Evaluation of University of Sydney STEM Teacher Enrichment Academy

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Introduction

Why STEM?

Current concerns about declining participation in STEM are well documented in Australia (Australian Industry Group, 2015; Office of the Chief Scientist, 2012, 2013, 2014) and across publications representing the views of governments across the globe (Freeman, Marginson & Tytler, 2015; Marginson, Tytler, Freeman, & Roberts, 2013; Tytler, 2007). In these, the concern is that youth in contemporary society are not choosing the school STEM subjects of science and mathematics, and higher education subjects of technology and engineering, in sufficient numbers to maintain a supply of STEM professionals, and a STEM-literate public, needed in contemporary technological societies. There is general agreement that declining participation in advanced level school mathematics and physical sciences, for instance, means that many young people are cutting themselves off from future productive pathways, from understandings of science and mathematics that will enable them to function effectively as adults (Marginson et al., 2013). There have also been concerns in Australia at evidence of declining performance of Australian students on international comparative tests (Martin, Mullis, Foy, & Stanco, 2012). At the societal level, there is a need to have a general population with the capacity and disposition to engage with STEM issues, and to bring STEM related skills to personal and community decision making (Marginson et al., 2013; Tytler & Symington, 2006). A key aim of governments around the globe is to have, as an outcome of school education including STEM education, adults who are flexible and imaginative problem solvers[1].

In general, STEM is now being taken as an opportunity to seriously consider the alignment of school experiences with the distinct and/or integrated experiences with scientific and engineering practices in the "real world." This curriculum field is, however, still young, and the nature of integration implied by STEM is varied and in many senses confused (Bybee, 2013; National Academy of Engineering, 2014). There is a need in Australia to explore, and clarify the nature of productive inter-disciplinary approaches to STEM education, as a way to engage students in the collaborative problem solving and reasoning processes characterizing STEM research and development practices.

Aims of University of Sydney STEM Academy

The purpose of the *STEM Teacher Enrichment Academy* (The Academy), run by the Faculty of Education and Social Work, University of Sydney in collaboration with the Faculties of Science, and Engineering and Information Technology, is to build STEM capacity through teacher enrichment and professional development. The program aims to enhance teachers' knowledge of content and pedagogy, and inspire them to pursue and expand their own interests in STEM. The Academy thus focuses on improving teaching and learning practices in the STEM subjects in the participating schools, and implies a dual commitment to enhancing pedagogy in the individual subjects, and through its mixing of

[1] See for instance http://pwc.blogs.com/psm_globally/2015/05/the-stem-imperative-future-proofing-australias-workforce.html

teachers of science, technology and mathematics and supporting inter-disciplinary projects, enhancing understanding and practice in integrated STEM approaches. The STEM Academy has an explicit requirement that teachers of science, mathematics and technology work together, but that did not exclude the possibility of single-subject innovations

The Academy program begins with a three-day residential program at the start of each Academy (November) for up to 70 teachers of year 7-10 mathematics, science and technology (in 2015-2016, 2 each of science, mathematics and technology teachers from each of 12 schools). This residential block (Workshop 1) is designed to enhance teachers' knowledge of content and pedagogy, inspire them to reinvigorate their classroom practice, and improve student engagement in STEM subjects. The Academy sessions are facilitated by the University's academic specialists and STEM leaders, as well as teacher/peer-led sessions.

Workshop 1 is followed by schools working over two full school terms on developing, planning and implementing STEM strategies in school-based teams. Academy mentors in Mathematics, Science, and Technology visit the Academy Schools to support this process. Teachers then return for a further two-day program (Workshop 2) to share their experiences, present evidence of teacher and student learning, discuss issues and challenges, and consider future initiatives. An online platform has also been developed to facilitate continuing discussion and sharing of resources between teachers across schools.

Executive Summary

The University of Sydney STEM Enrichment Academy responds to growing concern in Australia about the engagement of students in STEM pathways and stagnation or loss of ground in student competence shown on international tests. There are increasing calls for a renewal of school STEM practices to support critical and creative reasoning and better prepare students for a life in a fast-changing world. The Academy aims to build STEM capacity through teacher enrichment and professional development. The Academy runs two multiple-day workshops for STEM teachers, between which school teams collaboratively plan, implement and report on innovative STEM curricula, supported by mentors.

This evaluation utilised a series of data processes including a survey of Academy teachers after each workshop, interviews and field notes, a survey of a previous cohort concerning sustainability, and case studies of selected schools. The report is organised under the ten research questions driving the evaluation. Overall the evaluation found substantial evidence of change in school practices and take up in particular of interdisciplinary STEM approaches. Aspects of the program that supported teacher and school change were identified, and a number of recommendations are made based on teachers' testimony, and analysis of school processes.

Responses to the research questions

1. There was substantial change in teacher and school practice across a range of structures of integrated STEM projects. These changes emphasised student-centred inquiry pedagogies, real world problems, and an emphasis on creative design. Engagement through design thinking was a key characteristic, and teachers became increasingly aware of theoretical constructs such as argumentation, or problem solving, to build their innovation around.
2. There was substantial implementation of interdisciplinary projects of a variety of types, across different year levels, and with different structural arrangements. Other teachers were frequently involved, and in a number of cases teacher expertise led to influence outside the school. Teachers at times struggled to identify disciplinary learning within these projects but there was nevertheless evidence of substantial student learning.

