LEARNING NANOTECHNOLOGY, BUSINESS AND COMMUNICATION BY ENVISIONING FUTURE PRODUCTS

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ABSTRACT

Optional interdisciplinary study modules were offered by the Faculty of Business, ICT and Chemical Engineering. The module “Nanotechnology - Future Prospects and Business Opportunities” was co-taught by teachers with different areas of expertise (nanotechnology, business, and English-language communication) by providing a design-implement experience. The aim was to broaden the students' views, develop their interpersonal and communication skills, emphasize the versatile skills needed in product development, and coach the students towards an entrepreneurial mindset. The module was conducted in interdisciplinary groups in English. Second-year chemical engineering, information technology and business students participated. The first week was used to produce and then group wild ideas for future products, applications or services based on nanomaterials. Based on the 10 most interesting themes, groups were formed for the rest of the module duration. After this brainstorming, activities concentrated on conceiving the future and potential new products. The design of envisaged products and business ideas was continued by gathering information while using business and innovation tools and practicing effective communication. During the final 2-3 weeks, the envisaged product and business ideas were described. Each week consisted of a Monday take-off session followed by independent and group work during the week and a work breakdown session on the Friday. In addition to tasks and group reports, the students individually reflected on their progress. Additional information was gathered by collecting feedback and by self- and peer evaluation. The students envisaged 10 future nanomaterial-based products with customer profiles and business models. Initially, many groups experienced collaboration difficulties which were, however, rapidly resolved. The feedback confirmed that most aims were achieved. While the students emphasized improvement in communication and collaboration skills, they also reported learning about business, nanotechnology, and social media and innovation tools. The word “interesting” was a common indicator of a mindset shift towards interdisciplinary team work.

KEYWORDS

Innovation process, design-implement, self-steering, group work, integrated learning, entrepreneurial mindset, standards: 2, 4, 5, 7, 8, 11.

INTRODUCTION

Innovation pedagogy (Lehto et al., 2011), developed in Turku University of Applied Sciences (TUAS), has been chosen as a strategic learning approach for all educational programs at the university. Innovation pedagogy and CDIO share many similarities and common goals (Penttilä et al., 2014) and the Faculty of Business, ICT and Chemical Engineering at TUAS has decided on CDIO as the educational framework and as the implementation method of innovation pedagogy for all students of the faculty. Most of the students of the Faculty attend BEng programs (Information and Communications Technology and Chemical and Materials Engineering), but the same principles of CDIO are also applied in the other programs, e.g., Business, International Business, Business Information Technology, and Library and Information Services. The different disciplines are also utilized in design-implement experiences by forming interdisciplinary student groups in different study modules. Nanotechnology - Future Prospects and Business Opportunities (15 ECTS) is one of the new study modules in the Faculty of Business, ICT and Chemical Engineering, where the interdisciplinarity and internationality of the module are expected to broaden the students' views and to provide the kind of versatile skills they will need in their future working life. Nanotechnology is as such an enabling and a horizontal technology and thus by nature also interdisciplinary. Consequently, it also has potential to give rise to wild ideas for new products and services. The business aspect of the study module comprised innovation and product development skills and the study module was designed with the intention of fostering the learning of nanotechnology, innovation, business and product development knowledge simultaneously with personal and interpersonal skills.

CDIO as an educational framework (CDIO) and studies on other pedagogic methods including practical tasks relevant to the real world (Savage et al., 2011) emphasize the improvement of personal and interpersonal skills and product, process, and system building skills, as well as disciplinary knowledge, and importantly, also the increased motivation of engineering students in higher education. However, achieving an increase in motivation while encouraging the students to adopt a mindset in favor of entrepreneurship is more complicated. Although it has been suggested that entrepreneurial skills and mindset develop during the course of entrepreneurship-related project-oriented, practical tasks, it is difficult to increase the motivation of students to accept the risk-taking and uncertainty in business (Beránek, 2015). The most common experiential learning method in entrepreneurship education has been the development of business plans, which has, however, also been criticized because it focuses on the execution of ideas and not so much on the conceptualization and development of good ideas (Wheadon & Duval-Couetil, 2014). Li et al. (2014) have developed a so-called CIE-CDIO cultivation mode by adding a creation, innovation and entrepreneurship (CIE) aspect into CDIO-based education. During the conceive step of CDIO, the students were provided lectures on creation, innovation and entrepreneurship, corresponding to the creation step of CIE. During the design-implement experiences, the students were provided integrated innovative design capacity training, and during the operation step of CDIO, the students created a business plan. It was shown that the students' creative consciousness and innovative ability improved and enthusiasm for entrepreneurship was stimulated. Jansen et al. (2015) have developed a more versatile approach, the Three Stage Student Entrepreneurship Encouragement Model (SEEM), which includes three specific steps: educate, stimulate and incubate. The goal of the education step is to awake potential entrepreneurs (e.g., by highlighting role models and success stories), the stimulation step supports the students in the transition from an idea towards a complete business plan (e.g., by providing tools for idea evaluation and pitching possibilities), and the incubation step nurtures startup operations (e.g., by providing networking opportunities, business plan competitions, incubator services and mentoring). They concluded that by using this kind of model, universities may effectively encourage entrepreneurship among students.

