A Modular Approach to Using the Engineering Design Process in Secondary Science Curriculum

Experiences in Singapore and the United States

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***Abstract*— As a result of classroom practice and Fulbright research in Singapore, a modular approach to employing the Engineering Design process to frame projects in secondary science curricula has been developed. It is meant to facilitate project design and implementation by teachers who have little or no background in engineering. The approach has been tried in classrooms in the United States and Singapore in biology, chemistry and physics classes. Research data indicates a better understanding of scientific concepts, more realistic knowledge of engineering and significant transfer of skills.**

The motivation for a more user-friendly approach is the need to incorporate more engineering into pre-university science to allow for more skills-based learning, real life connections and compliance with the Next Generation Science Standards (NGSS). A Fulbright grant to study science education in Singapore, in particular at the School of Science and Technology, allowed an action-based research plan to be implemented to assess the development of performance tasks framed in the engineering design process. Triangulation of data based on student pre- and post-surveys, extensive classroom observation and teacher and student post-activity interviews provided clear qualitative data indicating better connection to scientific content and more divergent thinking than in traditional verification focused lab activities.

Keywords*— *secondary school engineering; engineering design; Singapore physics; project based learning

I. . Introduction

Students, more than at any time in the past, live in a designed world. They live in a world full of the applications of what they learn in science class. Understanding the process used by engineers to apply science to the development and refinement of technology should be an important component in developing future citizens who will, at least, be consumers of technology and, quite possibly, be involved in the creation of those technologies. Most high schools face a number of restrictions in implementing a separate course focused on Engineering Design. Scheduling time, personnel and material and space considerations can make the addition of a separate course problematic. High school science teachers often feel ill-equipped to teach a course focused on engineering. The strength of high school teachers is often deep experience in introductory science education and the ability to judge student interest. Since engineering is the application of science, incorporating the Engineering Design Process (EDP) into science curriculum seems to better suit making connections in the STEM fields accessible for all students. Exposure to engineering is considered critical in the National Research Council (NRC) Framework for K-12 Science Education and is a key component of the Next Generation Science Standards (NGSS). "Defining and solving the problem, that is, specifying what is needed and designing a solution for it, are the parts of engineering on which we focus in this framework, both because they provide students a place to practice the application of their understanding of science and because the design process is an important way for K-12 students to develop an understanding of engineering…" [1]. In other words, using the EDP to frame project- and problem-based learning provides opportunities to apply new ideas and increases exposure to engineering in existing courses. Extensive experience with this approach in physics classes in the United States led to a Fulbright research project to investigate the effectiveness of the an Engineering Design approach to frame Performance Tasks in secondary physics classes in Singapore.

II. Rationale for the Use of an Engineering Design Approach

Developing a more modular approach to incorporating engineering design makes it less intimidating for high school science teachers to begin to move from verification labs to design based projects. Time and training constraints make it difficult for teachers to implement extensive engineering projects while attempting to convey the content knowledge, as required by high stakes testing, and encouraging skills-based learning in line with 21st century thinking and pedagogy. A modular approach highlighting one or more steps in design along with clear connections to scientific content provides a transitional model for incorporating engineering. Creativity and group work form the background for all projects, as techniques for divergent thinking, criteria determination, scaling, optimizing, systems thinking, prototyping, design of experiment (DOE), modification and presentation of results are individually highlighted. Students learn how to engineer over the course of many projects while actively reinforcing subject area content. This approach exposes a wider range of students to engineering, adding to the number who may choose to pursue post-secondary engineering programs as well as supporting increased 21st century technological literacy and interest in STEM applications.

A. Engineering Design as a Framework for Project Based Learning

A key characteristic of Engineering Design is that the resulting artifact or solution is engineered to meet specified goals given real world limitations. By exploring both the possibilities and the limitations of science in providing solutions to problems, students are forced to acquire a more comprehensive and balanced understanding of scientific concepts. In thinking through all of the ramifications of a project, they employ "systems thinking" and develop a realization that the real world is not a highly controlled environment and that many different factors are connected. Time formerly spent on learning the very specific, targeted and formatted skills employed in many science labs can be devoted to creativity and connections.

