Supporting STEM Curriculum Implementation with Professional Learning: The University of Sydney STEM Teacher Enrichment Academy

Judy Anderson
Director STEM Teacher Enrichment Academy
Sydney School of Education and Social Work
The University of Sydney

the corresponding author’s e-mail address: judy.anderson@sydney.edu.au

Abstract. Based on the need for schools to improve students’ capabilities in science, technology, engineering and mathematics (STEM) and to develop students’ 21st Century skills, school systems are implementing a range of STEM education initiatives. As there is no STEM curriculum in many countries, teachers are faced with designing new lessons and new subjects as well as developing new learning approaches. While secondary school teachers may have expertise in one of the STEM subjects, few have expertise in more than one so the need for professional learning support is critical to the success of such initiatives. A group of experts at the University of Sydney has developed one program that has produced positive outcomes for teachers and students. Members of the group from the STEM Teacher Enrichment Academy work with school teams to help them identify a clear purpose for their STEM initiative, to design a program to address the purpose and to support them in implementing and evaluating the program with their students.

1. Introduction
Unlike other countries, it is not compulsory to study mathematics or science in the senior secondary school (grades 11 and 12) in most Australian states and territories. While enrolment patterns in mathematics and science subjects revealed small declines in the 1990’s, there have been larger declines since 2000[15] and in the state of NSW, there has been a 13% decline since 2001 of students studying the more challenging calculus-based mathematics courses – necessary pre-requisites for many tertiary STEM degrees[17]. There are also declining enrolments in some STEM-related degrees at university level with declines in the number of mathematicians and scientists in the workforce and predictions that Australia will need many more to meet workplace demands into the future [19]. Coupled with these concerns, Australia’s performance on the international assessments of TIMSS and PISA, has declined with fewer students meeting the highest benchmarks [21].

There are many factors influencing student engagement in secondary schooling. An investigation was conducted into the lower participation of students in senior mathematics in Australia, by surveying teachers and careers advisors, and conducting focus group meetings with students [18]. Of the four main factors identified in the report, poor pedagogical practices, perceived level of difficulty,
perceived relevance of mathematics are three key issues worthy of investigation in the STEM context. Many students also perceive science subjects to be difficult and uninteresting and frequently make decisions early in their schooling to discontinue their study as soon as possible [14,8]. One strategy to counteract these issues suggests mathematics and science should be taught using inquiry-based learning through real-world problems, allowing students to see the relevance of the content they are learning, particularly if the subjects are connected or integrated [8]. While subject integration is not a new concept, connecting mathematics and science curriculum with the other STEM subjects of technology and engineering has the potential to enhance student engagement and develop students’ 21st Century skills [6,23].

Integrated learning can be implemented in classrooms in multiple ways [8] which could involve connecting content, connecting processes or using themes to link key ideas. Further, integrating curriculum could involve a multidisciplinary approach, where teachers from two or more of the STEM subjects co-design integrated tasks, lessons or units of work so that students have a synthesised, integrated approach to learning STEM content [6]. To date, there has been little research conducted into the efficacy of STEM integration and application in secondary classrooms [4,12] but there is some evidence to suggest that STEM integration is successful in increasing student engagement within mathematics classrooms [24]. Based on the assumption that students benefit from opportunities to connect knowledge across the curriculum, a professional learning approach was developed to support teachers in planning and implementing connected approaches in primary and secondary schools.

Since its inception in 2014, the STEM Teacher Enrichment Academy has held 11 programs reaching more than 650 teachers in 120 secondary and primary schools in NSW, Australia. This paper describes the approach for secondary school teachers, presents the findings and subsequent changes to the program from the first two trials with 130 teachers from 25 secondary schools, describes the retrospective evaluation strategy for the secondary school programs delivered between 2014 and 2017, presents the overall large scale data evaluation strategy for 2018 onwards, and outlines some early evidence of the success of the STEM Academy for teachers and their students.

