Engineering Education for the Millennial and Generation Z Learners

Engineering Principles and Practice: A Year 1 Module in NUS Faculty of Engineering

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1. Introduction

There is a worldwide trend of declining interest in engineering. This discipline doesn't enjoy the same level of popularity as it used to in the seventies and the eighties. There are different reasons behind this, some of which are beyond the control of engineering colleges. For example, the rigor required to earn engineering degree is disproportionately high to the average earning in engineering profession compared to many other disciplines. We as engineering educators cannot resolve this matter. Engineering is an essential profession for any country, and we must produce good engineers to maintain the growth. But we cannot produce good engineers if we do not attract good students to engineering. It is one of our responsibilities to make engineering education more attractive to the students and to inspire them to remain in this profession.

Engineering education is known to be very rigorous and difficult. Engineering colleges should look into this aspect and try to make engineering studies attractive to the modern generation of students. The students of engineering colleges nowadays - the Generation Z learners, have a different mind-set than that of our generations. The experience, skills, and expectations of the millennials and Generation Z students should be taken into consideration while developing ways to instruct future engineers.

In this paper, we first analyse the nature of the millennial and Generation Z learners. Then we try to understand the expectations of the industry. That is followed by a set of recommendations for working with millennials and Generation Z learners. Finally, we shall present the development and implementation of a pair of modules to be offered to first year engineering students over two consecutive semesters. These modules are currently being offered in the Faculty of Engineering of the National University of Singapore.

2. Learning style of the millennials and generation z

Those who were born between 1980 and 1999 are known as the millennials, and those born between 2000 and now are the Generation Z. Students in colleges and universities now belong to one of these two groups.

Members of the millennials and the Generation Z have grown up in a world that is always connected. Effectively, the whole world is at their fingertips. With the help of smart phones, they can access the internet anytime, anywhere. This has a major impact on the way they learn new things. Finding information is not a problem for them. Unlike their parents, they do not need libraries for gathering information. If the lecturer in their classroom gives merely an answer that can be found by Google search, they won't be interested to be there. They can listen to lectures given by professors from prestigious universities through online videos. Moreover, they are free to choose any professor, and they will go for the one who they find the most interesting. They can listen to multiple professors for the same topic. They can learn the topics of their choice whenever they like, from wherever they want, and at a comfortable pace.

These students want independent, self-paced learning with opportunities for collaboration [1]. They do not want to be taught by a 'sage on the stage' instructor. They do not like to be taught, rather they prefer learning in collaboration with peers. They would like to have an instructor who facilitate the learning by creating a conducive environment where the students can interact with peers of similar mind-set. But they still need an instructor who can help them to develop relevant and practical skills. The information available on the net is vast but some of it may be misleading or even wrong. The students need the instructor's guidance to extract correct information from the plethora of it available on the net. Contrary to common belief, these students prefer face-to-face communication over emails or taking on the phone [2].

A survey done at the Northeastern University in 2014 suggested that 72% of sixteen to nineteen-year-olds feel they should be able to design their own course of studies in the university instead of following a recommended study schedule provided by most of the universities of today [3]. The survey also revealed that nearly two third of those surveyed believed that learning entrepreneurship was important, and a similar percentage said that they preferred face-to-face interactions with peers and not interaction through social media.

It has been suggested that video games should be integrated into learning facilities because immersion in video games changes the structure of the brain of an avid video game player which affects the way this generation thinks and learns [4].

Millennials and Generation Z learners prefer a broad spectrum of learning strategies with learning materials delivered to cater to their visual, auditory and even kinaesthetic needs. Their attention span is very short. They will lose interest if the same format of engagement is continued for long.

These learners are aces at "googling" and discovering information from the net. As a result, providing a piece of information to them has no value. They would like to see the relevance of that piece of information to their lives. So contextualization of the topic is necessary to attract their attention. Students would report lower level of communication satisfaction and engagement in classroom with a talkaholic instructor, but content relevance tempers the negative association between instructors' compulsive communication and students' communication satisfaction and engagement [5]. This clearly proves the positive effect of contextualization.

Though their parents were used to authoritarian teaching style, the millennials and Generation Z do not like it. These children grew up in an environment where decisions and actions are constantly justified. They will ask for rationale behind anything they have to learn. Although they are cynical about authority and don't assume we have their best interests at heart, they value communication and information, and respond well when we explain why we use certain methods of teaching and assessment. We can "sell" them on the wisdom of our reading selections, assignments, in-class activities, and rubrics, reinforcing the fact that we are the experts in our field and in teaching it. But then, as experts, we should have solid, research-based reasons for our choices. If so, we can share these reasons with them.

