Supporting K-12 STEM reform through K-12 STEM Learning Workshops at Singapore University of Technology and Design

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Keywords: K-12 STEM, Active Learning, K-12 Reform, International Collaborations

INTRODUCTION

As our world is facing major technological, economic and social challenges, many governments around the globe have identified deficiencies in Science, Technology, Engineering and Math (STEM) education, while at the same time they recognize that STEM fields are the drivers of future technological and economical advancement [1-2]. "As reported through the international literature, countries have developed strategies that propose solutions to these STEM education deficiencies. Strategies have included different specialized programs for the primary, high school, and university education levels"[3]. Singapore is actively pursuing STEM reform both at

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the K-12 and at the University level. This paper describes why and how the Massachusetts Institute of Technology (MIT) has supported K-12 STEM Learning Initiatives at the new Singapore University of Technology and Design (SUTD) during the first 3 years of SUTD's life.

1 STEM REFORM IN SINGAPORE

1.1 The MIT-SUTD Collaboration

In 2010, the Massachusetts Institute of Technology (MIT) began collaborating with the Singapore Ministry of Education to create the Singapore University of Technology and Design (SUTD). The goal of this collaboration was the development "of a new engineering-oriented university that will reach the Engineer of 2020 vision, while in parallel addressing the timely formation of an institutional identity and culture that borrows from those of MIT"[4]. "In planning for this project, the MIT-SUTD Collaboration staff identified three crucial pathways in which to focus their efforts towards institutional transplantation: faculty development, state-of-the-art undergraduate curriculum design, and initiatives related to student life and student leadership" [5]. To support these efforts over the last 5 years 94 courses have been provided by MIT to SUTD, 26 new SUTD faculty have already spent up to a year at MIT to receive training in active learning, design-based learning, and collaborative learning pedagogies [6], and 6 student exchange programs have taken place [5,7]. This institutional transplantation endeavor gets enhanced by the parallel development of the International Design Center, a research center with facilities both at the MIT and the SUTD campus, and academic and industrial partners from allover the world.

1.2 STEM reform at the High School level

Development of SUTD complements Singapore's efforts to reform STEM education both at the pre-collegiate and at the university level. Singapore, with one of the fastest growing economies in the world, very quickly understood the need to become a knowledge driven economy. Despite the great growth, Singapore is also facing challenges. "The challenges facing the Singapore education system in the new millennium are unique and unprecedented in Asia. Demands for new skills, knowledges, and flexible competencies for globalised economies and cosmopolitan cultures will require system-wide innovation and reform." [8] Singapore has invested a great amount of resources in strategic education planning for the next decades to come, and part of the planning includes reform of the pre-collegiate Junior Colleges (JCs) and Polytechnics STEM education.

Major initiatives began in 1997 with the *Thinking Schools, Learning Nation* plan [8-9], which "pushed the system towards a more student-centred, active learning paradigm, with the aim of producing autonomous and independent learners"[9]. Since then Singapore has initiated a movement from a more traditional education system towards a schooling system that implements a revised inquiry based STEM curriculum. Traditional teaching methods were regarded as "undesirable" and "it was intended that these methods be replaced by 'progressive' pedagogical approaches, such as collaborative learning and differentiated teaching" [9]. The necessary technological infrastructure to support the reform is also provided to the teachers in order to enhance their teaching with Information and Communication Technologies.

2 K-12 STEM LEARNING WORKSHOPS AT SUTD

2.1 Strategic Planning and purpose of the workshops

As the MIT-SUTD Collaboration has been working towards the development of SUTD a variety of strategic educational development choices have been made. One such choice was the support of K-12 STEM Learning workshops, designed by two MIT instructors with assistance from SUTD faculty and staff, and offered to Singapore secondary education teachers. These workshops supported the three following major educational objectives.

1. By providing K-12 STEM Learning workshops, designed specifically by the MIT instructors to address active learning, problem based learning and collaborative cohort based learning, the MIT-SUTD Collaboration and the SUTD administration actively support the Singapore Ministry of Education (MOE) attempts to reform K-12 STEM education. Besides the K-12 STEM teachers, MOE staff members, involved in curricular reform, were also invited and attended the workshops.

2. The educational structure of SUTD, in contrast to other universities in Singapore, focuses on design-based learning, active learning and cohort based learning pedagogies. A strategic goal of the MIT-SUTD Collaboration and of the SUTD administration is to position SUTD on the Singapore education map at the center of active learning based education. By having the new SUTD faculty and staff supporting the K-12 workshops, they are given the opportunity to get the necessary training to be able at some future point to provide a series of active learning workshops to the K-12 STEM community on their own, and thus scale the numbers of workshops and participants.