The aim of this study was to determine whether a strongly inter- and multidisciplinary approach manages to broaden the views of the students, develop their interpersonal and communication skills, emphasize the need of versatile skills when developing new products, and steer the students towards an entrepreneurial mindset. Another aim was to study whether the design of envisaged future products and services provides some new aspects for design-implement experiences. The implementation framework of the study module was a product development funnel such as are commonly used in product development (Wheelwright & Clark, 1992). It visualizes the work flow and advancements through the various phases of the product development process. The framework consisted of four steps, idea creation, concept development, product development, and product management. The product development funnel and its relation to conceive-design-implement-operate are illustrated in Figure 1. Instead of lectures, creative problem-solving tools and instructions for information retrieval and reading circles were provided to foster creativity, information sharing and collaboration. The students were encouraged to take risks and constantly iterate ideas and concepts to enable the use of new information in the creation of new combinations and product concepts. The business model canvas (Osterwalder & Pigneur, 2010), instead of business planning, was used for fast prototyping and visualization of different business logics. Communication skills improvement was integrated into the study module using a model (illustrated in Figure 2) developed by Nonaka & Takeuchi (1995), emphasizing active integration of communication.

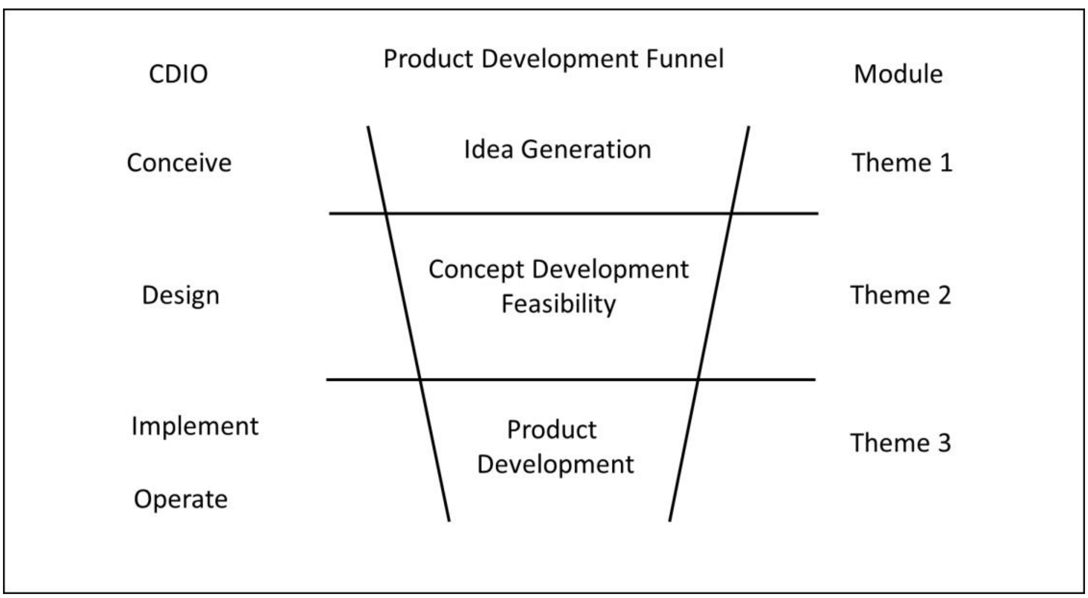

Figure 1. The study module framework.

