FACILITATING 21ST CENTURY SKILLS IN ENGINEERING STUDENTS

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Abstract

Engineering education is at an important juncture more than ever before – engineers need to play an important role in creatively solving global and complex challenges related to energy, health care and environment; they need to work with an understanding of multiple disciplines in collaborative teams that are culturally and philosophically diverse; cultivate complex communication and social skills; and, among other things, engineers need to be able to explain science and technology to a society that is increasingly more doubtful of its impact and intentions despite enjoying the comforts that come with the progress in engineering & technology. This growing pace of innovation, both in terms of products and business models, is also likely to make the job of an engineer quite challenging. Engineers must, therefore, learn to work with ambiguity, diversity of disciplines and with humility regarding their own skills and abilities.

To prepare engineers for the global workplace, it is clear that a traditional engineering curriculum which is content heavy will not be sufficient. There are already indications that there is a significant gap between what undergraduate engineering students are taught and assessed and what the professional engineers and industry practitioners expect them to be capable of (Felder, R.M., On-the-Job Training, Chemical Engineering Education, Vol. 42, No. 2, pp. 96-97, 2008). This gap will significantly widen unless intentional, well-targeted measures are put into place in engineering education to specifically foster 21st century skills. Learning outcomes, curriculum design, classroom practices, learning and assessment tasks all have to be coherently crafted and implemented so as to facilitate a flexible, personalized and significantly meaningful experience for the student.

The paper begins by exploring students' knowledge and skills of the 21st century that are needed for the modern engineer. We provide our perspective on aspects of curriculum design, impactful classroom practices and methods of assessment that can be expected to form the bedrock of engineering education for the next decade. Our paper will only attempt to throw light on the immediate path ahead based on progress made in understanding how learning works, how information and communications technology can augment good teaching and learning methods and how assessment practices (which remains a major handle to drive the learning process) may be re-envisioned to help students grapple with grand societal challenges and equip them with philosophies, concepts, ideas and imagination for contributing to the greater good of humankind.

Keywords: Engineering Education, 21st century skills.

1 INTRODUCTION

Engineering education is at an important juncture more than ever before. Although basic engineering concepts don't change, the knowledge explosion, the ever-increasing complexity in which engineers work and the changing global economy demand for new paradigms to shape professional skill sets and competencies of new engineering graduates. As outlined in the Grand Challenges for Engineering by the National Academy of Engineering, USA, engineers will be required to play an important role in creatively solving global and complex challenges related to energy, health care and environment. They need to work with an understanding of multiple disciplines in collaborative teams that are culturally and philosophically diverse; cultivate complex communication and social skills. And, among other things, they need to be able to explain science and technology to a society that is increasingly more doubtful of its impact and intentions despite enjoying the comforts that come with the progress in engineering & technology. This growing pace of innovation, both in terms of products and business models, is also likely to make the job of an engineer quite challenging. Overall, engineers must learn to work with ambiguity/uncertainty, diversity of disciplines and with humility regarding their own skills and abilities.

The fact that we live in a highly-connected, knowledge-based world reinforces the need for new sets of engineering competencies and professional skills to take on the Grand Challenges in a sustainable manner. Engineering education should therefore not merely focus on local challenges but should attend to regional and global opportunities. Workplace demands that future engineers be technically qualified, flexible, problem solvers, creative and dynamic thinkers, however classroom practices and learning spaces have not really adapted themselves to best facilitate such learning.

It is clear that a traditional engineering curriculum that is heavy in technical content will not be sufficient to prepare engineers for the global workplace, Felder (2006) rightly points out that engineering education has been "teaching the wrong stuff" by focusing merely on equipping students with analytical and problem-solving skills. Other evidence suggests that engineering education is holding onto approaches to problem solving and knowledge acquisition that are out of alignment with professional practice (Duderstadt, 2008; Sheppard et al., 2008). The current model places technical problem solving at the core of "accountable disciplinary knowledge" (Stevens et al., 2008) while giving superficial attention to professional competencies. Engineering students see educational experiences like internships, international exposures and projects as more representative of what it means to be an engineer than their in-class experiences like lectures and discussions, and describe a steep learning curve once they enter the workforce (Atman et al., 2010).

