STEM academics as leaders through the establishment of networks and ongoing activities to ensure their skills and knowledge were continually developed and retained beyond the life of the project. A major outcome of this phase will be the STEM Expo and Showcase (April 2016), which will create further leadership opportunities for STEM academics and an Australia-wide STEM network of emerging learning and teaching leaders.

Data collection

Data for the case studies was collected from teaching staff, industry mentors and students enrolled in the cross-disciplinary projects to understand the learning and teaching outputs of the cross-disciplinary activity. These data were collected in semi-structured interviews and in survey format (Appendix B). All students enrolling into the courses or workshops were invited via email to register their interest in cross-disciplinary learning experiences and their interest in being interviewed as part of the research project. Academic staff and students who agreed to be involved in this research answered a series of 5 questions about the learning activities and their opinion of the value of such learning activities. Analysis was undertaken both quantitatively and qualitatively and by an independent project manager, using software and survey tools. The survey relied on aggregate data only, and semi-structured interviews were also conducted with individual student and staff.

Project timeline

Table 1 shows a list of project phases and events over time in the project.

Table 1: Project timeline over 24 months including project phases and project deliverables

Project timeline	1/2/14-31/7/14 (6 mths)	1/8/14-30/1/15 (6 mths)	1/2/15-31/7/15 (6 mths)	1/8/15-31/1/16 (6 mths)
Phase 1: Build Ecosystem of senior and emerging STEM academics, courses commenced, communities practice united in ecosystem *Deliverables:* • STEM Ecosystem industry roundtable • STEM Ecosystem e-newsletter • Two cross-disciplinary courses • Industry mentoring: CSIRO/EA • Evaluation process commences				
Phase 2: Secondment of emerging STEM academics, STEM courses, STEM project video produced *Deliverables:* • Mentoring by UQ staff • Two cross-disciplinary ecosystem courses • STEM Ecosystem e-newsletter • Academic publications in peer-reviewed works • Industry mentoring: EA/MSC				
Phase 3: Continuation of STEM/industry courses and ecosystem *Deliverables:* • STEM Ecosystem Industry Roundtable (sponsored) • STEM Ecosystem e-newsletter • Two cross-disciplinary courses at two partner universities • Project video clip • Mentoring by UQ • Evaluation process continues				
Phase 4: STEM Learning and Teaching leadership network established *Deliverables:* • STEM Ecosystem conference • STEM Ecosystem monograph • Academic publications in peer-reviewed works • STEM ecosystem learning and teaching repository (electronic) • Final project report • Evaluation process completed				

Chapter 3 STEM Ecosystem resources and outputs

Project resources and outputs

The STEM Ecosystem project utilised the skills and capacity of the project team and the project reference group to achieve a vast number of outputs across a broad range of engagement. Table 2 shows a summary of project outputs against the project deliverables.

Table 2: Project outputs and evidence against project deliverables

Project Deliverables	Evidence
Staff-led cross-disciplinary STEM learning and teaching projects across lead and partner universities	• **Water Innovation Challenge, Singapore** - RMIT University, Semester 1, 2014 • **Katherine Project** - RMIT University, Semester 2, 2014 • **Urban Ecology Symposium** - RMIT University, Semester 1, 2015 • **Vivid 2015**, The University of Sydney - Semester 1, 2015 • **Engineering the Paramedic Experience** University of Southern Queensland - Semester 2, 2015
A STEM Industry Roundtable	• **Industry Breakfast**: "*What does industry want in STEM Graduates?"* November 2014 (50 invited guests from industry and education attended the event) (Appendix C)
Multi-mode resources – Project e-newsletter, project video and STEM monograph	• **E –Newsletter** – Six issues have been published and distributed to mailing list (Appendix D - I) • **Project videos** – four videos have been produced • **STEM monograph** (peer reviewed) – Cross-disciplinary courses (case studies) form chapters in the monograph – release date 11 April 2016
Academic publications in peer-reviewed works	• **Conference poster and pecha kucha presentation** – "The STEM Ecosystem Project: building cross-disciplinary industry-led work-integrated learning in science, technology, engineering and mathematics" (ACEN, October, 2014) (Appendix J) • **Peer reviewed conference paper** – "Navigating the lifelong learning boat through uncharted water" (HERDSA, July, 2015) (Appendix K: Abstract) • **Peer reviewed publication** – "Making something out of mathematics," (Journal of Educational Leadership, October, 2015 issue, in press) (Appendix L: Abstract)
A STEM learning and teaching conference in early 2016	• **STEM Ecosystem Showcase and Expo** - 11 April, 2016, RMIT University
A STEM learning and teaching repository that is electronic and interactive	• **STEM Ecosystem google website** has been established. Newsletters, videos and project documents and resources arising from the case studies are available on the website https://sites.google.com/site/stemecosystemproject/

