From Competent Student to Confident Engineer: Redesigning Engineering Education in Response to Economic and Social Change

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Abstract
In this paper we discuss the concept of key competencies that have to be fostered during engineering studies. We describe the didactic challenge linked to teaching these competencies. We then present the design of a module at Lucerne School of Engineering and Architecture allowing students to develop and deepen such key competencies.

Keywords: curriculum development, engineering education, Bologna Declaration

1. INTRODUCTION

In Europe numerous engineering curricula are being redesigned to comply with the Bologna Declaration. The Bologna descriptors provide the basis for the European reform processes. Research into the needs of industry, its satisfaction with graduates and the experience of alumni themselves prompted the Lucerne School of Engineering and Architecture (HTA Lucerne) to go a step beyond 'Bologna'. Specific competencies were identified which our graduates should possess to face the challenges of an increasingly international marketplace requiring self-confident team players, who are both knowledgeable engineers and skilled communicators.
Swiss students enter our Universities of Applied Sciences after having served an apprenticeship, which affords them the knowledge and skills needed in a trade. During their apprenticeships apprentices are generally closely guided. For these young people studying means not only enlarging their knowledge base but also changing their mind-set and developing their personalities. It entails not only learning to direct and reflect on their own work, but also deepening their understanding of society, opening their eyes to foreign cultures – beyond geographical and professional borders – and developing concepts of their prospective and potential roles and responsibilities.
Towards these ends, relevant key competencies must be identified. Didactic methods must be defined that foster the development of these competencies in students. These methods must then be integrated into the new curricula, i.e. incorporated in complementary and progressive modules. In this paper we present our approach to fostering relevant competencies during Bachelor studies in engineering.
This paper is organized as follows: In section 2 we present the competencies of future engineers as defined by the HTA Lucerne. Section 3 points out the didactic challenges that must be faced to obtain the required competencies. In section 4 we present one first-year module which promotes acquisition of some of the relevant key competencies. Section 5 summarizes the paper.

2. FROM COMPETENT STUDENT TO CONFIDENT ENGINEER

Most students entering a Swiss University of Applied Sciences have successfully finished a four-year apprenticeship and possess a Federal Certificate of Proficiency in their profession. Parallel to that they have attended vocational school and additionally prepared for the

professional baccalaureate either with a technical or economic focus. Some students have acquired a general university entrance diploma and additionally completed a one-year internship in industries in a field related to their future studies. Their practical experience constitutes an unconditional entrance requirement to Swiss Universities of Applied Sciences. Thus, all our students have a well established base of professional knowledge and practice.
One main pillar of studies at a Swiss University of Applied Sciences is the enlargement and the deepening of the technical knowledge of students. Our institution, the Lucerne School of Engineering and Architecture, commits itself to providing a strong and solid base of relevant engineering knowledge to all our students. We strongly believe that this is fundamental to educating future engineers. But this knowledge is *not* sufficient for future engineers.
Economic and working conditions and technologies have changed considerably within the last decades and so have the job descriptions of engineers. An engineer of today no longer can adjourn to her office and concentrate on solving technical problems on her own. In today's world she works together with different people from different disciplines. She must be able to explain her findings to experts as well as to clients and decision makers. She must adjust to changing environments and situations and devise flexible solutions. Awareness of the impact of engineering products and processes not only in our daily lives but also on our natural environment and social structures has grown, leading the general public to hold engineers responsible for products and processes they develop.
University education must enable future engineers to meet the demands of industry, of an increasingly international marketplace and of society. To do so, it is necessary to (a) define relevant competencies and to (b) apply didactic methods which are suited to developing/strengthening these competencies.

We base our concept of key competencies on findings of a Swiss project conducted under the OECD program on education indicators (INES) over the period 1998-2002. The main conclusions are published in [1]. *Competences* are defined as the ability "to meet demands or carry out a task successfully". Competences "consist of both cognitive and non-cognitive dimensions." In [1] it is further stated that "competences are only observable in actual actions taken by individuals in particular situations."
Key competences are "important across multiple areas of life and […] contribute to an overall successful life and a well-functioning society. […] [T]he definition and selection of key competencies depends on what societies value. […] [B]asic principles of human rights, democratic values, and objectives associated with sustainable development constitute a common, normative basis for selecting key competencies. […] [C]oping with the manifold complex demands and challenges of modern life facing individuals and society as a whole calls for the development of critical thinking and a reflective and holistic approach of life."[1]
Under the program the following key competences have been defined:

1. "Acting autonomously
    a. ability to defend and assert one's rights, interests, responsibilities, limits, and needs
    b. ability to form and conduct life plans and personal projects
    c. ability to act within the big picture/the larger context
2. Using tools interactively
    a. ability to use language, symbols, and text interactively
    b. ability to use knowledge and information interactively
    c. ability to use (new) technology interactively
3. Functioning in socially heterogeneous groups
    a. ability to relate well to others
    b. ability to cooperate
    c. ability to manage and resolve conflicts." [1]

As stated above, these competencies are relevant in multiple areas of life. The degree of importance of single competencies depends on the specific characteristics of the context of individuals and groups. The required level of competence equally depends on the specific context.
Performing successfully as an engineer requires a medium to high level of competence in all competencies mentioned above.

