

ORIGINAL ARTICLE

Effectiveness of student engagement pedagogies in a mechatronics module: A 4-year multi-cohort study

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ABSTRACT

This paper investigates whether students will be more engaged in solving real-world and open-ended engineering problems when student-centred learning pedagogies are introduced. In-class demonstrations, case studies, multimedia presentations, and a two-day end-of-semester student conference were implemented in a Mechatronics module on Instrumentation and Sensing to complement the lectures. Data from the university-administered student feedback report were analysed for the four years that the pedagogies were implemented. The major finding from this work suggests that a multi-background, multidisciplinary, and multinational student audience have responded favourably to the combination of pedagogies that were introduced.

INTRODUCTION

A computer – with Internet connectivity – is nearly in every home. Based on 2010 data, more than 70% of adults (i.e. 18 years old and above) in the USA can access the Internet through a computer, cellular phone or other mobile devices.¹ In the UK, 73% of households have Internet access and 30 million adults used the Internet every day or every other day.² In Singapore, 84% of households have at least one computer. Eighty-two per cent of these computers have Internet access.³

The Internet is emerging to be the largest repository of learning materials. These advances in technology are changing how students prefer to learn. Anyone who can connect to the Internet has free and convenient access to high quality sources of information like video-recorded lectures, course notes, and tutorials. For example, the OpenCourseWare programme was initiated in 2002 to make the digital publication of university-level educational materials freely available to the public. Currently, there is a consortium of more than 200 higher education institutions that have given open access to their course materials.⁴ Stretching these initiatives further, an online learning platform called edX was jointly launched by the Massachusetts Institute of Technology and Harvard University.⁵

edX will provide video lessons, embedded testing, real-time feedback, student-ranked questions and answers, collaborative web-based laboratories, and student paced learning. There is also the Khan Academy, a non-profit organisation, that has already published a library of over 2600 tutorial videos covering topics from basic arithmetic to differential equations, organic chemistry, and history.⁶ At the time of writing, Khan's Internet-based tutorials have been viewed more than 120 million times. The Academy has received donations from private individuals as well as hefty grants from giant corporations like Microsoft and Google.

Engineering practitioners must not only be capable with the technical fundamentals, but they should also keep the global, cultural, and business contexts in mind.^{7,8} The inter-relationships of these factors are not reflected in traditional class instruction, which strongly rely on textbook-based problems that may have been overly simplified. In contrast, real-world engineering problems are complex, ill-structured, without a clear solution, have conflicting goals, and can be presented in a number of ways.^{9,10} The limitation of traditional in-class problems to transcend to more authentic problems has led to an observation that the traditional approach contributes to the lack of preparation of the graduates for the engineering profession.¹¹

The traditional lecture-based classes still dominate the landscape of engineering education. Prince and Felder¹² characterised the sequence of this deductive method as follows: The lectures typically begin with a presentation of the general principles. Then, the principles are used to derive mathematical models, and illustrative applications of the models are shown. Next, students are given homework on similar derivations and applications. Lastly, the students are tested on their ability to solve similar problems on exams. In a three-year study of enrollment patterns and interview responses of 335 students on seven campuses, Seymour and Hewitt¹³ described the reasons why 55% of these students have left the science, mathematics or engineering program. They also found an attrition rate of 40% between the first year until the fourth year of engineering studies. One of the main reasons cited was the poor pedagogy. Prince and Felder¹² argued that the traditional approach alone may not be an effective motivator to keep the students interested as they are reduced to passive recipients of information rather than being actively involved in their own learning process.

Consequently, some students have learned how to game the system: they have become exam-smart.¹⁴⁻¹⁸ These students are focused on achieving high exam marks, but not on the deep understanding of a subject. They have developed a keen sense of the type of questions that are likely to come out in the exam. They go to the extent of sifting through end-of-the-chapter questions and past examinations, which they thoroughly answer. They ask upfront whether a topic is examinable or not. They tend to accept everything in the textbooks and lectures

without asking questions (i.e. a surface approach to learning¹⁹⁻²¹). Innovative teaching and learning activities unsettle them.

Many educators have been promoting inductive teaching and learning.¹² This paradigm leans on the tenet that there is an intrinsic motivation to learn when people clearly perceive that there is a need to know.²² In general, the inductive approach begins with a case to analyse or a realistic problem to solve. The students then generate hypotheses and they gather information to solve the problem. Methods under this approach include case-based teaching, problem-based learning, and project-based learning, to name a few. As compared to the didactic approach (i.e. an approach that gives emphasis on the teacher who plays an active role in the transfer of knowledge and the students are passive receivers), the inductive approach shifts the responsibility to the students for their own learning and discovery while the teacher facilitates the learning process. The inductive and deductive teaching approaches are complementary, but it was suggested that students gain more if inductive teaching precedes deductive teaching.¹²

This paper presents a four-year multi-cohort study in implementing strategies towards student-centred teaching and learning. Specifically, this paper sought to answer the effectiveness of student-centred learning approaches in engaging Mechatronics students at the Faculty of Engineering of the National University of Singapore. The next section describes the Mechatronics module that served as the test bed for student-centred teaching and learning initiatives. Then, the implementation details of the pedagogical methods are described. Finally, the results and the discussions of the study are given.

The Sensors Module for Mechatronics

The word Mechatronics, coined in 1969, came from the combination of ‘mecha’ from mechanisms and ‘tronics’ from electronics.²³ The word has evolved to describe an engineering design philosophy that encompasses the integration of mechanical and electronics engineering, together with intelligent computer control in the design and manufacture of products and systems.²⁴ At present, industrial automation systems, robots, washing machines, digital cameras, transportation and vehicular systems, among many others, are mechatronic in nature.