A design approach leads to divergent thinking as students work to apply the science they have learned to generate possible solutions. The idea that there is no one right answer provides a much more realistic scenario. Real problems are rarely isolated and always have multiple solutions. Jonassen finds that ill-structured nature of design problems requires "designers" to specify criteria, find a solution path and integrate multiple knowledge domains [2]. Increased transfer is demanded by such activities.

Science teachers teach science, not engineering and not design. As a result, a framework that helps them keep science paramount is critical to both learning goals and professional comfort level. If design is to be a predictive rather than a trial and error endeavor, the process of thinking before acting is critical. It is necessary for design to be a systemic approach to avoid the "prospect of wandering endlessly in search of a solution" [3]. Putting knowledge to use to make something is an opportunity to verify the model forming in a student's mind. It makes the abstract idea concrete. An understanding of the link between the design (form) and the intended goal (function) encourages systems thinking or the ability to see the interrelatedness of parts. In addition "Engineering activities and goals are not trivial and can be intrinsically motivating because they engage a natural desire to make things and they tap into the curiosity that comes from wanting to learn how things work" [4].

B. Incorporation of 21st Century Skills

Educators and policy makers worldwide refer to the need to instill 21st century skills in today's students. The goals of education need to shift to developing a solid conceptual framework and to equipping students for lifetime learning and non-routine problem solving. Education is no longer about how much you know; it is about knowing how to learn. The OECD states that "We live in a fast-changing world, and producing more of the same knowledge and skills will not suffice to address the challenges of the future. A generation ago, teachers could expect that what they taught would last their students a lifetime. Today, because of rapid economic and social change, schools have to prepare students for jobs that have not yet been created, technologies that have not yet been invented and problems that we don't yet know will arise" [5]. It makes no sense to focus on facts that we know and problems that are formulaic and routine when we are educating students who will live in a future we can't fully imagine. Engineering can allow for the incorporation of the 21st century skills into science curricula. The Association for Supervision and Curriculum Development (ASCD) states that it is crucial for curriculum to be designed to "connect the content knowledge to real-world applications and problem situations that enable students to see how what they are learning connects with their lives and the world around them. The work that is asked of students must be authentic work that is relevant and that mirrors real life"[6]. This description could be that description of engineering. If we hope to attract creative innovators to technical fields, we need to provide opportunities for them to create in school. Continuing to teach science as a compendium of facts and using lab exercises that are rote and routine will discourage the very students we need to attract.

III. Comparison of the US and Singaporean Education Systems

A. General Overview of the Singaporean Education System and the Role of Skills-Based Learning

Singapore has a well-developed modern education system. Approximately 650,000 students are enrolled in about 350 schools in a strongly centralized system. It is a highly successful program, both in terms of literacy rate, close to 95%, and success on international assessments. Out of 65 countries and economies that took part in the Programme for International Student Assessment (PISA) 2009, Singapore students ranked fifth in Reading, second in Mathematics and fourth in Science. Singapore also had the second highest proportion (12.3%) of students who are top performers in all three domains according to the OECD and the Ministry of Education. Latest results from the OECD state that "Singapore scores highest in the PISA 2012 assessment of problem solving, with 562 points on the PISA proficiency scale" [7]

Since its independence from Malaysia in 1965, the Singaporean government has been committed to developing the population to be the country's strongest resource. Education has long been a top priority and the system has its roots in the Cambridge system. Key assessments at the 6th grade level (PSLE), at the end of secondary school (O level exams) and then at the end of Junior College (A level exams) determine pathways available to students. In recent years, alternative routes have increasingly been made available, but the weight of high stakes testing is well-entrenched in society and change in terms of focus on testing has been slow in coming.

