Premier’s Macquarie Capital Science Scholarship

Engaging students in Science: Current approaches in the United States of America

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Study Tour Overview

As a recipient of a Premier’s Macquarie Capital Science Teaching Scholarship 2012, I undertook a study tour of the United States of America (USA) in October 2012 which explored innovative techniques and technologies to engage students in science while maximising student learning outcomes. I undertook a combination of formal training, classroom observation, and interviews with educational experts and conferences. Table 1 shows the organisations visited on the study tour.

During the study tour, four specific approaches to teaching science were investigated, as follows:

* + **Project Based Learning**: explored by attending the Fall Residency at the High Tech High group of schools in San Diego, incorporating formal professional development and classroom observations.
  + **Integrated teaching of science, technology, engineering and mathematics** (STEM): explored through visiting specialist STEM schools in New York, Connecticut and Massachusetts and attending the STEMtech conference in Kansas City, Missouri.
  + **Modelling Instruction**: explored through meeting with academics at Arizona State University, attending a session of ASU’s Model-it course, and observing teachers implementing Modelling Instruction at schools in Arizona and New York.
  + **Embodied learning through interactive, immersive, digital games** (SMALLab): explored through observing SMALLab and Flow systems at schools in Phoenix and speaking with Dr. Mina Johnson-Glenberg from SMALLab Learning.

Project Based Learning at High Tech High

High Tech High is a purpose-built group of nine charter schools in San Diego, California. As charter schools, the schools are funded by the California government but privately run, catering to a non-selective students chosen through a lottery system to represent the diversity of the San Diego population. The High Tech High philosophy is to prepare students for the world beyond school though personalised, project-based learning which is connected to the real world.

Variations of project based learning are in place in schools all over the world. However, High Tech High projects have some specific characteristics which help them work particularly successfully:

* 1. **Authentic projects.** Projects are meaningful for both staff and students, as they connect to both the academic discipline and the real lives and interests of the students.
  2. **Real world connections.** Projects explore the world outside school and connect students with professional adults in the wider community.
  3. **Hands-on learning.** In the projects at High Tech High students are not just writing about their learning. They are applying their learning in hands-on ways: designing, creating, performing and building.
  4. **Significant, permanent products.** High Tech High holds regular exhibitions where every student’s projects are showcased to the community and the project work is also displayed around the school. This puts a responsibility on the students to produce work which they would like everyone to see, and as a result the work has quality and permanence.
  5. **Respect for the design process.** The teachers and students at High Tech High incorporate the iterative nature of design into the projects. Since students are creating tangible artefacts they need to undergo the cyclical process of creation, evaluation and modification in order to perfect their work.
  6. **Time.** In order to do this well, significant amounts of time need to be allocated to these projects. Classes may not work on their project every day, however students need an extended time to work, reflect, evaluate, and modify which could involve a lesson or two each week over the course of a term.
  7. **Student voice.** The students at High Tech High often have a meaningful role in making decisions about their own learning and their school in general. Students know that their opinions matter, and providing them with this responsibility allows them to take ownership of their learning.

Effectiveness of Project Based Learning at High Tech High

From observation, the Project Based Learning approach implemented at High Tech High successfully engages students in all subject areas. Students are actively engaged in the learning process, and they take pride in their work. Students are skilled at articulately and enthusiastically explaining their projects and the learning they were getting from them.

The students sit standardised state tests at the end of each year. However, due to the time spent on large-scale projects, aspects of the state curriculum may not be covered at High Tech High every single year and the school is not required to cover all of the state standards that are assessed. However, High Tech High students have historically always done reasonably well. They are able to apply their knowledge and understanding to new situations, and perform solidly even in topic areas they have not studied.

More important to the High Tech High administration is college-readiness. One hundred per cent of their students are accepted into college, with a college retention rate of 82% (McBain, 2012). Note that this is a non-selective school which uses a lottery system to ensure they have a representative sample of students from the San Diego area, so the college acceptance level is not just a product of the socio-economic level of the students.

Relevance of High Tech High’s Project Based Learning for New South Wales Schools

Project Based Learning can help develop meaningful, engaging, student-centred learning and assessment if implemented well. Project Based Learning could be incorporated into programs of work within New South Wales (NSW) schools, especially in the year’s 7-10 curriculum. Indeed, Project Based Learning approaches are already being implemented in many NSW schools. However, these projects may lack some of the features of successful High Tech High projects listed earlier, such as extensive time, tangible products, or real connections with the adult world outside school.

Especially difficult in NSW is the aspect of time. NSW schools do not have the same freedoms as High Tech High to choose to focus on a particular content area at the cost of other areas of the syllabus. As a result, finding the time in the school year to spend a significant, dedicated amount of time on a single project could be difficult. However, projects can still be carried out, they just need to be carefully designed to cater to a range of syllabus outcomes so that enough time can be spent working on them.