Additional project outputs include:

- The WorldSkills Expo demonstration in Perth 2014
- The Water Innovation Team Challenge in Singapore 2014
- RMIT University Teaching Award for the Water Innovation Challenge project, 2014 awarded to a collaborative team across STEM disciplines for their innovation in delivery and outcomes
- Framework for future STEM projects (Appendix M)
- Checklist for STEM cross-disciplinary projects (Appendix N)
- Commendations from VC and DVCs (The Sydney of University), Vivid 2015
- Newspaper print and video, Vivid 2015, The Sydney of University, published recognition of the cross-disciplinary STEAM team and emphasised the impact on the student learning experience

Factors critical to success

The STEM Ecosystem project has been a great success on many measures. The project team have identified some factors that were critical elements of this success. These include:

- The involvement of The University of Queensland as partner was vital to both phase one and two of the project as their track-record in cross-disciplinary learning and teaching provided valuable mentoring to build staff capacity at the other institutions. The involvement of The University of Queensland as a project mentor in the project also fuelled on-going exchanges with emerging practice in the partner and other universities.
- Collaboration and sharing of good practice across the partner universities greatly enhanced the development and evaluation of the case studies, and was seminal in the development of the STEM Ecosystem.
- The involvement of senior learning and teaching ALTC/OLT scholars on the project group along with industry partners from the CSIRO, Manufacturing Skills Australia and Engineers Australia on the reference group ensured that the results were widely disseminated and reviewed for impact across the sector and in STEM industries.
- The involvement of students in all aspects of the project, especially in the evaluation and dissemination of the outcomes.
- The energy, efforts and enthusiasm of the staff who led the case studies, which readily transferred to the students and assisted greatly in their engagement and learning experiences.

Implementation of outcomes in a variety of institutions

This project combined and connected expert and respected teams of researchers in the area of STEM education. All of the project team hold or have held leadership roles either within their discipline or their institution and all have wider sector networks. The team has a viable communication plan involving the professional bodies (Engineers Australia, Manufacturing Skills Australia) and industry to further develop the project outcomes for long-term change in STEM learning and teaching leadership. The project reference group was heavily weighted towards STEM leaders in their industry associations or organisations. This enhanced not only industry dissemination and embedding of the project outcomes, but offered opportunities for active leadership and role modelling to the academics in the STEM Ecosystem.

These factors have resulted in the following implementation of outcomes across institutions:

- On-going STEM cross-disciplinary course offerings at RMIT University (Sustainable Systems Engineering, MIET 1280)
- The University of Sydney involvement in Vivid Sydney from 2016 onwards
- Cross-disciplinary course elective offering at USQ in STEM disciplines, “Engineering the Paramedic Experience”, 2016
- Maintenance of STEM Ecosystem website for a further three years by RMIT University
- Anticipated attendance of over 150 academics from six institutions at the STEM Ecosystem Showcase and Expo, April, 2016
- Distribution of the STEM Ecosystem monograph to 38 Higher Educational institutions nationally.