Instrumentation and Sensors is a specialised module offered to graduate engineering students. The module teaches the students the analytical skills and practical design in instrumentation and sensing. The module comprised two parts and is taught by two lecturers. The first part covers the fundamental measurement and instrumentation concepts, while the second part presents

various sensors, their operating principles, and their applications. The learning objectives of the module are as follows: (1) the student is expected to learn how to design and implement basic instrumentation systems; (2) describe and explain the working principles of different types of sensors; and (3) design and implement basic monitoring and control systems with the selection of the appropriate sensors. This paper describes the author's experience on the second part of the module. Table 1 shows the syllabus.

METHODOLOGY

Students' Backgrounds and Team Dynamics

The class is multinational. Students (74% male, 26% female, all 22 to 30 years old) typically come from Singapore, China, India, Malaysia, Indonesia, the Philippines, Vietnam, Thailand and Myanmar. The class was organised into groups at the start of the second part of the module (week 8). In 2009 and 2010, the class sizes were 58 and 96, respectively. The maximum number of team members was deliberately set to 5 to reduce the number groups for easier manageability. In 2011 and 2012, the number was further reduced to 4 based

Table 1. Module Syllabus Starting from Week 8

Week no.	Topic	Summary
8	Commercially available sensor systems	Capacitive. Quantum Tunneling Composites. CyberGlove, Motion tracking sensors. Demos. Project Description.
9	Tactile sensing	Definitions and classifications. Development of the field. Applications. Biological and engineered tactile sensors. Skin material issues. Soft and flexible tactile sensors. Case studies.
10	Mechanical sensing	Potentiometer. LVDT. Strain gages. Load cells. Semiconductor strain gages. Force sensors. Accelerometers. Case studies.
11	Thermal sensing	Definition of temperature. Metal resistance versus temperature devices. Thermistors. Thermocouples. Solid state temperature sensors. Case studies.
12	Optical sensing and Machine vision	Fundamentals. Photoconductive detectors. Photodiode detectors. Phototransistors. Encoders. Components of machine vision systems. Digital image processing. Case studies.
13	Break	Preparation for the conference
14	<i>2-day student conference</i>	

on the student feedback. The class sizes were 69 and 49, respectively. Typical enrollees of the module come from mechatronics, electrical, mechanical or environmental engineering disciplines. Hence, the students were advised to have a group composed of members coming from different disciplines for maximised learning benefits, interaction, and perspectives.

Teacher and Module Assessment

The University Registrar's Office administers an online student feedback exercise. The university recognises this exercise as an important element of the university's quality assurance of education. This exercise is usually conducted two weeks before the start of the examination period. The students are assured that the information they provide is strictly anonymous. The results are released to the relevant teachers after the examination results are finalised for that particular semester. For the teaching staff, the student feedback has the potential to affect the annual performance reviews, promotion, and tenure. While the university encourages all the students to complete the survey, the exercise is non-compulsory for the students. Those who complete the survey are given bidding points for them to be prioritised in the courses that they select in the succeeding semester. The same student feedback instrument was used to evaluate the students' acceptance of the pedagogies. On average, there was a 48% response rate for the four consecutive years of data that were collected.

Data Analysis

The University Registrar-administered survey included a 6-item questionnaire on the teacher's effectiveness and a 1-item overall effectiveness assessment. The students rated these on a 5-point Likert scale, wherein 5 represents strongly agree, and 1 represents strongly disagree. The 6-item questionnaire included the mean and standard deviation for the teacher. In addition, the mean scores for all the lecturers in the department and in the faculty were included in the report for the same teaching activity (i.e. lecture-based modules). As for the overall effectiveness, the report included the frequency distribution of the students' replies on the 5-point scale for the teacher, the department and the faculty. Lastly, the students' qualitative comments were also provided.

Earlier researchers²⁵⁻²⁷ have cautioned that the data from Likert scales are to be analysed using inferential statistics for ordinal data, and non-parametric tests such as chi-squared, Spearman's Rho, the Mann-Whitney U, or the Kruskal-Wallis test were recommended. However, given the limited data that were available (i.e. mean and standard deviation for the teacher and only the mean for the department and faculty scores), none of those tests could be conducted for the 6-item questions. Thus, only an analysis of the descriptive statistics was done.

For the overall effectiveness, a metric called agreement rating was defined as the sum of ‘agree’ and ‘strongly agree’ responses, with positive signs assigned to these. On the other hand, the scores for ‘strongly disagree’, ‘disagree’ and ‘neutral’ were combined and were assigned with negative signs. The written comments in the student feedback were also analysed. Each comment was evaluated on whether it described the strength of the teacher or the module (i.e. positive) or whether the teacher or the module needed improvement (i.e. negative). The proportion of positive comments was calculated. A score of more than 50% indicates an increasingly positive student learning experience as the score approaches 100% and an increasingly negative learning experience as it approaches 0%.

In-Class Demonstration

To augment the lectures, in-class demonstrations were implemented to provide a balance in the students’ acquisition of information. The Felder-Silverman model²⁸ characterised learners according to whether they learn better visually (with pictures, diagrams, flow charts and demonstrations) or verbally (with written and spoken explanations). Demonstrations provide a multi-sensory means to describe an idea, product, or concept that may otherwise be difficult to grasp by verbal description alone. An earlier work that made use of demonstrations in engineering classes reported an increase in student attendance from 30% to 80%.²⁹ The two demonstrators are described below.

Demonstration no. 1: Introduction to Mechatronics: The interest and attention of any listener should be captured at the opening statement. Considering that students have notebook computers and tablets with Internet access in class, students can easily tune out if there is no compelling reason to pay attention. On week 8, an attempt to generate the student’s curiosity was started even before the first sentence was uttered. A robotic seal, named Paro (Paro Robots Inc, USA), was placed in front of the class for students to interact with. This robotic seal is an excellent example of a mechatronic system. It has sensors, actuators, mechanisms, power source and embedded control. These themes were expounded on and the role of sensors in a mechatronic system was emphasised. The robot’s reactions were shown when the sensors at the whiskers, flaps, body, and the tail were touched. A student was also called in front to snap his or her fingers in order to test the robot’s sound localisation feature.

