# Engineers in Hospital: An Immersive and Multidisciplinary Pedagogical Approach for Better Solutions

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## Abstract

The Faculty of Engineering (FoE) at the National University of Singapore (NUS) and the Department of Rehabilitation Medicine at the Singapore General Hospital (SGH) recently launched the country's first Engineering in Medicine (EIM) program co-taught by medical professionals and engineering educators. Engineering students in this program gain a deeper understanding of rehabilitation medicine via immersive training in hospitals and first-hand interactions with patients, and their doctors and therapists. The experience enables students to appreciate the complexity of treatments and challenges faced by the patients and clinicians. As part of the EIM program, students learn to apply their insights and adopt a user-centric approach to design solutions to meet the needs of patients and clinicians. We also expect the direct contact with patients and their caregivers to engender in the students a greater sense of ownership for their projects, and motivation to produce practical and affordable solutions. This paper describes the motivation for launching this EIM program, and lessons learned in the early phase of the program.


## Introduction

Engineering is an integral element in many branches of medicine today. Advancements in these areas depend not only on clinical expertise, but also expertise in many areas of engineering including genetic engineering, tissue engineering, biomechanics, and technology-driven breakthroughs in imaging, diagnostic and therapeutic medical systems. Also, successful adoption of technology in medicine depends on an interdisciplinary cooperation among specialists in the various medical, rehabilitation and engineering fields.

In spite of the interdisciplinary nature of Engineering in Medicine (EIM), curricula development and the training of specialists in Medicine and Engineering in Singapore have by and large been conducted independently. Engineers and doctors are not trained to work with each other and do

not know how to tap the expertise on the "other side". An outcome of this is the development of technology and/or devices, supposedly for medical applications, with little clinical value in reality. Conversely, clinicians lack awareness of the potentials of emerging technology and fail to exploit these in their work[1].

Another factor contributing to the current situation is that collaborations between medical and engineering researchers in Singapore are typically funded by research grants. However, access to such grants is highly competitive. A failure to secure continual funding sees the end of such collaborations and results in a vicious cycle of stagnant development of core EIM knowledge, falling further behind in standards and difficulty in obtaining future funding.

To avoid a perpetuation of this state of affairs, the Faculty of Engineering (FoE) at the National University of Singapore (NUS) and the Singapore General Hospital (SGH) collaborated to launch an EIM program in August 2012, conducted by the Engineering Design and Innovation Centre (EDIC)[2] of the FoE, and the Department of Rehabilitation Medicine and the Division of Allied Health of SGH.

## Rationale for Partnering with Rehabilitation Medicine

Rehabilitation medicine is an ideal and natural partner to pilot such collaboration. Firstly, rehabilitation is a broad specialty and is not primarily disease specific. It handles impairment and disabilities that can occur in any of the major medical and surgical diseases and disciplines like neurosciences, orthopedics, cardiology, cancer, psychiatry, geriatrics, trauma and internal medicine. Secondly, given the rapidly aging population and better acute medical care, the demand for rehabilitation is huge and is exponentially rising. Hence the Engineering in Medicine program is projected to play a large integral role. Thirdly, rehabilitation physicians are amongst the very few specialist physicians who through the nature of their training have the innate capability to communicate and integrate well with engineers. These specialists are both medically and rehabilitation trained and able to give a firm grounding in medicine and rehabilitation, essential in such a collaboration. Lastly, the armamentarium of interventions in rehabilitation are diverse and include not just pharmacologic medications, but a wide array of diagnostic, monitoring and therapeutic instruments and devices built around an engineering core.

Hence rehabilitation medicine provides an easy platform for the engineering students to integrate with the field of medicine and develop solutions.