Integrated Teaching of Science, Technology, Engineering and Mathematics

The areas of science, technology, engineering and mathematics (STEM) are fundamentally linked in many real-world careers; however, this connection is less clear in schools. This has resulted in the idea of integrated STEM teaching: as these subjects are fundamentally connected in the real world, they should be taught in an integrated way so that students can see the connections. However, whether this integration occurs on a subject, project, or extra-curricular level varies from school to school.

Integration can occur on a subject level through the addition of separate STEM subjects which are additional to the traditional science and mathematics subjects. This was observed at three specialised Math and Science high schools which were visited. The Science and Technology High School of Southeastern Connecticut and the High School of Math, Science and Engineering have both introduced additional streams of engineering and / or biomedical subjects that students take in addition to their normal science classes. Massachusetts Academy’s additional STEM subject was a student-selected research project rather than a traditional curriculum-based subject.

Integration can also occur at a project or unit level. Project Based Learning lends itself to cross-curricular projects, and cross-curricular projects within the STEM subject areas allow students to see the connections between the more theoretical subjects they study and the more hands-on products they create. This was evident at High Tech High, although other Project Based Learning school networks such as the [New Tech Network](http://www.newtechnetwork.org/) also advocate these types of cross-curricular projects.

The final way some educators approach the integration of STEM subjects is through running STEM-based clubs and activities. An individual teacher can run a club based on their own interests, as was occurring at both the Science and Technology High School and Massachusetts Academy. Alternatively, teachers can help students participate in wider externally led STEM programs, such as the national [FIRST Lego League](http://firstlegoleague.org/) and [FIRST Robotics](http://www.usfirst.org/roboticsprograms/frc) competitions, or the [MIT InvenTeams program.](http://web.mit.edu/inventeams/)

Effectiveness of STEM Integration

It is difficult to gauge the effectiveness of elective STEM programs as students often self-select to undertake these programs based on interest and ability. This includes the additional subjects at the specialised schools as well as extra-curricular programs. However these students do generally maintain their interest in STEM through this participation. For example, of the students who participate and are selected in the MIT InvenTeams program, 70% go on to study STEM at university (L. Estabrooks, personal communication, October 28, 2012).

In contrast, integrated STEM projects within non-specialised schools aim to target all students, rather than those who are already inclined towards these fields. Research has shown that well-developed and implemented integrated STEM projects or course can improve many students’ understanding of science concepts (Venville, Rennie & Wallace, 2003; Ross & Hogaboam-Gray, 1998). In addition, students who undertake cross-curricular STEM projects may also be more likely to maintain interest in this area throughout school and into their tertiary studies. Whilst High Tech High does not focus on STEM studies, the integrated and hand-on nature of projects at High Tech High has encouraged more students from those schools to enter STEM fields: 38% of High Tech High college graduates have graduated with degrees in STEM fields, as opposed to 17% of US graduates generally (McBain, 2012).

Relevance of STEM Integration for NSW Schools

Integrated teaching has gained some attention in Australia and some schools already implement integrated classes or projects at time. In general, NSW teachers do not have the flexibility to create additional STEM subjects for students as is occurring at the specialised schools visited. However, in Stage 4 in NSW, students already study three of the STEM subjects: Science, Technology and Mathematics. Despite this, students may not always see the links between these subject areas.

An effective way to remedy this would be to introduce cross-curricular projects which students carry out in multiple STEM subjects. However, in the US the integrated projects observed always involved the collaboration of teachers from two different disciplines. As a result implementing cross-curricular projects would require collaboration between a group of dedicated, committed teachers from different faculties. Although this may be difficult to achieve logistically, this is possible in NSW schools.

Modelling Instruction

Modelling Instruction is a teaching method primarily designed for teaching Physics and Chemistry. Modelling Instruction was developed by David Hestenes, an academic from Arizona State University, over 20 years ago and over 3,000 teachers across the US have attended a modelling workshop and are implementing modelling in their teaching (Megowan-Romanowicz, 2011). Modelling is based around the idea of students developing their own conceptual models to explain phenomena.

Instead of telling students the 'correct' model we expect them to adopt, Modelling Instruction brings out and challenges existing beliefs, and allows students to develop their own conceptual framework to explain the phenomena being investigated. By getting students to independently come up with new models, they actually retain and believe them. This is an iterative process: ideas need to be established, explained, tested, and revised continually in order to develop robust models which can explain a range of physical principles.