Felder (2008) also emphasises that there is a significant gap between what undergraduate engineering students are taught and assessed and what the professional engineers and industry practitioners expect them to be capable of. This gap will significantly widen unless intentional, well-targeted measures are put into place in engineering education to specifically foster 21st century skills. Engineering leadership should therefore take an intentional (as opposed to a *just-in-case* approach), systemic, integrated approach in which learning outcomes, curriculum design, classroom practices, learning and assessment tasks all have to be coherently crafted and implemented so as to facilitate a significantly meaningful experience for the student.

2 21ST CENTURY SKILLS

Singapore has accomplished considerable success in modernizing educational system and achieving a high level of academic performance in its students. To achieve a rapid transformation to the 21st century learning system, the Ministry of Education (MOE) introduced a new, "Teach Less, Learn More" initiative. The aim is to signal and implement a further shift in focus from "quantity" to "quality" in education (Ministry of Education, 2011).

In today's global economy, sharing of information, collaborative team work, innovative thinking, problem-solving and decision-making are key competencies necessary for an engineer. There has been a significant shift from merely mastering manufacturing skills to emphasising information/knowledge services (Scardamalia et al., 2011). The increased use of technology is also transforming how students work and build new social practices. According to the National Research Council (2011) report, five skills namely adaptability, complex communication skills, non-routine problem-solving skills, self-management or self-development; and systems thinking – are becoming increasingly valuable. Numerous research studies and reports (Partnership for 21st Century Skills (P21), 2005; Trilling & Fadel, 2009; Binkley et al., 2010) have identified the key skills needed to succeed in the 21st century globalised world. They are:

- **Creativity and innovation:** The ability to create new ways of thinking and be able to find solutions to new problems by being innovative enough to build new products and services.
- **Critical thinking and problem-solving:** The ability to apply higher order thinking to new problems and issues, use appropriate reasoning to analyse problems and be able to make appropriate decisions needed to solve problems (non-routine problem solving using critical thinking).
- **Communication:** The ability to communicate effectively in a wide variety of forms and contexts for a wide range of purposes by using multimodal communications and technologies.
- **Collaboration:** The ability to work in teams where they are able to effectively generate, share and use ideas.
- **Information literacy:** The ability to access, evaluate, synthesise and share information from multi-disciplinary/interdisciplinary sources.

- **Technology usage:** The ability to identify appropriate technology tools and use them efficiently, ethically, and effectively.
- **Career/Life Skills:** The ability to become self-directed and independent learners who can adapt to change, manage projects, take responsibility for their work, lead others and produce results.
- **Personal/Social responsibility:** The ability to develop cultural competence in working with others by recognizing and respecting cultural differences while working on diverse cultural and social backgrounds.

3 PREPARING ENGINEERS FOR THE GLOBAL WORKPLACE

It is been widely criticised that traditional engineering education practices like lectures and lab sessions are inadequate in preparing engineering students for being effective professionals. This is more so when the lectures turn out to be monologues and the laboratories are recipe driven rather than inquiry driven. Traditional classroom and laboratory practices encourage a passive form of learning within a compartmentalised curriculum (Duderstadt, 2008). Therefore, it is important for engineering education to re-build a curriculum that focuses strongly on collaborative and interdisciplinary projects, tasks and assignments. Such activities would require students to be involved in active learning strategies, be engaged in high-level problem-solving skills and be able to participate in team building activities and forge collaborative partnerships amongst multidisciplinary teams (Kalonji, 2005).