## Objectives of the EIM program

The main objective of the EIM program is to bridge the gap between the major fields of medicine and engineering by providing engineering students a deeper understanding of medicine, via immersive training in hospitals and first-hand interactions with patients, doctors and caregivers. This program is Singapore's first Engineering in Medicine (EIM) program which includes multi-year and multi-disciplinary project teams from the Faculty of Engineering (FoE). The program includes EIM modules co-taught by engineering faculty and clinicians to the undergraduate students from different engineering departments. The engineering students work on their EIM projects in groups for up to three years, starting from the second year till the final year of their engineering degree. The EIM project counts towards the design projects in the third year, and final year project (FYP) in the final year of the undergraduate study.

## Structure of the EIM Program

The EIM program is part of the Design Centric Program (DCP)[3] of the FoE. The DCP takes in students from different engineering disciplines to work together in multi-disciplinary project groups. Each project generally belongs to one of a few broad DCP themes, such as in Future Transportation System (FTS), Engineering in Medicine (EIM), and Smart and Sustainable Cities (SSC).

The current structure of the three-year EIM program is shown in Fig. 1. During Semester 3, which is the start of the second year, students undergo a 13-weeks hospital immersion training. Semester 4 and Semester 5 are the design project phases, where students identify a problem to work on and then to build up the solution. During this phase, mentors from the hospitals i.e., medical doctors, therapists and nurses, are identified for the student projects. These projects are also supervised by the FoE. At the end of Semester 4, students are expected to demonstrate their project concept by applying some engineering principles on a prototype. A working prototype is expected at the end of Semester 5. In Semester 6, students are given an opportunity to go for

Student Exchange Program (SEP). Students are encouraged to go on the SEP to other universities in different countries. Such exposure is important in widening the students' perspectives. Students are also encouraged to continue working on their EIM project while they are on SEP. This experience exposes the students to the real life problems of working with multi-location teams. When these students return in Semester 7 they are expected work on their final year projects (FYP), where they refine their solution and develop a high-resolution prototype. During the FYP stage, students can either work on implementing their solutions to the hospital's environment or expanding the scope of their projects.

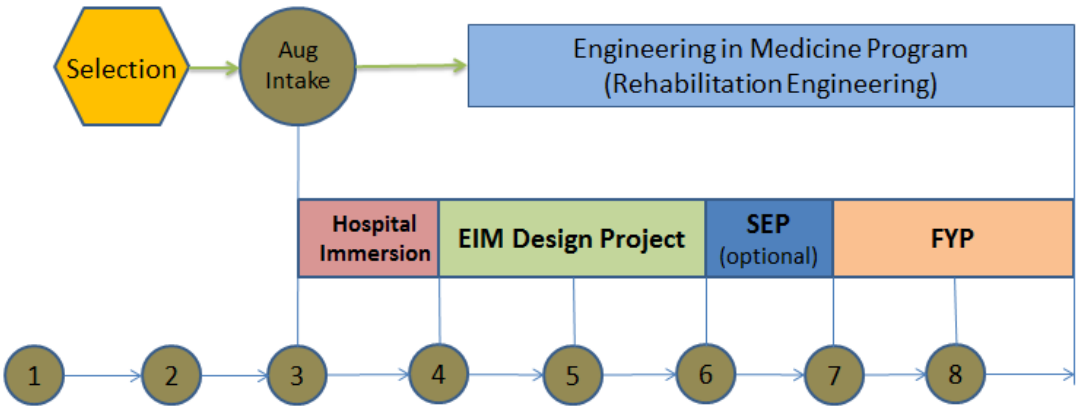


Fig 1: Time-line of the EIM Program

**EIM Modules**

The EIM modules are co-taught by the engineering faculty and the clinicians from SGH. These modules consist of classroom lectures supplemented with regular periods of hospital attachments and guided observations, and culminating in the completion of an EIM project under the co-supervision of clinicians and FoE staff. The modules provide an immersive head start for the engineering students to acquire familiarity with clinical environments and the various clinical specialties involved in rehabilitation medicine. Although this model of engaging students is not new to FoE, it has been previously applied in purely engineering settings.