Millennials and Generation Z learners prefer a relaxed learning environment, with minimum pressure and more freedom to complete assignments. These children grew up receiving complete attention from their parents. They grew up seeing older adults who had shown more interest in their lives. They want similar attention in the classroom. They perform better when an instructor connects with them on a personal level, when they feel that the instructors care about them. When they first come to the college, they are still attached to their parents and not far from the nest where they are accustomed to near-constant interaction. If we show that we care about them by calling them by name, asking them about their weekends, promising we will do whatever it takes to help them learn, stating how much we want them to be successful, and voicing our high expectations of them, we can earn their loyalty and trust. This in turn will help them learn better.

Just coming out of the shadows of their parents, these children often respond well to structure, discipline, rules, and regulations. If we have them set up a code of classroom conduct, they will generally honour it. If you promise that you will answer their email at a specific time each day and you follow through, they will not expect you to be available 24 hours a day, seven days a week. Students generally respect any policy as long as it is clearly stated with an exception of a handful ones who may try to pressurize the instructor to bend the rules. What millennials consider unprofessional is an instructor's (apparent) disorganization, ill preparation, or inability to stick to the syllabus.

3. Desired learning outcome of engineering education

Engineering education has evolved over the last two hundred years. A history of engineering education in America was authored by Reynolds and Seely in 1993 [6]. In the early days, the USA and many other countries followed the engineering education in Britain which was based on apprenticeship. In that system, an apprentice would learn the trade under the supervision of an experienced surveyor, draftsman or machinist. As the demand for engineers started growing, this apprenticeship approach was unable to meet the demand of engineers needed. Producing engineers through a well-defined college education seemed necessary to meet this demand, and the first approach was to follow the classical college model of instruction.

But classical college model could not produce engineers for a growing country and the need for specialized engineering programs was felt. The first engineering program was established by US Congress in 1802 at the US Military Academy at West Point following the model of the French Ecole Polytechnique with a focus on mathematics and science

The engineering was not a respectable field of study in those days. A number of universities offered engineering training in the first half of 1800's but many of them did not offer a degree; rather a certificate of completion was given. Some of these programs were influenced by the English mechanics' institutes which provides vocational education to workers [2].

Some universities, e.g., Alabama, Georgia, Maryland, Mississippi, Missouri, North Carolina, and Virginia, integrated engineering coursework into the traditional Bachelor of Arts (BA) curriculum. The first truly engineering degree in civil engineering degree was offered by Rensselaer Institute in 1835, followed by Polytechnique College of Pennsylvania in mechanical engineering (1854) and in mining engineering (1857). MIT was the first to offer electrical engineering degree in 1882 and the first chemical engineering degree was from University of Illinois in 1895.

What should be included in engineering curriculum, as well as the proper balance between practical and theoretical education were being debated from the beginning. Mann Report (1918) suggested a common curriculum during the first two to three years with a balance between industrial practice and the study of science and mathematics. Wickenden study (between 1923 and 1929) called for the introduction of economics and humanities and set in motion a movement to begin accreditation of engineering schools. The Hammond report (1940) proposed two stems in engineering education – a main stem of science, maths and technology, augmented by a humanities stem to reflect the non-technical work in management

A wave of development of new technologies such as radar, aerodynamics, material science, and the atomic bomb, came after the World War II. But the physicists with advanced theoretical training were at the forefront of these developments. Deficiencies in engineering education came under scrutiny. The Grinter report (1956) recommended more emphasis on mathematics and engineering sciences (mechanics of solids, fluid mechanics, thermodynamics, heat and mass transfer, electrical theory etc.). This resulted in large inflow of government sponsored research money, start of graduate programs in engineering, and preference of faculty with research experience to faculty with industry experience. Practicing engineers began to complain of the growing disconnect between university preparation and the skills needed by practicing engineers.