STEM Ecosystem project linkages with the OLT's program objectives

The OLT promotes and supports change in Higher Education institutions for the enhancement of learning and teaching. The outcomes of the STEM Ecosystem project address the following OLT program objectives for leadership for excellence in learning and teaching grants (Table 3):

Table 3: OLT program objectives for leadership for excellence in learning and teaching grants against project outcomes

Office for Learning and Teaching Objectives	STEM Ecosystem Achievements
Promote and support strategic change in higher education institutions for the enhancement of learning and teaching, and the benefit of the student experience	• Five STEM leadership cross-disciplinary case studies across three universities: RMIT; Uni Syd; USQ
Raise the profile and encourage recognition of the fundamental importance of teaching in higher education institutions and in the general community	• WorldSkills Expo demonstration event, 2014 • Vivid 2015, Sydney • Urban Ecology International Symposium, 2015 • WIC, Singapore showcase event, 2014 • Teaching award, RMIT University, 2014 • Commendation VC The University Sydney, 2015
Develop effective mechanisms for the identification, development, dissemination and embedding of good individual and institutional practice in learning and teaching in Australian higher education	• STEM Ecosystem monograph featuring the various case study approaches • Six nationally distributed newsletters • Four videos featuring each of the case studies • Four conference papers/presentations (ACEN 2014: HERDSA 2015; ICE, 2015; BEAN/CUBENET 2015) • STEM Ecosystem website of project resources • STEM Ecosystem Showcase and Expo, 2016
Identify learning and teaching issues that impact on the Australian higher education system and facilitate national approaches to address these and other emerging issues	• Framework for future STEM projects • Health Habitat/RMIT contract, 2015 • STEM Ecosystem Showcase and Expo, 2016
Develop and enhance a deep understanding and knowledge of the learning process appropriate to the disciplines being taught	• Public website of resources • New cross-disciplinary STEM course at USQ

STEM Ecosystem project links with the OLT's strategic priority areas

The STEM Ecosystem project addressed two out of the four OLT strategic priority areas for leadership for excellence in learning and teaching (2013, p.10).

1. **Consolidating leadership by building on the outcomes of projects funded in earlier years under the Leadership for Excellence in Learning and Teaching Program**

- ALTC project: CUBENET/BEAN (Professor Poronnik, The University of Sydney, Universities Biomedical network, 2012)
- Lifelong Learning Pathways (Mills & McLaughlin, 2010-2012)
- ALTC Discipline Scholar for Engineering (Professor Hadgraft, Central Queensland University)
- OLT National Teaching Fellow 2012 in STEM networks (Dr Liz Johnson)
- OLT National Teaching Fellow 2013 in STEM workforce (Professor Pauline Ross)

Members of the project team and reference group were represented in various capacities in these projects, ensuring collaboration and on-going opportunities for sector-wide implementation of project outcomes.

2. **Disciplinary and cross-disciplinary leadership to enhance learning and teaching through leadership capacity-building in discipline structures, communities of practice and cross-disciplinary networks**

- Five STEM leadership cross-disciplinary case studies across three universities: RMIT University; The University of Sydney; University of Southern Queensland
- STEM Ecosystem monograph featuring the various case study approaches
- Public website of project resources and information
- Six nationally distributed newsletters over 24 months
- Four videos featuring each of the case studies
- Four conference papers/presentations (ACEN 2014; HERDSA 2015; ICE 2015; BEAN/CUBENET 2015)
- STEM Ecosystem Showcase and Expo, April, 2016
- WorldSkills Expo demonstration event, 2014
- Vivid 2015, Sydney
- Urban Ecology International Symposium, 2015
- WIC, Singapore showcase event, 2014

Chapter 4 Dissemination, evaluation and impact

Dissemination

The project deliverables enhanced dissemination and improved sector-wide understanding of the need for STEM cross-disciplinary projects and the ongoing development of STEM academic staff as learning and teaching leaders. On-going dissemination during the project allowed the opportunity to receive feedback, the potential to continually attract STEM academic staff and the capacity to modify the ecosystem based on feedback. This strategy offered a chance to involve external and new stakeholders, to establish informal partners and to extend ownership. The dissemination strategy adopted in this project involved senior academics from partner universities who were in a position to bring about change in learning and teaching practices at their institutions.

Dissemination of the project through information provision

This involved the distribution of information in written form to universities, professional bodies and accrediting authorities. Distribution occurred throughout the life of the project in accordance with the staged methodology. Distribution channels included emails, the STEM learning and teaching repository, formal peer-reviewed papers, staff development guidelines, website information, e-newsletters, videos and the STEM Learning and Teaching Showcase and Expo (April 2016).

Dissemination of the project through engagement

This approach was an extension of disseminating the research and aimed at promoting acceptance and adoption of the project outcomes at other institutions. The dissemination initiatives included:

1. STEM Academics Network: Forming an ecosystem of STEM academics who will advocate change in STEM learning and teaching based on evidence and innovative exemplars of courses and cross-disciplinary projects.