By and large, the current undergraduate engineering education focuses on students acquiring content knowledge rather than preparing them for professional practice; this often results in students taking a surface learning approach rather than deep learning approaches. The discipline-focused program structure with its narrow but heavy workload promotes a passive learning approach where less than desirable amount of thinking and collaboration happen. However, according to a study by Prince (2004), active learning benefits student engagement; collaborative work is found to enhance academic achievement of students, their attitudes towards learning, and retention of students to the programme. Lattuca et al. (2006) point out that employers assessed the teamwork and communication skills of engineering graduates as "at least adequate". While is accepted that it is extremely important for engineering education to produce technically competent graduates, the time is apt for enriching and broadening engineering education to foster generic, transferable skills.

Stanford University President Hennessey (2006) stated that solving these problems will require *“deep collaboration and intensive investment.”* Hence to address the gaps, engineering education must make considerable changes in the programme to:

- Innovate engineering curriculum to develop the necessary 21st century skills and competencies in its students;
- Focus on learning (not teaching) to enhance the learning experience of the students by integrating diverse classroom techniques, using complementary technology, implementing new learning strategies and address different learning styles of students;
- Develop engineering educators’ skills and competencies through continuous professional development where they understand better on what it takes to practice the engineering profession as well as be able to effectively catalyse student learning (Morell & DeBoer, 2010). Faculty members must understand "How Learning Works" and use such understanding to good effect (Ambrose et al., 2010); and
- Introduce and integrate assessments to assess the 21st skills imparted (National Research Council, 2011).

4 PEDAGOGY AND TEACHING INNOVATIONS

In the 1990s, Singapore started “Thinking Schools, Learning Nation” initiative to promote critical thinking and problem solving in schools. A review of the math and science curriculum was introduced in 2001 to create more time and space for “engaged learning” while the “Teach Less, Learn More” initiative in 2005 focused on providing more innovative teaching methods. According to Darling-Hammond, Singapore represents a nation that sees its future in the knowledge and expertise of its people, and has taken up the challenge of creating a 21st century education system in a tripartite partnership between the Ministry of Education, the National Institute of Education and the schools (National Institute of Education, 2009).

The “Teach Less Learn More” initiative (MOE, 2005) encourages teachers to rethink on three items: (i) why they teach, (ii) reflect upon what they teach and (iii) to reconsider how they teach. More importantly, it emphasises a strategy that moves away from “for a life of tests” or “grade-centric” approach to “for the test of life” or “value-centric” approach. This model motivates teachers to excite passion for learning and understanding in their student learners than to merely rush through the syllabus. It promotes a differentiated personalised teaching, moving away from a “one-size fits all approach”. Through appropriate guiding, facilitating, mentoring and modelling, teachers are able to foster engaged learning in their students leading to a high spirit of innovation and enterprise.

All of these efforts resulted in Singaporean students’ rise to the top of the world in math and science. Thus, taking the cue from the schools, engineering educators in Singapore universities have moved from content coverage to skills/competency development in students – they are covering less so that the students can discover more by themselves through structuring and scaffolding of teaching, creating authentic, realistic and challenging assignments that are solved by “designed” student groups working together etc. Educators are beginning to make *good* use of ICT to deliver content online and free up class time for achieving higher order educational objectives.

According to Morell & DeBoer (2010), engineering education literature tends to emphasize on what needs to be changed, how the change should be driven and who should drive the change but fail to provide guidelines for teachers on best practices and roadmaps to become better educators and professionals. Change and innovation start best within individuals and grow in communities of practice. Centres’ for Teaching Excellence (or their equivalents) in campuses or in Faculties/Departments have a major role to play in fostering and transferring innovations and good practices. When such centres are not available, engineering educators could resort to reading educational journals that cater to specific disciplines and the general ones. Engineering educators ought to bring in their curiosity, measured scepticism, willingness to experiment and indulge in scholarship to the teaching and learning process as well. Some of their time could be devoted to participating in educational seminars and conferences, being active in educational societies and even contributing to educational journals. Without innovations to curriculum, pedagogies, assessment/grading and the learning spaces, engineering will see continued attrition of the best student brains to other disciplines. We outline some innovations from NUS Engineering in what follows:

4.1 Curriculum innovation

Current global challenges such as climate change, clean energy and ageing-related healthcare issues, require creative engineering solutions that integrate knowledge from multiple disciplines. Taking this into consideration, the National University of Singapore (NUS) has introduced curriculum changes to the engineering education by introducing flexible, innovative and alternative learning pathways that strongly emphasise cross-cultural, cross-disciplinary and problem-based learning.

