INTEGRATING INNOVATION PEDAGOGY AND THE CDIO APPROACH – TOWARDS BETTER ENGINEERING EDUCATION

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ABSTRACT

The relationship between innovation pedagogy and CDIO (Conceive – Design – Implement – Operate) raises many questions. Are there common elements, or do these approaches conflict, or can they be integrated somehow? In this paper we discuss similarities and differences between innovation pedagogy and CDIO and how these approaches are interconnected. The objective of innovation pedagogy, developed at Turku University of Applied Sciences (TUAS), is to provide the students with innovation competences in order to enable them to participate in innovation processes in their future working places and develop them. In working life, different types of knowledge is needed in innovation creation and innovative solutions are created through collaboration of people with different backgrounds. Both CDIO and innovation pedagogy are developed and implemented in close co-operation with businesses and industries in order to answer to this challenge. At TUAS, the integration of the innovation pedagogy approach and the CDIO approach aims to provide diverse social and multidisciplinary learning environments and thus enhance the development of innovation competences. The research on integration opportunities of innovation pedagogy and the CDIO approach is described through CDIO standards in order to explore the similarities and differences in both initiatives.

The outcome of our discussion is that the CDIO approach and the innovation pedagogy approach can be integrated. They face similar challenges and share very parallel goals and objectives, and thus their integration can help engineering education to develop to the needed direction. The findings and the value of this paper extend the concept of knowledge in the learning context to support the development of innovation competences by integrating the CDIO approach and the innovation pedagogical approach.

KEYWORDS

Innovation pedagogy, engineering education, learning outcomes, innovation competences, integration, Standards: 1–12

INTRODUCTION

Clark (1998) writes that enterprising universities are those that actively seek to move away from close governmental regulation and sector standardization. An entrepreneurial university

seeks to innovate how it operates and functions in its business (Clark 1998). Both the CDIO (Conceive – Design – Implement – Operate) approach and Innovation Pedagogy provide tools and framework to make that shift and differentiate in the higher education markets. In addition, successful universities will always seek to improve their performance in teaching and research (Shattock 2010). This continuous improvement is one of the key points both in CDIO and Innovation Pedagogy too.

The report of the Confederation of Finnish Industries (2011) emphasizes the transformation of society towards an information society where the capacity to work for new and improved solutions becomes crucial. Education has to promote creativity and adopt methods from working life: experimenting with others without the fear of making a mistake will be encouraged. Future education has to focus on skills in addition to knowledge and working in groups. Furthermore, versatile learning methods prepare students for the changing working life. The CDIO approach and Innovation Pedagogy both focus on these relevant and important issues in education. Since certain similarities exist it is interesting to discuss how these approaches or frameworks can be integrated. In our earlier research, it has been discussed from the pedagogical viewpoint (Penttilä & al. 2013) and from the communicational viewpoint (Penttilä & Kontio 2014) how the CDIO approach is interconnected with innovation pedagogy. The aim of this paper is to ensure wider understanding of the implementation, opportunities and challenges of the integration of these approaches for engineering education.

INNOVATION PEDAGOGY – THEORETICAL FOUNDATIONS

The core idea of innovation pedagogy is to bridge the gap between the educational context and working life. Learning and teaching processes are to be developed so that they provide improved competences for the students and enable personal and professional growth. Learning is deeper when previously gained knowledge is continuously applied to practical contexts. Creating new services, products and organizational or social innovations – new added value – requires both knowledge and skills, which are applied to an innovation process. (Kairisto-Mertanen et al. 2012; Gibbons et al. 1994; Kairisto-Mertanen, Penttilä & Putkonen 2010; Nonaka & Takeuchi 1995; Nowothy & Gibbons 2001; Nowothy & Gibbons 2003.) The approach can also be extremely useful when rethinking learning environments, which according to innovation pedagogy are social and multidisciplinary (Kairisto-Mertanen, Penttilä & Putkonen 2011). A learning environment is most frequently understood as the physical or virtual surroundings meant and built for learning purposes. In innovation pedagogy the social aspects of working and learning are emphasized and group processes where learning happens in multidisciplinary teams form an essential part of the whole process of learning. A social learning environment is formed by people with different talents and competences and by the interaction enabling collaborative learning. Equally, also the tasks in working life often require knowledge and skills which do not belong to the scope of a single discipline. (Penttilä & Kairisto-Mertanen 2011; Watts et al. 2012; Penttilä & Putkonen 2013.)

