Integrating Global Systems Development Skills into the Engineering Curriculum

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Abstract
Educating the ”global engineer” has been identified as a priority by leading international engineering organisations such as the Royal Academy of Engineering in the UK[1], and NSF in the USA[2], among others. While the calls for changes in education to prepare the engineer of 2020 for the world in which she will work have been strident, there are still many questions surrounding how should this be achieved in practice? Inspection of degree programs reveal that competencies stated as learning outcomes for the degree are often more or less non-existent in the learning outcomes for the courses comprising the degree. There are many reasons for this gap, e.g. attitudes such as “competencies can’t be taught” and “competencies will evolve by themselves (by practice in the subject)” and crowding the degree program with a multitude of compartmentalized rather small pure subject courses, and we will in this paper address the unfamiliarity among both degree designers and individual teachers regarding what global engineering competencies are and how they can be assessed. We will especially focus on the progression aspect.

In this paper we describe a curricular innovation which we have been developing over more than a decade, in which Swedish students work in collaboration with students in Finland, China and America in project based learning environments in two upper level subjects. The goals are to help to develop global engineering competencies and experience, and appreciation for the importance of these skills for future working life. The two courses focus on working in an international context, where the complex demands associated with completing a systems design and implementation task on time are combined with factors such as time-zone differences, the challenges of working in a foreign language, and cultural differences in terms of work culture and community.

1. Introduction

Development of competencies in teamwork, cultural awareness, professional communication are well established goals of engineering education. These skill sets and competences are described in the ABET accreditation criteria (see www.ABET.org), as well as in the newly established ACM/IEEE Computer Science Curricula 2013 (www.computer.org), and similar criteria can be found in the national educational goals of many countries. Swedish engineers are increasingly pursuing careers abroad, this is a direct consequence of the size of the Swedish economy and industry base. Consequently it is vital that engineering education in Sweden should foster global engineering skills.

What is then required of the “global engineer”? What competencies are needed and how can they be developed? Grandin et al.[10] identify several areas in which they recommend that the curriculum should be strengthened. Among these are increased awareness of the global nature of the engineering enterprise. The UK Royal Academy of Engineering report[1] also identifies the need to address the increasingly global nature of the engineering profession, however, focuses more on the specific challenges facing UK universities. Another recent initiative in the area is the “Attributes of a Global Engineer” project directed by Hundley et al.[11]

Our work in this area commenced as a collaboration between Grand Valley State University in Michigan, USA and Uppsala University, Sweden in the late 1990’s[7]. The early attempts were based in a Problem Based Learning (PBL) environment with one or two student teams comprising students from

both universities and a primary focus on technical achievement and competencies was reflected in the assessment. From 2000 the initial PBL course expanded to a larger cohort, and a range of mentorship components and teamwork assessment items were added. The course and assessment approach used at that time is described in Pears et al. 2001[17].
In 2005 we introduced international collaboration in a semester long project course, where the Uppsala students work with students at an American university. This course has an explicit focus on competencies suitable for global collaboration and different pedagogical challenges with this has been investigated in an action research manner[3-9,14,15]. The goals are to help to scaffold progressive development of global engineering competencies and experience.

The paper is structured as follows. We describe the evolution of the curriculum reflecting on the instructional design and the challenges associated with assessing student engagement and development in the skills and competencies that the course aims to develop. An analysis of student reflections is presented which provides insight into what the students experience and how their awareness of the challenges of working in a global context develop throughout the course.

2. Reflections on the Curriculum

Some common features of professional work that are seldom represented in University classrooms and practical exercises are associated with the open-ended problem specifications common to most industry environments. Such specifications are often formulated in rather fuzzy high level terms. An open-ended problem specification places different demands on learners than traditional university practical work or course assignments.

Aspects of professional working settings that we consider important include analysis of the problem space and proposal of a feasible solution, identification of appropriate tools and techniques with which to solve the problem, managing and working in a team and learning about working with people from different cultures.