Demonstration no. 2: Deconstruction of Roomba: Reverse engineering, dissection or taking apart an engineered product has been said to promote the systems thinking skills of students about existing designs.^{8,30} On the topic of optical sensing (week 12), reverse engineering techniques were used to describe how infrared sensors were implemented in a robotic vacuum cleaner. Initially,

the robot was allowed to roam and clean the lecture theatre with the purpose of generating the curiosity and interest of the students. The Roomba (Sage, iRobot Corp., USA) is an interesting example of how a mechatronic system was able to effectively make use of optical-based sensors. Students were asked to guess and locate the total number of emitter/detector pairs in the robot. There are 10 sensor pairs in the Roomba. Figure 1 shows a deconstructed view of the robot's bumper. The students were further asked on the possible reasons why the designers have selected optical sensors over alternative sensors like mechanical switches for the bumpers.

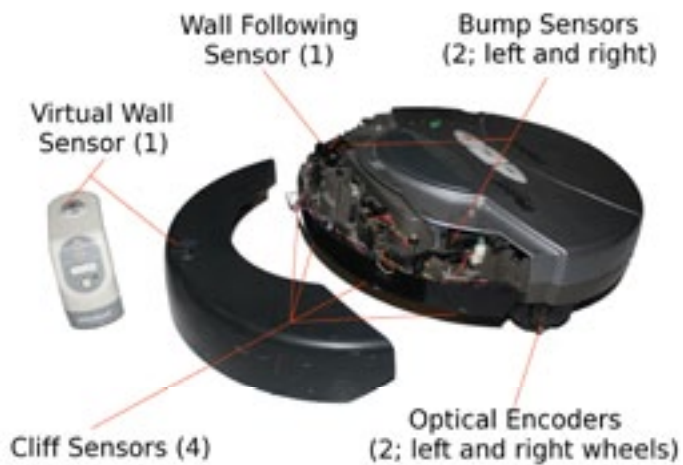


Fig. 1. Deconstruction of the iRobot Roomba vacuum cleaner. The 10 emitter detector pairs of infrared sensors are shown.

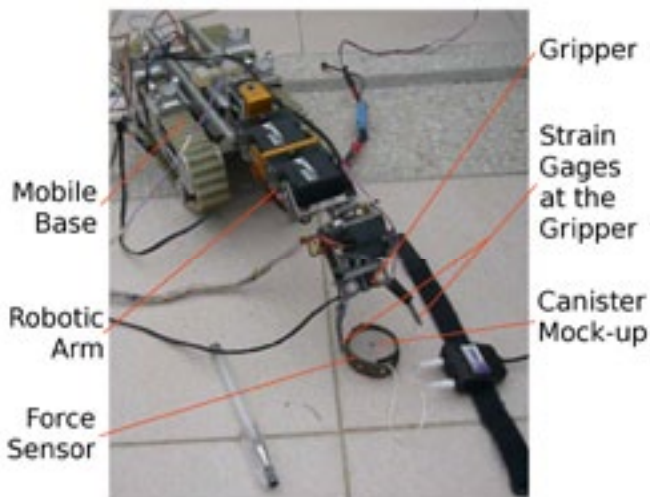


Fig. 2. The TombTrekker robot. Reach-grasp-lift-deposit experiment to characterise the force-voltage relationship of the contact forces.

Case Studies

One case was presented to the students for the topic on mechanical sensing (week 10) and the other on thermal sensing (week 11). The cases were presented at a later stage of the module to ensure that the team members were already familiar with each other. According to Herreid,³¹ good cases should tell a story: it focuses on an interest-arousing issue, it must have pedagogic utility, it is relevant to the reader, and it should have generality. Please see the Appendix for an expanded description of the case studies.

Case Study no. 1 - Strain Gages on a Robotic Gripper: This case describes the sensing principle and implementation issues in using strain gages. The students will be able to appreciate the masking effects of changes in ambient temperature on the sensor readings. The case was a result from the Tomb Trekker Project, a joint initiative of the Departments of Mechanical Engineering, and the Electrical and Computer Engineering at the National University of Singapore (NUS) (Fig. 2). The case was presented using a robot that was designed to explore the Queen's Chamber of the Great Pyramid of Giza in Egypt. Two artefacts are needed to be retrieved: a pin and a canister-like object. These were left behind in the airshaft by previous robot explorers. Strain gages were mounted on the robot's gripper. Without proper compensation to varying temperatures, the readings from the strain gages will be inaccurate. This case study discussed the effects of temperature on strain gages and possible solutions were explored to address the problem.

Case Study no. 2 - Prosthetic Hand with Lifelike Warmth: The case study on thermal sensing highlighted the psychosocial issues on the loss of fingers or hands and replicating these with lifelike prostheses. One of the main problems that amputees experience with their prosthetic limbs is the non-natural appearance, movement, and the queasy feeling of cold touch of the prosthesis. Technical specifications of components were provided to allow students to design a sensory system that will measure the user's skin temperature and replicate the warmth of the skin in a prosthetic hand. After the students have discussed their solutions, a working prototype was described and presented to the class.

Multimedia Presentations

A picture indeed speaks a thousand words! However, fully operational mechatronic systems are not as interesting in pictures alone. Better impact can be achieved through multimedia enhancements. When used to support lectures, multimedia presentations were reported to have improved the students' attitudes toward the subject and increased the enthusiasm by both students and teachers alike.³² The use of multimedia in education is in accordance to the multi-

channel communication theory, which states that there are several channels of communication and presenting two or more of these channels will result in better retention of information and learning.^{33,34}

Multimedia no. 1 - eLearning Module on Tactile Sensing: A 4-chapter, 80-minute eLearning module on tactile sensing was prepared using the Breeze platform (Fig. 3; Adobe Presenter v7, Adobe Systems, Inc. USA). Breeze is a plug-in to PowerPoint for including content-rich audio and video that is packaged into a stand-alone Flash website. The Breeze presentation can be accessed through the university's Integrated Virtual Learning Environment (IVLE).