The enhancement programmes offered at NUS broaden the engineering students’ education. Programmes such as Industrial Attachment Programme (IAP), Vacation Internship Programme (VIP), Technopreneurship & Incubation Programme (TIP), Innovation Programme (IP), Undergraduate Research Opportunities Programme (UROP) and Independent Work Programme (IWP) provide students with personalised and non-traditional learning opportunities. Students are free to select one or more of these programmes based on their learning interests. These programmes enable students to:

- translate theories learnt in the classroom into practice in a real world environment;
- instil the right kind of work attitude and professionalism through interaction and collaboration with industry professionals and thus be better prepared for careers in the future workplace;
- acquire skills to be able to think critically and creatively and be involved in the intellectual process of inquiry;
- promote independent-learning as well as collaborative team-work;
- understand the effective use of technology in the workplace; and
- appreciate and/or challenge current engineering practices.

One of the recent curriculum innovations introduced at the NUS Faculty of Engineering is the Design-Centric Curriculum (DCC) that provides students the opportunity to pursue a Master’s degree from one of the leading partner universities after an undergraduate degree at NUS. In putting together the DCC, its leadership designed this four year integrated curriculum to provide students support, challenge and intensity to explore material in greater depth and make strong connections between theory and practice through thematic multi-year, multi-disciplinary design projects. Real-world practical designs, self-learning, collaborative work, systems thinking and engineering technology management are embedded within modules right from the first year. Projects selected under the curriculum are centred on the *big and complex questions* such as climate change, transportation issues, natural disasters and healthcare for the elderly. It is hoped that the DCC will invoke a spirit of innovation and entrepreneurship in students.

A second example for curriculum innovation is the “Global Engineering Programme”. This programme provides a global learning experience and an early exposure to research. Students in the programme have the opportunity to spend at least one semester at a partner university overseas, participate in overseas summer programs and community projects. Students are mentored by a select pool of faculty members and can participate in activities to enhance their communication and leadership skills.

4.2 Learning experience

Research indicates that students in the STEM (sciences, technology, engineering and mathematics) disciplines learn best through active activities conducted in small-group settings. Active learning involves students in meaningful learning activities/tasks and gets them to be reflective of their experience (Bonwell & Eison, 1991) thus deepening their involvement and understanding. Inquiry based learning, small group discussions, interactive computer simulations, problem solving, case studies, guided designs; in-class writing exercises are some of the activities that can be used for active learning (Bean, 1996; Bonwell & Eison, 1991). A study conducted by Prince (2004) on 480 engineering students taking 23 different courses where both active learning and lecture methods were employed, provides evidence that students who participated in courses that included active learning methods achieved significantly greater learning gains and also reported a better learning experience compared to courses that employed only traditional lectures.

The engineering programme at NUS has adopted (and is increasingly adopting) instructional and assessment approaches that encourage active, collaborative, task-based/project-based learning. Lectures are interspersed with active learning tasks either through the use of quizzes, clickers or polls that enable students to actively participate in the lectures. Collaborative learning tasks deliberately get interdisciplinary or multicultural groups of students to work together towards a common goal. The use of discussion forums and/or chat-rooms on the learning management system serves to enhance the productivity of students when they next meet face-to-face to complete the assigned task. Scaffolding is provided to students involved in these projects by teachers modelling for them the methods to break complex tasks into several manageable sub-tasks, sequencing them and coming up with timelines to complete each of them. Setting appropriate challenges, putting them into groups, scaffolding their learning experience, modelling analysis and problem solving skills for them all help students develop a better professional identity as an engineer. Minimally, these approaches culminate in students developing a healthier perspective of the subject and come out with products for the real world.