At Uppsala university we have introduced a two course sequence that directly target graduate outcomes that contribute to the effectiveness of graduates in the global workplace. We place particular emphasis on teamwork (in the context of geographically distributed projects), communication and presentation skills, and intercultural competence (by which we mean awareness of other cultures norms and the impact these can have on professional practice). Students are introduced to structured teamwork and intercultural communication and collaboration in the first course, "Runestone" at the end of the third year of academic studies. This is followed up in the fourth year by students taking the IT in Society course (ITiS)[14], where they encounter a larger and more open-ended project. The sequencing of these courses in relation to the total degree curriculum is illustrated in Figure 1.

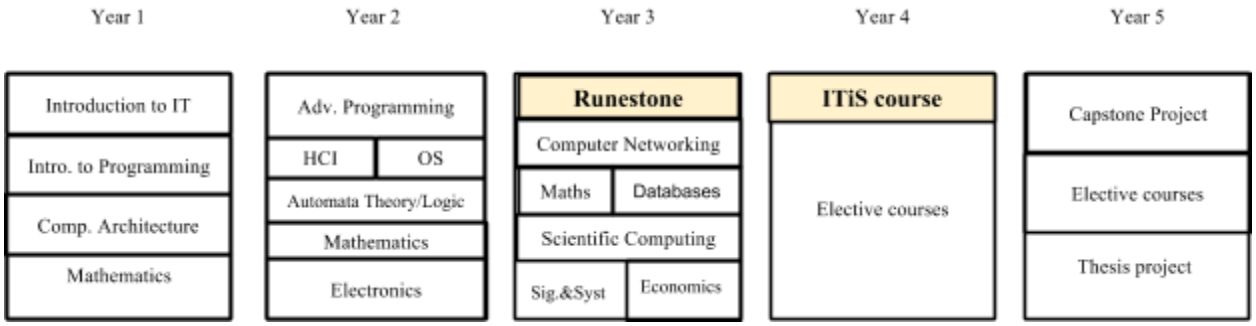

Figure 1: Overall structure of the IT programme.

Our approach to developing and reinforcing global workplace skills centres around active scaffolding and exposure to cultural, geographical and communication based workplace challenges. The approaches taken in the two courses described in this paper are rather different, since they are designed to extend and complement one another. The first course in the sequence provides a structured "artificial" project environment, in which the problem to be solved, and deliverables, are defined by the instructor and are more limited and completely specified. The second course focuses on negotiation with external stakeholders. These negotiations include defining the content and scope of the project, and what the project will deliver.

2.1 Runestone

The objectives of the Runestone course are to give students experience with a problem and work situation which requires them develop a greater level of self-reliance, teamwork, negotiation and communication skills, integrate and use theoretical knowledge from earlier courses, and (through experience of a wider systems development project cycle) understand that the theories we teach in subjects like software engineering are not prescriptive and do not always lead to timely delivery and successful products.

By working to realise these objectives we hope to provide students with valuable experience relevant to their future working life in the "safe" educational environment. By "safe" we mean that students can successfully complete the course and gain a pass even if their technical solution to the problem is non-functional. Passing the course thus depends much more on working processes and sincere attempts to put theory into practice, than it does on developing a successful and robust hardware/software system.

Current collaborators in the course are Tongji University in Shanghai, China, Turku University of Technology, Turku, Finland, and Uppsala University, Uppsala, Sweden. Teams of six to seven students (three to four students from two of the collaborating institutions) work on implementing a distributed system to control an embedded systems device in a remote location. This means that teams will consist of Swedish and Finnish, Finnish and Chinese, or Swedish and Chinese students. We avoid allocating teams which include students from all three sites. Such teams have shown themselves to be impractical to manage given the changes in time zones and study schedules.

Assessment is based on a combination of individual and team achievements in a range of areas.

Teamwork and Communication: evaluating the organisational ability of the team and the manner in which the team presents itself and works as a unit to achieve its goals. This includes individual marks for those elements of the reporting for which individuals are responsible, as well as peer evaluation of the contribution of each member by the other members of the team (at the conclusion of the project).

Teamwork and the process of collaboration is closely observed during the project and the teams are required to report regularly. Development of written communication skills is through critique of the bi-weekly reports the teams present. Each report is presented using online synchronous chat communication, this allows the instructors to look at concise communication skills, ability to organise and use time effectively, as well as observe the internal team social dynamic.

Project Management: evaluating the interim progress reports and the online meetings in which the team reports on progress. Assessment here focuses on the ability of the team to plan realistically and work towards reaching the milestones they have defined.