Unique Features of the EIM Modules

The EIM modules are built around the expertise of staff from FoE and the hospital, and provide students with the fundamentals of the EIM. The systematic training of students from different engineering disciplines in the same setting and through a structured curriculum in this program is a marked departure from the ad hoc learning acquired by students during attachments to the hospitals. Students in typical attachment programs to the hospitals do not receive proper grounding in the fundamentals and what they learn, and the projects eventually proposed by them, are solely dependent on what the they happen to encounter on a given day, i.e., by chance.

In the EIM modules, patients with specific diseases and signs are introduced to EIM students. Students come in contact with patients suffering from ailments like stroke, traumatic brain injury, spinal cord injury, amputations, Parkinson's Disease and geriatric conditions. These patients include those already residing in the inpatient wards and/or those visiting the clinics for follow-up checkups. As part of their training, students routinely interact and observe first-hand the impairments, disability and handicaps of these patients.

To quickly gauge students' knowledge during and at the end of the modules, students are required to take a test at the end of each module. A typical test includes multiple choice questions (MCQ) and open-ended questions to test the students' observation skills and ability to draw insights from their observation. Students are also required to submit a module evaluation form at the end of each module. This regular assessment practice, which assesses learning performance and the staff's teaching effectiveness, is another departure from current student-attachment practice.

The EIM modules also incorporate talks, seminars and discussions relevant to EIM and Singapore. These include:

- Discussion with senior medical students, particularly the ones with a background in engineering. These students offer viewpoints and development suggestions for EIM, with a richer perspective.
- Sharing by engineers and physicians deeply involved with well-known Medical-Engineering programs particularly the Singapore-Stanford Biodesign (SSB) program and the Agency for Science, Technology and Research (A*STAR) of Singapore.

- Exposure to Ethics in Medicine and the Institutional Review Board. This is a necessary element in EIM as the engineering students are involved in Medical Intervention and working with human subjects.

Observation and Interviewing Techniques

To achieve the objective of giving the engineering students a deeper understanding of the needs of various stakeholders such as the patients, clinicians and caregivers, observation and interviewing techniques are taught at the university before the students begin their immersion in the hospital. It is important for the students to build up a habit of observing their surrounding and the interaction of people with systems, and be able to identify problems from the observation. An example of a field exercise is the task of observing the eating places and social activities in the students' residential estates. Students are required to talk to fellow residents to understand their problems and needs, and identify the areas where such facilities are not user friendly. They are then required to share their findings with their fellow classmates in the following class and get feedbacks.

Good observation must be coupled with effective interviews in order to gain an understanding of how people feel, develop the ability to empathize with them, and produce tacit knowledge. Students are introduced to various types and characteristics of interviews, good interviewing questions, methods of recruiting subjects, general techniques of interviewing, general issues and challenges with interviewing, and ethics in interviewing. An example of a class exercise is the task of asking a partner for information on a specific experience. Students are required to dig deeper for information from their partners so as to capture enough findings to define a problem. They are then required to generate ideas to seek feedback from their partners.

The importance of defining a problem is emphasized throughout this training. Defining a problem too narrowly could limit the ideation process and defining it too broadly could lead to dilution of ideas. To enable the students to improve their problem definition, students are instructed to build "low resolution" prototypes after ideating for concepts. These prototypes can be built from inexpensive materials such as paper, cardboard, foam and clay, and can also be in

the form of sketches, scripts, software, video, website, and story-telling. The objectives of building the prototypes are to articulate the identified problems to the stakeholders and to get feedbacks from them[4]. The feedbacks from the stakeholders help the students gauge the usefulness of the concept and capture additional insights. Since little resources are put into making the prototypes, students can ditch or modify their idea early in the design process without developing too much attachment to the prototype.

Institutional Review Board (IRB) Course

To ensure the students carry themselves in an ethical manner when dealing with human subjects, they are required to register, attempt and pass the online training instituted by the Collaborative Institutional Training Initiative (CITI)[5]. This becomes important especially when the students undertake a research project in their senior years. The students are required to pass the two basic courses: Social and Behavioral Research Basic Course and Social and Behavioral Responsible Conduct of Research (RCR) course. They are required to submit the training completion report to the EIM program coordinator at the end of the hospital immersion training in Semester 3.