3. The range of supports for teachers and schools built into the program, in particular teacher release, and time for teams in the workshops to plan together and network with other schools, were key to collaboration across STEM disciplines.
4. The experience of Aduino boards and 3D printers were not uniformly taken up in STEM project work but served as useful tools for a few schools' projects.
5. Students' experience of the inter-disciplinary project work improved motivation to learn, created excitement, and developed collaborative group work and planning skills, according to teachers. Interviews with students showed an appreciation of the creative challenge of design work and some evidence of a shift towards considering STEM careers.
6. Teachers other than Academy teachers experienced raised awareness of STEM education and there was evidence of capacity building and changed pedagogy in schools beyond the core team.
7. Changes that occurred in schools and classrooms included increased confidence in inter-disciplinary practices, developing collaborative planning processes, and developing pedagogical and curriculum expertise that at times influenced change beyond the school.
8. The first STEM Academy participants reported, more than a year on, a range of ongoing STEM activities, including further school planning and implementation of STEM initiatives, changed pedagogy and in some cases leadership of STEM across schools and raising the profile of teachers and schools.
9. Aspects of the STEM Academy program structure that particularly contributed to sustainable change included quality input during the workshop programs, time for school based implementation through collaborative teams, on-ground support, and opportunities for sharing and reflective evaluation in the follow up workshop.
10. Based on challenges identified by teachers and their stories of experience in promoting change, a range of recommendations have been suggested. These are summarized below. Among these is endorsement of the flexibility shown in responding to teacher feedback on the workshops. Ongoing experience in what are still largely uncharted waters of interdisciplinary STEM provides a unique opportunity to pull together schools' ideas and experience and feed these back into the workshops.

Recommendations

1. That workshops allow teachers from each discipline to become familiar with current thinking in each of the STEM disciplines, and in particular to focus on the contributions that each discipline can make to interdisciplinary activities, and how deeper disciplinary learning can be further supported.
2. That opportunities for teams to collaboratively plan and share ideas for interdisciplinary activities be retained and increased in both workshops.
3. That the experience and ideas of previous cohorts continue to be used to inform planning, but that increasingly this is done strategically through the development of a framework that clarifies the dimensions and outcomes of STEM interdisciplinary work.
4. That in particular schools are apprised of the practical examples of the range of STEM activities that have been successful, and the challenges they can expect and strategies they can tap into.
5. That selection processes be refined to increase the commitment of participating schools.
6. The STEM Academy should maintain its commitment to evaluation and its flexibility in response to teachers' feedback.

Evaluation Report

The research questions asked for the evaluation form the headings to each section of the report.

1. Has the STEM Academy experience led to change in teachers' use of inquiry/problem solving/argumentation practices in mathematics and science classrooms?

Many Academy teachers after Workshop 1 reported raised awareness about STEM related pedagogies and ways of thinking (inquiry learning, problem solving, and argumentation). In terms of new learning, mathematics teachers tended to identify problem solving, and science teachers' inquiry and argumentation: the topics of focus in their discipline sessions. ICT teachers more frequently reported gaining familiarity with technological tools (e.g., 3D printers, Aduino Boards). They expressed a desire to learn more about pedagogies employed in other disciplines, which was not an area of focus in their discipline sessions.

By Workshop 2, most teachers and schools had shifted towards a greater commitment to and confidence with integrated STEM projects. Although several schools focused on STEM in individual discipline settings, the predominant focus was on integrated STEM projects. This was substantially driven by the nature of the Academy structure, with teachers from mathematics, science, and technology invited to work together in workshop sessions, and at school. In addition, this working together was perceived by many Academy teachers to be a requirement of Academy participation. The questionnaires from both November 2015 and May 2016, and the field notes for both workshops showed that integration was the most commonly selected project type and that planning such projects was found to be highly engaging.

Many but not all teacher feedback after Workshop 2 identified sharing of ideas, experimentation, observation, analysis of student data, and reflection as valued activities. Teachers developed various positions about features required for engaging students in STEM:

> *[W]e have found that group work that is based on relevant, contextual topics helps to support student engagement in STEM programs.*
>
> *My experiences have confirmed that student centred, hands-on, project based learning works. There needs to be links to real world problems as well. Cross-curricular helps but is not essential*
>
> *[What engages] is topics and ideas that connect to the child and their immediate environment and lifestyle with a focus on futures*

These processes were becoming embedded in the talk of Academy teachers. There was increased awareness of effective STEM pedagogies:

> *Students need to see the value in the projects ... otherwise they will not engage ….*
>
> *Be flexible and be willing to change what you are doing if the students are responding well. Seek student input and give them a voice and choice. Less talking by the teacher ...*
>
> *Giving structure and required skills but leaving students to find solutions and be creative in the way that they do that.*
>
> *Data collection and evaluation steers and drives most projects. Identifying a "problem" and working towards a "solution.*

The school reports to the Academy mid-2016 emphasised a shift towards student centred, inquiry pedagogies as a key aspect of change. Case studies undertaken in late 2016 supported these findings. Case Study 1 student and teacher interviews showed the embedded nature of Design Thinking in the projects undertaken (see student learning, Question 5).

From responses such as these it was clear that the experiences of the Academy participants both within the workshops and in subsequent collaborative innovation in STEM have led to insights into what engages students and provides opportunities to learn. Included were many strategies that are consistent with STEM education practices previously recognised as productive and with the developing Academy community of practice. Changes can be seen in Academy teacher awareness of student centred pedagogies, meaningful, authentic and purposeful tasks, data generation and evaluation as useful task features, and cross curricular contexts, as factors promoting deeper learning. Their advocacy for argumentation and problem solving as appropriate approaches to learning in STEM, and evidence of their confidence with these ideas, contrasted with the earlier questionnaire responses where teachers commonly requested more support in learning about such ideas.

Teachers from Case Study 2 (November 2016) reflected on the process they had employed in developing their Billy Cart project.

> *... our focus was getting more and more engagement from the kids. We had our Billy Cart. What we were doing was putting down concepts. So physics was there, we had project based obviously was super important, race course design was being implemented. All these different things- Argumentation- So that was just kind of like our basis for putting it all together* [Science teacher].