Problem analysis and specification documents are requested early in the project and critiqued, they also form the foundation of part of the final team grade. Teams are asked to provide an implementation timeline in the form of a Gantt Chart, in which the major sub-project dependencies should also be identified. An open source project management tool (Redmine) is used to track "billable time", and adjust workflows as time mis-estimations become apparent over the course of the project.

Technical Achievement: evaluating the complexity of the milestones the team set, and the levels of technical achievement reached during the product development process. Assessment is based on professional code development and the sophistication of the final product.

While the area of technical achievement remains in focus the marking scheme for the milestones focuses on reporting, professionalism, project activity, work diaries, time logs, and individual weekly reflections on what has been learned and achieved.

2.2 IT in Society (ITiS)

The objectives if the ITiS course are to provide students with substantial knowledge and ability concerning the interplay between technology, users and organisations based on relevant areas in human-computer-interaction, psychology and system construction, as well as experiences in real systems developing projects. The learning environment set up to achieve that the students reach these objectives is centered around a project where the students work in an intercultural and distributed setting collaborating with an external client. The expectations are that the students should be able to interact both with the client and among themselves to define what the problem is and how it should be addressed. They should furthermore be able to evaluate their agreement from perspectives such as ethics, sustainable development, work environment, economy and usefulness.

It is also a learning objective that the students should be able to evaluate and analyze their own abilities and competencies regarding working in an intercultural and distributed project, as well as develop strategies that lead to lifelong learning. The focus on competencies suitable for a global engineer is thus more explicit than in the Runestone course.

In ITiS we collaborate with Rose-Hulman Institute of Technology, Indiana, USA, where they run a companion course[14]. All students work together in one project addressing an issue presented by an external client, who since 2004 has come from the health sector. The number of students have varied between 12 and 28 and has been one factor for the students to relate to when organising their work. Other complicating factors are that the expected study load in the two courses are different and they have different start and end dates. The complexity in this project is higher than in the Runestone course, but these students have an advantage in that they actually meet face-to-face at least once since all American students come to Uppsala for one week early in the project and some come back for a week towards the end.

Assessment is, as in Runestone, based on a combination of individual and team achievements in a range of areas. The grading is in this case only on a pass/fail scale. Below is a list of aspects assessed in the course.

Reflecting: Evaluating the ability to reflect on one's own contribution and that of the team. Writing reflections is a powerful tool when it comes to both scaffolding the students and for the teacher to follow "where" the students are. This is a method that suits a constructivist view of learning in that it gives the students an opportunity to contemplate issues from new perspectives. This is augmented by scaffolding the students regarding how to reflect beyond the mere descriptive form. Reflection assignments have also been used to highlight crucial aspects in the course, e.g. to consider how to act in order to avoid difficulties with cultural differences in the international collaboration on an individual basis.

Reflections are also important as a means to help the students cope with unusual educational settings, such as open-ended group projects, and learning goals different from the traditional knowledge oriented[15]. The importance of the latter has been apparent in the final reflection assignment, where it is obvious in the individual meeting that some students have learned much without quite realizing it.

Learning Contract: Evaluating the ability to identify and follow a learning contract regarding which professional competencies to develop during the course. The learning contract consists of three parts, the first is to describe in their own words the three chosen of the nine presented. The second is to describe how to develop these competencies in the course and the third, and most difficult, is to describe how they and the teachers can assess that development has occurred.

Intercultural competence is one of the professional competencies the students can chose from and it is also one of the more commonly chosen. This is also one where we see a clear improvement during the course[4,3].

Collaborative Writing: evaluating the ability to contribute to a joint report both in terms of one's own writing and helping others contribute. The constructive controversy concept mentioned in the next issue has been one way to address how to collaborate in writing a joint report, where the idea is to help the students bring up joint issues in a way that reaches all in the cohort.

Another form of scaffolding and also a mechanism for assessing the individual students is a three stage writing assignment. The first stage is for each student to produce text for the joint report including a description of where it will fit in the report. The second stage is to provide feedback to a fellow student

according to some guidelines on how to give constructive feedback. The last stage is to reflect on the value of the feedback. The last stage has been a joy to read for us as teachers, since the students in general showed a very mature and nuanced attitude in their reflections, e.g.