As a result of government initiatives to focus on skills-based learning, curriculum has been and is continuing to be modified to offer more depth and understanding. Initiatives such as Thinking Schools, Learning Nation (TSLN) and Teach Less, Learn More (TLLM) coupled with increased Ministry of Education focus on 21st century skills, provide the foundation for these changes. In announcing the vision for schools of the future in 1997 (TSLN) Prime Minister Goh Chok Tong stated that "A nation's wealth in the 21st Century will depend on the capacity of its people to learn. Their imagination, their ability to seek out new technologies and ideas, and to apply them in everything they do will be the key source of economic growth. Their collective capacity to learn will determine the well-being of a nation. . . Learning will not end in the school or even in the university. Much of the knowledge learnt by the young will be obsolete some years after they complete their formal education. . . The task of education must therefore be to provide the young with the core knowledge and core skills, and the habits of learning, that enable them to learn continuously throughout their lives. We have to equip them for a future that we cannot really predict" [8].

Policy aside, the reality in Singapore is that change in the education system has been slow in making its way into the enacted or classroom curriculum. In a sense, the country is a victim of its' own success and most of the current policy makers, administrators, teachers and parents are products of a system that has transformed the country in just a few decades. In addition, assessments have been slow to change since the need to objectively score large numbers of tests places limits on formats and grading procedures. Singaporean researchers have found that students continue to be immersed in an environment where standardized, high-stakes assessment is emphasized A number of researchers have even found that "thinking skills" are taught as explicit facts and techniques to be remembered and instruction in them focusses on drill and practice, a highly prevalent form of knowledge transmission in Singaporean classrooms[9]. Although the use of formative assessments is encouraged by the Ministry of Education, summative assessments are still far more prevalent [10].

The Physics curriculum in Singaporean secondary schools, which are equivalent to grades 7-10 in the United States, is based on the Cambridge "O" Level syllabus. It is presented in a spiraling approach at all grade levels and has fairly low level inclusion of math. It is primarily a conceptual physics curriculum. In a typical school, classes can be as large as 40 students, but in more specialized schools they can be as small as 20 students. Students have about three to four hours of class per week and lab exercises consist of highly scripted verification based activities. In order to begin the move toward more authentic assessments, many schools have longer "Performance Task" projects in their syllabus. This prepares students for recently introduced nationwide SPA (Science Performance Assessment) testing.

As part of the move to provide more pathways for students, schools with different types of entrance procedures and focuses have been developed. This is similar to some of the approaches seen in the United States in terms of charter schools, arts magnet schools and STEM schools. The School of Science and Technology (SST) is one such secondary school. The mission of the school is "to develop world-ready and future-looking leaders versatile in the 21st Century competencies and adept in the use of technology". SST is designed for "students who learn best in an active applied learning environment, where conceptual understanding and transference of disciplinary content knowledge and skills are fostered through cognitively demanding hands-on applications set in real world applications" [11]. The project that will be discussed below was conducted with five Secondary 3 level classes and two physics teachers at SST. It was designed to test the viability and effectiveness of using the EDP to frame a Performance Task.

B. Key Similarities in Science Education and Issues between the United States and Singapore

The biggest issues facing both countries stem from the need to attract creative people to technical fields and to insure that all citizens have a reasonable level of technological literacy. Students need to be educated to innovate and invent. Linear delivery of material, combined with drill and practice reinforcement do little to attract creative thinkers to the field.

In both countries, awareness of engineering career options is limited. Few students see engineers as creative or socially aware professionals. Even fewer know what they do and how they do it. Given that they live in a highly engineered world surrounded by technological artifacts, this indicates a gap in education. The US National Academy of Engineering states "If young people do not know much about engineering or have a skewed view of what it means to be an engineer, we cannot expect them to seriously consider engineering as a career. And the ability to attract creative young minds to engineering is directly tied to the nation's innovation capacity, which many experts believe is in decline. Finally, knowing something about how the human-designed world has been created—and by whom—is a cornerstone of technological literacy, an important attribute for life in the 21st century" [12].

In both the US and Singapore, science curricula are essentially lists of facts and concepts to be mastered (memorized). The Next Generation Science Standards (NGSS) represent a bold move towards skills based models, but they are not yet reflected in enacted classroom curriculum. In Singapore, the Ministry of Education states "To be future ready, our young need to be able to think critically, assess options and make sound decisions. They should have a desire to learn, explore and be prepared to think out of the box. They should not be afraid to make mistakes and face challenges that may at first appear daunting"[13]. In both countries, teachers are still justifiably unconvinced that deeper understanding of fewer ideas will translate well to tests that look for superficial knowledge of a large number of facts.