2. The STEM Teacher Enrichment Academy: Setting the Context
Since 2014, the Faculty of Education and Social Work has been collaborating with the Faculties of Science, and Engineering and Information Technology, to build the nation’s STEM capacity through teacher enrichment and professional development with the establishment of the STEM Teacher Enrichment Academy – see http://sydney.edu.au/stem/academy/. The academy’s flagship is a multi-day residential program for up to 70 secondary teachers of mathematics, science and technology designed to be foundational in enhancing teachers’ knowledge of content and pedagogy, and inspiring them to reinvigorate their classroom practice. The overall Academy aims were to:

1. support teachers’ knowledge and understanding of, and abilities to implement, pedagogical strategies promoting student engagement in STEM subjects;
2. enhance teachers’ knowledge of content and approaches to teaching mathematics, science and technology, demonstrated in their design and implementation of tasks and units of work;
3. encourage the development of multidisciplinary units of work and/or projects;
4. develop a community of practice between cohorts of STEM teachers by offering ongoing support and engagement through an evolving website, newsletters, and STEM events; and
5. develop teachers’ knowledge of STEM-related projects in the broader community as well as knowledge of STEM programs at University and STEM careers.

With a focus on examining content and processes from the STEM subjects, Academy sessions were facilitated by the University’s academic specialists and STEM leaders. The program involved a three-day residential session at the University followed by up to two full school terms developing, planning and implementing STEM strategies in school-based teams. Teachers then returned for a further two-day session at the University to share their experiences, present evidence of teacher and student learning, discuss issues and challenges, and consider future initiatives. Each cross-disciplinary school team of two mathematics, two science and two technology teachers worked together to develop
inquiry-based learning approaches to implement both within their subject discipline as well as across the subject disciplines [16]. Additional support was provided to school teams by professional mentors who visited participating teachers prior to, during and in between the two on-campus sessions.

Modelled on commonly agreed core features, the Academy professional learning approach incorporated a content focus, active learning, coherence, duration and collective participation [10]. Each session within the program focused on content from either one of the separate curriculum STEM subject areas, or sought ways to demonstrate how the content connected, overlapped or complemented curriculum topics. Participants were actively engaged in discussing practice, sharing ideas, and critiquing examples of STEM activities, projects, lessons or units of work. They also worked in their teams to review scope and sequence charts and school programs, to redesign their approach to implementing STEM on their return to school. With common shared goals, there was a clear purpose to our work providing coherence and clarity for individual teachers as well as school teams. The program was delivered over at least six months of a school year allowing time for design and trialling of programs, sharing of outcomes, and redesign for future implementation. Finally, we sought to strengthen individual teacher’s connections to their school teams, to encourage schools to share ideas and collaborate with other schools who identified similar challenges, and to develop a community of practice facilitated by an online Edmodo site where plans, resources and ideas were shared.

To evaluate the efficacy of the Academy approach, the first two trial programs were externally evaluated by academics from other Australian universities [2]. Both external teams used surveys of teacher participants and interviews with a sample of teachers but the second team also conducted two case studies of exemplary schools to seek students’ perspectives and to identify key drivers of school change supporting the implementation of STEM programs. A summary of the results of the two external evaluations is presented in the next section of this paper.

3. Outcomes from the First Two Trial Programs in Secondary Schools

For the first Academy, 60 teachers from 13 schools visited the University in November 2014 and returned in March 2015 (see Table 1 for sector representation). While most schools were Sydney based, four were clustered near a country town in the central West of NSW. This small country hub of schools enabled greater opportunity for collegiality, an essential ingredient given the small size of these schools with some teachers reporting feeling isolated and with limited access to quality professional learning. Like the first Academy, the second involved 70 teachers from 12 schools with a country hub of two larger schools from a regional town and took place in November 2015 with a subsequent return to the University in May 2016. When selecting each group of schools, we sought diversity in socio-economic status, gender composition, and size to provide a range of knowledge and experiences.

| Year | Department of Education | Catholic Systemic | Independent | Total schools |
|------|------------------------|------------------|-------------|---------------|
| 2014/15 | 8 (1 female) | 1 | 4 (2 male, 2 female) | 13 |
| 2015/16 | 7 (1 male) | 2 (1 female) | 3 (1 male, 1 female) | 12 |

Analyses of teacher data revealed the features most supportive of school team design and delivery of STEM approaches included the provision of planning time, mentor input, and the structure and content of the program which began with a focus on the separate STEM subjects, allowing teachers to develop new skills and pedagogical strategies, before exploring multidisciplinary approaches. Initially focusing on the individual STEM subjects was adopted because mathematics and science teachers make limited use of inquiry-based learning in lessons than is recommended in research and in curriculum documents [1,3].