Multimedia no. 2 - Machine Vision: Machine vision is the application of a broad range of mechatronic technologies for inspecting objects in order to remove defective products from production. The system primarily relies on the acquisition of images, processing these images, and controlling other machines (e.g. conveyors, robot arms) to control the quality of objects.³⁵ Because such systems have been proven to automate production, improve product quality and reduce wastage, machine vision systems are being used worldwide in many industries, like semiconductor, electronics, packaging, automotive, consumer goods, and pharmaceuticals. I could not find any other means to present application cases of this topic except through multimedia. Interestingly, suppliers of machine vision equipment have produced videos, which comprehensively describe what machine vision is, the subsystem involved, and the application examples.

End-of-Semester Student Conference

Structured as an open-ended problem, the students were asked to investigate topics based on their own preferences. The problems can be from diverse areas but were not limited to the following:

- Sensing for mechatronics, robotics, and product development
- Sensing for healthcare and rehabilitation
- Characterisation of activities of daily living
- Analysis and design of user interfaces
- Biomechanics in sports
- Measurements in human-human and/or human-robot interaction
- Energy harvesting
- Haptics, psychophysics, and sensory perception
- Sensing in the virtual world
- Application of the topics above, including areas such as in education, entertainment and games, art, and music.

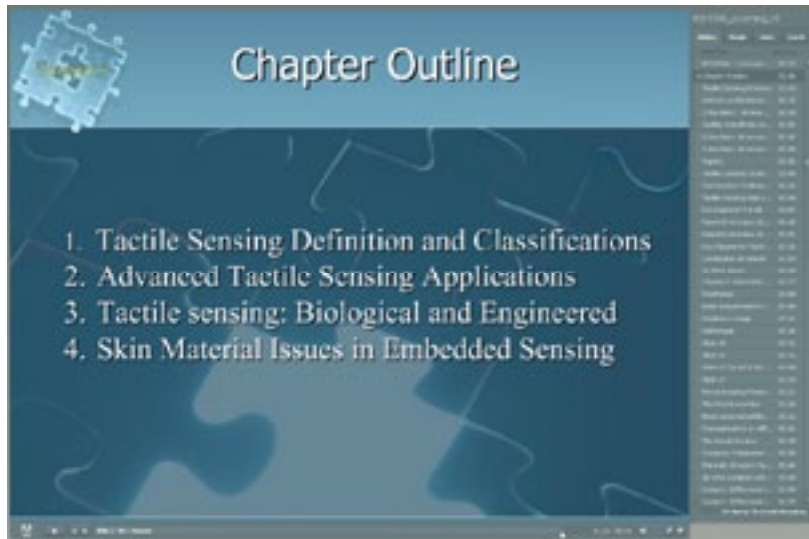


Fig. 3. Screen shot of the eLearning module on Tactile Sensing. The panel on the right outlines the title of each slide and the duration.

The students were provided options to make use of commercially available sensor systems and/or sensor components. Sensor systems are ready-to-use and may be easily adapted to the experimental design. There were various sensor systems that were available at the lab. In case these sensor systems were not suitable for a project's requirement, the students were advised to design their own instrumentation system for the sensor that they need. The sensors available in the lab are shown in Table 2.

Upon selection of a general problem area, the students were asked to justify in front of the class why the problem is interesting. The groups were given a couple of days to refine their ideas and submit an abstract. The abstracts were evaluated according to the novelty and whether the project could be completed according to the limited time and resources. Once the abstract has been approved, the students were given the responsibility to conceive, design, and conduct the experiments or build their projects. For each group, a 6-page IEEE conference format paper was required to be submitted and presented in class. In the 4 years that the student conferences have been running, 62 papers were completed (Table 3). Since then, there were 7 papers that were refined and were accepted for presentation to international conferences.³⁶⁻⁴² Two of these were selected for special issues in journals.^{43,44}

Table 2. Available sensor systems and sensor components

Force/Pressure	
FingerTPS, Pressure Profile System Inc., CA, USA	The system utilises highly sensitive, capacitive-based pressure sensors to reliably quantify forces applied by the human hand. It is a practical, user-configurable, comfortable sensor solution that connects wirelessly to a computer.
TactoPad 2x2, Tactologic Ltd, Hungary	TactoPad 2x2 is a general, small, contact-force mapping system, consisting of four (2x2) three-axial taxels in an array. The three-axial signals of the four taxels provide the possibility for basic 6 DOF, dynamic, spatial-temporal tactile measurements on arbitrary objects. The system has software for acquiring, visualizing, and storing data.
Flexiforce Force Sensor, Tekscan, Inc, MA, USA	A Flexiforce sensor is a 0.2 mm thin flexible sensor that measures force. The sensor is based on piezoresistive effect, in which resistance is inversely proportional to applied force. The data acquisition needs to be designed.
Quantum Tunneling Composites (QTC), Peratech Ltd, UK	QTC is a composite material made from conductive filler particles combined with an elastomeric binder, typically silicone rubber. While in an unstressed state the QTC material is an insulator; with any form of deformation the material starts to conduct and with sufficient pressure, metallic conductivity levels can be achieved. The data acquisition needs to be designed.
Pressurex, Sensor Products, Inc., NJ, USA	Pressurex is a pressure indicating paper that gives the relative pressure distribution between two surfaces in contact. Upon contact, a grayscale pressure distribution profile is recorded on the paper. The colour intensity of the resulting image reveals the relative amount of pressure applied to it. This pressure indicating sensor film is 0.5 mm thin, which enables it to conform to curved surfaces. Further image processing is necessary to obtain the pressure distribution.
Displacement/Motion	
CyberGlove, CyberGlove Systems, LLC, CA, USA	The CyberGlove II motion capture data glove is instrumented with up to 22 high-accuracy joint-angle measurements of the hand and stores data to the computer wirelessly. It uses resistive bend-sensing technology to transform hand and finger motions into real-time digital joint-angle data.
Fastrak, Polhemus, VT, USA	The system tracks the position (X, Y, and Z Cartesian coordinates) and orientation (azimuth, elevation, and roll) as the sensor moves through space. It comes with the data acquisition system and the software interface to the computer.
Temperature/Humidity	
Infrared thermometer gun, Mini 62, Fluke Corp, WA, USA	This tool can measure the temperatures of hard-to-reach, hot, rotating surface in a non-contact manner by infrared. The temperature range is from -30° to 500°C.