In general, US teachers in most areas see high school science classes approximately one hour more per week for formal classes than Singaporean teachers. But in Singapore, extra review and problem solving sessions seem to be mandated more frequently. In the end, the hours of exposure per student per week are probably close to the same.

The role and importance of high stakes testing in Singapore cannot be over-emphasized. In addition to state administered exams, there are additional term and semester exams that reflect content on national assessments. The result is that a great deal of time is spent preparing and reviewing for national assessments throughout a young person's career in the Singaporean system. Students and teachers in the US are not immune to the impact of standardized high stakes exams mandated by states. In addition, very competitive high school students in the US have concerns that are very similar to those of Singaporean students. College admission pressures drive demands for high grades on transcripts, extensive success on Advanced Placement exams and a need to learn how to "test well". Those pressures on students impact teacher choice of how and what to focus on in the classroom. In both countries, a great deal of what happens on a daily basis is determined by assessments that are out of the teacher's control.

C. Key Differences in Science Education and Issues between the United States and Singapore

Despite limited public knowledge of engineering careers in both countries, engineers are viewed as professionals in the United States. The view that it is a field for the "select few" still predominates. Engineers in the US typically command some of the highest salaries right out of college. In Singapore, engineering is not a field held in such high esteem. Many students view it as more of a technical education field, and not as high in stature as financial and business careers. That is a view that is engineers and educators are trying to change, but it affects the type of student attracted to the field. Unlike the US, Singapore graduates a sufficient number of engineers, but innovative technology initiatives stress creativity and vision.

Although there is state mandated testing in the US, parental focus on testing is minimal in comparison to Singapore. In many areas of the US, state testing is more a reflection on the school and the teacher. In Singapore, test results from 6th grade on influence and, to a large extent, determine the child's path through the rest of the education system and subsequent career choices. Everyone, from parents to students to teachers and administrators focusses on high stakes test results. Change has been slow in coming. The enacted classroom curriculum is still very much governed by test content and the nature of large scale testing makes designing authentic assessments for skills-based learning problematic.

The most significant difference between the education systems of Singapore and the United States is the level of control. Education in Singapore is highly centrally controlled, whereas in the US state control results in 51 different systems. Change in Singapore is driven from the top down and input is sought from industry, academic researchers at the National Institute of Education and other vested interests. Teachers at a given grade level teach the same curriculum in order to prepare students for testing that is nationwide. To a certain extent, this has limited teacher autonomy and responsiveness, but that is beginning to change in the face of independent schools and government policies encouraging a focus on skills.

In the United States, the wide range of systems and the disparities that exist within states due to funding formulas create a broad spectrum of issues. Most science teaching remains fairly conventional, due to the difficulty of orchestrating sweeping change. There is, however, more opportunity for teacher-driven pedagogical change due to increased autonomy in the de-centralized US system. In addition, some states have already moved to include engineering design and principles in state standards, paving the way for the implementation of similar changes suggested by the NGSS.

There is a need for math, chemistry and physics teachers in US high schools. Physics teachers in particular are in short supply. The Physics Teacher Education Coalition of Cornell University states "At this critical juncture, the US faces a current and future shortage of science, technology, engineering and mathematics (STEM) professionals. This shortage is due in no small part to a critical shortage of qualified high school physics teachers. High school physics is a prerequisite for nearly all STEM careers. The shortage of physics teachers is leaving too many US students unprepared for college study in STEM disciplines. America lags far behind most of our global competitors in physics training"[14]. Active learning techniques require a very strong knowledge base. Teachers need depth of knowledge to anticipate preconceptions and to have confidence in their ability guide students to correct models and ideas. In Singapore, most physics teachers were physics majors and have a secondary education degree. Teachers are held in high esteem in Singapore and physical science majors see it as a viable career path. In general, teachers have higher salaries than many other professions that require a strong math and science background. As a result, Singapore does not face the level of shortages in the STEM teaching fields that the US must contend with.