MODULE STRUCTURE AND IMPLEMENTATION

An inherently horizontal and multidisciplinary field of technology, nanotechnology constitutes an excellent context for striving for the interpersonal learning outcomes specified in CDIO Standard 2. Thus, in the present case, the entire module was conducted in interdisciplinary student groups whereby each one of the 10 groups consisted of 5 to 7 members. The groups were formed based on the students' initially expressed interest in different subject areas such that each group had both information technology and chemical engineering students as members, and one group also had one business student as member. The aim of this composition of the working groups was to emphasize the need of versatile skills and a multidisciplinary approach when developing new products, and the students' teamwork skills were to benefit from working in groups. Background material was provided and some of the week tasks intentionally requested the students to reflect on their group work skills. The working language of the module was English. Not only were all meetings with the instructors conducted in English; 8 out of 10 groups had one or more members whose native language was other than Finnish and consequently, the working language of these groups was English both naturally and out of necessity. The non-Finnish speakers were all students in the English-language degree programme in information technology at TUAS.

The total duration of the module was 9 weeks. The module content was divided into three themes, each processed for three weeks (see Table 1). The weekly timetable was organised in a consistent manner such that each week started with a 2-hour take-off session with the instructors on Monday morning, and on Fridays, the week's work was pulled together with all students and all or, on a few occasions, at least two of the instructors present. On the Monday, a basis was constructed and instructions were provided for the week's work which was then mainly conducted in groups although during some weeks, there were intermediate meetings with the instructors. Background lectures on nanotechnology were provided at the beginning of each theme, including the basics of nanotechnology, applications of nanotechnology, and success stories, i.e., description of SMEs with new and innovative products based on nanotechnology. In particular, halfway through the module, the business teacher met twice with each work group to discuss their specific project, and the English language & communication teacher met each group once over Skype for Business to practise using the program and to check on the group's progress. As a general guideline, the groups were instructed to plan and set a goal for their week's work after the take-off session on Monday, to dedicate Tuesday and Wednesday to information retrieval, reading and week-specific tasks, and to hold a reading circle and compile their group report on Thursday.

The reporting system built into the module comprised both weekly individual reports in the form of a learning diary, and weekly group reports. Some background material was provided by the teachers each week, and students were instructed to find material in line with their specific project topic. In the individual diaries, reflection on given week-specific topics was expected, and in the group reports, the groups were to account for how they had arranged their group work that week, what materials they had shared, and what learning outcomes there were. The use of the RefWorks online research management and writing tool, licensed by TUAS, was expected and encouraged. A special interim report task was scheduled for the groups at the end of each 3-week theme. The first interim task comprised producing a business model canvas and personas for customer analysis (van Dijk et. al, 2010). As the second interim task, the students conducted a Skype for Business meeting (pitching their ideas), inviting the teachers as participants. The final interim task consisted of creating a poster on the group's 2050 nanotech product or service concept and presenting it during a poster exhibition.

All tasks assigned during the module were specifically designed with the intention of fostering the learning of disciplinary knowledge simultaneously with personal and interpersonal skills as well as product, process, and system building skills in the spirit of CDIO Standard 7. Active learning methods (Standard 8) were applied, emphasising the engagement of students in manipulating, applying, analyzing, and evaluating ideas. Such methods included small-group discussions, learning cafés, feedback from students about what they were learning, and simulations of professional engineering practice, for which purpose the Skype for Business tool, among others, was used. In addition, a number of other web-based or social media tools were used to enhance communication and to increase motivation. These included the terminology tool Quizlet and the virtual bulletin board Padlet. The use of various tools, such as the 3-12-3 Brainstorm method and the 4Cs for information-splicing (Gray et al., 2010), mind maps, business model canvases (Osterwalder & Pigneur, 2010) and stakeholder analyses (Mendelow, 1991) was encouraged for creative problem-solving in concept development. The Business Model Canvas is a dynamic development tool to convert business ideas into concepts and products. Unlike a business plan, it offers a way to experiment and prototype different business models in a tangible and structured way with its nine building blogs. Visualization helps the designer to communicate different scenarios and share his/her understanding of a business within the team and to other stakeholders.