**Instructors**

The EIM modules are co-taught by the engineering faculty and the clinicians from the hospital. The instructors consist of the clinicians from the hospital's Department of Rehabilitation Medicine and the teaching staff from the FoE.

From the hospital, the instructors include the Head of the Rehabilitation Medicine, Senior Consultants, Consultants and Registrars of various sub-specialties in Rehabilitation Medicine, Physiotherapists, Occupational Therapists, Speech Therapists, Music Therapist and Senior Nurses. These instructors are involved in teaching the students the basic medical modules of different sub-specialties in Rehabilitation Medicine, walking them through patient observation and diagnosis, and introducing them to various rehabilitation equipments and rehabilitation methods.

From the university, the instructors include the engineering professors and lecturers from diverse engineering backgrounds, such as Mechanical Engineering, Electrical Engineering, Computer Engineering, Bio Engineering, and Human Factors in Engineering. Their role is to supervise the students in terms of gaining user empathy, problem definition, ideation, making prototypes, testing and providing the relevant engineering knowledge needed in the projects.

**Anticipated Outcomes**

An anticipated outcome of the EIM program is to facilitate the development of effective engineering solutions to help patients and their caregivers in the rehabilitation process and beyond. The engineering solutions are co-created by the engineering students and medical professionals.

Before any solution is proposed, the students must know how to identify the right problem. Hence, this program also aims to build up the problem formulation skills of the engineering students through the user-centric design approach. The students enter the hospital to observe and interact with the patients, caregivers and medical professionals to identify the unmet medical needs.

Through identifying the problems on their own, it is expected that students will gain ownership of their projects and have higher motivation to strive for better solutions for the users. The students are also expected to be able to ideate and communicate their ideas effectively to all the stakeholders. These include the patients, the medical professionals, faculty members and the fellow students. Feedbacks from the stakeholders are important for refinement of the concepts so that more effective engineering solutions may take root.

**Assessment of Students in EIM Immersion Program**

The assessment of the students consists of four components. These are discussed as below:

Attendance and Participation

To ensure that the students get the greatest benefits out of this learning opportunity, it is important that students attend all the hospital immersion classes. To reinforce their learning, it is also important that students ask questions during the lectures and observation sessions. At the end of each class, each student is asked to share his or her observation and thoughts for the day. Passive students are identified by the faculty members and encouraged to speak up.

Presentation

At the end of the 13 weeks hospital immersion, the student groups are required to give a final presentation of their problem formulation and prototyping. This presentation is graded as a group. The presentations are attended by the Engineering Faculty members, and the hospital clinicians involved in the program.

Prior to this final presentation, after the mid-term vacation of semester 3, the student groups are given an opportunity to give a short presentation on their Interviews, Observations, Problem Formulation, Ideation and Prototyping. This first presentation is not graded, but serves as an opportunity for the students to share their ideas and get feedback from their fellow classmates and engineering professors.

Report

The students are required to submit individual reports touching on their Immersion Experience – interviews, observations, problem definition, ideation, and prototyping. This report is graded individually.

Quizzes

To reinforce their learning, the students are given two sets of quizzes. The first set is on interviewing, observation, ideation and prototyping techniques, which are taught to the students during the first ten hours of pre-immersion training, and is given before the students begin their immersion training. The second set of quiz is on Rehabilitation Medicine. It is set by the

hospital, and is given at the end of the thirteen weeks hospital immersion training. The quizzes are graded individually.

**Selection of the First Batch of EIM Students**

For the pioneer batch of the EIM program, an invitation to apply was sent to all the engineering students who had completed their first year of study in the FoE in early August 2012. Fifteen students were selected from three departments after an interview exercise conducted by academic staff of the university. These three departments were the department of Mechanical Engineering (5 students), the Department of Electrical and Computer Engineering (3 students) and the Division of Bioengineering (7 students). The students were assessed on their attitude and aptitude related to rehabilitation medicine and the requirement of the nature of the program. Some important parameters used to select the students include the passion shown towards EIM, willingness to work in a team, past experience in handling uncertainties and the majors of the students.