Table 2 (continued). Available sensor systems and sensor components

Thermo-Hygrometer-Clock, RS stock no. 408-6109	This instrument measures the relative humidity and the temperature in the room.
Others	
Gaze tracker, FaceLAB 5, Seeing Machines, Ltd, Australia	This system can track remotely and in a noncontact manner eye movements; head position and rotation; eyelid aperture; lip and eyebrow movement, and pupil size.
Heart rate monitor and data recorder, Timex, Timex Group, WA, USA	This device allows one to measure heart rate or record the data for later study. The device consists of a chest strap transmitter and a receiver on the wrist.
Blood pressure monitor, Omron Hem 7300, Omron Healthcare, Japan	The device is used to measure blood pressure. This tool is typically used to determine whether the experimental subject is in a relaxed state.

RESULTS

Effectiveness of the Pedagogies

The 4-year data from the university-administered student feedback system are shown in Figure 4. The survey had 6 question items. The scores given to the teacher were compared side-by-side to the mean scores of all the lecturers at the department and at the faculty for the same teaching activity (i.e. lecture-based modules). Except for 2010, all of the teacher's scores for the 6 items were higher than the department and faculty scores. For 2010, the teacher's scores were slightly above or below the department and faculty scores. For the 4 years of data, the highest mean score of 4.64 was achieved in 2012 for item E (i.e. the teacher has helped me understand how to apply the knowledge), followed by 4.55 in 2009 for item C (i.e. the teacher is approachable for consultation).

Overall Effectiveness

The students were also asked to rate the teacher's overall effectiveness. The University Registrar provided the data on the frequency distribution of responses on a 5-point rating scale for the teacher, department, and the faculty (Fig. 5). In the inaugural year of implementation, the agreement rating for teaching effectiveness was 94%. The agreement ratings for the department and faculty

Table 3. Papers for the student conference (2009-2012)

2009	2010	2011	2012
<p>Session 1: Mechatronics and Rehabilitation</p> <ol style="list-style-type: none"> 1. Measurement of print head assembly motion in an inkjet printer using tactile sensors 2. Analysis of the range of contact forces to actuate Paro, a robotic seal 3. Rehabilitation of handwriting skill for stroke patients 4. Experiment on door opening for elderly people 	<p>Session 1: Rehabilitation</p> <ol style="list-style-type: none"> 1. Force analysis of the ring finger and implications of a missing ring finger as inputs for finger prosthetic design 2. Analysis of grasping manipulation of human hand in hygiene activities 3. Enhancement for artificial limb: comfort zone for a child holding a prosthetic hand 4. Analysis of force profile and study of grasp on human hand 5. Hand stroke sign language to speech conversion system for speech impaired people 	<p>Session 1: Mechatronics and Human-Computer Interaction I</p> <ol style="list-style-type: none"> 1. Cyglove: Gesture-based learning to handle objects in virtual environment 2. A non-intrusive human fatigue monitoring system 3. A CyberGlove-based network activation 4. Autonomous flying machine with ground robot 5. Face tracking webcam based on computer vision 	<p>Session 1: Human-Computer Interaction</p> <ol style="list-style-type: none"> 1. Comparative study on the effect of paper-based and digital reading on the onset of sleep 2. Relation between heart rate and player experience in video games 3. Study on conducive environment for cardiovascular patients 4. Study of visual fatigue in students and effects of caffeine in fatigue
<p>Session 2: Force and Motion Analysis in Human Activities</p> <ol style="list-style-type: none"> 1. Palm force characterisation on push-up exercise 2. Analysis of force profile and the study of grasp in a lid opening action 3. Simulating the buttoning and unbuttoning of a shirt using tactile sensors 4. Analysis of fingertip forces involved in the usage of spectacles 	<p>Session 2: Mechatronics</p> <ol style="list-style-type: none"> 1. Design and development of a self-balancing bicycle robot. 2. Slapping a robotic face: Be wary when you slap your child 3. Speaker induced vibration on laptop hard disks at different locations of chassis 4. Laptop overheating: effects and solutions 5. Rear flashing lights for vehicle emergency braking 	<p>Session 2: Force and Motion Analysis in Human Activities I</p> <ol style="list-style-type: none"> 1. Analysis of forces involved during hugging 2. Study to detect sitting posture 3. Analysis of force by touch while doing activities 4. Force analysis of different social interactions 5. Analysis of forces during object transfer from robotic to human hand 	<p>Session 2: Force and Motion Analysis in Human Activities</p> <ol style="list-style-type: none"> 1. Analysis of human hand motion of manipulating caps on bottles 2. A fall detector based on smart phones 3. Motion analysis of cardiopulmonary resuscitation 4. Comparative study of forces involved in different styles of handwriting