Table 1. The structure of the study module.

Theme	Objectives	Tools introduced
1:Wild Ideas	• finding application area of interest • bonding with the like-minded & having wild ideas • understanding horizontal nature of nanotechnology • improving brainstorming & information retrieval skills	• Brainstorming tools • Ideation techniques • Personas • Business Model Canvas • Quizlet for nanotech terms • RefWorks
2: Getting a Grip of Nano	• understanding what nanomaterials are, what nanotechnology is, what services & products are available and how they are based on nanotechnology • understanding the innovation process • being able to communicate this understanding to others and to participate successfully in an innovation process; selling ideas	• NABC method for pitching • 4Cs customer needs tool • Skype for Business • Padlet walls
3: Nano, Inno, Anno 2050	• application of knowledge of nanomaterials and nanotechnology to generate feasible and viable service and product ideas / prototypes • concept development & understanding the next steps • convincing communication skills to ensure fluent progress of the development process	• Stakeholder analysis

The students were instructed to give an elevator pitch, a short and concise sales presentation of a business idea which, when delivered using NABC value proposition and convincing presentation techniques, creates interest and with a neat closing, persuades the interlocutor to ask about the next steps (Carlson & Wilmot, 2006). It answers important questions: who is the customer and the important customer, what the market need is, how the problem is solved, what the benefit per cost for the customer is, and why the solution is superior to the competition.

Theme-based Implementation

Within a CDIO context, it is important to provide students with opportunities to develop their personal and professional skills along with subject knowledge. In engineering education, the teaching and learning of communication and foreign language skills is commonly arranged either by teaching engineering content in the target language, whereby the focus is on the content and not on the language, or by offering the students separate language and communication courses. There is, however, evidence that neither practice is optimal from the language skills learning point of view. According to Ament et al. (2015), for instance, an integrated content and language approach is more effective than a solely content-based English-medium instruction model for university level content courses, if linguistic gains are the desired outcomes of the programme. Yau et al. (2011), on the other hand, describe the twinning of a core chemical engineering module with a teamwork & communication module, taught by separate faculties. While students are reported as having benefitted from the twinning initiative, several issues and challenges related to the general arrangement are mentioned, particularly with regard to timetable and administration. "Nanotechnology - Future Prospects and Business Opportunities" was designed to develop the students' language and communication skills not only by using English as the medium but by explicitly focusing on said skills parallel with the technological and business content. Ida Klasén (2011) aptly describes this approach with her model of communication aspects in engineering education where the two main principles 'learning to communicate' and 'communicating to learn' are combined with an integration dimension which ranges from passive to active (see Figure 2).

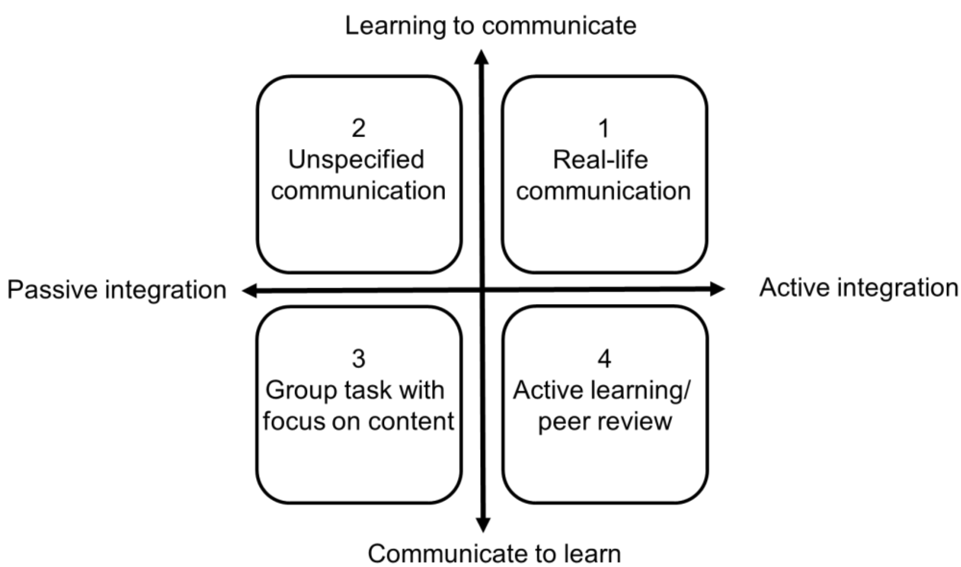

Figure 2. Communication aspects in engineering education (adapted from Klasén, 2011; originally by Nonaka & Takeuchi, 1995).