2. Conferences: Project participants presented at relevant conferences and reported project findings to the wider sector. STEM Ecosystem Showcase and Expo and STEM workshops in conjunction with Higher Education Conference will be held in April 2016.

3. STEM Monograph: Best practice learning and teaching STEM cross-disciplinary work was developed through the STEM Ecosystem and formed the basis of the monograph on successful STEM projects across Australian tertiary institutions.

Evaluation

Evaluation occurred continuously throughout the project. The evaluation framework was undertaken by an independent expert academic, Professor Tony Luff. Professor Luff, a retired academic from Monash University has extensive experience in tertiary education quality review processes, and was familiar with STEM learning and teaching research and leadership models. Professor Luff attended a range of project team and reference group meetings and provided advice and support for the project. The evaluation focussed on the content and design of the project, with results disseminated to project staff. At the later stages of the project (18-24 months) his summative evaluation provided an overall perspective of the project, focussing upon the value of the project for accountability and continuation purposes. The final evaluation report is provided as an attachment (Appendix O).

Impact

This project was funded before the implementation of the IMPEL ladder, and as such, the project team did not complete an impact plan prior to commencement of the project. However, the project impacts have been summarised in Table 4 for convenience.

Table 4: Project impact mapped to the IMPEL model (Tilly Hinton, OLT resource, 2014)

	Anticipated changes at:			
	Project completion	**Six months post-completion**	**Twelve months post-completion**	**Twenty-four months post-completion**
Team members	- New partnerships with STEM educators in other universities - New partnerships with STEM industry formed	- Four Peer reviewed journal papers submitted for publication	- Four Peer reviewed papers published and cited - Conference presentations at HERDSA & ISSOTL	- Project work provides evidence for team member academic promotion and successful future grant applications
Immediate students	- STEM student enrolments in cross-disciplinary course/workshop maintained	- New STEM programme offerings at USQ, Uni Syd.	- STEM students involved in mentoring into the cross-disciplinary courses/workshops	- GST evidence of satisfaction of cross-disciplinary courses/ workshop
Spreading the word	- Hits, views and links into project website - project videos, newsletters, publications and monograph	- STEM Showcase and Expo event, April 2016	- Hits and views on project website	- Unsolicited requests for further copies of monograph, videos or website material
Narrow opportunistic adoption	- Cross-disciplinary courses continue at lead institution	- Partner unis invited to present at the STEM Showcase and Expo event, 2016		- Project team members invited to CUBENET/BEAN 2016
Narrow systemic adoption	- Project team members invited to join other STEM projects and grant applications		- Partner unis continue to offer cross-disciplinary courses/workshops	
Broad opportunistic adoption	- Non partner unis request additional copies of monograph, videos and case study guides		- Non partner unis offer STEM cross-disciplinary courses	Demonstrations at WorldSkills - Expo and Showcase, 2016 and Vivid Sydney, 2016
Broad systemic adoption			- Project recommendations noted by Office of Chief Scientist in policy papers	

The impact of this project will also continue after the project finishes. The STEM Ecosystem has created its own learning and teaching momentum which will be self-sustaining. A number of other mechanisms will also assist, including:

- Academic publications in high quality journals so that results are widely available for reference and future research;
- The STEM Ecosystem monograph which will be sent to all Heads of School of STEM disciplines and relevant university STEM leaders both nationally and internationally;
- The STEM Ecosystem website, which will be maintained three years post-project by lead institution; and
- The 2016 STEM Showcase and Expo event, which will impact upon approximately 150 academics and students.

Chapter 5 Conclusion and recommendations

> *"The global economy is changing. New technologies and smart companies lead. New industries and new sources of wealth are emerging. New skills are required for workers at all levels. Australians must decide whether we will be in the forefront of these changes or be left behind"* (Office of the Chief Scientist, 2014).

