A Case Study of a Microsystems MSc Curriculum

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Abstract

This paper tries to define the contents of master's programmes in Nanotechnology or Nanoengineering. This emerging technology holds large promises for industrial innovation and we need to prepare graduates properly as they will be confronted for most of their future careers with these new developments. The nano-world is a multidisciplinary world and the shortest way to a bad curriculum is filling it with a conglomerate of subjects from all disciplines. We should look for a philosophy and try to integrate disciplinary knowledge. Some of these questions are discussed and an implementation for a master's programme under the umbrella of Electrical Engineering is presented.

Introduction

As microsystems and nanotechnology become ever more important in industry and society, the need for highly educated and highly skilled young people grows. Industrial innovation in highly industrialised countries is becoming a condition for survival since more high technology development and production tends to spread globally involving regions hitherto merely involved in manufacturing and assembly. Micro- and nano-engineering are one of these innovations. Micro- and nanotechnology are new and disruptive technologies and are very multidisciplinary in nature. As a result, the demands for new employees in these areas are different from the classical disciplines and ask for a targeted approach towards education. It may be not sufficient to start with a traditional curriculum in physics or electrical engineering and add a few optional courses. The education builds on a broad but cohesive basis that crosses several traditional disciplines, has adequate scientific depth and teaches integration and the ability to communicate and co-operate with experts from various disciplines. It is important to distinguish between *science* and *engineering* in these newly developing areas. Issues that need to be addressed through the curriculum as a whole include:

- Scientific depth versus scientific width and multidisciplinary approach;
- Science versus systems engineering;
- Co-operation with (inter)national partners and industry.

At Twente University a master's track Microsystems and Microelectronics is defined under the umbrella of an Electrical Engineering MSc programme entirely devoted to nanoengineering. A separate MSc in Nanotechnology exists purely to prepare graduates for a research career in this area. The nanoengineering track prepares graduates for an engineering career: integrating the nanostructures into new functions and systems (for 'the market'). Graduates hence should be prepared for an industrial career fuelling innovation (and making business). These two perspectives are different and the challenge is to define that difference and reflect it in the curriculum. The master track in nanoengineering builds on a BSc in EE (or applied physics or equivalent) so fundamentals of electronics, signal analysis, dynamic systems etc are present.

The master phase is strongly coupled to the research strengths in Twente. We believe that value and attractiveness for students can only be achieved in a combination with research strengths. Furthermore, the relevant and often expensive facilities are only locally available in these areas. In Twente and for the broader environment of Electrical Engineering, the relevant areas are micro/nanotechnology, telematics and information technology, biomedical engineering, embedded systems and mechatronics. The Twente BSc curriculum offers a mix of a major program with one or more minors, allowing the student to mix between relevant technological areas or adding skills in, for instance, business management.

Multidisciplinary aspects

The basis of the MSc curriculum for the track nanoengineering (or Microsystems and Microelectronics as it officially called, since nano*systems* is still some distance away) is formed by 3 courses: Technology, Material Science and System on Chip design. These three compulsory courses should be set up as courses for *nanoengineering* in a broad sense and not as an addition of top-down IC-technology and bottom-up self assembly or semiconductor physics with on top some optical material science. Here the integration should take place where a coherent nanoengineering perspective is given. At present there are no books that describe these areas from that perspective, but there is a wealth of literature on the separate subjects (IC-technology, optical technology, magnetic, MEMS, bioMEMS etc). In technology this means that apart

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from different types of deposition techniques attention must be given to top-down (lithography), bottom-up (self assembly), substrates, interfaces, and characterisation. In material science it should be X-tal structure, semiconducting, magnetic, optical and mechanical properties, interfaces, and quantummechanics in relation to these. The design 'course' should focus on present day design flows for integrated systems allowing for traditional electronics and possibly optical, magnetic and MEMS integration of functions. After these courses the traditional disciplinary technology and material science courses can be elected. Then multidisciplinary integration is achieved for one part through practical tasks and research assignments, in the areas of

- IC-design
- semiconductor components and reliability
- systems and materials for information storage
- integrated optical systems
- micromechanical systems
- lab-on-chip
- testing of microsystems

Especially in these practical assignments and research assignments, the co-operation with our research institutes is essential. For microsystems, this work is mostly focused within the national Nano-technology institute MESA+. Other areas are telecommunications networks (RF, optical devices) and biomedical systems (sensing, lab-on-chip, materials). Both depth, integration and width are thus hopefully addressed.