This argument on what should be there in an engineering curriculum continued throughout the history of engineering education. Recently, the argument has shifted from the content of the curriculum to the skills and attributes that engineering graduate should have. Not all engineers continue to stay on a technical track. A small percentage of graduates pursue higher education and the rest goes to the work force of which some get involved in management. Hence the desired attributes of an engineering graduates are

i. A good understanding of engineering science fundamentals,
ii. A good understanding of design and manufacturing process,
iii. A multidisciplinary systems perspective,
iv. A basic understanding of the context in which engineering is practiced,
v. Good communication skills,
vi. High ethical standards,
vii. An ability to think critically and creatively – independently and cooperatively,
viii. Flexibility – ability and self-confidence to adapt to rapid or major changes,
ix. Curiosity and desire to learn for life, and
x. A profound understanding of the importance of teamwork.

One should keep this list of attributes when designing the curriculum of an engineering degree.

4. Recommendations for working with millennials and generation z

Educators around the globe have been trying to identify the characteristics of the millennial and the Generation Z learners [7]-[9]. With these learners in our class, education is less about the transfer of fact-based information, and more about exploring and building the future together with the students. When we deal with the students of today, it is not the question of just defining the generation, rather it is a question of the mind-set. Understanding the new mind-set is the key to improving education.

Don't Teach but Augment Student's Experience

The current generation don't feel the need to become 'textbook smart'. They know that information is easily available online which can be gathered independently. Let them do things and let them share their experiences – in other words, encourage peer learning.

Prepare the Students for a 'flatter' world

This generation understands that the growth of new technologies offers a level playing field. In today's world, certificates are less important, personal talent and skills count more. Engineering education must aim to enhance the market value of the students. We should allow students to be creative, and to be able to find ways on their own. These students can come up with amazing solutions if we give them the space and time. As educator, we inspire them to take new challenges. At the same time, we should be ready to be challenged by them.

Students of the modern age are considered as risk adverse [1]. Instil in them the truth that failure is part of the design process. Then encourage them to be creative even if that creative solution leads to failure. Use open-ended and divergent problems so that students get the opportunity to exercise creativity.

Integrate Active Learning

Active learning helps to create excitement in the class and, as a result, enhances the learning experience of students [10]-[11]. This is particularly true for the millennial and Generation Z learners who have grown up immersed in technology. They have seen and used handheld digital devices. However, they do not necessarily understand how these devices work. Investigating everyday items such as touch screen, electric motors, and motion detectors can provide and accessible starting point for class projects. Give them projects that cannot be solved by searching the internet. These problems should be ill-defined and, may have multiple solutions depending on the points of view of the solver. Then it will be instructor's responsibility to lead the students through the process of understanding the problem, understanding relevant engineering/scientific principles, understanding the limitations, and then developing potential solutions. It can be easily understood that such approach requires additional class time and more student-instructor interactions. One possible way is the "Flipped classroom" where pre-recorded lecture content is made available online to the students prior to holding the face-to-face session. This provides the opportunity of self-paced and more independent learning as desired by the millennial and Generation Z learners [12].

All institutions may not have the facilities to create online contents. But lots of good quality materials are already available online, e.g., MIT's OpenCourseWare and Khan Academy.

Integrating active learning requires freeing up lesson time by giving up traditional lectures. When we do that, significant amount of learning is driven by the student. If a student is not responsible enough, he/she may not go through the online materials before coming to the classroom. And an ill-prepared student will find it difficult to take part in discussions and other activities in the classroom and hence will not keep pace with the rest of the class. Moreover, activity-based learning sessions take longer time compared to the traditional approach of teaching. The students do not get the opportunity for tutorial type problem solving. It is being questioned whether students retain more in activity-based learning. Another problem with flipped classroom is the size of the class. In traditional lecture-based approach, an instructor can deliver the learning materials to few hundred students in a big lecture theatre which not possible with flipped classroom and, therefore, activity-based learning requires greater resources.

Help Students to Extract Answers from an Ocean of Information

When the students are required to gather information from the internet, they will be exposed to an overwhelming amount of information and they may not be well equipped to find the good answers to challenging questions. Use of prescribed sources only is helpful in preventing the students from being misled by false information. However, that goes against the principle of encouraging students to explore new knowledge. Therefore, instead of restricting the students to a few prescribed sources, it is better to teach them how to critically evaluate the information. Instructor can find a source that provides false/misleading information, bring it up for discussion during an interactive session, and help the students to analyse the information. We should also teach them how to integrate information to form solutions to complex problems.