3
Feedback from the external evaluations indicated teachers wanted more examples of STEM integration including sample tasks, projects, and lessons – interestingly, when we did provide such examples, it was not always evident to teachers how they might use them and how the tasks connected with curriculum requirements. Indeed, there appears to be a need to make the connections between the STEM subjects more transparent for teachers [12], particularly when they are presented with already-prepared multidisciplinary tasks. These observations further highlighted the siloed nature of secondary school teaching with teachers being most comfortable with their subject specialisation – to adopt a STEM curriculum perspective, teachers require horizontal expertise and they need to “boundary cross – stepping into unfamiliar domains” [7]. Teachers also need to come to terms with the issue of inconsistency in language in curriculum documents [12] although some have addressed this by focusing on the engineering design process or systems thinking [6]. Regardless of these concerns, all school teams developed and implemented a STEM approach and were willing to share their experiences (successes and issues) when they returned for the second on-campus session.

Because the schools were diverse, particularly in relation to whether the teachers from different subjects had worked together before coming to the Academy, the approaches they initially adopted were equally diverse. Some of the approaches used by Academy schools included:

1. embedding more cross-curriculum applications within regular subject-specific lessons (egs, exploring half-life in mathematics lessons; using virtual worlds in science to collect data to model and investigate real world ecological problems);
2. conducting multidisciplinary investigations in several STEM subject lessons to design solutions to problems (egs, improving the recycling system at the school; designing a new grandstand for the school football field);
3. undertaking an extended investigation over several weeks or school terms to design an artifact (eg, designing an energy efficient home on a nearby plot of land);
4. redesigning the STEM curriculum program for a whole grade around themes or big ideas such as mission to another planet; human diseases and prosthetics; and better parks and gardens;
5. creating a STEM elective for grade 9 and 10 students; and
6. inviting STEM speakers to the school to share their career pathways and experiences within a range of workplaces.

While this list may appear to be a rather eclectic set of approaches without any real cohesion, it recognises and accepts that schools were at different places in designing integrated curriculum and in embracing substantial change to curriculum design and delivery. Our acceptance of such diversity acknowledges that schools need to consider the needs of their students, the competence and interest of teachers, the overwhelming influence of siloed assessment in schools, and that real change takes time.

Our experiences from the first two Academy programs revealed some schools moved more quickly to developing multidisciplinary STEM approaches because of earlier experiences of writing integrated units of work, and working together as a team. Some teams were cohesive and had already worked on projects together, some teams were dominated by one or two teachers who already had a plan which they wanted to implement regardless of other teachers’ views, while other teams had never worked together on creative programming and curriculum design and needed to spend time getting to know each other. Team building and effective whole school planning have now become critical components of the Academy and these begin with each school before they attend the first session at the University. Preliminary planning meetings include the school principal and other school leaders who need to play a key role in supporting the development of STEM initiatives which frequently have implications for timetabling, teacher allocation to classes, alignment of STEM subjects on timetable lines, and resourcing. During the preliminary meeting, schools are encouraged to use school-based data to begin their planning.