STEM skills are critical to the economic management and success of Australia. STEM skills are the lifeblood of emerging knowledge-based industries, such as biotechnology, information and communications technology (ICT) and advanced manufacturing, and provide competitive advantage to established industries such as agriculture, resources and healthcare. These are all industries and global networks to which Australian graduates will be drawn. An education in STEM fosters a range of generic and quantitative skills and ways of thinking that enable individuals to see and grasp opportunities. These capabilities, including deep knowledge of a subject, creativity, problem solving, critical thinking and communication skills are relevant to an increasingly wide range of occupations. They will be part of the foundation of adaptive and nimble workplaces of the future. This project has demonstrated leadership in STEM education by using these capabilities as the basis for cross-disciplinary teamwork projects that have enhanced student discipline learning and built capacity in STEM discipline academics.

The STEM Ecosystem project has achieved all of its objectives and created sustainable evidence to maintain the momentum in STEM leadership capacity beyond the project. Table 5 illustrates the project's objectives against outcomes and achievements.

Table 5: Project objectives and project achievements

STEM Ecosystem Objective	Project Outcome/Achievement
The provision of operational and strategic leadership and interdisciplinary connection for the existing and developing communities of practice in STEM disciplines across the four project universities and further spreading to the wider sector	• Six project newsletters • Interactive website, detailing teaching resources and artefacts • Case study monograph • Case study videos • STEM Ecosystem Showcase and Expo, 2016
The provision of opportunities for current STEM staff to demonstrate, lead and collaborate by utilising existing STEM courses in cross-disciplinary projects showing the commonality of STEM discipline skills	• Case studies at three universities • Case study videos • Peer reviews of leadership capacity • Conference and journal papers • Case study monograph
The connection of STEM academic staff with current industry leaders	• Staff/industry mentoring • Vivid 2015, Sydney • Industry–based projects at Katherine Communities • The Urban Ecology Symposium, 2015 • WorldSkills demonstration event Perth, 2014 • Industry roundtable • The STEM Ecosystem Showcase and Expo
The enabling of confidence and capacity-building in STEM academics, including early career academics	• Five case studies at three universities • Student engagement and qualitative feedback data • Industry employment invitations to students • STEM Ecosystem monograph
The creation and links into, existing learning and teaching repositories of best practice approaches to integrated cross-disciplinary courses and projects	• Project website uploads and downloads • Case study videos • Links with CUBENET and BEAN
The creation of national leadership recognition of cross-disciplinary STEM learning and teaching	• STEM Ecosystem Showcase and Expo • STEM industry roundtable • STEM Ecosystem monograph • Conference and journal papers produced • WorldSkills Expo demonstration in Perth • WIC Expo in Singapore • Commendations from VC and DVCs at Sydney University

Challenges

Successful adoption of the ecosystem and the showcase case studies by the lead and partner universities involved a number of challenges. These included:

- Level of enthusiasm, confidence and experience of academic staff not directly involved in the project to engage in the process;
- Level of understanding of the importance of pedagogy in STEM cross-disciplinary projects;
- Appropriate administrative support and resources being available to assist with the daily running of the projects;
- The willingness of academic staff to balance their workload to implement the cross-disciplinary courses/workshops; and
- Appropriate encouragement, support and recognition of the value of the projects by senior management of the university.

Recommendations

Australia's STEM tertiary academics must be equipped to deliver course content with confidence and inspiration, and develop all students to their full potential. Curricula and assessment criteria should prioritise curiosity-driven and problem-based learning of STEM—STEM as it is practised—alongside the cross-disciplinary knowledge that STEM requires. The tertiary education system must ensure that students not only acquire knowledge, but also learn how to apply and adapt this knowledge to a variety of contexts.

Students must have clear pathways from the classroom to a career in the future STEM economy. Our needs and our capabilities must align. Therefore the STEM Ecosystem project team recommends that:

- The effectiveness of partnerships between school, vocational education and training providers, research agencies, universities and STEM professionals and businesses be developed and evaluated through:
    - The trialling of STEM cross-disciplinary models of learning and teaching at non-partner universities over the next two to three years and
    - The continuation of existing cross-disciplinary courses, workshops and learning innovations at the lead and partner universities.
- The National Innovation and Science Agenda (2015) be advanced through:
    - The compulsory inclusion of cross-disciplinary work-integrated unit/courses in all undergraduate STEM degrees in Australian universities.