The development of these competencies is a life-long process which starts in early childhood and is not concluded on acquisition of a university degree. In fact, education at university level marks a key period in defining and developing students' personalities. Concepts of appropriate professional conduct evolve in this period of life. For these reasons we have redesigned our curricula to incorporate not only engineering competencies but also key competencies.
Based on research into the needs of industry, their satisfaction with graduates and the experience of alumni themselves, the Lucerne School of Engineering and Architecture identified the following competencies to be integrated into our curricula: independence, ethical responsibility, flexibility, creativity, being a team-player, inter-connected thinking, communicative skills and the awareness of one's own strengths and limitations and those of one's discipline, contributing to multidisciplinary discussions and projects.

3. THE DIDACTIC CHALLENGE

Teaching is often understood as conveying knowledge from one person to another. Competencies are strongly linked to individual behavior and cannot be taught in a classical sense. Instead, students must have the chance to develop competencies themselves. The didactic challenge consists therefore in creating suitable settings in which to offer students such opportunities.
Constructivist approaches can be helpful to develop ideas but cannot be fully applied. According to the constructivist learning theory learning means re-constructing knowledge in the learner. The competencies the students have to learn need not only be linked to their knowledge but also to their behavior.
Consequently we must provide students the possibility to develop and strengthen key competencies in settings that allow them to gain experiences, to make their own decisions, to do some research, to work in a team and to cope with uncertainty. In short, students must have the chance to experiment: to act and to make mistakes.
Various didactic methods aiming to activate students have been developed, e.g. case studies, educational projects, and the Keller plan technique[1]. During the process of curriculum development we evaluated several didactic approaches with respect to their potential of developing and strengthening key competencies in students. Based on this evaluation, we decided to meet the didactic challenge by using a combination of problem based learning and project oriented education as presented in [2].

4. DEVELOPING COMPETENCIES WITHIN A FIRST-YEAR INTERDISCIPLINARY MODULE

One challenge in designing the modules is the tight time frame available as enough time must be reserved to enlarge the students' technical knowledge and foster their technical competencies. This is the reason why we have incorporated teaching methodologies which utilize technical topics or content as the trigger to develop both professional and other competencies. In our institution we have designed several modules to allow students to develop the competencies mentioned in section 2. In the first term all students attend a module which specifically aims at key competencies and where the technical content plays a subordinate role. The competencies addressed are equally relevant for the studying process; most have not been addressed sufficiently during apprenticeship and secondary school. The main objectives are to raise students' ability to study and to arouse their curiosity for engineering subjects.
This module among others is mainly based on the problem based learning as well as the project oriented method but also draws on other teaching methods/didactic concepts.

[1] The individualized instruction method "Keller Plan" has been defined in 1968. It is based on small units of written material and the concept of mastery learning. An experience report is available at: http://www.mcmaster.ca/cll/posped/pastissues/volume.1.no.1/the.keller.plan.htm.

4.1. The Methods

The first-term module is arranged around a students' project. This project is not an educational project in the classical sense. A field of enquiry is presented to the students, who then choose and define one problem within this field. The chosen problem is then investigated and a solution is proposed by the students. Thus the fundamental educational methods are *problem-based learning* and *project oriented learning*.

Inputs on the problem solving cycle, creative techniques, presentation techniques and time management are strewn in by professors using classical *lectures*. *Feedback cycles* and *discussion groups* support students in developing a solution to their problem.

4.2. The Setting

The fields of enquiry which are the subject of the module's projects are broad and relevant to multiple disciplines, e.g. the future of energy in Switzerland. Students form groups of 6 to 8 persons from different programs of study (ICT – Information & Communications Technologies, electrical engineering, mechanical engineering in the 'engineering' offering / architecture, civil engineering, HVAC&SE – Heating, Ventilations, Air-Conditioning & Sanitary Engineering in the 'building construction' offering). Each group formulates its own project. Professors and assistants help them to avoid unrealistically large projects. But the student groups themselves are responsible for defining *their* project.

Professors of the various disciplines involved (engineering, communication/languages and project management) present relevant inputs to the students and provide feedback to the project results related to their domain.

Assistants receive training to serve as *coaches* to the student groups. They have regular meetings with the groups and discuss current steps and results with the students. Discussing with coaches instead of the professors directly prompts students to take more responsibility for their own project and results.