The method provides a structure for exploring and developing student conceptions about phenomena. Some of the key features of the Modelling Instruction approach are the following:

* + **Student-centred groupwork.** Modelling is student-centred, focused on group work with students sharing their ideas with their group and then the class. Students work in groups of 3-4 and must work together and explain ideas to one another to develop some sort of agreement.
  + **Whiteboards** Students use portable group whiteboards to explain their ideas to each other and the class. Groups of students may develop an answer to a question or problem posed by the teacher on their whiteboard, or they may collect and analyse experimental data on the whiteboard. The nature of a whiteboard and the freedom to erase mistakes frees students from the fear of putting down the wrong thing as they can change their board easily as their understanding develops.
  + **Board meetings** Groups of students share their whiteboard answers in 'board meetings', which consist of students sitting in a circle showing and explaining their whiteboards to each other and coming to a collective understanding of the phenomena being explored. During this time the teacher takes a backseat, letting students guide the discussion through their own questioning.

Through this process students develop their own individual understanding, and the whole-class sharing allows groups to question one another and correct each other’s' misconceptions.

Effectiveness of Modelling Instruction

The Modelling Instruction method has been shown to be highly successful in improving student learning outcomes in Physics. In order to evaluate this, researchers developed a test called the Force Concept Inventory which assesses conceptual understanding of the force concept, specifically targeting common student misconceptions (Jackson et al., 2008). Using this test before and after teaching, data has been collected from over 30,000 physics students which shows that Modelling Instruction significantly improves student understanding when compared with other teaching methods, especially traditional, lecture-based teaching (Jackson et al., 2008).

However, another strength of Modelling Instruction is that students not only have developed a clear understanding of the material but can also clearly articulate this understanding to others (Jackson et al., 2008). This develops through the use of the whiteboards in a group work setting: students are forces to share with one another and justify their opinions to others, firstly within small groups and later between groups in the class at the board meeting. Observationally, students in modelling classes were skilled and enthusiastic about sharing and explaining their ideas.

Relevance of Modelling Instruction to NSW Schools

In NSW there are a number of limitations which would make using this approach difficult. In the junior years of science from years 7-10, the fact that the sciences are taught together means that there would rarely be a long block of time in which students could develop their modelling skills. In years 11 and 12 when the sciences separate, the heavily content-driven Higher School Certificate (HSC) syllabuses for Physics and Chemistry would make it difficult to spend the time required for students to learn slowly through experimentation and the development of models. As a result, full implementation of a Modelling Instruction approach may not be possible in NSW schools.

However, there are aspects of Modelling Instruction which could be adopted in NSW. Most easy to implement would be the use of whiteboards to develop student understanding of physical phenomena. Schools could provide whiteboard space either on the walls or on portable boards for students to use to develop group explanations to share with the class. Students could be asked to conduct experiments or make observations and then explain these observations on the whiteboards using relevant words, diagrams and equations. Using whiteboards in this way could be a simple way of ensuring learning is collaborative and student-centred.

Embodied Learning and SMALLab

Embodied learning is a theory developed by researchers from Arizona State University which suggests that by moving learning into a three dimensional, physical space students can learn more effectively. In order to encourage this ‘embodiment,’ [SMALLab Learning](http://www.smallablearning.com/) has developed two different technological tools which create three dimensional interactive learning scenarios for students. Both of these tools allow students to move their learning into an interactive, kinaesthetic, collaborative space.

The full SMALLab is a system that uses up to 12 tracking cameras to tracking movement over a three dimensional space, whilst projecting an image down onto a floor. The result is that multiple users can interact with a 'learning scenario', moving around and interacting with the digital image projected onto the floor. Using tracking wands, students can move objects in a 3D environment in accordance with the learning objectives of the scenario.

The smaller and more portable alternative is SMALLab Learning's Flow systems, a system which uses a XBOX Kinect add-on to capture motion in order to interact with learning scenarios projected onto a screen or Smartboard. Students interact with the simulations by moving their hands and arms. This Flow runs similar scenarios to the full system and new scenarios are continually being developed by SMALLab Learning in collaboration with teachers.

Effectiveness of Embodied Learning and SMALLab

The theory behind embodied learning has been backed up by various studies into student learning and the relationship between abstract ideas and physical movements. This research has shown that when students gesture whilst learning information they have improved retention of content (Johnson-Glenberg et al., 2012). Similarly, research into embodied digital games played on the Flow and SMALLab systems has shown consistent positive effects on student learning (Johnson-Glenberg et al., 2012; Tolentino et al., 2009). However, these positive effects when using technological tools for embodiment have not been compared with the learning benefits obtained when gestures and embodiment takes place without technology.