For the students, one of the three teachers being an English language and communication teacher was presumably as such a reminder that these skills were to be worked on while studying field-related content. Examples of activities designed as described by the four blocks in Figure 2 are provided below.

- Block 1, Learning to communicate with an active integration approach, "Real-life communication". This approach means that students develop their skills when using subject content in an environment or situation natural for an engineer in his or her occupation. The students were, for instance, asked to conduct an online meeting to pitch their futuristic nanotech-related concept to a financing board.
- Block 2, Learning to communicate with a passive integration approach. An example here would be the weekly tasks where the students were asked to watch a video or read an article and discuss it in their diaries but where no specific form was required of the discussion.

- Block 3, Communicating to learn with a passive integration approach. The idea here is that the students learn to communicate by working on the subject content. Examples include group discussions, brainstorming sessions and reading background material.
- Block 4, Communicating to learn with an active integration approach. An example would be the students writing real-time content questions on Padlet bulleting boards while their peers were giving talks or presentations.

DATA COLLECTION AND METHOD FOR EVALUATION OF LEARNING OUTCOMES

The aims of the study were based on the learning outcomes defined for the module and the fulfilment of the aims was studied by analyzing the module feedback, self-evaluation and peer evaluation forms, follow-up discussions, weekly reports (both oral and written) and poster content and their presentation. In addition, the students separately described the innovation process learning by answering specific questions (typical phases of an innovation process, effect of innovation process on learning, use of innovation tools, visualization of ideas, concepts and solutions, and the clusters and partnerships needed for envisaged products). The poster and its presentation in a separate poster session constituted the final report. The goal was a convincing (both from the viewpoint of technology, business, innovation and communication) poster presentation on a nanotechnology-based product that could be reality in 2050. Thus, a variety of assessment methods was exploited for learning assessment in compliance with CDIO Standard 11. The main source of data for evaluation of learning consisted of the module feedback form (2/3 of the students that participated actively in the module filled the module feedback form) and the posters. The collected feedback data was analyzed by qualitative content analysis. i.e., by identifying and categorizing the core consistencies and meanings.

The learning outcomes of the study module:

- The students are able to describe how nanotechnology will change manufacturing, materials, products and services in the future.
- The students are able to assess business opportunities related to nanotechnology and nanomaterials.
- The students are able to communicate more effectively in different business situations and with actors from different fields.

There were three questions in the study module feedback form:

1. What did you learn? Think of, e.g., nanomaterials, business models, English language and communication skills, social media and innovation tools (e.g., Skype for Business, Quizlet, Padlet; business model canvas, personas).
2. Comment on the way the course is implemented.
3. Any other comments you would like to make?

The self-evaluation form also included a comment window, where several students made comments about the group work, its dynamics and team spirit. Continuous self-reflection in the weekly reports (both in individual learning diaries and group reports) and separate analysis of the innovation process learning provided some additional data about the learning and group work. The poster and presentations in the poster exhibition showed whether the group was able to produce a convincing poster, and to present it in a convincing manner.

RESULTS & DISCUSSION

The group work resulted in visions for 10 future nanomaterial-based products with analyzed customer profiles and business models, presented in a poster exhibition at the end of the study module. Many product visions combined electronics, software and biotechnology or chemistry, and one of the common topics was clean technology, especially clean energy, which shows that the students were interested in environmental and ethical issues related to future products, services and solutions. This may depend on several factors. Environmental issues, cleantech, resource efficiency and circular economy are common topics in today's media, but the students were also provided material where environmental and ethical issues were emphasized in innovations and in the planning of new products (e.g., reverse innovation, i.e., innovations likely to be used first in the developing world) and some of the international students in the groups were from countries of low electrification rate where new solutions are often based on solar energy. Regardless of the reason, in planning, the students took into account social responsibility in accordance with CDIO Standard 7. The content of the posters also showed development in the business ideas during the study module. The brainstorming and the first ideas of the student groups followed the "quality equals quantity" principle, but clear development was seen halfway through the study module (during follow-up discussions and in pitching), and finally, clearly more solid, crystallised and feasible concepts were presented in the posters at the end of the study module. However, determination of customer needs (in 2050) and the use of personas remained difficult throughout the study module. This was expected because most of the students were engineering students, focusing on technology, but some change in mindset was observed towards the end of the study module.