**Experience with First Batch of EIM Students**

For the first batch of students admitted in August 2012, the pre-immersion training in observation and interviewing skills took up ten hours over three weeks. For the subsequent ten weeks, the students attended weekly immersion classes in the hospital. Each class lasted between 4-8 hours in the hospital. The classes consisted of lectures taught by the doctors, therapists and nurses, and also observations in the wards and rehabilitation gyms. Examples of topics covered during the lectures are: introduction to physiotherapy, stroke and spinal cord injury and the related rehabilitation equipments. For the purpose of patient interviews, patients were pre-selected and their consent was sought by the doctors through the hospital's procedure of consent seeking, such as explaining to the patients the objectives of the students' interviews, and the signing of consent forms by the patients who agreed to be interviewed. Students were allowed to interview the patients in groups of five, for 15-20 minutes per session.

To facilitate the administration, arrangement of laboratory tours and project discussion, the students were grouped into five groups of three students each. Each group consisted of students from at least two departments. Table 1 shows an example of a five hour session at the hospital.

Table 1: An Example of a weekly hospital Immersion class

| Session 1 (1hr) | Session 2 (1hr) | Session 3 (1hr) | Session 4 (1hr) | Session 5 (1hr) |
|---|---|---|---|---|
| Introduction to Neuroanatomy & stroke | Spinal Cord Injury | PT/OT Gym Observation | Ward / Patients Observation | Debrief on Observations |

At the end of each class, debrief sessions were carried out with the students and faculty members to discuss the observations made and insights gained for the day. This was to reinforce their observation and interviewing skills, and also to encourage knowledge sharing among the students. Each student was also required to fill out an observation sheet and a feedback form required by the hospital.

Problems Encountered

Some of the problems encountered during the running of the pioneer program are highlighted below.

First, access to patients was limited within the given time frame at the hospital. The regular class of the students was from 2PM to 6PM every Wednesday. The class was scheduled on Wednesday afternoon because this was the day and time where most engineering students did not have other classes apart from the EIM program. The students could only gain access to the patients during the fixed timings arranged by the hospital. It was difficult to grant extra time for the students to speak to the patients due to constraints posed by the hospital administration and the ethical guidelines. For example, each class often ended after 7PM, by which time, the hospital administration would be closed for work, and the patients would also need to rest for the night. It was also difficult to arrange for the students to visit the hospital on other days as the students belonged to different departments, and they had different timetables to adhere to in the different engineering departments.

Second, the students relied heavily on the medical professionals for advice on the feasibility of their ideas, during their limited time in the hospital. Some student groups sought the affirmation of the medical professionals to prove that their ideas were sound.

During the preliminary presentation in early October 2012, when students produced low-resolution prototypes to demonstrate their concepts, it was found that some groups' ideas were very product-centric, and not user-centric. Few interviews and observations were made which were relevant to their proposed concept. Some groups made assumption on the motivation of patients, instead of deriving the needs and insights from patient interviews and observations. The students did not sufficiently look beyond the hospital for sources of interviews and observations. This problem also surfaced during other discussion and consultation sessions with the students. The students were advised to go beyond the hospital for their interviews and observations. However, at the end of the immersion program, it was still found that not enough interviews and observations were made by the students, as shown during their final presentations.

Lessons Learnt

The university faculty members had a debrief meeting and it was concluded that the students were not sufficiently grounded in the observation and interviewing philosophy. A stronger message was needed on the importance of doing more field observation and interviews. The pre-immersion class during the first three weeks may not be sufficient to instill the importance of interviews and observations in the mindset of the students.