IV. Implementing an Engineering Design Project in a Singaporean School

A. Summary of Project and Research Goals

After observing physics classes at various levels for several weeks and developing several project ideas, it was decided that the five Secondary 3 Physics classes at SST would be the best fit for a meaningful EDP project. They were studying mechanics and had just finished forces and were transitioning to energy concepts. That would be followed by moments (torque) and stability concepts. Based on curriculum content and the ability to compare and contrast the project with previous experience in the US, a mousetrap powered vehicle project was proposed and received enthusiastic support from the administration and faculty.

The project itself was fairly simple: to build a mousetrap car using a simple Victor mousetrap as the engine and to design to maximize both speed and distance. Since these are opposing design considerations, one requiring a rapid transmission of force and one requiring slow release of potential energy, students had to learn about optimization and balancing tradeoffs in addition to other problem solving skills. The problem was left fairly open ended by using only two constraints: the spring of the mousetrap could not be altered in any way and there needed to be three or four wheels. The overall project was framed in the engineering design process (EDP) and it was made very clear to students that all design decisions and modifications had to documented and related back to science. Students worked in groups of four and were required to maintain a group Engineering Notebook (ENB). The project was planned for six 55 minute class periods with time allotted afterward for presentations. Teachers in Singapore chose to focus on the engineering skills of matrix decision making to develop criteria, optimization, and clear documentation and communication of the process and results.

Research methodology was based on triangulation from three inputs. Students were given pre- and post-surveys to quantify changes in their understanding of the physics concepts and of their understanding of engineering. In addition, every class period was observed, and in some cases, taped. Post activity interviews were conducted with 12 students of various abilities, along with more in-depth debriefing of the teachers involved. It should be noted, however, that the system was not closed and most data was used to indicate qualitative trends rather than firm quantitative results. Since each class of 20-21 students was different and there were two different teachers involved, it was difficult to isolate and control variables. In addition, some students were attending review and remediation classes on the topics involved and there is always a factor of independent outside tutoring (tuition) in the Singaporean system.

The two over-arching skill and concept areas that were focused on were (1) energy transfer concepts and (2) the introduction to and use of the Engineering Design Process. In simple terms, the energy stored in the mousetrap spring is transferred via work done by a lever arm and string to exert torque on the axle and becomes kinetic energy. The transfer system is analogous to a real car with rear wheel drive. The engine is replaced by the mousetrap spring, but the physics concepts are the same. Auxiliary ideas and concepts involved conservation of energy, acceleration, friction, rotation, torque and stability issues. The use of the EDP was new for the students, so it was decided to focus on techniques for developing and choosing designs using criteria, optimization and the role of the engineering notebook in documenting the practice.

Most of the students had a basic knowledge of kinematics, with expected confusion about acceleration, new knowledge of forces and a developing knowledge of energy concepts. Math skills in general showed solid grasp of Algebra 2 and Geometry. Little exposure to engineering was evident, but some basic ideas of design were retained from Secondary 1 classes two years earlier. Because of the culture of the school (SST), all students were familiar with and comfortable working in groups.

B. Issues Encountered During the Project

The two biggest issues encountered during the project were access to materials and time constraints. The initial roadblock to the project was the difficulty in finding simple mousetraps in Singapore, or elsewhere in Southeast Asia. A change in project design was discussed but the value of being able to compare it to a similar US project was deemed significant. Mousetraps were shipped form the US for the project. Another unexpected issue was that access to and variety at craft stores and do-it-yourself centers was limited in Singapore. In the end we were able to source everything we needed or make viable substitutions.

The Secondary 3 physics classes only meet three times per week. Project time had to be divided around classes allotted for review of material that had recently been assessed and had proven challenging for most students. The project was limited to six class periods, basically two classes per week over a 3-4 week period. The March break occurred during the project time frame and students worked on their vehicles outside of class during that week. Unfortunately, many instructors of other courses assigned project work during that time and students felt rushed and unable to prioritize. It would have been better to have construction occurring in class or with teacher observation in order to insure students thought through choices and did not resort to trial-and-error. In addition, one more class to allow for testing modifications would have been helpful. As in any school, some absences occurred due to illness, commitments other than class, competitions, and issues that were strikingly similar to scheduling conflicts in the United States.