In addition to the learning gains, both of the SMALLab technologies have a positive effect on the engagement of students as the interactive nature of the devices encourages active student participation. Students were observed enthusiastically wanting to participate in the activities. In addition, this participation is by necessity collaborative, and encourages students to develop their teamwork and communication skills.

Relevance of Embodied Learning and SMALLab to NSW Schools

Although the full SMALLab system is unlikely to be installed in NSW schools due to the expense involved, SMALLab’s Flow system could be a useful tool in NSW classrooms. It an interesting and engaging way of teaching material that appeals to the students, and could be an interesting addition to many classrooms. Especially as the number of learning scenarios available increases, the Flow software and Kinect add-on could be a useful and engaging addition to a Smartboard or projector to supplement other teaching method.

However, the embodied learning research has shown that adding a physical dimension to learning has a positive effect even when implemented without technology. As a result, all NSW teachers should attempt to incorporate physical aspects into classwork especially when working with abstract ideas.

Conclusion

All four of the teaching approaches explored on the study tour have benefits on the engagement and / or the learning outcomes of students in science. Although they are not all immediately transferable to NSW schools, there are specific elements of each which could be implemented in schools here.

Some of the modifications which teachers and schools could introduce would be the following:

* + Adapt existing projects to fit the seven characteristics of successful projects at High Tech High.
  + Introduce exhibitions of learning where student work is displayed to parents and community.
  + Once a team of interdisciplinary teachers is on board, introduce new cross-curricular projects which combine STEM subject areas.
  + Introduce portable whiteboards into the classroom on which groups of students are required to explain phenomena to the class.
  + Incorporate physical movement into lessons of theoretical content in order to embody the learning process.

The common theme to all of these teaching methods is a focus on student-centred rather than teacher-centric learning. By making small changes to the way science is taught, students can be encouraged to stay interested in science, see the connections between science and the world outside school, and achieve to the best of their ability.

**Table 1 - Organisations Visited on Study Tour**

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| --- | --- | --- |
| **School / Organisation / Conference** | **Organisation type** | **Primary reason for visit** |
| [**High Tech High**](http://www.hightechhigh.org/?show=schools) San Diego, California | Charter school\* | Learned about their innovative school structure with a focus on Project Based Learning |
| [**Arizona State University**](http://modeling.asu.edu/) Phoenix, Arizona | University | Attended a [Model-it](http://modelit.asu.edu/) course session and consulted with Colleen Megowan, Robert Culloden, and Kelli Gamez-Warble about Modelling Instruction |
| [**Arizona School for the Arts**](http://goasa.org/) Phoenix, Arizona | Charter school\* | Observed teachers implementing Modelling Instruction in teaching Chemistry and Physics |
| [**Pardes Jewish Day School**](http://www.pardesschool.org/) Phoenix, Arizona | Independent school | Observed SMALLab Flow System (interactive classroom technology) used in classes |
| [**Phoenix Country Day School**](http://www.pcds.org/) Phoenix, Arizona | Independent school | Observed SMALLab System (digital interactive 3D classroom space) |
| [**SMALLab Learning**](http://smallablearning.com/) Phoenix, Arizona | Educational technology company | Consulted with Dr. Mina Johnson-Glenberg about Embodied Learning theory and SMALLab |
| [**Marymount School**](http://marymountnyc.org/) Manhattan, New York | Independent Catholic school | Observed the innovative FabLab with 3D printers and other fabrication tools |
| [**Trinity School**](http://www.trinityschoolnyc.org) Manhattan, New York | Independent school (formerly Anglican) | Observed and interviewed teachers implementing Modelling Instruction in teaching Chemistry and Physics |
| [**High School of Math, Science and Engineering**](http://www.hsmse.org/) Manhattan, New York | Public magnet school \*\* | Observed and interviewed teachers implementing Modelling Instruction in Physics |
| [**John Jay High School**](http://klschooldistrict.org/schools/john_jay_high_school) Cross River, New York | Public school | Observed and interviewed [a teacher implementing Modelling Instruction in Physics](http://fnoschese.wordpress.com/) |
| [**Science and Technology Magnet High School of Southeastern Connecticut**](http://www.nlstmhs.org/) New London, Connecticut | Public magnet school \*\* | Explored the specialised magnet school with a focus on STEM subjects including Engineering and Biomedicine |
| [**Massachusetts Academy of Math and Science**](http://www.massacademy.org/) Worcester, Massachusetts | Public magnet school \*\* | Explored the specialised, selective magnet school with a focus on STEM subjects |
| [**STEMtech Conference**](http://www.league.org/2012stemtech/) Kansas City, Missouri | Conference | Explored STEM education and various student pathways to STEM careers |

\* Charter school - publicly funded school which is privately run

\*\* Magnet school – public school with specialized curriculum, not based within a traditional school district

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