Teachers reflected that if there had been time to debrief together back at school after the November 2015 Workshop 1, they might have realised of the connectedness of the different approaches promoted in the discipline based sessions, and built a common language about ways of thinking across disciplines. A mathematics teacher who was not exposed to 'argumentation', a core feature of the Workshop 1 science sessions, articulated the link between this and problem solving in mathematics, reflecting:

> *"It sounds like something that for future we should say to them* [The Academy]*, I think everybody- [should be exposed to it] ... because my understanding of it is something that we could all be using".*

Academy teachers in Case Study 2 showed that they continue to support the development of the Academy after their Academy year has ended. This provides evidence of how much they identify with the Academy

2. Has the STEM Academy support for the design of interdisciplinary projects led to their implementation in classrooms?

There were many innovative ways in which schools positioned integrated projects within their school. In a few cases these lay outside disciplinary timetable structures, but there were many models of inter-disciplinarity projects within the timetable constraints of single discipline classes. Models included dedicated blocks of time during the year where all disciplines worked on the same project (e.g. Water 4 Life, 7 weeks), technology students (spread across all maths and science classes) bringing parts of the Billy Carts to science and mathematics classes for advice and assistance; classes in the three disciplines working on the same theme at the same time using different disciplines as resources as needed (e.g., Space: Rocket design, construction, and testing), and projects undertaken in technology where science and mathematics teachers were available as resources. A broad range of projects were presented in Workshop 2 and Final Reports. Common features included: research, design, construction, testing, and refinement. Constructions undertaken included:

1. Lamps with attention to luminosity and appropriate materials

2. Billy Carts / Dragsters with attention to materials and features to optimise their performance
3. Gardens within given constraints and attention to various features including aesthetics, and sustainability of plants
4. Rockets with attention to design to increase performance
5. Wastage Systems
6. Water Sustainability Processes
7. Costed proposal and scale model of escape capsule for International Space Station
8. Construction of toys with a balancing feature
9. Formulation and presentation for one or other side of debate: ‘You are what you eat’

Year 7 and / or 8 were the levels of focus in ten of the twelve schools. One school included year 11 students to support year 7 activity. A number of these schools also implemented additional STEM projects across other year levels. The other two schools introduced STEM at year 9 and year 10 respectively. The type of project implemented at year 10 will inform the development of a year 9 project in that school as well. Half of the schools implemented their projects only in their Gifted and Talented classes and in three of these schools implementing in the Gifted and Talented classes was as a Pilot study. At least one of these schools is extending their project to their normal stream classes in 2017.

To varying extents, all schools included staff beyond the Academy Team. Some Academy teams included one or two teachers (e.g., those teaching in STEM disciplines in the level under focus, or as resources, such as enlisting the librarian for historical research into the previous use of land in a technology project). Other Academy teams included whole faculties. The case studies show that in at least two schools, the STEM Academy Team raised the STEM education awareness of their whole school, and at least one Academy team involved community members. This included community members and STEM teachers organising a Motor Show of vehicles through time (which connected with their Billy Cart Project), and Regional Office who supported the development of the Academy application, and subsequently encouraged this school to provide professional learning for other schools. This STEM team also enacted their strongly held obligation to increase the STEM capacity of other teachers in the STEM program, through provision of resources and advice, and / or as a ‘guide on the side’ during STEM classes.

> *Just encouraging people to think outside the square a little bit ... And be a bit more creative in their teaching.*
>
> *I feel I had lots of ideas and people [non-Academy Teachers] contributed things to that but didn’t actually run with ideas unless I made them happen. Unless I pushed them. ... They did really well. But I didn’t know a lot of what they had done in there. ... when we were putting this together ... “Wow, they had all these photos and great” -- I thought wow this is fantastic.*

Learning through interdisciplinary activity

With regard to teachers identifying possible learning outcomes, schools were in general able to identify curriculum dot points associated with learning processes that related to their projects. Far fewer demonstrated they could specifically link discipline content within these dot points to what was actually occurring in their project. Only a very small number of schools (including the case study schools) were able to go beyond listing of curriculum dot points in their reports, and naming the discipline sub-topics topics in their presentations. These schools with greater awareness of discipline content within projects were able to demonstrate how discipline content was employed along with discipline processes during project activity. There has been a shift in awareness of curriculum dot points associated with particular projects for most schools through the Academy year. Many teachers have shifted from an inability to identify much discipline content in integrated projects (post Workshop 1) to being able to recognise discipline-specific curriculum outcomes in projects (after Workshop 2). For many schools though, extending this shift to recogising how discipline content and processes are employed together in specific projects is a work in progress. The Director and her team have started to address in 2015-2016 and should continue to do so in the 2016-2017 year.

Some academy teachers reported strategies that helped them design, modify, or implement interdisciplinary tasks. These included:

> *Start with a project that originates in one particular KLA then expand it to find the other KLA outcomes that are already there or that can be added with some tweaking of the original plan* [Teacher of Science]
>
> *Most productive day was when entire STEM team worked with the STEM class for 4 consecutive periods* [Teacher of Mathematics]
>
> *Develop short and extended activities by triangulation of key skills of inquiry, problem solving, innovation and data-driven decision-making across all KLAs involved.* [Teacher of Technology]

Ideas teachers suggested could help in developing and implementing interdisciplinary tasks that would engage students in identifiable learning, show the innovative ways in which various schools and teachers approached STEM activity, and demonstrate innovative thinking within the cohort concerning the development of tasks. Currently however, clearly articulating the learning emerging from interdisciplinary projects still needs to be further addressed. The STEM Academy is well placed to develop leadership in this area.

3. In what ways has the STEM Academy enabled further collaboration between the STEM disciplines within and across the school?