<p>Session 3: Human-Computer Interaction</p> <ol style="list-style-type: none"> 1. Characterisation of typing forces for keyboard design 2. Utilising tactile sensors to compare the forces and the speed of a user's text input using an iPhone and a Nokia 1110 3. Characterisation and comparison of fingertip forces used in touch-typing on full-sized and netbook-sized keyboards 4. Feasibility study of emergency charging system for a mobile phone using a piezoelectric micro generator 	<p>Session 3: Human-Computer Interaction</p> <ol style="list-style-type: none"> 1. Analysis of fingertip forces on an iPad and a computer keyboard 2. Evaluation of the effects of different optical mouse sensitivity settings on user performance 3. Keyboard protector effect on finger tapping force 4. Force characteristics on air mouse and conventional mouse 5. Ergonomic study of computer pointing devices 	<p>Session 3: Mechatronics and Human-Computer Interaction II</p> <ol style="list-style-type: none"> 1. Gaze and heart rate variability-based drowsiness detector study using a driving simulator 2. Gesture analysis for cut, copy and paste operations 3. Piezo-charger: concept to generate power using embedded piezo rubber 4. Analysis of force exerted on thigh and measuring pain threshold 	<p>Session 3: Mechatronics</p> <ol style="list-style-type: none"> 1. Movement of lower limbs for exoskeleton design 2. Effect of acceleration on the discomfort of standing passengers in public rail transportation systems in Singapore 3. Design of darts trainer for beginners 4. Development of analysis systems for pressure tactile sensor film
	<p>Session 4: Force and Motion Analysis in Human Activities</p> <ol style="list-style-type: none"> 1. Data analysis of the usage of chop sticks using tactile sensors 2. Analysis of fingertip forces and motion involved in the guitar strumming 3. Biomechanics of human hand performing interaction gestures 4. Measurement and analysis of the player's arm controls in the game of table tennis 5. Force distribution on base of foot during high-heeled walking 	<p>Session 4: Force and Motion Analysis in Human Activities II</p> <ol style="list-style-type: none"> 1. Force analysis and grip measurement of everyday objects using tactile sensors 2. Force analysis of handwriting of different font size between Myanmar and Singaporean 3. Tactile sensing for grasping in human and prosthetics 4. Wearable fall detector 	

were 86% and 85%, respectively. In the second year of implementation, the agreement ratings were 77%, 85% and 84%, for the author, department, and faculty, respectively. In the third year, the teacher received a rating of 95%; one student gave a neutral response, while no one gave a response of disagree or strongly disagree. The satisfaction rates for the department and faculty were tied at 86%. In the fourth year, the rating was 44% for ‘agree’ rating and 56% for ‘strongly agree’ rating, for a total of 100% agreement on overall effectiveness. The department and faculty ratings were 88% and 89%, respectively.

Students’ Qualitative Responses

There were a total of 27, 30, 12, and 25 comments for 2009, 2010, 2011, and 2012, respectively. The proportion of positive comments is shown in Figure 6. Overall, the data shows that the student’s learning experience was generally positive with the proportion of positive comments to be 0.7, 0.6, 0.75, and 0.8 for 2009, 2010, 2011, and 2012, respectively. The positive statements can be categorised according to student-teacher interaction and the quality of the pedagogies that were introduced. The suggestions for improvements can be categorised according to team dynamics, lecture content, and exams.

DISCUSSION

The major finding from this work suggests that a multi-background, multidisciplinary, and multinational student audience have responded favourably to the in-class demonstrations, case studies, multimedia presentations, and the 2-day conference that showcased the students’ projects. These pedagogies contributed to the generally high agreement of the students on the 6 specific questionnaire items on effectiveness and the overall agreement on the effectiveness of the pedagogical approach. In the fourth year of implementation, the students gave a 100% agreement on the overall effectiveness of the module. Furthermore, the qualitative feedback provided substantial insight to the student’s learning experiences and preferences, which could not be elaborated by the quantitative measures:

“The teacher brings to the class a product related to the lecture and demonstrates it in the class, and if possible even passes it to the students so that we can have a closer look. It kindles one’s thoughts, and was a motivation for me.”

“Case study approach and illustrations of mechatronics system using real systems and video make the class very interesting.”

“Teaching with multimedia is really appreciated.”

“Project work gave me an insight into the sensor application and gave me my first IEEE paper.”

“His approach towards the module and the project he gave us was very informative and interesting. He evoked my interest towards research.”

Engineering educators play a significant role in providing a two-way interaction through consultations and timely feedback. The main project required students to submit and present a conference-styled paper by the end of semester. From Figure 4, item E (i.e. The teacher has helped me understand how to apply the knowledge) was considerably higher than the department and faculty scores in 2009 and 2012, with about 0.5 to 0.7 differences in the mean scores (on a scale of 1-5). The scores could be attributed to the immediate appreciation of theoretical concepts from the application examples that the students received from the in-class demonstrations, case studies and multimedia presentations. Importantly, the problem-solving activities that each group member underwent until the end of the 2-day conference may have contributed to the result. Furthermore, it can be observed that in 2009, item C (i.e. the teacher is approachable for consultation) achieved the highest mean difference of 0.57 and 0.60 as compared to the faculty and department scores, respectively. In spite of the lower scores for 2010 as compared to the other years, the scores for the item B on timely and useful feedback and item C on the approachability of the teacher for consultation were higher than the average scores for department and faculty. One possible explanation for this is that the open-ended nature of the end-of-semester project compels the students to consult with the teacher. These results imply that the teacher is still relevant because immediate guidance and feedback could not be provided by online sources in the context of the specific design problems of the students. As a significant output from this module’s 7-week guided research period, 7 papers were accepted and presented at international conferences. Among these, two were published in special issues of journals.