4.3. The developed Competencies

A wide range of competencies are developed within this setting. We describe competencies using the terminology of [3]. In [3] competencies are divided into instrumental, interpersonal and systemic competencies.

Instrumental Competencies

Instrumental competencies include cognitive abilities, methodological capacities, technological and linguistic skills.[3] Students use different instrumental competencies during their project. They need to *analyze* and *understand* the field of enquiry to develop their own project idea. They must *communicate* within their group, i.e. they must be able to communicate with colleagues from other disciplines. Students also are required to report to their coaches and discuss current project ideas with them. Students need to *plan* their project and to *organize* their tasks. To define their own project and to find a solution, they must *retrieve* and *analyze* information from different sources. Furthermore, a successful project depends on *problem-solving* and *decision-making* competencies. A wide range of instrumental competencies is thus fostered through the project assignment.

Interpersonal Competencies

The students work on their project in a *multidisciplinary team*. Inherent in their work is the development of a wide array of competencies. They must become aware of, be willing to defend and assert their personal professional interests, strengths, limits and needs. They should develop an interest in and accept contributions and criticism from other persons and disciplines. They must learn to function in a heterogeneous group: cooperating, assuming responsibilities, and managing and resolving conflicts. These competencies are continually assessed during the term.

Systemic Competencies
The projects allow students to apply their professional knowledge and to gain research skills in *finding solutions* to the problem they defined. *Creativity* is required in *developing new ideas*. During the project, students *acquire new knowledge* and *apply* it. As problem-based learning in multidisciplinary teams will be new to our students, they have to *adapt to new situations.*

4.4. The Structure

The module is a 6 ECTS module (requiring 180 hours total student workload) and takes place during one whole day a week. Vital to the didactic design is the fact that the entire first week of the term is completely reserved for this module. This week is devoted to forming the groups, introducing the field of enquiry and providing short inputs on presentation and research techniques. Much time is allotted to the groups, who define their student projects with the support of their coaches. At the end of the week each group presents a rough outline of their project to the other groups and the professors, who give a first feedback to ensure that the scope and aims of the projects are reasonable.
From the second week onwards students meet once a week. On this day key-note lectures and lessons are given by the different professors. The remaining time is reserved for the project work, about 130 hours per student in the course of the term. At least once every two weeks the coach assists the student group.

4.5. The Challenge

Whether the desired competencies can be developed within the described module depends on the balance found between guiding students and letting them learn from their own experiences. If students are too closely guided, they are deprived of the possibilities to assume responsibility in the project process and to make their own decisions. Though group dynamics play a subordinate role, allowing group dynamics to work is prerequisite to developing the capability of working in a team. On the other hand, if students are poorly supervised, the defined projects risk being too ambitious, possibly leading to frustration or even resignation in the event of serious problems with the project or in the team.
To find the right balance we decided to offer two different forms of guidance. The *professors* take care that the topics are properly defined and that the students are aware of the milestones of their project. They provide in-depth feedback at the end of the project and can be contacted in the event of serious problems with the project or the team. Assistants are trained to take the role of *coaches*. They

- ensure their groups adhere to the milestones
- supervise without getting involved in the actual group work
- help clarify questions without answering them themselves and
- help the students reflect on their own cognitive processes, group interaction, and work methods.

In short, the students cannot just pass decision making or responsibilities to the coaches.

4.6. Sequel Modules

One single module can only constitute the first step in fostering the required key competencies. Therefore a second module has been determined as a follow-up module. Project management and oral and written communication issues are discussed more systematically and reflected with respect to the experiences made in the first term. Thereafter, from the second year of studies on, students use the technical knowledge and key competencies acquired in tackling further learning projects in multidisciplinary teams. In the third year two project modules are held allowing students to work in industrial projects.
By this approach we offer students many possibilities to strengthen their key competencies and to apply them in different settings within different projects related to their fields of study.

5. CONCLUSION

The Lucerne School of Engineering and Architecture seized the opportunity afforded by the Bologna Declaration to reflect on the strengths and weaknesses of its curricula, on the changing demands of industry and needs of society. Acknowledging the importance of key competencies for future engineers, our institution has developed a new concept which integrates the promotion of engineering knowledge along with key competencies. By implementing the problem based learning and project oriented learning approaches, our modules allow our students to develop and strengthen their key competencies while expanding their technical knowledge. We believe that by

- relying and building on our (Swiss) students' sound technical knowledge and practical professional experience,
- sparking their curiosity in their own and neighboring fields,
- holding them responsible for and enabling them to reflect on their own learning processes and outcomes,
- supporting them in communicating and working effectively in multidisciplinary groups,
- confronting them with and enabling them to cope with challenging interdisciplinary projects,

we will succeed in developing our students' key competencies along with their engineering expertise,
Our competent students will graduate as confident engineers.

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