Science versus system engineering

Several dilemmas prevail: a focus on components (present emphasis in nanotechnology) means that solid physics/chemistry should be the background (and would require additional training for EE students). A focus on systems would connect well with EE (or any other engineering branch) but would not be innovative since not connected to new components. There is even a dilemma between a components or material orientation: physicists do research in many new phenomena which are hard to exploit in a system but still worth researching. We perceive our role strongly in the engineering domain: ultimately make money out of new devices…

An integrating force is given by the fact that the curriculum supports the knowledge chain from materials and technologies through devices up to systems. Not only the multidisciplinary width of such an approach, but also the multidisciplinary nature of devices and systems is a strong force in creating relevant cohesion within the curriculum. It is of paramount importance that through electrical engineering the systems-approach is leading. It is very tempting to investigate innumerable interesting effects in the nanoworld, but it is the challenge to focus on *exploitable* effects from an implementation aspect in a working and manufacturable system. This should not be a conservative approach and may well be a conditio sine qua non for further financing in the field.

An open issue is still whether system engineering itself should 'enhance' its paradigm. We are well versed in determinable systems with precise specs and functionality. In biological systems other architectures prevail with self correction and functions that defy mathematical description. In nanotechnology these systems might meet the classical systems. How can we prepare the future generation engineers for that? Coming developments will stimulate us to find answers when a clear pattern develops of the type of work our graduates will be doing.

International co-operation and co-operation with industry

Since a number of years, we offer international masters curricula to foreign students. There is a strong selective process for aspiring students. There is a cost-of-living scholarship program supporting this.

Furthermore, it is strongly encouraged for our students to plan one of their curricular projects or research assignments outside of the university, and favourably abroad. This will strongly increase a student's experience and self-esteem in our ever more international environment. It also supports the strong relations we have been building and are continuously improving with a large number of international partner institutions. In most research projects carried out at the university international partners are involved, enhancing this perspective.

With a multidisciplinary curriculum, a strong link with the industrial environment is important. We have a number of items in place that support this:

- We have a number of part-time professors that hold key positions in industry. Their influence on research and education is crucial in this regard.
- There is a cluster of (often spin-off) companies working closely together with our research institutes in all of the key research areas, leading to day-to-day communication.
- Within the curriculum, there is room for practical projects carried out under supervision of key industrial researchers, in many cases within the company.

The relation with the nanotechnology curriculum

Our university also runs a master program in nanotechnology, the core of which is located within the disciplines of Applied Physics and Chemical Engineering. This program also is very multidisciplinary in its approach and has a much less emphasis on system integration.. Since micro- and nanotechnology are strongly related subjects within our research groups and within the MESA+ institute, there is a relation between the two, despite the phase difference in the evolution of these two fields.

We regard microsystems as a strongly enabling technology for nanotechnology. Nanotechnology integrates chemistry and physics along with biomolecular science. Many of the current system concepts and analysis tools in nanotechnology are a mix of microsystems and nanotechnological elements. For the future, we expect an increasing mutual influence of these technologies. In the long term the concept of 'system' as we see it in engineering as a deterministic entity with clear specifications and behaviour, may evolve to less deterministic systems in life science with architectures build on self repair and self organisation. Since research on systems and technologies is combined within MESA+, and with a number of chairs supporting both curricula with various classes, we are in an excellent position to make full use of the relation between the fields of microsystems and nanotechnology within our curricula.