A critical first component of designing a STEM strategy in any school is defining a clear purpose or vision for the school. We encourage schools to use data to help develop a STEM plan and to identify any issues they may want to address – the types of data they might use include:

- enrolment patterns in the STEM subjects in grades 11 and 12;
post-school university degrees and other programs their students pursue;
• National Assessment Program for Literacy and Numeracy (NAPLAN) data and other school-based assessment data;
• student attitude, engagement and aspirations data;
• parent and community interests and expectations; and
• teacher knowledge, interests and experiences.
School team members may also wish to use research to help develop their plan including information about:
• improving attitudes to mathematics and science [22]
• breaking down silos to develop 21st century skills [9];
• promoting ‘real world’ problem solving in teams [20];
• improving the uptake of higher level mathematics, science and technology in senior grades [17]
• increasing female student enrolments in STEM subjects in the senior grades [17];
• increasing Indigenous student enrolments in STEM subjects [11];
• developing STEM literate citizens [6];
• preparing students for the workplace [6].
A vision statement could be developed from a purpose such as [6]:
If we want students to learn how to apply knowledge, their education experiences must involve them in both learning the knowledge of STEM disciplines and reacting to situations that require them to apply that knowledge in contexts appropriate to their age and stage of development (p. x).
Having developed a vision for STEM, school teams then need to develop policies, programs and practices for implementation [6]. These should all be accompanied by appropriate resourcing including team leadership, staffing, materials and support from other stakeholders such as parents and community members.
One of our greatest challenges in the STEM Academy has been building a community of practice between schools and participating teachers. While on campus, teachers willingly discussed ideas with teachers from other schools, and engaged in worthwhile sharing of resources and teaching ideas but after returning to school, teaching and other priorities quickly take over and appear to limit teachers’ capacity for ongoing sharing in the online community. In some schools, finding time to meet as a school team was enough of a challenge and proved to be an inhibiting factor in moving plans forward. For schools to become STEM Academy participants, we had requested principals provide time for teachers to work on their projects but this was not always achieved and remains another challenge to be addressed.
The two case studies of exemplary schools from the second STEM Academy program demonstrated how change in curriculum structures can be achieved with an enthusiastic and committed team leader who has school executive support. Both schools held regular STEM team meetings, developed strategies to share planning documents and files, were flexible enough to accommodate last minute changes to school routines which frequently took valuable time away from classrooms, informed parents and community members about their STEM projects and invited them to be involved, and took a broader perspective than just one class aiming to embed STEM project work across a whole grade with as many teachers involved as possible. Students were more engaged as they could showcase their work to the rest of the school, better understood how STEM can help to solve real-world problems, with at least some students reconsidering their aspirations and post-school STEM pathways. While the data presented in this section are limited to the first two programs, they did provide useful feedback and led to several changes in the Academy program – this approach to using teacher feedback for improvement has been ongoing with each program evolving to best meet the needs of teachers. However, our fundamental principles have remained the same with a focus on inquiry-based learning, embedded in curriculum requirements, involving cross-disciplinary teams of teachers from each school, collaboratively working together with Academy personnel to design and deliver quality multidisciplinary programs for their students.
4. A Retrospective Evaluation for STEM Academy Programs from 2014-2017

Since the first two Academy programs, we have been working with a post-doctoral research fellow (Dr Debbie Tully) to develop an overall evaluation strategy which was designed in two phases. Phase 1 took a retrospective approach to evaluation through interviews with past participating secondary schools from 2014-2017. Within this period 306 teachers from 57 schools participated and from this pool, semi-structured interviews were completed with participants from 20 schools: five principals, 18 STEM team leaders/teachers and nine STEM teachers. Interviews were conducted between six months to three years after their school’s involvement with the Academy to probe the STEM initiatives in their school, their perceptions of the impact of the Academy, adjustments made to their school’s curriculum to accommodate STEM teaching and learning, their involvement with communities of practice, partnerships with industry, and efforts to sustain STEM initiatives in their schools. All interviews were transcribed so that content analysis could be undertaken, as data were coded and labelled with the primary themes outlined in the STEM Academy’s aims and goals. Secondary themes were determined through an open coding process. The focus of Phase 1 was to evaluate how, and in what ways, the aims and goals of the STEM Academy were accomplished in schools after completion of the Academy program. Key findings are listed below under the two themes of sustainability and growth of STEM programs and the key drivers leading to sustaining and expanding STEM programs since participation.