More and more modules in engineering have been designed to enable students to work in teams where they collaborate with one another rather than compete. This enables student teams to foster close bonds, seeking each other’s help to approach challenging or complex tasks that have no obvious, single solution. To give students significant learning experiences, programmes like the innovation programme allow students to learn via the process detailed below:

- Find a Problem – “method of irritation”[1] is used to identify a problem,
- Understand the problem – by asking the “who, what, why, where and how” questions,
- Formulate the problem – simplify the task by breaking into manageable parts,
- Brainstorm the problem – through idea generation, evaluation, peer review and incubation,
- Develop a prototype – a workable solution, and
- Present the problem and solution – communicate the problem and proposed solution,

In this context, students learn by knowing the problem, applying prior knowledge and sharing their own personal experiences (connecting with the problem), collaborating with their team members thereby developing themselves and their peers. They demonstrate curiosity and creativity, become self-regulating and become adept at communicating their work through presentations and reports.

[1] The basic objective of “method of irritation” is to find something that is irritating or that can be considered as a shortcoming.

A second example for a varied learning experience is the Engineering Science Programme that boasts of multidisciplinary curriculum, inter-module and integrated design projects encouraging students to transfer and assimilate knowledge gained from the modules. One of the projects undertaken by a team of ESP students titled "Solar-Powered Golf Buggy" received the faculty-level Innovation & Research Award at NUS. It was the case of an interdisciplinary, hands-on design project which created a perfect collaborative learning experience for the team in assimilating their knowledge from various disciplines such as mechanics, electronics, thermodynamics, solar energy, storage systems to design their buggy. The team was able to transform their initial thoughts/ideas into reality with expert guidance from mentors and other faculty members who had multidisciplinary expertise. This is what students had to say of their learning experience:

> *"The course had truly enlightened me and provided the relevant skills to think laterally, creatively, logically and critically in identifying solutions and fusing them together. Being able to deploy theoretical knowledge into creative real-life research has been a truly beneficial takeaway for me."*
>
> *"A great learning experience and intellectually challenging – More importantly, I learn the importance of teamwork, leadership and overcoming the odds."*

4.3 Enrichment programmes outside the curriculum

The Centre for Development of Teaching and Learning (CDTL) at NUS offers the "Learning for Success" programme that enable students to hone their 21st century skills. These include sessions on communication, thinking, effective writing, critical thinking, stress management, time management, mind-mapping techniques, study and interpersonal skills, and effective use of technology. Understanding the importance of communication in the 21st century, students are exposed to strategies to apply scholarly thinking and standard language, explore different modes of communication through a series of activities planned during communication skills workshops, one-on-one consultations and summer camps.

Engineering students are exposed to sessions like "Preparing effective scientific presentation" that allow students to explore effective strategies for structuring their research/project presentations, to rethink the design of visual aids, and let them converge on a best delivery style that most suits them. Additionally, CDTL publications provide helpful information, resources and tips on effective learning for the 21st century, reading, writing, time management, oral presentations etc. Some of the publications include:

- "The Effective Student: A Guide to Learning for the NUS Student" which is helpful in introducing successful learning strategies and campus resources;
- The Write Right Guide: An NUS Writing Guide that promotes effective writing skills; and
- Successful Learning series provides additional learning support in the form of one-page articles.

Over the years, we have seen that the take-up from engineering students is the highest for these enrichment opportunities – this indicates the magnitude of the accumulated demand and acknowledgement from engineering students on the importance of such skills for their future.