3. SUTD is still a new university working towards establishing its academic position in Singapore. Although the administration already hosts numerous events, like open houses, to introduce SUTD to the K-12 community and to prospective students, an important objective was to expose K-12 teachers to an in-depth introduction to SUTD pedagogical methods through their participation in the workshops.

3 THE WORKSHOPS

Participants in the workshops were primarily teachers from Singapore's Junior Colleges (JCs) and a small number of Polytechnic, Integrated Program (IP) and International Baccalaureate (IB) teachers. In addition, a small number of MOE staff participated in each workshop. Science courses in Singapore JCs are typically lecture-based with anywhere between 250 and 500 students with smaller recitation sections (groups of about 50 students) meeting twice weekly. This format is similar to most STEM university courses in the United States, namely large lectures and smaller recitation sections, but in both instances student watch teachers "cover" material in a passive-learning environment.

SUTD was designed to provide a new paradigm for twenty-first education in Singapore. The educational format is primarily cohort-based learning where students meet in cohorts numbering between 45 – 50 students for all of their classes. The cohort structure allows for much more interaction between students and their instructor with many diverse types of "hands- on" exercises to help the student learn the material. The cohort classrooms at SUTD were designed with the MIT Technology Enabled Active Learning (TEAL) classrooms in mind. To help the wider community of Singapore educators understand how SUTD implements active learning, workshops JC, Polytechnic and IB teachers were invited to participate in workshops that explored active-learning methodologies. As presented in *Table 1* a total of 6 workshops with a total number of 241 teacher participants have taken place so far.

Table 1. K-12 STEM Learning Workshops at SUTD

SUTD Active and Interactive Pedagogy Series	No of Chemistry Teachers	No of Physics Teachers
Active Learning and Interactive Teaching	34	43
Active and Interactive Pedagogy – Kitchen Chemistry	33	
Active and Interactive Pedagogy – General Chemistry	29	
Active and Interactive Pedagogy – General Physics		36
Making Chemistry More Interactive in the Classroom	34	
Problem Solving Methodologies for Physics		32

3.1 The first workshop

The first K12 STEM Learning workshop was run in January 2014 under the supervision of Dr. Peter Dourmashkin, from Massachusetts Institute of Technology (MIT) Physics Department and Dr. Patti Christie, from MIT's Experimental Study Group (ESG). ESG is a cohort based freshman program that has been run at MIT for over 45 years. Both Drs Christie and Dourmashkin have taught in this program. SUTD faculty further assisted the two MIT instructors to implement the workshop. To help make the workshop relevant to the participants, initial surveys were sent out to collect background information about the participants teaching experience; in particular how they generally taught their subject, workshop expectations, challenges that they face while teaching their subject matter, experience with active learning, and the listing of three topics that they believe their students struggle with. The material was collected from the participants and analysed by the workshop instructors. For the chemistry participants, a follow-up survey asked for specific input about a list of topics. The participants were asked to provide a sentence that describes a key concept they would convey to their students. For example: for Acid and Bases, one example sentence could be: how do you get the students to understand how a buffer works?

The first workshop had both Physics and Chemistry participants together, with a total number of 43 Physics and 34 Chemistry teachers. The day and a half program started with a general introduction to active learning. Teachers then divided into their specific discipline groups and had discipline specific example lessons on active learning. As part of the workshop, participants were then divided into small groups and developed specific lesson plans designed to incorporate active learning into their specific classrooms. Based on the initial surveys from the workshop participants, the smaller groups were chosen in such a way to allow the participants to solve specific learning issues that they had encountered in their classrooms. All of the materials presented in the workshops were made available via on-line shared folders and all participants were granted free use of all materials.

Upon completion of the first workshop teachers were invited to participate in a follow up survey designed to evaluate the workshop. Findings of this study indicated that teachers encountered some difficulties at the first part of the workshop which was common both for the Chemistry and for the Physics teacher, as they had a hard time to follow, or simply did not find interesting, the cases where active learning examples did not relate to their own discipline. Teachers appeared to find the second part of the workshop beneficial as the content was more relevant to their discipline and indicated willingness to participate in future workshops, provided the content would be relevant to the course they teach, and to suggest the workshops to colleagues. To facilitate future workshops the instructors decided to keep the two Chemistry and Physics groups separate at all times in the future. Furthermore teachers were also asked to indicate more topics/concepts they would be interested to explore in the future, and their suggestions were taken into consideration into the design of the next set of workshops.