4.1. Sustainability and growth of schools: STEM programs post Academy

Interviews with teachers from the 20 schools indicated:

- 95% of schools continue to offer their original STEM Academy project in their curriculum;
- 90% of schools have expanded STEM curriculum and projects beyond their initial Academy project;
- 65% of schools have added a grade 9 and 10 STEM elective subject;
- 85% of schools have an ongoing STEM professional learning team that regularly meets to plan, design and discuss the implementation of STEM curriculum; and
- 70% of schools have established links in forming a partnership with industry and/or local community organisations.

In addition, most schools are involved in STEM related student outreach programs and/or STEM related competitions with their local universities. While timetable issues were present in most schools, teachers and school leaders were creative in ways to work flexibly with their team to ensure program delivery. For most schools, their targeted STEM students (typically grades 7 and 8) have yet to reach their final year of school, but a few schools from the earlier Academy programs have indicated an increase in student interest to select STEM related subjects in the senior school.

4.2. Key Drivers in Partner Schools in sustaining and expanding STEM programs post Academy

As was indicated through the evaluation of the first two trial Academy programs, program success hinges on the support of school leadership and the executive team in providing time and resources to further STEM teaching and learning. This includes a team of dedicated teachers who meet regularly in a professional learning community to plan and implement school-based STEM initiatives/curriculum, and a designated STEM leader who is given a time allocation in this role. Programs are likely to be sustained and expand if a collegial hub or community of practice of STEM teachers is created which includes other teachers in the school who did not attend the Academy led by a passionate and dedicated STEM leader. Typically, there was growth in STEM curriculum with expanded opportunities for students to experience authentic, “real-world” STEM learning throughout grades 7 to 12 and/or students to experience STEM learning outside the classroom through STEM clubs, STEM competitions and STEM based excursions. There was also evidence of continuing involvement with university STEM outreach programs that connects students to STEM learning as well as growth in partnerships with businesses and community.
5. The Large-scale Evaluation Strategy for Programs from 2018
Phase 2 of the evaluation strategy involved large-scale data collection from teachers and their students in all programs from 2018 onwards [2]. The design was informed by research into the factors influencing curriculum innovation in schools including supportive school leadership; quality, targeted professional learning; changes in teachers’ values and beliefs; collaboration between teachers; student-centred learning environments; and instructional guidance that advances learning [5]. These key factors and the Academy program objectives informed the overall evaluation plan for the STEM program, which is designed as a mixed-methods protocol, with both questionnaire and interview components, measuring outcomes for principals/school leaders, teachers and students. Parent and industry partners are also considered (Figure 1). Based on a large STEM project conducted by the Friday Institute at the North Carolina University, we adapted questionnaires designed and validated by that research group, for teachers, students and parents – the T-STEM survey, the S-STEM survey and the P-STEM survey [24]. We are currently in the process of collecting and analyzing these data.

![Figure 1. STEM Academy program evaluation model](image)

6. Summary and Conclusions
Our approach to professional learning of secondary STEM teachers is a multi-day residential program delivered on the University campus or in large regional towns in NSW. To date we have worked with about 650 primary and secondary school teachers to develop their capacity to design and deliver multi-disciplinary STEM programs to their students. Aimed at improving student engagement, by enhancing teachers’ knowledge and understanding, early data suggest we are having impact on student uptake of STEM subjects via the increased selection of STEM electives in grades 9 and 10 and intentions to enrol in higher level mathematics and science in grades 11 and 12. Our large-scale data collection strategy in 2018 will provide additional information about student attitudes and engagement in the STEM subjects before and after schools implement their STEM strategy.

Schools have adopted a wide variety of approaches to implementing STEM education – frequently these decisions have been based on available personnel, teacher interest and resources but school structures can act as impediments to innovative practices. In summary, our evaluations to date indicate successful schools have
• a clear vision and purpose;
• support from school leadership;
• an energetic and resourceful STEM team leader;
• space and time to meet and plan together;
• a STEM plan with a timeline and tasks allocated to team members;
• a commitment to move slowly and purposefully;
• intention to bring others with them (teachers, parents, community); and
• capacity to find solutions to challenges.