4.4 The use of "Teaching Practicums" to enhance student learning

An earlier study at NUS quantified student feedback comments into descriptor categories. This study showed that the teachers from engineering and science disciplines got higher mentions of descriptors such as "effective lecture notes", "concise notes" and "detailed notes". This indicates that teachers from the hard disciplines still rely more on (mass) lectures, reflecting the more detailed and structured nature of the field. As Morell & DeBoer (2010) point out, it is important for teachers to understand the engineering professional practice both before and during the academic career. Such understanding is often built through professional development programmes organized by central units and reinforced subsequently through peers and mentors located within the engineering faculty.

NUS aims to "provide a high quality educational experience that stretches students, is globally-oriented, and develops skills and values to enable them to reach their full potential." To help achieve this, CDTL offers professional development programmes for faculty members and graduate teaching assistants on various aspects of teaching and learning. Faculty members with less than three years of teaching experience in higher education participate in a Professional Development Programme (PDP) consisting of a core module, elective modules and a teaching practicum. The core module focuses mainly on generic teaching principles and practices, while elective modules focus on various aspects of teaching and learning, including skills in facilitating understanding, questioning, using resources, critical thinking, addressing student motivation, course assessment, instructional design and the use of information technology. The practicum component requires participants to undertake action research in their classrooms and share their findings with the NUS community via seminars and in-house publications.

The practicum component provides an opportunity for new faculty members to develop their teaching (and by extension, enhance student learning) through experimentation, critical reflection, discussion with colleagues, and documentation. It requires teachers to plan and design a pedagogical project that involves an untried (by the teacher) educational goal or pedagogical strategy, evaluate its feasibility and effectiveness and finally reflect upon the possible modifications to achieve greater educational value and effectiveness. Some of the recent experiments tried out by the participants include: effectiveness of in-class buzz groups, short in-class quizzes; out-of-class activities; effective use of complementary technology tools (e.g., social media, blogs, wikis, web-based tutorials, iPADs, classroom response systems, discussion forums); and alternative forms of assessment.

4.5 eLearning Week

eLearning is becoming an increasingly common aspect of higher education - in fact, the flavour of the day is MOOCs (massively open online courses) that are accessed by several hundred thousand knowledge seekers. eLearning uses online media for flexible anytime, anywhere delivery of content, facilitates interactions between students and between the teacher and students employing a variety of technology tools. For eLearning, NUS has built on the success of its in-house developed learning management system namely Integrated Virtual Learning Environment (IVLE). Since its inception, a powerful suite of web-based tools and resources have been developed by the IVLE team for faculty members to supplement their classroom teaching. This system forms the backbone of almost all of the eLearning that happens on campus.

NUS introduced the eLearning week (eLW) in 2009 mainly to ensure business continuity in case the University has to close for a few weeks due to pandemics or other disasters. For one week, classroom lectures and tutorials are suspended and the NUS community uses IVLE and other online platforms to teach and learn. The annual eLW has encouraged a good number of faculty members to explore and understand the usage of technology tools for teaching and learning, as well as provide an opportunity for the University to stress-test its ICT capacity and infrastructure.

Recently, the Faculty of Engineering conducted its eLW. This exercise saw many faculty members exploring various options such as: online audio-video lectures using screencast or Adobe Breeze, virtual tutorials using Web-Ex, organise project groups using IVLE, stimulate online discussions and chats, use blogs and wikis, create webcasts and podcasts. Both faculty and students identified “convenience (anytime, anywhere learning)”, “flexibility for students and lecturers”, “encourages and promotes independent learning”, “greater participation in forums generating prolific discussion”, “possibility to revise/replay lectures” and “saving time and money” as factors that motivate them to use eLearning.

This exercise also paves way for trying the idea of flipped classroom for selected topics. The flipped classroom approach could be adopted to deliver content that is traditionally disseminated during lectures in classroom by the use of online presentations, videos or webcasts. This will allow students more time to understand content outside of the classroom, while allowing precious class time for inquiry, collaboration, stimulated discussions, interaction and applying knowledge. Proper use of eLearning has the potential to push engineering education to be more learner-centric. The NUS Faculty of Engineering has also recently launched an initiative to promote blended learning.