C. Results

As has been noted, the difficulty in maintaining closed systems with good variable control makes it difficult to accurately state quantitative changes. Trends were determined significant if there was strong positive correlation in all three measurements employed. Student results on surveys, depth of discussion during the activity and student self-assessment during interviews were considered strong indicators. Improvement was determined to have occurred if it was indicated by survey results, in class observations and student interviews. An increase of greater than 20% or more in correct answers and explanations was considered to be valid improvement.

Areas where improvement was noted are:

- Correct depiction of horizontal and vertical forces
- Awareness of the normal force
- Relationship of torque to rotation
- Motion in the absence of net force (i.e. non-accelerated motion)
- Factors affecting kinetic energy
- Role of and factors relating to friction

Areas of little or no improvement:

- Distinguishing between power and energy
- Understanding of negative acceleration
- Relating motion of car to direction of wheel rotation
- Understanding of action/reaction forces; 3rd Law pairs

Perhaps most significantly, close to two thirds of the students reported on surveys and in interviews that they understood forces, energy, moments and rotation better as a result of the project. While many students still struggled with concepts like acceleration versus velocity, those who grasped the distinctions showed a solid understanding.

Prior to the activity, students listed designing, building and working with machines as the three principal focuses in engineering. Their understanding seemed to broaden post-activity with designing, planning and building listed as being fairly equal in importance. Pre-activity descriptions of engineers were stereotypical and similar to those listed by US students in studies. Qualities of engineers were hard-working, very good at math and science, careful and determined. SST students did list creative as being an important attribute pre-activity, perhaps due to their exposure to design in other activities. Post-activity descriptions gave more weight to creativity and added descriptors of social and analytical problem-solvers.

The Singaporean teachers involved were very supportive of the role of criteria and decision matrices in democratizing group decisions. It is a technique they hope to extend to future projects. It was also noted that students readily attacked the conflicting parameters of distance and speed and worked hard in terms of trade-offs and optimization. Several groups attempted to develop linear mathematical models in order to look for the intersection. They seemed far more comfortable applying math than their US counterparts.

D. Trends and Issues Noted During Observations, Discussions and Interviews with Students

- Most groups seem to work well, and the idea of the project manager as the point person seemed to be readily accepted. Groups without a strong leader floundered a bit. Interestingly, groups that were the least focused and organized were all all-male groups (anecdotal).
- As is always the case, student involvement picked up when cars were ready for unofficial testing.
- Most students attempted to "speak physics" when questioned about design choices and modifications. However, in many groups, it was often clear that one student had assumed the role of group physicist.
- Students had to be constantly reminded to write things down. Many recognized the benefits of this in retrospect when preparing presentations.
- It took 1-2 classes before students started to feel "expert" enough to defend their choices to instructors and other group members.
- At the start of official testing, a fear of failure was prevalent ("kiasu"). Some groups were afraid to try, despite the fact that the best of the three runs would count.
- Students seemed very comfortable presenting. All addressed the audience without prompting and groups worked to insure that every member had a voice. Presentations were well formatted.
- Students showed a level of comfort with CAD drawings and were adept at using Google Sketch Up.
- Many students reported being surprised and gratified by seeing that their cars would work based on how they applied the physics they had learned in class.
- Approximately one-fourth of the students felt that they needed more time, particularly for trouble-shooting and modification.
- Many found the modification stage to be like solving a puzzle and enjoyed the process.

E. Comparisons to US Students

The following qualitative comparisons are based on the behavior of US students in physics and engineering classes over the past three years. Students in the US were approximately two years older than the SST students in the project.