Contextualize the Learning

Most of the millennial and Generation Z learners do not like abstract learning. As they have the habit of questioning '*why am I doing this*?' any attempt to teach them topics with no connection to the world around them will switch them off and they will not feel engaged. It is important to show the applications in real life of the scientific principles or mathematical concepts discussed in the class. An example is the solution of ordinary differential equations (ODE). In traditional engineering curriculum, students learn ODE in a mathematics lesson without understanding where and how these can be useful. This topic can be contextualized using the example of a physical system, such as, a car suspension. Similarly, a lesson on diode characterization can use an RGB diode and the instructor can explain its connection with LED display. Learning is a process of connecting new information about the world to an existing framework of knowledge. Students should be guided to make the connections between the topics learnt and the world around them.

Encourage Teamwork

Allow students to work in groups. Give an open-ended and ill-defined question to the class, divide the class into small groups and let them discuss the problem. In this way, the students will learn from each other. More importantly, exploring knowledge with others of similar mind-set can be more effective than getting the answer from an instructor. Even for hands-on activity or coding, students learn more effectively when they cooperate with peers.

Introduce the students to Common Engineering Sense

Engineering is about solving real world problems. Though engineers do thorough calculations in their design and problem solving, a good starting point is often an estimate. They have a very good sense of estimating the real quantities. Engineering students should develop this skill of rational guessing and estimating physical quantities in the real world. Give them exercise that cannot be solved just by plugging in some numbers in a formula but needs some reasonable estimates to start with. Through an intelligent combination of guess and estimation, students learn how to acquire the skills that most practicing engineers have.

Assess Their Performance as They Progress and Give Feedback

Assess students' performances frequently and give feedback. Also engage the students in the assessment process. For any assessment component – a written report, an oral presentation, a hands-on activity – inform the students in advance about the expectations. After the exercise, give feedback to the student by telling what percentage of the target has been achieved and what can be done to improve the performance. Grading the assignment is, in a way, a feedback. It is very common but not very effective as the student is left alone to find out his strength and weakness. Feedback should be given such that the student can develop strategies for detecting errors. This will lead to developing self-appraisal techniques which the student can apply throughout the life. Feedback should be provided as soon as possible so that the student revisit the work and use the feedback to enhance learning.

5. Epp: an innovative engineering module in faculty of engineering, nus

Considering the characteristics of the Millennial and Generation Z students, there is an imminent need for changing of pedagogy in engineering schools. Many engineering schools around the globe have taken initiatives [13]-[15].

Traditional way of teaching engineering is structured into two or three segregated stages – Lecture, Tutorial and Laboratory experiments. This approach has its own merits, but its limitations may make the new generation students disinterested in learning. Lectures on fundamental topics, e.g., statics, equilibrium and basic circuit laws, are widely available on the internet – some of them are very high quality. Moreover, a student can find one that suits his/her style best. If we repeat such lectures in front of a class, most likely we'll lose the students. They will not pay attention to what the lecturer says. We can easily substitute these lectures by on-line materials and, thus free up time from students' timetable and use it for more interactive and participatory learning – the pedagogical style that the new generation learners prefer.

Moreover, lectures are not suited for teaching higher order thinking such as engineering applications, analysis and synthesis. It doesn't help developing a student's practical skills which often require controlled motor skills.

In traditional approach, the engineering principles are taught separately from engineering practice. It also compartmentalizes the topics; when you teach about motor you don't talk about mechanical strength. As a result, the students master different topics separately and do not see any link between them – at least in the first two years of engineering education. In this way, we may produce engineers who lack competency in engineering skills though their grade card suggests that they have excellent technological knowledge. Engineers in the real world do not work in silos; engineering jobs are often multi-disciplinary and not purely technical.

To address these shortcomings, we at the NUS Faculty of Engineering implemented two new modules, Engineering Principles and Practice I and II, run over two consecutive semesters in the first year. The modules try to achieve three sets of learning outcomes –

(a) Engineering skills: what engineers do?
(b) Engineering principles: what engineers know and how they apply that knowledge?
(c) Professional skills: safety awareness, communication skills etc.

Both modules are taught with the approach of

(1) Flipped classroom to save contact time and to let students learn at their own pace,
(2) Experiential learning to enhance engineering skills,
(3) Contextualized materials so that students can connect the theory to the real-world applications,
(4) System-level thinking to avoid learning in a silo, and
(5) Group learning.