5 CLASSROOM INFRASTRUCTURE

The hardware components of the learning environment i.e. learning spaces influence learning significantly – they are important for both individual work and team activities. NUS is well-positioned at the forefront in terms of technology, infrastructure and expertise to provide technology-integrated learning. The Global Campus Initiative launched more than a decade ago enables staff and students to fully exploit IT for education. The campus-wide high-speed network at NUS links all computing resources on campus such as the email, IVLE, web-based online applications, application software, library’s online catalogue, webcast facilities, and computer clusters. Students can own a laptop through the Student Notebook Ownership Scheme. Lecture theatres, seminar rooms and tutorial rooms are well-equipped with necessary technology. Classrooms with smart podiums give instructors access to presentation technologies, the Internet and the ability to record and webcast lectures.

21st century learners prefer active, participatory and experiential type of academic learning styles to be in sync with their personal lives. To foster 21st century learning skills – higher-order thinking abilities, communication skills, and multi-disciplinary ways of learning, a relook at the learning spaces was launched at NUS. The current focus prompted the University to look at flexible design of learning spaces that could incorporate collaborative and computer-mediated aspects to the usual lecture-style classrooms. The use of classroom response systems (clickers) and mobile phone technology (questionSMS) have been exploited by NUS engineering educators to enable instant student feedback feedback on student's understanding of key concepts, any confusions or misunderstandings of materials during lectures. The Singapore-MIT Alliance (SMA) (a graduate education and research collaboration between NUS, Massachusetts Institute of Technology (MIT), and Nanyang Technological University (NTU)) uses smart classrooms and video conferencing facilities allowing students and lecturers to interact and collaborate during lectures. This also gives engineering students in all the three institutions to participate in co-taught modules offered by eminent educators from the three institutions. NUS has also embarked on "living-learning" spaces where academic work (classes, tutorials and other learning activities) is held at the student-staff residences. This model tightly integrates learning with life for students and exploits the multi-tasking capabilities of current generation of students.

6 ASSESSMENT OF STUDENT LEARNING

Assessment and grading are known to have a very large effect on students' approach to learning. These major handles must be leveraged upon carefully – assessment tasks in engineering should increasingly involve group work (with appropriate measures to ensure individual accountability) and facilitate cooperative learning. At the NUS Faculty of Engineering, the quality of assessments are stressed upon rather than their number – assessments are more intentional (to facilitate the achievement of specific learning outcomes), authentic (related to what's happening in scientific communities and industrial practice), and dense in terms of skills needed to solve them. Assessment tasks are extrapolative in nature as opposed to working within bounds of what was covered in class and more importantly involves analysis, synthesis and evaluation rather than the plug-and-chug genre that dominates most assignments and projects in engineering courses.

It is common for educators to usually tend to model and mimic in their curriculum and instruction, the content and format of high visibility assessments and spend a significant amount of classroom time for preparation of the tests. However, research studies on games and online learning communities identifies problem-solving as a key concept (Gee, 2007). Understanding student experiences in such environments of problem-solving will lead us to rethink the way we define key skills and design assessment tasks. Hence, it is important for engineering education to transform in ways – educational standards and assessment – that will enable students to acquire the much needed sophisticated thinking, flexible problem solving, collaborative and communication skills needed for the workplace.

Pellegrino et al. (2001) identified that every assessment designed should involve three fundamental components: "a model of how students represent knowledge and develop competence in the subject domain, tasks or situations that allow one to observe students' performance, and an interpretation method for drawing inferences from the performance evidence thus obtained." In a 2011 interview, the Harvard President, Faust indicated that "thinking about assessment in different ways—how we evaluate students, faculty, methods, and courses and programmes" is crucial for a broad push for innovation and experimentation. According to Griffin et al. (2012), assessment tasks and situations should be (i) aligned with the development of significant 21st century skills, (ii) adaptable and responsive to new developments, c) largely performance-based, d) able to add value for teaching and learning by providing valid information that can be acted on by students, teachers, and administrators, e) able to meet the general criteria for good assessments (i.e. be fair, technically sound; valid for purpose, and part of a comprehensive and well-aligned system of assessments at all levels of education).