The study module feedback confirmed that most of the aims were achieved and learning outcomes fulfilled. The students emphasized that their communication, English language and collaboration skills improved, but they also reported learning about business, innovation process, nanotechnology, and social media and innovation tools. In their group reports, several groups mentioned having taken the aim of improving their English seriously to the extent that they spoke English even when the non-Finnish speaking group member was not present. The improved collaboration & group work skills were mentioned only in 14 % of the feedback forms, the other skills were all mentioned in at least 55% of the feedback forms. Some students emphasized in their comments that they had difficulties with collaboration within the group, but most groups overcame it fast. Some students requested more guidance (both from the viewpoint of disciplinary background, information retrieval and support for collaboration within the group), which is common in any project-based learning, which requires self-discovery and self-steering. The participants were second year students and the module started already in beginning of the autumn semester and most of the students had experienced earlier only one corresponding shorter course, the introduction to engineering according to CDIO standard 4. In other words, they do not yet have many design-implement experiences and corresponding and many of them still think that the lecture-based teaching is better. Some of the problems in the group work were related to different cultures, but in general the comments reflected the common agony of some students when changing the mindset towards self-steering, and consequently all students in the group did not always do their share in time. However, criticism is also a sign of development, and this was also verified by some of the groups that described difficulties in the beginning and better group work towards the end of the module.

Some of the students criticized the lack of lectures, especially regarding nanotechnology. Four introductory lectures were provided on nanotechnology, two of them during Theme 1 and one at the beginning of Theme 2 and 3, respectively (to support an entrepreneurial mindset, one focused on SMEs with new, promising products based on nanomaterials). In addition, during the lectures, the students wrote questions on Padlet walls, which were then commented on and discussed during a later lecture. To support learning, nanotech-related links and review articles were provided and the groups complemented their nanotechnology knowledge by information retrieval. The results were presented both in written form and orally as part of the weekly reporting, and the students received feedback for their reports. In spite of the provided materials and regular feedback, the nanotech information retrieval and reporting were found difficult, but another reason for criticism was the same as in the case of group work; some students had difficulties with self-steering and consequently in group working, and they did not do their share in information retrieval and reporting in time. To overcome this, the study module implementation could be developed to include several brief "coaching sessions" with the groups to support self-steering, group work and information retrieval.

The implementation of the module contained even other parts affecting the entrepreneurial mindset. The students were faced with uncertain conditions (e.g., in oral reporting on Fridays), where they had to rapidly complement technological and business aspects of their product idea. It has been suggested that the successful future strategist will exhibit an ability to rapidly sense, act, and mobilize, even under uncertain conditions. The ability to master complexity is crucial in the contemporary business environment. According to entrepreneurs such as Schwab and Branson, it is critical to use skills such as thinking in pictures, employing analogies, and synthetizing information relative to the aims (Haynie et al., 2010).

CONCLUSIONS

In conclusion, fruitful ground was provided by the pedagogical approach for an integrated learning experience where the learning of disciplinary knowledge and communication skills were simultaneously fostered (CDIO Standard 7). Most of the aims were achieved.

- The group work resulted in visions for 10 future nanomaterial-based products with analyzed customer profiles and business models. The initial wild ideas had developed into more solid, crystallised and feasible concepts by the end of the study module.
- The students showed interest in social responsibility in the planning of future products and their communication and collaboration skills improved while they also learned about business, nanotechnology, and social media and innovation tools. Thus, a design-implement experience (Standard 5) can also be applied to envisaged products.
- The word "interesting" (and similar) was a common indicator of a change in mindset towards interdisciplinary team work, a prerequisite for an entrepreneurial mindset.

However, to improve the design-implement experience of the study module in the future, more short meetings, "coaching sessions", will be held with the groups to support the group work and self-steering of the students, i.e., to help students to trust themselves and to better tolerate uncertainty, which also are prerequisites for the entrepreneurial mindset.

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