7. References
[1] Anderson J 2005 Implementing problem solving in mathematics classrooms: What support do teachers want? (In P Clarkson et al EdsBuilding connections: Theory, research and practice Procs of the 28th An Conf of MERGA 89-96 Melbourne: MERGA)
[2] Anderson J, Holmes K, Tully D and Williams G 2017 STEM professional learning: Evaluating secondary school teachers and students' experiences (In A Downton et al Eds We are still learning/Procs of the 40th An Conf of MERGA 586-603 Melbourne: MERGA)
[3] Barron B and Darling-Hammond L 2008 Teaching for meaningful learning: A review of research on inquiry-based and cooperative learning (In L Darling-Hammond et al Powerful learning: What we know about teaching for understanding pp 11-70 San Fran: John Wiley)
[4] Bruder R and Prescott A 2013 Research evidence on the benefits of IBLZDM (Math Edn vol 45 chapter 8 pp 11-22
[5] Bryk A, Sebring P, Allensworth E, Easton J and Luppescu S 2010 Organizing schools for improvement: Lessons from Chicago (Chicago: Uni of Chicago Press)
[6] Bybee R 2013 The case for STEM education: Challenges and opportunities (Arlington, VA: National Science Teachers Association)
[7] Clarke D 2014 Disciplinary inclusivity in educational research design: Permeability and affordances in STEM education (Keynote address at STEM Education and our Planet: Making Connections Across Contexts)
[8] Davison D, Miller K and Metheny D 1995 What does integration in science and mathematics really mean? (Scl Sc and Math vol 95) pp 226-230
[9] de Bruin L and Harris A 2017 Fostering creative ecologies in Australasian secondary schools (Aust J of Ter Edn vol 42) pp 23-43
[10] Desimone L 2009 Improving impact studies of teachers' professional development: Towards better conceptualisations and measures (Edal Rer vol 38) pp 181-99
[11] Dreise T and Thomson S 2014 Unfinished business: PISA shows Indigenous youth are being left behind (ACER Oc Essays)
[12] English L 2016 STEM education K-12: Perspectives on integration (Int J of STEM Edn vol 3)
[13] Friday Inst for Edal Inn 2012 Teacher efficacy and attitudes toward STEM survey (NC: Au)
[14] Jenkins E and Neslson N 2005 Important but not for me: Students' attitudes towards secondary school science in England (Res in Sc and Tech Edn vol 23) pp 41-57
[15] Kennedy J, Lyons T and Quinn F 2014 The continuing decline of science and mathematics enrolments in Australian high schools (Teaching Sc vol 60) 34-46
[16] Mack J and Walsh B 2014 Mathematics and science combinations NSW HSC 2001-2011 by gender Technical paper
[18] McPhan G, Morony W, Pegg J, Cooksey R and Lynch T 2008 Maths? Why not (Canberra: Department of Education, Employment and Workplace Relations)

[19] Office of the Chief Scientist 2016 Australia’s STEM workforce: Science, technology, engineering and mathematics (Canberra: Commonwealth of Australia)

[20] Sanders M 2008 STEM, STEM education, STEMania (The Tech Ter vol 68) pp 20-26

[21] Thomson S, Wernert N, O’Grady Eand Rodrigues S 2016 TIMSS 2015: A first look at Australia’s results (Melbourne, Vic: ACER)

[22] Tytler R, Osborne J, Williams G, Tytler, Kand Cripps Clark J 2008 Opening up pathways: Engagement in STEM across the primary-secondary school transition (Canb: AustrDEEWP)

[23] Vasquez J, Sneider C and Comer, M 2013 STEM lesson essentials, Grades 3-8: integrating science, technology, engineering, and mathematics (New York: Heinemann)

[24] Venville G, Wallace J, Rennie Land Malone J 1998 The integration of science, mathematics, and technology in a discipline-based culture (Scl Sc and Math vol 98) pp 294-302