The Academy Team helped develop cross-discipline team collaboration in various ways. In the November 2015 Workshop 1 sessions, they provided professional learning about pedagogical approaches and ways of thinking, illustrations of innovative integrated resources / tasks, time in sessions for team planning, and they set the task of working together to design and present something new. Further support included the provision of time back at school to continue planning, a meeting between each Principal and the Director to emphasise that the funding provided was for teacher release, and mentor support in schools to address challenges encountered and provide advice. As schools developed their integrated projects teachers appeared to gain confidence in coordinating inter-disciplinary activities with the discipline-based curriculum. In Workshop 2, responding to feedback from Workshop 1, extensive time was dedicated to school teams presenting their projects, and subsequent STEM team planning time. There was a buzz of excitement and anticipation as teachers dispersed to the two rooms in which the presentations would take place. It was audible that this excitement was about presenting their own school projects, and anticipating hearing about those of other schools. Intense interest in presentations was displayed through the attention paid, the questions asked, and the spontaneous visits of some school teams to the team tables of other schools later during team planning time. Within-school and across-school collaboration was evident.

Case Study 2 provided an illustration of the extended and in-depth cross-discipline collaboration that can develop through Academy participation. This team undertook a group interview and explained that the fortuitous combination of their team (where two staff were in acting positions for the year) contributed greatly to their successes. They had not worked together as a team prior to the Academy invitation. They met prior to Academy attendance and prepared and came excitedly with many ideas. Advice from the Academy Director to start small and concentrate on doing one thing well led to their focus on year 10. There were many factors set up by the STEM team that also helped them work effectively together:

- A joint website
- Their two staff rooms containing the STEM team were in close proximity, and all within a particular discipline were in the same staff room
- The project was set up with the students (and teachers) going in and out of each discipline area and the technology class to see what was happening /add support and so forth.
- Quality of the team, all were teachers who set goals and were keen to pursue them
- Professionalism of the team, willing to spend enormous amounts of time in the Christmas holidays to have everything set up and ready to go.

The collaborative nature of the STEM team was illustrated in their joint interview where they often started to brainstorm about improvements to something they were reflecting about.

Time and opportunity for schools to form teams and develop a coherent approach to STEM was a crucial aspect of the Academy's innovation. In some schools the achievement of a shared purpose proved very difficult, and in all schools a process of communicating and collaborating across and beyond the team required strategic effort. Achieving buy-in from any uncommitted teachers, and the wider school community, required a managed process. Academy teachers described various strategies: providing tasters of activities in a non-threatening way, spending time in the classes of other teachers in a coaching style process, and / or providing and discussing the resources to be used. All schools had achieved a measure of success in this respect.

4. Has the STEM Academy experience of Aduino boards and 3D printers enabled new practices in technology / engineering classrooms?

Although Workshop 1 Technology sessions focused predominantly on how to use new technologies, and many of these Academy technology teachers provided feedback that these sessions had been useful to them, some also provided feedback that they wanted to know more about the content and pedagogies in other disciplines to help in the design of integrated projects. This raises questions about what else could be useful in these technology sessions in Workshop 1, or whether a joint discipline session might be more useful for achieving this. Additional information that adds to considering this question was provided through the final reports from each school. Only two STEM Teams explicitly reported using 3D printers, each for design of parts within their broader project. One of these teams also used Arduino based technologies. These new technologies were employed as functional tools that supported the achievement of the design (hot rods, rockets) rather than as the main focus of the projects. The question becomes, would such usage still have occurred if less time had been dedicated to learning how to use these new technologies.

5. What is the students' experience of new STEM practices?

Teachers in the case study schools reflected on the benefits to students of the STEM program. These included descriptions of student passion, and excitement in coming to class, deep understandings of content, and increased ability to work on groups and plan investigations:

> *"They just seem to be getting better at group work, they seem to be better at planning investigations, that side of things, and wanting to be collaborating in a group."*
>
> *"I can see that passion is actually growing within students and they're actually understanding that this works. They're engaging in what they're learning."*
>
> *"just watching the kids be really excited to come to class."*

Student interview responses further confirmed that Academy goals were being achieved in some schools at least. Ten students across the two case study schools were selected by teachers who were asked to include students whose orientation to learning had changed through STEM education participation. This gave opportunity to examine why such changes had occurred. It was found that student autonomy in learning, design thinking and associated creativity, and learning more connected to the world outside school were influences, and that the aspirations of these students had generally shifted more towards STEM careers.

For Case Study 1, all six students drew attention to the autonomy they had in STEM-Ed and the focus on learning for a purpose rather than just learning to reproduce information for assessment: "Compared to learning in other classrooms this [STEM-ED] tries to use your brain more, it challenges you more". Each student identified the design thinking embedded in STEM-ED as crucial to what made STEM education different, and engaging for them. Students did not necessarily use that terminology but it was evident in what they described. One student captured the cyclical nature of the process of trying to solve a problem within certain constraints, testing the product and then working out how to proceed in an environmentally friendly way:

> *"we are given like strict materials that we can use ... it helps us to think about 'how to use this in a productive way like an effective way so that we don't waste any materials but ... if it doesn't work we try not to use more materials but if we have to use more materials then we will but we are trying to make it as effective as we can"*

This design process appeared crucial to changes in career aspirations of students who had previously not considered a STEM career. The career aspirations of all students interviewed shifted more towards pursuing STEM careers, for example, one girl stated:

> *"[In primary school I preferred] Art [as] more creative but like now with science [it is] not so right and wrong but gets more like creativity ... I like Art still now but Sci and Tech I like ... now and careers in that area."*

Another girl, who wanted to be a teacher or missionary nurse included engineering as an aspiration when the excursion to the university drew her attention to engineers helping others:

> *"I wasn't really thinking about being an engineer in primary school but then when we had the STEM-ED camp ... visit[ed] the university and we got to see ... different engineers and what projects they do ... it really like inspired me because it ... showed me that we don't just learn this stuff in school- and then not use it in real life- you can ... use the information you have learnt ... to make a difference"*

The creative opportunities available through the Design Thinking Process and an awareness that engineering can involve helping others influenced these changes.