The results are in accordance with some of the leading theories on learning. Problem-based learning, project-based learning, and case-based teaching are some of the examples of student-centred learning methods under the umbrella

of inductive teaching and learning.¹² Inductive teaching and learning methods impose more responsibility on students for their own learning than the traditional lecture-based deductive methods. Proponents of constructivist learning theory like Piaget⁴⁵ and Vygotsky⁴⁶ postulate that knowledge has to be actively constructed by the mind of the learner through his or her own experiences. Biggs⁴⁷ suggests that teaching should begin with content and experience that are already familiar to the students so that they can draw on their prior knowledge. This is in contrast to the deductive approach wherein the presentation of new material is taught in abstract and is out of context to the mind of the student.

There are two caveats in the implementation of the pedagogies. First, there will be resistance to the initiatives. The combination of 4 pedagogies, which included an open-ended conference-styled final paper, for a graduate module was not common at the department and the faculty. As such, the students needed to get familiar with the teaching innovations. The data showed that the variances for the inaugural implementation year in 2009 were larger than following years (a larger standard deviation implies the lesser robustness of the mean value). Some students may have initially felt uncomfortable with such pedagogies. Some of the qualitative comments also show that a few students preferred the traditional approach whereby the lectures are strictly oriented toward exams.

Second, teaching support and the class size are critical to success. In all these activities, the teacher and the teaching assistant devoted a significant amount of time each week for group consultations and coaching, Saturdays and Sundays included. Brainstorming session and equipment briefing with each group can last up to two hours. Figures 4 to 6 show that there was a significant dip in the mean scores for 2010. This can be explained by a 65% increase in student numbers from 2009 to 2010 (i.e. the number of students was, 58, 96, 69 and 49 for 2009, 2010, 2011 and 2012, respectively). The supervision of 12 groups in 2009 was still manageable even without a teaching assistant. This was not the case with the 20 groups in 2010. It was during that year when it was difficult to hire a teaching assistant who had sufficient competency in managing the various sensors and experimental platforms. The staffing issue was corrected in 2011 and 2012 and their mean scores were comparable or better than that in 2009.

The Internet is revolutionising how education is being delivered at the student's own time, pace, and interest. The latest technological developments and initiatives are disrupting the status quo in higher education. If the motivation in attending lectures is to simply gain general domain knowledge as traditionally offered, there are educators who are questioning whether the students' physical presence at the classroom is still needed. In fact, they are raising the alarm

on the precarious future of higher education if the current state continues.⁴⁸⁻⁵¹ However, analogous to learning swimming, learning with the Internet alone is not sufficient as is swimming in the bathtub does not suffice; the proper environment and coaching are needed to float and more so, to compete. This paper described examples of effective strategies that can engage students to learn. The results suggest that engineering educators are still relevant and they play an important role in increasing students’ motivation and providing immediate feedback that can speed up the delivery of high impact results. The teaching strategy needs to shift – with urgency – from teacher-centred to student-centred learning. Not doing so will doom engineering educators to irrelevance.

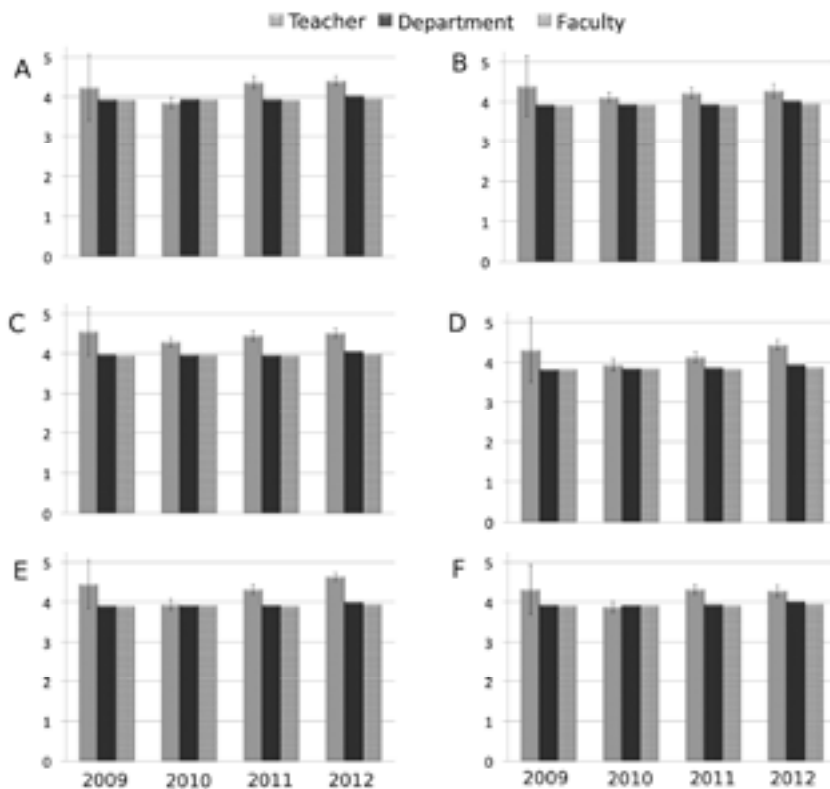


Fig. 4. Four-year data from the student feedback. The mean scores from the 5-point Likert scale (5 = *strongly agree*; 1 = *strongly disagree*) were compared for the teacher, the department, and the faculty. (A) The teacher has enhanced my thinking ability. (B) The teacher provides timely and useful feedback. (C) The teacher is approachable for consultation. (D) The teacher has increased my interest in the subject. (E) The teacher has helped me understand how to apply the knowledge. (F) The teacher has enhanced my ability to learn independently.