- To meet the demand of today's STEM careers and professions of the future, the skills of STEM graduates should be further explored through annual industry roundtables sponsored by DVCs Academic/Education and PVCs Learning and Teaching in each of the lead and partner universities.

The roundtable should be focussed upon:

  - Reports of Graduate Destination Surveys (GDS) and other employability data on STEM graduates;
  - Discussion and promotion of STEM cross-disciplinary initiatives across tertiary education;
  - Presentations from key STEM leaders around cross-disciplinary learning opportunities; and
  - Presentation of a policy paper to government on the relevance and future employability opportunities in cross-disciplinary STEM learning.

- The STEM pipeline and the involvement of non-STEM discipline students in cross-disciplinary projects and learning approaches be enhanced through:
  - The assignment of academic credit to cross-disciplinary learning innovations, workshops and courses for non-STEM students.
- The repository of project artefacts and STEM resources on the project website be maintained through ongoing funding from the lead university.

The STEM Ecosystem project recommendations also align with the following national policy documents and recommendations:

STEM: *Australia's Future*, Australia's Chief Scientist, September, 2014 (Office of the Chief Scientist, 2014).

1. Helping to teach STEM as it is practised, in ways that engage students, encourage curiosity and reflection, and link classroom topics to the 'real-world'
2. Using curricula and assessment criteria, to promote the development of long lasting skills—including quantitative skills, critical thinking, creativity, and behavioural and social skills—in parallel with disciplinary knowledge
3. Supporting the national interest by maintaining the pipeline of STEM graduates, and increase the recognition of STEM education and careers as a public good
4. Initiating mechanisms to encourage student uptake into STEM courses, with particular regard to presently less popular core STEM courses and subject
5. Advising students and explaining the value of study in the core STEM disciplines and the pathways to work it opens, not only in STEM-related fields

Vision for a Science Nation **Responding to STEM: Australia's future, Australian Government consultation paper, June 2015** (Commonwealth of Australia, 2015).

1. Accepting that universities need to continue to develop their courses to respond to the need to cultivate a more entrepreneurial culture in Australia. This could be done through entrepreneurial skills training embedded in formal university courses or extracurricular initiatives

2. Supporting the national interest by maintaining the pipeline of STEM graduates, and increasing the recognition of STEM education and careers as a public good

3. Increasing the cross-disciplinary skills of STEM graduates, to meet the demands of today's STEM careers and the professions of the future

4. Creating opportunities for community and greater industry engagement with science and technology

National Innovation and Science Agenda Statement: *Welcome to the Ideas Boom*, Office of the Prime Minister (Commonwealth of Australia, December 2015).

1. Inspiring STEM literacy through use of cross-disciplinary work-integrated teams

2. Expanding opportunities for women and other non-represented groups in STEM through industry role models and courses and networks that support workplace equality and

3. Equipping young Australians to create and use digital technologies

A final thought

STEM is an important part of our nation's development. This project has expanded the reach of STEM in universities and across tertiary staff. A thorough STEM strategy is about far more than simply igniting a passion for a particular STEM discipline in our classrooms. It is about applying STEM cross-disciplinary skills to enhance our capacity which will translate into direct benefits for our society through improvements in our economy, new opportunities for our industries and advances in our standard of living. The changes we need to make demand commitment and a collaborative effort.

We must not only celebrate the success of this STEM Ecosystem, but dream large of all students and staff understanding the value of cross-disciplinary STEM to address the challenges we face as a country, and to ensure we can maximise our opportunities in a rapidly evolving and increasingly competitive global economy.

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Appendices

The final report appendices have been published separately. Please refer to the following link

http://www.olt.gov.au/project-stem-ecosystem-building-cross-disciplinary-leadership-capacity-science-technology-engineerin

Appendices include:

Appendix A Deputy Vice-Chancellor Certification

Appendix B Staff and student survey questions

Appendix C Industry breakfast flyer

Appendix D – Appendix I STEM Ecosystem project newsletters

Appendix J ACEN Conference 2014 poster presentation

Appendix K HERDSA 2014 Conference paper

Appendix L Journal article 'Making something out of mathematics'

Appendix M Framework for future STEM projects

Appendix N Checklist for STEM cross-disciplinary projects

Appendix O External evaluation report

Appendix A Certification