Students interviewed from Case Study 2 were the students still at school late in Year 10. Their favorite subjects included design, metal work, PE, and technology. Only one of these four students (one girl) intended to study two mathematics subjects in Year 11.

The connected nature of their learning through the Billy Cart project was evident in their joint interview. Students remained in their discipline classes and the Billy Cart parts sometimes came with Design and Technology (D&T) students to maths and science classes. One boy reported a benefit of STEM projects as having more time to learn because of the connected nature of the learning:

> *"it the good thing about it is that some of the science ... D&T and maths and everything- they are sort of related so it is sort of easier to catch up on everything- so it is a bit easier to learn so say we are doing the Billy Carts- sort of everything- all the aspects are covered ... in the*

three subjects ... so you get a bit more time to learn [because] ... you have got to get them all covered"

The other boy added:

"like even the signs in the ... like building of the Billy Carts- wheel sizes and all that ... yeah like the speed and the ... gravity- how fast it will travel with wheel sizes"

and one of the girls contributed:

... that's where you use maths for a lot of measurement so during class we went down to the D&T rooms and we ... measured up ... the chassis and yeah we cut it out in D&T

The students had identified the connected nature of the learning and the interconnected nature of the discipline classes. They also showed interest as they made links between the Motor Show and their Billy Cart learning. Cars from early in the 20^{th} Century through to modern cars were displayed. The STEM teacher team were astounded with all the discipline based learning that emerged through the Motor Show. This included: changes in the shapes of the cars over time and how this related to aerodynamics, increased safety features, differences in the materials used, differences in the dimensions of different parts of the car (e.g., wheel diameter, tyre width), differences in performance, and the potential to represent all of this on timelines. One boy who had hovered over whether to do the easier maths or the more rigorous maths at year 11 shared that he had decided to do the more rigorous mathematics because he could see purposes to mathematics now.

These student interview excerpts show these projects are achieving goals that are valued by the Academy and beyond. Students are engaged in their learning, making decisions about it, and developing deep understandings as a result. In addition, this is positively influencing their aspirations in the shift towards STEM careers. Consistent with the previous findings that many teachers have trouble identifying discipline based learning specific to integrated projects, the teachers of these students were astounded at what their students were able to identify. This school was one of the schools in which Academy teachers were able to identify discipline knowledge embedded in STEM projects, in interviews and their final report to the Academy. This raises a question: How much of this embedded discipline knowledge did teachers become aware of through interactions with their students? And if such interactions contributed to this learning, is there a way the Academy can build on this finding as part of optimising future Academies?

Interview comments from teachers from Case Study 2 show changes in students' subject selection at upper secondary school too:

"One thing that was already working quite well was Design and Technology as a stage six subject, so we thought if we started injecting a little bit more of the way in which we collaborated and worked together in TAS with maths and science that we might be able to create something that would engage students a little bit longer, keep them working a little bit harder and really promote that spirit of curiosity and entrepreneurship that a lot of young kids have and try to catalyse that and turn it into something that worked for them.

"So, we're very pleased with seeing the level of engagement, their mindsets, their attitudes, their willingness to go outside of the confines of the timetable classes to be able to get the work done. I think that's been something that has been a real treat for us so far. A lot of those students are going to go into physics and chemistry and wanting to do the extension maths courses, so I guess time will tell as we track their progress towards the HSC, 2019 or 2018, whenever they sit it. That's when we'll start seeing HSC data that might start speaking to the success or otherwise of the STEM-ed program that started in stage four for these kids".

6. Has the STEM Academy experience led to change in other STEM teachers' classrooms within the school?

As outlined above, in many schools the STEM project work involved STEM teachers outside the Academy team, and in some cases other teachers also. Beyond the fact of involvement in STEM innovation projects, the case study interviews provided evidence of changes in perception and practice for teachers in Academy schools more generally.

Non-Academy Teacher Reflections

"I think the academy for me just endorses what I actually believe. It's given me a passion that it's out there and that other people actually grasp that whole idea of making learning really relevant. It's part of a life-long learning process".

"I'm always looking out for where the maths is and then trying to tie it all back in, which is a challenge for myself. It's always hard when you're teaching indices or something where you go here's the rule, just do it, versus can we actually apply this to something that we're doing. … Team teaching ... we can bounce ideas off each other. Then ... [the School Leader, Academy Teacher Mathematics] has got a lot of maths experience and he's the one that can just whip out all these connections. So I feel supported"

This reflection from a non-academy teacher showed support received, realisation that students forgot what they were 'taught' prior to the project (in preparation for it), and that embedding mathematics within contexts can be difficult:

"We realized that didn't work when in week 10 the kids were like we don't remember anything, because it wasn't valuable to us back then, because we didn't realize that we needed it for our project"

"In one of our projects the children had to make an infographic about a disease, they were learning about diseases and systems and everything in science. Part of an infographic is displaying data, so they were able to look at integrity and displaying data in maths and take what could be sometimes normal lessons"

Trying to get across to kids what's the difference between a column graph and a histogram can be really hard, but when they've got their own data that they need to interpret, they need to make the choice and it just seems that being forced to make the choice is kind of working for them, rather than this is the column graph exercise and this is the histogram exercise, and they don't really get to compare the different types of graphs."

This teacher is also demonstrating a recognition of where mathematics is employed in the integrated projects undertaken.

Academy Teachers Reflections

Academy teachers in the case study schools pinpointed various strategies they had used to encourage other teachers into STEM education and to develop their expertise over time.