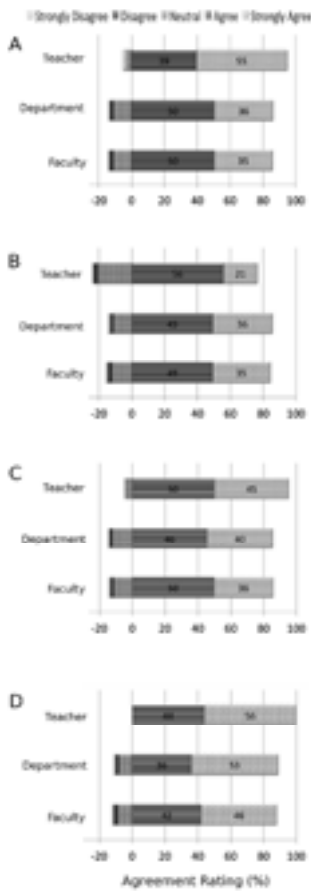


Fig. 5. The frequency distribution on the 5-point Likert scale on the student’s response on the overall teaching effectiveness for (A) 2009, (B) 2010, (C) 2011, and (D) 2012. The agreement rating was determined to be the sum of agree and strongly agree responses.

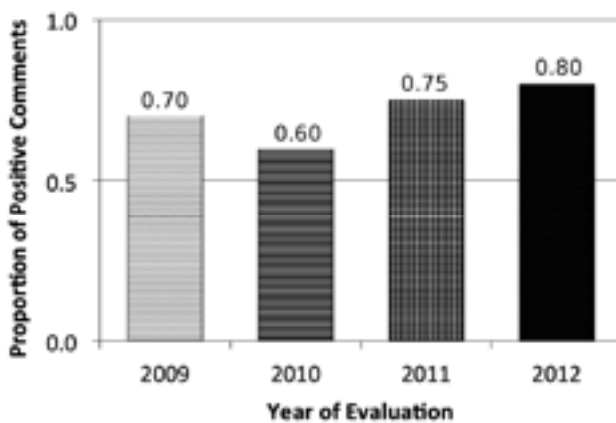


Fig. 6. Proportion of positive comments from the student feedback. A score of 50% and above indicates an increasingly positive student learning experience as the score approaches 100% and an increasingly negative learning experience as it approaches 0%.

APPENDIX: CASE STUDIES

Strain Gage Case Study: Strain Gages on a Robotic Gripper

The objective of the project was to develop a robot that will explore and study the airshafts in the Queen's Chamber of the Great Pyramid of Giza in Egypt. Your goal is to recommend a solution to a designer of a robotic gripper. As part of an undergraduate student capstone project, a student was tasked to develop the robotic gripper that will reach for an object, grasp it, pick it up, and move the arm to place the object in a holding compartment in the robot. The student anticipated that the robot's human operator will have minimal or no visual feedback to determine whether a successful grasp-lift-deposit has been made. The student proposed to mount strain gage sensors on the tips of the gripper. The student conducted experiments to determine the voltage output of the strain gage and its relationship to the grasping force. The initial voltage-force results at the lab's temperature (i.e. 23°C) were not consistent when the experiment was conducted outside of the lab (i.e. temperature: 26°C to 32°C). What is causing the erratic voltage variations in the strain gage data?

The case is a vivid example on the need to compensate for the effects of temperature on the installation of strain gages. El-Giza, Egypt is known to have hot and arid weather conditions, with temperatures from 9°C to 36°C depending on the season. The temperature in the ancient airshafts could vary, while the preliminary experiments on the robot were done elsewhere with temperatures of 23°C to 32°C. The resistance of strain gages will be affected by changes in temperature. As an illustrative example, calculations were made on how much the resistance will change given a temperature variation of 1°C. The basic equation is governed by $R(T) = R(T_0)[1 + \alpha_0\Delta T]$. Simplifying the equation leads to $\Delta R = R_0\alpha_0\Delta T$, where ΔR = resistance change due to temperature change; α_0 = temperature coefficient of resistance, which is assumed to be 0.004/°C; ΔT = 1°C and $R_0 = 120 \Omega$ as the nominal resistance of metal wire. The masking effect of temperature on the resistance will be apparent. The design solution consists of strain gages that are mounted in pairs with one active gage in the direction of deformation while the other strain gage (i.e. dummy gage) is positioned parallel to that of the active gage.

Thermal Sensing Case Study: Temperature Sensing and Regulating the Warmth of a Lifelike Prosthetic Hand

Touch is communication at the most basic level. What happens when one's arm or hand is lost because of an accident, disease or war? The common recourse of people who had limb loss is through prosthetics. The prosthetic device must

be able to allow the amputee to conceal the usage of prosthetics. This will help the amputee, especially those who are in the early stages of limb loss, to cope with psychosocial issues and to ward off the social stigma.

As a designer, you are tasked to propose a system that will regulate the warm skin temperature of the prosthetic hand. A healthy human body has a core temperature of 37°C while the surface of the human finger is at about 27°C to 32°C in normal ambient conditions. A prosthetic hand that was made from soft silicone rubber has been pre-selected for you. The temperature of this material takes the temperature of the environment. The prosthetic hand can be custom-built depending on your design specifications. The surface of the prosthetic hand should have a temperature that matches the skin temperature of the user. Assume that the room temperature is 21°C. Propose a sensing and heating system design based on these requirements. Solutions using block diagrams are sufficient. The following components, and their data sheets, are available:

- thermofoil heater (Kapton heaters, Minco, USA)
- temperature sensor (LM335, National Semiconductor, USA)
- transistor, a MOSFET, to control the heater (IRF630, Fairchild Semiconductor Inc., USA)
- microcontroller of your choice
- other electronic component of your choice

Thermal conductivity is a physical property of a material that characterizes the ability of that substance to transfer heat. The thermal conductivity of wood is about 0.1 to 0.15; steel has about 43; and rubber has about 0.13, all with units of W/(m·K). For example, steel has higher thermal conductivity so the heat from one's hand flows into the metal quickly. This creates a cold sensation of the metal. Would it be possible to replicate the human skin temperature using silicone rubber, which is a poor conductor of heat? If so, how can this be accomplished? What is the role of thermal conductivity in the transfer of heat from the embedded heater to the surface of the skin material? What is the contribution of the temperature sensor? Where should it be mounted?

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