> *"The way the reviewer provided the feedback was very easy to identify the points in which I should work upon, and as I mentioned in the beginning, his comments includes critical thoughts that I make great use of."*[6]

Teamwork Including Communication Skills: evaluating the ability to function in an intercultural team and to present and receive information both in writing and orally. This is the main part of the assessment and it includes evaluating the final report produced by the student cohort. The students are encouraged to work on their own, but we do provide guidance for each sub-group that is formed. This guidance is a means for us to be able to assess the students and to detect if there are any not participating.

The students are in many cases not accustomed to this form of education and we have seen that providing some scaffolding is important. Constructive controversy[12] is one way of providing scaffolding[8]. The controversy part is important in providing alternative ways of thinking about an issue and to anchor it in the minds of the students. The constructive phase is the part that makes this concept important in an educational setting such as this, since it helps the group (team) to find a common view. This is closely related to the process of forming a community of practice (CoP)[13], which is a way to see individuals and identify those that seem to be peripheral. To see these students and either help them move towards the center of CoP or find a way to leave the project at an early stage is essential.

3. The Student Perspective

The student perspective can be captured at various times and in various forms. It is not uncommon for us to receive comments from students long after the courses have ended where the students convey insights about the respective courses. These comments often stem from the students feeling awkward about having been critical to the value of the course while it ran and especially in the course evaluation. Examples of comments are:

> *"It was really frustrating when the client changed his mind about what we should do and how this was dealt with in the course. This influenced what I thought about the course in a negative way, but now when I work on my master thesis I realize that I am much better prepared for the interaction with the environment in which this work is carried out."*

> *"Um, I really think I should apologise for the awful course evaluation I gave you, I currently work developing flight management systems with people from many other countries. Now I realise how important the "Runestone" course was! I benefit from that experience every day.ll"*

> *"It was frustrating to see that the groups without international students made more technical progress, but I would not have swapped with them. I learned skills that I believe will be of high value in the future."*

Both courses give the students freedom regarding how they approach the problem and do not have any "right" answer, which is very much the case in global engineering. This is something the students are ill-prepared for and indicate that the progression chain regarding developing competencies valuable for engineers working in a global environment. Comments that illustrate how ingrained students are regarding engineering as a discipline where engineers come up with "the answer" to a problem through the use of technology are similar these:

> *"We didn't believe you really meant that we should come up with how to design the project ourselves. We thought that you would step in and tell us how to do this."*

> *"Can you tell us how we should have worked on this project?"*

One approach we have used to deal with the students unfamiliarity with open-ended problems augmented with working together with students from other cultures have been to be very explicit about the pedagogy and the importance of own involvement and taking decisions early in the course.

The connection to the Runestone course is often stated in the IT in Society course when the students are asked to present themselves ….

> *"We had real problems with the international collaboration in the Runestone course and I want to make use of what I learned in this project."*

An interesting comment from a leader in the capstone project in year five at the final presentation was that he believed that his competence to act as a leader for a group of fifteen students from several different cultures during the full time semester long project had to a substantial amount been due to his experiences in the Runestone and the IT in Society courses. The setting was quite different, but he said that he felt better equipped and had greater confidence regarding dealing with issues coming up, especially having a greater awareness of culture being a source for frustration. He also believed that he could see opportunities stemming from having a diverse work force due to the earlier courses.

4. Conclusions

Designing curricula to develop and assess the spectrum of skills required for engineering practice in the 21st century presents many challenges. In this paper we describe a curriculum intervention that we have refined over the last decade to help students to develop these skills during their engineering studies at university. The initiative and collaborations upon which it is based require maintenance, but have shown themselves to be sustainable despite changes in the teaching staff and constellation of participating institutions.

Our analysis of the student's experience draws on material from reflection exercises included in both courses. This analysis highlights some of the challenges that a shift in student learning culture towards increased focus on global workplace skills entails. In particular that it is important to provide students with an opportunity to develop and hone their skills over time. Student reflections in the second course often refer to their experiences in the prior course, and this seems to provide them with both motivation to test new approaches, as well as increased confidence in their ability to deal with these types of challenges.

Overall we have found the approach to be an enriching one for both staff and students, and recommend that similar initiatives be taken in other engineering programmes to prepare graduates for an increasingly global working future.

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