- SST students were not as interested in bigger, better, faster. Most were at first happy to just reach the minimum 4 meter distance.
- Classes were quieter overall during the building phase.
- Singaporean students seemed to need a little more structure. They may have benefitted from more forms, worksheets. This issue was determined to be age-related in subsequent discussions with teachers.
- SST students were not as enthusiastic at first, but once a functioning car was ready the same degree of ownership, pride, involvement became apparent as in the US.
- There was much less questioning during the introduction phase ("lecture"), about the same once group work and building began.
- There was less need for instructor approval or affirmation during the process. US students often want to show you their good idea or a feature of their car. On the positive side- this is an opportunity for some formative assessment, guidance; the downside is that it may indicate

that US students may not have the confidence or it may be a manifestation of the “trophy for showing up” mentality.

- In general, deadlines did not seem to have the same force as in the US. By the end, in the testing phase, cars were at least on time. But worksheets, notebook materials and sometimes presentations did not meet deadlines. This may just be an SST culture phenomenon.
- In general, students were careful to allow every group member to have a role in the presentation. This is sometimes an issue in group presentations in the US. All groups respectfully greeted the audience.
- Student attention to elements of the provided rubric was not as literal as it is in the US. US students use rubrics as a checklist. If Singaporean students did, it was not as apparent.
- Singaporean students were not as willing to question other groups. Presentations were received politely and with little comment from other students.
- Peer evaluation forms were generally high at SST. There is far more variance in the US.

During the project and in instances that involved exchange and sharing with Singaporean students and teachers, some key attitudinal and cultural differences that are significant to active learning became apparent. In general, the classroom in Singapore is still a hierarchical society, where the teacher is regarded as expert and commands a high level of respect. US classrooms tend to have a little more of a collegial feel and students are more likely to question a teacher. Active learning requires accessibility on the part of the teacher and more of a role as a coach or facilitator. In an active classroom, a significant amount of learning occurs through questioning of fellow students and teachers. This seems to be a more natural fit in the US.

As importantly, making mistakes needs to be highly valued. Scientists are often wrong and engineers rarely get optimal solutions the first time around. Questioning in Singapore is often thought to imply that something is not quite right, i.e. a “mistake”. Making mistakes is difficult for anyone striving for excellence to tolerate at times, but it is even more difficult in a society that has, as a whole, been very successful. Singaporeans will freely admit to being “kiasu”, which can be translated to mean afraid of losing out. Whatever the pros and cons are of kiasu behavior, it manifests itself in the classroom as a fear of being wrong. This makes open discussion and questioning challenging. Even in professional settings with other teachers, there is a hesitancy to ask questions or to use techniques like brainstorming or white boarding to generate ideas and models.

It is also significant to note that Singaporean students and teachers are, in general, more reflective than their US counterparts. Many activities are followed by “de-briefing” type discussions. Singaporean students seem more comfortable identifying meta-cognitive strategies and show more awareness of their own learning styles. While this increased reflection was a positive in most instances, it was clear that at times it limited truly divergent thinking and experimentation.

V. Summary and Issues to Consider Moving Forward

In conclusion, the Engineering Design Process provided a useful framework for a Performance Task in Secondary 3 Physics classes in Singapore. Using the EDP at the School of Science and Technology resulted in improved understanding of concepts and an increased awareness of engineering. As in the United States, replacing a conventional verification lab with an EDP based project provided a clear pathway for the application of science and a framework to maintain focus on concepts. It gives students exposure to the creative, innovative nature of science and engineering. In an educational environment where the focus is increasingly on 21st century skills, the EDP gives teachers and curriculum designers a framework to showcase the importance and application of creativity, critical thinking, collaboration and communication while maintaining clear connections to the subject content.

Some of the biggest obstacles to incorporating more engineering in secondary science are teacher preparation and finding time in an already crowded syllabus. Using a modular approach focusing on several specific engineering design practices made the project more manageable for both students and teachers. Replacing traditional verification labs with EDP projects can minimize the scheduling and resource impacts. It allows teachers to expose students to engineering skills in smaller “packages”.

This research indicates that including engineering design in the science curriculum should be viewed as a win-win proposition. Students can learn through application and the question “When will I ever use this?” can finally be answered. But more importantly, students and teachers will develop a better understanding of the highly engineered 21st century world that they live in. It is difficult to predict and adapt to the future without first understanding and appreciating the present.

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