In EPP, the students take top-down approach for understanding a complex engineering system. Some familiar gadgets and devices, e.g., smart phone, drone, PV generation system and e-Vehicle, are used as the system under study. In traditional engineering curriculum, students learn fundamental science and mathematics in early years, and are exposed to such complex systems only in the fourth year and, in some cases, in the third year. At the beginning of EPP I, students deconstruct these complex systems from functional point of view. They discuss in small groups and under the guidance of the instructor. The aim is to get the given complex system broken down into smaller subsystems and their interconnections with the help of a block diagram. Then they investigate individual blocks and explore the relevant engineering principles theoretically and, if possible, through simple experiments throughout the semester.

The learning happens in a studio environment – ideally a room that has (1) easily adjustable seating arrangement, (2) LCD monitors and white boards, and (3) commonly used laboratory tools and equipment. The adjustable seating arrangement makes it conducive for group discussion. LCD monitor and white board are used by the instructor for explanation, and also by the students to develop skills for effective communication. Students carry on all the learning activities, i.e., discussion, problem solving, hands-on experiments, and mini projects, in groups which make them to learn how to work in a team. It also helps self-directed learning. Active and peer-learning lead them to develop an inquiring mind. The learning is guided and enhanced by constant interaction between the students and the instructor.

Effective communication is one of the desired attributes of an engineering graduate. Each student makes a formal presentation on a given topic once in a semester. The topic of presentation in any session is usually related to the engineering principle learnt in that session. The student explores different sources to prepare his/her presentation and is free to seek help from the lecturer or anyone else. The knowledge acquired is shared with peers during the presentation. The class is encouraged to ask questions. This practice helps to develop the habit of asking questions and, as the semester progresses the students start asking good questions.

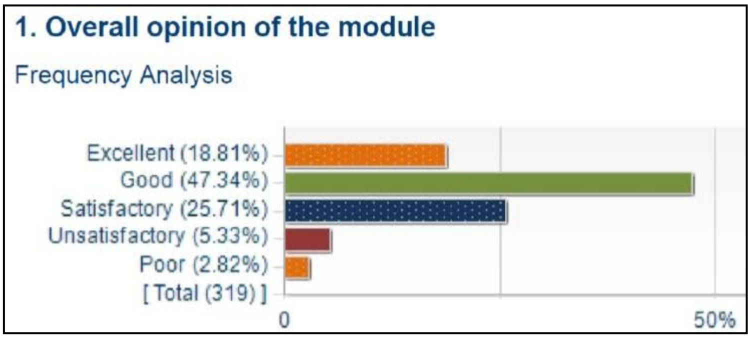
Discussions can flow freely but monitored by the instructor so that they don't go out of track. During these discussions, the students do not jump into detailed calculations or applying known formulae. Rather they learn to use intelligent guess, estimation, checking conformity of dimensions, and back-of-envelop calculations. As a result, these discussions lead them to appreciate the engineering sense of dimensions and numbers.

Engineers are visual thinkers. EPP encourages students to use visualization as and when required. Python and Excel are used but there is no traditional teaching of programming. For example, they are taught basic operations of Python, and whenever there is a need for using Python, the skeleton script is provided so that they can try different things. We found that some students find on their own the right script from the internet. This testifies the point that the millennial generation prefer self-learning.

The pre-eminence given to mathematics in engineering schools persuade the young student that there is limitless potency in theoretical calculations and give him blind faith in their results. The student fails to understand and to feel intuitively the physical reality. The student who knows how to set up and solve the mathematical equations is rated the best regardless of his intuition of reality. In EPP, we try to avoid that kind of assessment. Instead the students are encouraged to think about the problems and their solutions; they can use all available resources for solving equations. Both mid-term assessment and end of the term assessment are open book, and have multiple choice questions. This helps to keep the students from developing the habit of memorizing formulae.

Student feedback

The module received good feedback from students. The figure below shows the overall opinion of the module after it was run for the first time. A list of qualitative feedback is given next. Altogether 319 students gave feedback. The tables below show a representative sample of students' qualitative feedback - about a dozen responses each to the two questions: (1) What I liked about the module, and (2) What I did not like about the module.



What I liked about the module:	
1	I like how peer learning is encouraged.
2	Elucidates that engineering is not about applying formulae blidly
3	It is very engineering and helps us to know something that cannot be attained from a lecture.
4	Focus is mainly on self-learning and understanding.
5	It is very engaging and applicable to real world engineering.
6	No stress and so we can learn at our own pace and have fun.
7	Active discussion between professors and students
8	It lets me get an overview of what engineering is like. I feel it will be useful as I was unsure what I was getting into when I took engineering.
9	It emphasizes on understanding instead of the usual studying simply to do well for examination.
10	The collaborative environment enables us to learn more important soft skills.
11	The relaxed and easy atmosphere during labs make us think and express our ideas freely.
12	This module successfully links many real-world problems to the concepts we have been taught in class.