3.2 Follow Up Chemistry Workshops

After the first combined workshop in January 2014 there have been three additional chemistry specific workshops in Kitchen Chemistry (July 2014, 36 participants), General Chemistry (July 2014, 27 participants) and another General Chemistry (January 2015, 25 participants). MOE staff also attended each of the workshops. At each workshop, SUTD chemistry faculty was invited to observe and assist in the active learning workshops. Under the guidance of Dr. Christie, not only were the teachers learning how to incorporate active learning techniques, but also the SUTD faculty were trained to run the workshops themselves as an outreach activity.

Teachers from JCs were the main population. The chemistry curriculum at the JC level consists of modified A and O levels course materials from UK. The syllabus is very full and detailed. Active learning is much different than they way this material is taught currently in Singapore. The current JC chemistry syllabus contains a large number of topics that need to be covered, and switching to an all active learning format was not going to be possible at this time. It was decided after the first workshop, to focus subsequent workshops on specific activities could be integrated into the JC syllabus to at least introduce the students to this different way of learning. Therefore the emphasis now shifted to the design of small-scale activities that the teachers could use within the context of their current syllabus. The teachers could take one class period and have the students do the activity. This shift was expected to make the idea of doing active learning in their classroom very approachable to all the JC teachers.

SUTD pedagogy is heavily based on cohort-based-learning, and the classrooms have been designed accordingly Because SUTD is a new university that has yet to build up a large body of alumni, it seeks a community of secondary education teachers who can direct students to the SUTD. The workshops introduced the local K-12 community to the SUTD learning environment by experiencing active learning in a cohort SUTD classroom. This allowed teachers to see how regular cohort-based science classes are taught, and hopefully describe this new process to their students and fellow teachers.

3.3 Follow Up Physics Workshops

After the first combined workshop in January 2014 there have been two additional physics specific workshops in Active Learning Pedagogies for Physics (July 2014, 36 participants), and Problem Solving Methodologies for Physics (January 2015, 32 participants). The second workshop in had a similar focus on active learning pedagogies as the first one. Based on the experience and feedback from the first and second workshops, the third workshop focused both on expanding the participants understanding of physics through active learning, and on how to apply that understanding in the classroom. In particular, the workshop sessions concentrated on introducing materials that could immediately be incorporated by the teachers into their Singapore high school physics courses. The workshop focused on difficult concepts (as suggested by the teachers), problem solving strategies, and active learning teaching strategies for Newtonian Mechanics. An important emphasis in the workshop was on utilizing materials from ordinary day experience as part of hands-on learning for the students. The workshop also focused on teaching specific problem solving methodologies for Newton's Laws of Motion, Momentum, Mechanical Energy, and Rotational Motion. An extensive problem library developed by the workshop leader, Dr. Peter Dourmashkin, was made available to all the participants. Furthermore workshop participants were introduced to "clicker questions" and the associated Peer Instruction teaching methodology developed by Prof. Eric Mazur (Harvard University).

In addition to training the K-12 teachers, MOE staff, SUTD physics teachers, and a visiting SUTD faculty member who will teach at SUTD during the Summer 2015, attended various sessions.

4 CONCLUSIONS

Although the K-12 STEM workshops appear to be very successful so far, bringing workshop leaders from MIT is not a sustainable and scalable model. SUTD is actively working on positioning itself as the active learning hub in Singapore, while also becoming a strategic partner to the MOE's efforts to reform STEM education in Singapore. Given this goal the MIT instructors are currently working on a transition plan regarding the K-12 STEM Learning workshops. The K-12 STEM Learning workshops at SUTD have served as a foundation for additional outreach activities at SUTD. In the summer of 2015 the workshops are expected to be co-designed by MIT and SUTD instructors, and to be taught by the SUTD faculty while the MIT instructors will mainly act as their mentors.

Furthermore, besides the short-term K-12 STEM workshops, there are now opportunities discussed for K-12 STEM teachers, but also possibly for teachers of other disciplines, to be able to come as visitors for a term, audit, observe and experience how teaching using active learning and design-based learning is approached in the SUTD cohorts classrooms during regular class hours. One more idea that has been explored, but not yet implemented, is for SUTD to host "sharing sessions" of the K-12 teachers or even SUTD faculty. During these sessions the teachers will have the chance to come and share their own experiences using active learning techniques in their classroom. Expectation is that these experiences can facilitate collaboration between K-12 teachers and SUTD faculty and educational staff, and thus forming an "active learning" network in Singapore.

5 ACKNOWLEDGMENTS

The authors would like to thank the MIT-SUTD Collaboration office and the SUTD administration and staff for their support of the K-12 STEM Learning Workshops.

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