Thus, it is fairly clear that students need to be weaned away from rote memorization model by eliminating assessments or tasks that focus on "Given this, calculate that" type of problems. Open-ended quizzes that stimulate students' creativity and enable them to think deeply about materials covered in lectures need to be introduced. One such example is a quiz designed by Felder (1987) for a Graduate level course where students were given a five-week take-home exam that asked students to make up and solve a final examination for the course. The students were informed that a straightforward “Given this and that, calculate that” type of questions would receive a minimum passing grade while those who demonstrate a deeper understanding of the material, apply techniques from other disciplines as well as evaluate the value of a design, product, or system would receive more credit. Though time-consuming, it achieves the goal of making students think deeply about the material.

As a local example, we could highlight an assessment task in a Chemical Engineering module on Process Modelling and Numerical simulation, where students do their own chosen experiments to identify critical variables that drive the performance of a system, plan and conduct experiments, collect data, build and validate models and use the model to optimize the conditions and maximize the system performance. Students also write brief research reports or make presentations in front of their peers and hone their communication skills. Systems considered by students included creation of a new fizz sports drink by mixing constituents in optimal proportions, making tasty chicken fried rice, popcorn etc. The connection to the real world and opportunity to involve their friends and family make this a deep and more engaging learning experience for students. The alternative traditional approach of providing standard data to students and seeing if they can apply the right statistical tests to arrive at conclusions does not provide this intensity and involvement in students. By participating in the whole cycle of planning, doing, recording, computing and decision making in a group, students are able to mimic what they would do in their professions later on. The teacher plays the role of a senior expert and guides the apprentices in their exploration and knowledge discovery process.

Yet another case involves getting students in a graduate Numerical Methods course to solve a moving boundary value problem by modelling the cooking of a potato. Students develop models by experimenting on potatoes, estimate parameters and use a constructed model to validate the model by predicting the cooking time for potatoes of different sizes. These experiments are less expensive to conduct, fun to do as a group-based inquiry and clearly establishes relevance of such learning for those intending to work in the food products industry, metal processing industry etc.

Grading procedures are a matter of University policy but there have been calls to consider criterion referenced grading rather than a norm based grading system. This provides an opportunity to use assessment for learning (as opposed to the traditional assessment of learning) and help students develop meta-cognition and self-direction skills. The assessment record can still get into the student transcript but without the associated grade point average implications – such a semi-safe grading policy may have beneficial effects on student learning. However, this call has to be made by the University administrators duly weighing its pros and cons.

7 CONCLUSION

Given the complex, social and technological challenges that this generation of engineering graduates will be called upon to solve, it is imperative for engineering departments to positively disrupt the mindset and learning habits of students through well-orchestrated, multifactorial efforts. Their learning must encompass 21st century skills almost as much as their technical knowledge and analytical skills. Any such endeavour would have to engage the entire spectrum of levers available to the faculty members: learning outcomes, classroom practices, out-of-class activities, assessment and grading. The *heavy* and *crowded* engineering curriculum perhaps has no choice but to accommodate the new expectations/requirements in a way that does not dilute its core. Engineering educators must take a hard and impassionate look to consolidate, intensify and reformulate engineering curriculum as a whole. Redundancies and low-yield teaching and learning activities need to be eliminated; classroom practices have to change and focus on learners and learning communities taking advantage of what we are being informed by research in the learning sciences and technology. Nostalgia about past practices and paradigms must give way to new thinking that foster stronger student engagement with their education and with their social, cultural and physical environment.

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