A longer and better way of training on observation and interviewing is required before the hospital immersion. There should also be more field exercises and more follow-ups before the next immersion program. Such exercises help the students to understand the concept of observation and articulating a problem better. The selected exercises should also train the students to start looking at problems from a broader perspective instead of being narrowly focused on a specific problem. Engineering students trained in their respective disciplines often fall into the trap of approaching a problem with a narrow (specific) perspective. A systems thinking approach to problem solving[6] is one of the techniques that can be taught to the students.

The low resolution prototypes produced by the students, during the preliminary presentation and final presentation, served as very good communication tools and allowed the instructors to fiddle with the "devices" and point out their likes, dislikes, and flaws with the concept, if any. The prototypes also gave the instructors the opportunity to reinforce to the students the importance of producing prototypes to capture unexpected findings, and not to confirm the initial findings.

An important lesson learnt was that the making of prototypes should be enforced and the teaching content in prototyping should be incorporated in the future running of the program.

It was seen that during the thirteen weeks of immersion training of the first batch of students, the students were given two assignments, a week after the preliminary presentation by the students. The first was to make them think through why their ideas did not yet exist in the market. The second one was to make them derive their insights from an observation they made in that class. It was found that the discussion between students and instructors was more vibrant after the announcement of the assignments. Hence, assignments should be frequently instituted to reinforce learning.

Follow-up with the First Batch of EIM Students

To reinforce the learning on the first batch of EIM students while they embark on the next phase of the program – the design project phase starting from Jan 2013, revision on the key points of observation and interview techniques was done with the students. The students were shown case studies, examples of observation done and interview data, and were given some field exercises to broaden their perspective to problems, apply their knowledge and improve upon their initial exercises. An example of the exercises was to observe the facilities and activities in a train station and adjacent amenities, identify problems or areas which were not user-friendly and analyze the issues causing the problems. The students were required to present their data in a week and the instructor benchmarked their results with the instructors' own data for assessment. Thereafter, the students' observations work in the hospital for the rest of the semester, was continuously assessed by the FoE supervisors attached to each project group.

**Moving Forward for the EIM Program**

A heavier workload will be required of the students to do meaningful fieldwork and also to test their commitment. This includes many observation sessions and extra lessons beyond the hospital, which could be conducted at nights.

During the final presentation by the students in Nov 2012, there were various comments made by the clinicians regarding the usefulness and feasibility of the concepts proposed by the students. It became clear that the clinicians should be the sponsors for the projects that the students undertake for the rest of the EIM program.

Following that, the Engineering Design and Innovation Centre of the FoE has struck an agreement with the Department of Rehabilitation Medicine of the hospital to assign a sponsor for each of the student projects.

Also, a living laboratory should be set up at the hospital to facilitate the students' access to the hospital's resources.

<u>The Integrated Engineering-Rehabilitation Living Laboratory</u>

A problem was highlighted earlier on the difficulty of students to gain access to hospital resources outside of the scheduled class timetable at the hospital.

The relevance and importance of a living lab quickly became evident in the light of this problem and other obstacles which prevent rapid translation of engineering design efforts ('bench') into relevant patient care systems ('bedside'). An integrated Engineering-Rehabilitation Living laboratory should be set up that can provide a common workplace where engineering minds and medical minds will likely create fruitful synergies and innovative outcome. Secondly, the concepts and prototypes can be quickly developed and tested with the end-users i.e., doctors,

therapists and patients in the very environment in which the end product will be used. An ideal location for such a lab will be somewhere closer to the hospital premises.

## Conclusion

The Engineering in Medicine program is a unique academic program with promising results. The progress of the program has been good so far and the staff will be working towards improving the program as it progresses. This program highlights the importance of multidisciplinary approach towards engineering education. This program not only involves engineering students from different departments but also supports interaction between engineering students and medicine professionals. Student immersion with the hospitals helps them develop empathy for the rehabilitation patients and care givers. As a result, the solutions generated by these students will be better suited to their user needs. Through this program, the engineering students develop a wider perspective of engineering problems and are able to appreciate the value of working in multidisciplinary teams.

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