"... it's the communicating ahead of time that needs to happen and more about what I'm planning to do so they can implement similar things. Also using common language across the things, and try to be deliberate, even more with science teaching where I can actually start teaching some maths concepts as well. Draw them out clearer and in the same way that maths have been introduced to them."

Both of these STEM teams had raised the awareness of school staff about STEM education, and included and built the capacity of other teachers in the school in various ways. Final reports from schools show that all schools have included at least one other teacher in their STEM activity.

Embedding Change

The STEM Academy School Teams in each case study had devoted time and energy to familiarising other teachers in their school with STEM practices. The Academy Team in the Case Study 1 had embedded design thinking in STEM-ED, as evidenced through student interviews (see Question 5). This team reported the following changes at school, resulting from the Academy's invitation to participate:

- an increased obligation, thus motivation, to succeed / extend the school's STEM activity because of the opportunity they had been given
- an increased confidence that their innovations were worthwhile, because they had been accepted
- a recognition by their school that their work was valuable
- a decreased resistance of other staff to engage, because their ideas had been recognised by the Academy. This encouraged others in the school to commit to the program or try similar ideas.
- Access to a network of schools with similar interests and challenges who they can bounce ideas with, and
- The increased awareness of STEM by school members contributing to the quality of STEM education provided.

This increased bringing on board of other teachers due to the raised profile of the STEM team arising from the Academy's recognition of their work helped to embed STEM practices in the school.

7. As a result of participation in the Academy, what changes have occurred in teachers' schools and classrooms?

The majority of Academy schools now have staff with expertise in STEM education and have developed STEM projects, that have generally taken the form of some type of integration of STEM disciplines in at least one class or level in the school and are intending to refine their STEM projects and / or extend the classes and or school levels at which STEM education occurs. In some instances, schools now have teachers with expertise that is recognised beyond the school who provide whole school professional learning in STEM education in their own school and in other schools. There are schools like the Case Study 2 school who provide a STEM Model to other schools in their region and beyond, run STEM conferences, loan out their staff to neighbouring schools as they develop STEM expertise, and through these multiple recognitions, have increased their likelihood of attracting further STEM funding to assist them in extending their innovations. One of the main priorities reported by this STEM team was developing a way of thinking in the teachers where it was okay 'to make mistakes' because you learnt from those mistakes and knew you needed to try something else. They reported progress with their teachers in this regard.

8. As a result of participation in the first STEM Teacher Enrichment Academy, what changes have occurred in teachers' schools and classrooms?

Teachers from the first STEM Academy (2014-2015) were invited to undertake an online survey in early 2017. They were asked to: "list up to five ways in which you consider you have built upon your Academy experience". Approximately 10% of the cohort responded. These respondents included teachers from each discipline, in schools with varying populations (less than 300 up to 2000), and teachers from both government and independent schools. The respondents did not include teachers from Catholic schools or regional schools, each of which were part of the 2014-2015 cohort.

While the respondents were self-selected, the story told was very positive in terms of the ongoing effects of the STEM Academy experience. These teachers reported that the STEM Academy experience had increased teachers' participation in STEM initiatives, and benefitted many students as a result. They perceived that their experiences through participation in the STEM Academy had contributed to a range of changes:

Benefitted their school:

"I have delivered Professional Learning to my whole Science faculty on Argumentation and incorporated this concept into assessment and teaching material."

Changed school programs:

"We are] now running in Stage 5. STEM cross curriculum project. In Year 10 a combined Science and Maths assessment is run with TAS support"

"Each faculty has up-STEMMED by seeking further professional learning and therefore enhancing engagement in their classes. -We have developed business links with Microsoft and Atlassian for staff PL & student mentoring"

Addressed the quality of their own STEM teaching:

"In teaching, [I] regularly try to be more engaging and demonstrate the real-life applications of Mathematical concepts"

STEM teaching in their school, other schools, and the broader community:

"DoE designated our school as a STEM Action school, so we mentor other government schools. -A large part of my HT role is leading STEM initiative across the school and in our wider community including school networks and parents"

Some reported that it had also led to increased student engagement, broadened perspectives of STEM and the sustaining of student interest in STEM

"I commenced STEM academy at the beginning of my first 5.3 year 9 class and continued with this group for year 10. It is now pleasing to see that about 70% of those students are now studying Mathematics and some Extension I."

Innovations in STEM curriculum have included:

"[I]ndustry links [made] to continue supporting students in developing coded projects"

"worked with and supported students in an after-school Coding club"

"Involved students in a variety of University programs e.g. Women in Engineering"

and development of teachers' own expertise further through research and professional learning

"[I have undertaken] A huge amount of pedagogical research into STEM"

These responses from Academy teachers in the first Academy cohort suggest that the benefits of participation in the Academy grew over time for the majority of those who responded and were reported as making no change for a very small number of teachers. Academy participation contributed to the development of leaders in STEM within schools and beyond, and the raising of the profiles of some schools. School programs included more STEM education, and Academy teachers mentor others in the school to cater for this. Academy teachers' practice has changed in various ways including giving more attention to providing engaging learning opportunities, and embedding argumentation into learning processes in the school.

9. What are the processes through which the STEM Academy has led to sustainable change in mathematics and science classrooms, and STEM interdisciplinary projects?

Sustainable change in schools depended on overcoming a range of ongoing challenges. These include practical issues of timetabling, and overcoming resistance from staff, and later new staff, in some cases students who are new to such processes, and to not losing ground with new curriculum priorities. The resistance from others was decreased in some schools by the higher profile the STEM Academy teachers and their work gained when they were invited to join the STEM Academy.