What I did not like about the module:	
1	Some of the concepts discussed in class were a bit hard to grasp (bending moment, second moment of area), if it was taught in a lecture setting it might have been easier to understand.
2	Heavy workload, a lot of CAs
3	The premise of the lessons being conducted is not very conducive. There is too many people in a lab room and the student's attention tend to wander when it is hard to look at the screen (the lab apparatus serve as obstructions).
4	Time management was not optimal. Due to some students not reading on material beforehand, time was wasted during lab sessions, especially on relatively easy topics.
5	It was first difficult (initially) to adjust myself to the new module without lectures and that is mostly dependent on studio sessions.
6	Two few equipment to use so waste a lot of time while waiting for other groups
7	Reading material provided is difficult to comprehend
8	The lack on emphasis on use of python early on. They expected majority to self-learn python More of what I would have preferred was that if lab submissions could be made during the same lab session online, it might have sped up efficiency.
9	There are no lectures.
10	Too much emphasis on independent learning
11	Moreover, the module required group work and that meant certain individuals in the group did not contribute for whichever components that are not graded. This makes learning harder for those individuals who are genuinely interested.
12	Peers with no intention to learn

The feedbacks shown above are anonymous. We also get feedback where students identified themselves. Two such feedbacks are shown below; both are from civil engineering department. The original intent was to design the EPP modules that would cover general engineering principles (e.g., equilibrium, conservation, flow and stability) and practices (e.g., measurements, software for computation & visualization, safety, and communication) that are applicable to all engineering disciplines. To keep the logistics for implementing such a module manageable, we started with only two departments – mechanical engineering and electrical engineering. While trying to strike a balance between diverse needs of different departments, it was later decided to let each department design its own content keeping the pedagogical approach unchanged. Now all engineering departments run their own EPP.

> *"In conclusion ,* ***the entire CE1102 process was similar to eating Sour Head candy where although*** *there were sour and distressing moment when disappointing mid-term results turned out to be disappointing and the heavy workload seemed unbearable, there were sweet momemts when the contents were interesting and the group discussions were enjoyable.* ***Lastly, after the Sour Head has dissolved, it left me craving for it again simply because the sweetness was actually worth the sourness. The only difference between an actual Sour Head and this module was that a Sour Head candy harms the health whereas this module is beneficial for the future Lee Jun Ping***

> *"Combining the readings with the weekly summary notes, I found it extremely taxing and difficult. However, it was during this period of suffering which I learnt most of what is expected of me as a Civil Engineer….The reading has allowed me to think different perspectives when considering our own* ***project…I am very thankful for CE1102 as it acted as the catalyst****….In CE1102, we were* ***allowed to think from the macro perspective and big picture view and this allowed my passion for Civil engineering to grow as I feel that our existence has its own purpose in society****….Thanks* ***to CE1102, a few of my friends and I signed up for the BCA-CDL competition on sustainable*** *development"* ***Lim Chee Meng***

Feedback from external stakeholders: The text below is copied from an email sent by an employer to one of the professors involved in the first two years of EPP.

> *"It was a pleasure speaking to you earlier.*
>
> *As mentioned, some of the interns I interviewed commented that they grew more interested in Engineering after taking the module on Engineering Principles and Practice. Some also mentioned that they wanted to pursue STEM-related careers. It is great that this module can generate such interest.*
>
> *Thank you for motivating Singapore's next generation of engineers."*

6. Conclusions

Worldwide trend of declining interest in engineering and change in learning styles of the new generations make us think seriously about the pedagogical approach adopted in engineering colleges. At NUS Faculty of Engineering, we have designed two first year modules to be run in consecutive semesters by taking into consideration both demand of the industry and the learning habits of the millennial and Generation Z students. These modules involve active learning with minimal teaching and encourages self-learning and peer-learning. The modules were well received by the students. However, it is worth mentioning that the proposed pedagogy demands greater resources both in manpower and infrastructure. We believe that the expenses involved in worth it for getting the students engaged and thus producing engineers with desirable attributes.

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