A large part of successful innovation was the development a shared understanding within the team, enabled by time in Workshop 1. Some STEM teams came together for the first time at this workshop. The opportunity to use time funded by the STEM Academy for planning, communication, and implementation back at school supported this process as did the Director's visit to each school principal reminding them of the funded time available and the need encourage Academy teachers to use it. The 'buy-in' of other teachers as they were enlisted to STEM programs required sustained planning, support, and professional learning. A variety of strategies were adopted by the STEM School Team to achieve this. The provision of dedicated time in Workshop 1 and back at school eased these processes.

Productive changes in schools, teachers, students, and programs that were evident and need to be sustained include:

1. The development of collaborative in school teams of STEM educators
2. The development of STEM networks across schools,
3. The introduction of STEM projects and changes to school programs that increased focus on STEM (at least for the Academy year), with the majority of schools intending to continue with these initiates and many intending to refine and / or extend them.
4. Increased levels of engagement and quality of learning amongst students
5. Student aspirations shifting more towards STEM related careers.
6. Schools and / or teachers being invited to participate in other STEM initiatives
7. 'Up-STEMMING' of other teachers within and beyond their own schools.

Some schools that have engaged deeply with STEM projects and programs are now sharing their expertise more broadly. The Academy has providing a springboard that some teachers have been able to utilise to develop their own and their school's profiles in relation to STEM expertise. The work of the Academy has snowballed with it now influencing teachers and schools beyond STEM Academy Schools.

How do Academy processes contribute to sustainability of these changes? Sustainable change was found to be a function of STEM School Team interactions with STEM Academy processes rather than a function of STEM Academy processes alone. These interactions sustaining change included:

1. Demonstrated faith in Academy teachers' ability to develop worthwhile STEM projects increased their confidence to do so.
2. The structure of Workshop 1 increased the focus on integrated STEM projects.
3. The presentations on Argumentation (in Science Discipline Session in Workshop 1), problem solving strategies (in Mathematics Expert Presentation, Day 1 Workshop 1), the inclusion of integrated projects in the Mathematics Resource Book, and the familiarising of Academy Teachers of technology with how to use new technologies in the field influenced how the projects developed.

4. The Academy Team listening to and responding to teacher feedback meant teachers influenced the directions taken in the Academy Program in positive ways.
5. Increased familiarity with the projects of other schools through the provision of large intervals of dedicated time increased the availability of projects to consider using or adapting. and informed schools of the challenges that could be experienced. A process of 'osmosis' of projects across schools is occurring.
6. Mentors engendered Academy School Teams with the confidence to use their expertise. For example, the Mathematics Mentor (Case Study 2) in that school for another purpose, encouraged the school to apply to the Academy, and the Technology Mentor encouraged the same school to share the expertise they had developed by planning and running of a conference.
7. The inclusion of industry in the Academy program (CSIRO Science and Mathematics in Schools Session, visit to University of Sydney Robotics Research Centre) has encouraged some schools to include industry visits in their programs.

A number of aspects of the STEM Academy program as described in this section are consistent with best practice in professional learning on school change. Chief amongst these were the structure of the program which provided quality input, time for school based implementation through collaborative teams, on-ground support, and opportunities for sharing and reflective evaluation in the follow up workshop.

In a program promoting relatively uncharted territory, flexibility and responsiveness to teachers' and schools' needs are important. The Director's capacity to flexibly implement changes during the Academy program meant that feedback from Academy Teachers had the potential to drive change, and teachers appreciated that their ideas were listened to. This meant they continued to make constructive suggestions throughout their time in the Academy.

School STEM Leader Perspectives

"... the overall benefit of a team of teachers committed to working together to essentially improve and drive forward our STEM program so that all year seven and eight students experience it, I think that's been a just goal. I think that really has made a very large difference to the viability of the [school] program in the long haul".

The Academy teachers who brought their timetabler (also a School Leader) along to the Academy markedly increased the ease with which planning occurred back at school. Once this leader saw first hand what was being achieved, he made STEM a priority and eased the logistics of implementing a STEM project in many ways with organisation back at school.

It was also important that schools developed a vision concerning the nature of the learning that was being targeted in these STEM innovations, as a conceptual 'glue' around which planning and pedagogy could be enacted. Where one case study school went into STEM education with the awareness that design thinking was crucial in each discipline, the other case study school developed realisations about the commonality of thinking processes across the disciplines in late November 2016 during their case study interview when they spontaneously began to compare problem solving processes, design thinking, and argumentation. Case Study 2 shows the work of the Academy is not completed after one year. If the schools engage, they can continue to develop further over time.

There was also an instance where an outside supporting body also catalysed the development of a school's profile (Case Study 2). The Regional Office had set up a STEM education team prior to this school joining the Academy. They worked with the technology STEM leader at the school to help her develop her application and prepare for STEM Academy participation. The outcomes of this school participating in the STEM Academy have been useful to the Regional Office, to other schools, and to the STEM Academy school team and their school. Two of the STEM Academy teachers are on the Regional Office STEM Education panel and others are brought in from time to time for their expertise. The Regional staff demonstrated how much they valued the expertise of the Case Study 2 STEM Academy Team in their interview (as someone who contributed to the development of STEM in the school but was not a teacher). These representatives stated:

> *You [have] ... expertise here- so how can we share that expertise across the city schools- so that the kids want to come here- And they also are better prepared for high school, because there's a big gap between primary and secondary.*
>
> *Because of what we've planned here, we've been talking with ... [the two STEM Academy Members of our panel ... you might have some kids here [Case 2 School] doing something ... out of routine- so, ... [you take two nearby regional schools] and teach the teachers how to do it, teach the kids how to do it. [The School Service Officer at the Regional Office].*

STEM Academy teachers have had various opportunities to share their expertise through this relationship, and the Regional Office provides ongoing support to the school.

10. How might STEM Academy program be optimized in future Academies to support sustainable change in teacher and school practices?

Throughout this report there have been challenges identified and many of them have been addressed already. Other challenges have been identified in discussions between the Director and the evaluating team and they will be addressed over time. In addition though, there are other recommendations that arise out of this evaluation. All Academy teachers, students, mentors, and the Director's reflections have helped in identifying these features that should be considered in looking at how to optimise the program. Firstly, those processes that influenced positive change (see Question 9) should be retained.

Secondly, that further consideration be given to the balance of activities occurring within Workshop 1 including that:

- like Workshop 2, it includes more whole group activities;
- Teachers from all disciplines have the opportunity to undertake activities together to raise awareness of ways of thinking and innovative pedagogies in the different STEM disciplines;
- Teachers from all disciplines have opportunity and support to interrogate integrated projects (including student responses to them) to identify discipline content and how it is employed through the support of innovative pedagogies that elicit design thinking / argumentation / problem solving activity;
- The one and a half days of planning and sharing of integrated projects be retained;
- Teachers from previous Academies continue to provide sessions about their projects to raise awareness of what is possible and how challenges can be overcome.

Possible activity to integrate into Workshop 1 includes:

- Allow those teachers / schools who have had more experience with STEM to share their ideas and experience early in the workshop
- Embed learning about pedagogies and thinking, and identifying content knowledge through the interrogation of exemplar integrated projects (e.g., Case Study 2 Project).

Other ways to consider optimising Academy processes include:

- Develop a list of important points that teachers are encouraged to address before and straight after attending Workshop 1 (e.g., timetable issues, debriefing) using advice from previous Academy teachers.

- That consideration be given to whether the small number of the schools that do not engage can be reduced further. This may be through considering the selection process, or providing additional resources to these schools, or by some other means. A way to reduce this may be through differentiation. Should there be two groups because those already involved in STEM have some knowledge of pedagogies and STEM integration? Or would this leave the others further behind because they do not have that STEM background? Could this be addressed to some extent by having those with some STEM background sharing early in Workshop 1?
- Through the developing experience of the Academy, develop a framework offering activities and advice on a range of dimensions of interdisciplinary STEM practices including a) the options for different types of STEM program, b) what to expect in the way of challenges, and strategies to overcome them, c) the nature of learning within STEM including disciplinary learning and critical and creative reasoning.
- All teams have opportunity to see and discuss all presentations (maybe video so the other half are available)
- That the roles of the mentors include support valued by teachers in interviews:
    - Inviting schools 'ready to grow' to apply for the Academy
    - Encouraging schools to share their STEM expertise
    - On request, providing professional learning to other teachers in a school

The mentor role should also continue to emphasise supporting teachers to develop understandings of what discipline knowledge can emerge from different projects.

There was a continual process of program optimisation occurring across the Academy year (Nov 2015-May2016) that was enabled by the reflective and responsive actions of the Academy Director Assoc. Prof. Judy Anderson. The evaluation team thus points to the importance of an Academy Director with such expertise as a necessary part of ongoing program optimisation. This process also relied upon the collaboration between the Director and the Evaluation Team so the selection of that team is also key to this process. In the discussions between the Evaluation Team and Assoc. Prof. Judy Anderson (The Director), the Director recognized and responded quickly to issues and ideas. This evaluation model was extremely productive because instead of waiting until the next Academy (2016-2017) to address potential issues, Assoc. Prof. Anderson has addressed or begun to address challenges identified, where possible, before Workshop 2 in May 2016.

Instances of changes made during the 2015-2016 Academy as a result of these collaborative discussions included:

- Decreasing presentations given by academics and increasing time interacting
- Including more time for feedback between schools in Workshop 2
- Greater mentor focus on drawing out the disciplinary knowledge within the interdisciplinary projects
- Addressing the 2014-2015 recommendation of strengthening links to industry with the visit to the university's robotics research centre and the inclusion of a presentation on Science and Mathematics in Schools (SMIS)

References

Australian Industry Group. (2015). *Progressing STEM skills in Australia*. Retrieved from http://www.aigroup.com.au/policy/reports

Bybee, R. (2013). The case for STEM Education: Challenges and opportunities. Arlington, Virginia: NSTA Press.

Freeman, B., Marginson, S., & Tytler, R. (Eds.). (2015). *The Age of STEM: Policy and practice in Science, Technology, Engineering and Mathematics across the world*. Oxon, UK: Routledge.

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). *STEM: Country comparisons*. Melbourne: The Australian Council of Learned Academies. Retrieved from www.acola.org.au.

Martin, M. O., Mullis, I.V.S., Foy, P., & Stanco, G. M. (2012). *TIMSS 2011 International Results in Science*. Chestnut Hill:USA. International Association for the Evaluation of Educational Achievement (IEA). Retrieved from http://timssandpirls.bc.edu/timss2011/downloads/T11_IR_Science_FullBook.pdf

National Academy of Engineering and National Research Council (2014). STEM Integration in K-12 Education: Status, prospects and an agenda for research. Washington, DC: National Academies Press.

Office of the Chief Scientist. (2012). *Health of Australian Science.* Canberra: Commonwealth of Australia.

Office of the Chief Scientist. (2013). *Science, Technology, Engineering and Mathematics in the National Interest: A strategic approach: A Position Paper*. Canberra: Commonwealth of Australia.

Office of the Chief Scientist. (2014). *Science, Technology, Engineering and Mathematics: Australia's Future*. Canberra: Commonwealth of Australia. Accessed October 27th 2014, at http://www.chiefscientist.gov.au/wpcontent/uploads/STEM_AustraliasFuture_Sept2014_Web.pdf

Tytler, R. (2007). Reimagining science education: Engaging students in science for Australia's future. *Australian Educational Review, 51*.

Tytler, R., & Symington, D. (2006). Science in school and society. *Teaching Science, 52*(3), 10-15.