The core of innovation pedagogy lies in emphasizing interactive dialogue between the educational organization and students as well as the surrounding working life and society. Accordingly, its conceptual core can be divided, as Figure 1 describes, into three different spheres in parallel to the three major actor groups benefiting from innovation pedagogy (Penttilä et al. 2011):
• final learning outcomes, creation of innovations and produced capability to participate in diverse innovation processes – having primarily to do with students, who are expected to create innovations while affiliating with working life

• learning of innovation competences alongside with study programme specific knowledge, skills and attitudes – being mostly connected with working life, which provides students with ideal surroundings to acquire the competences needed in innovation processes and in future working life in general

• meta-innovations – referring to the necessary cornerstones needed for learning according to innovation pedagogy; the elements enabling innovation pedagogy to be applied, including methods of learning and teaching utilized in the learning processes by the faculty members together with the students, enhancing both the creation of innovations and innovation competences.

Metainnovations are essential requirements for innovation pedagogy to succeed, as they enable the emergence of the so-called cornerstones of innovation pedagogy in any learning environment. These cornerstones include innovative learning and teaching methods, cross-disciplinary learning environment/boundary crossing, integrated and extensive research and development activities, flexible curricula, versatile and development-oriented assessment and concentration of acknowledging the importance of entrepreneurship and service production as well as internationalization in the level of research, development and student engagement. Metainnovations contribute especially to the development of students' interpersonal and networking competences.
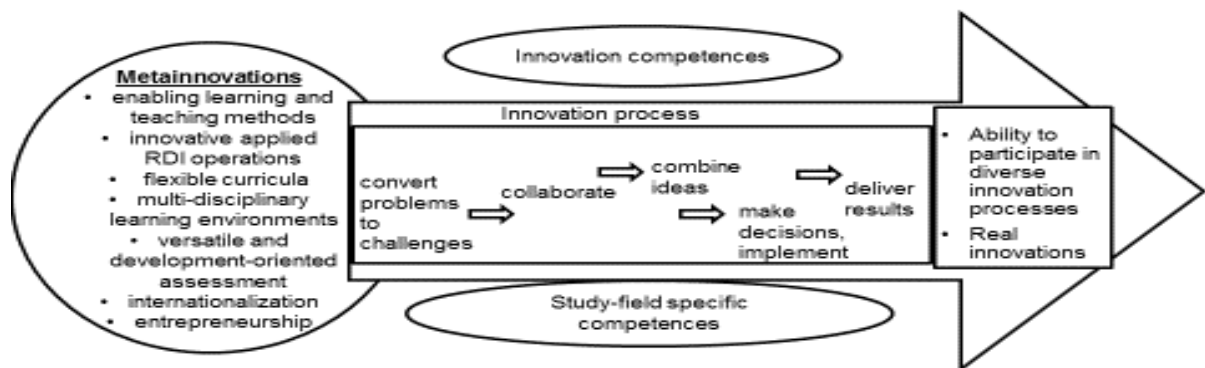

Figure 1. Methods, objectives and learning outcomes according to innovation pedagogy

Innovation competences are learning outcomes that refer to knowledge, skills and attitudes needed for the innovation activities to be successful. The innovation competences drawn up at TUAS follow the European Qualifications Framework and comprise three levels: individual, interpersonal and networking innovation competences. The individual level includes creative problem solving, goal orientation, and systems thinking; the interpersonal level focuses on the abilities to work and co-operate in teams, and the networking level covers the abilities to create, maintain and develop networks in a multidisciplinary and multicultural environment as well as to communicate and interact in an international environment. Innovation competences are learned gradually as new information is added to our knowledge structures. Innovation competences are developed together with study-field specific competences in such a learning

environment which is as close to an innovation process; students work with authentic problems in multidisciplinary teams, combine ideas, make decisions, implement, evaluate and deliver results. (Räsänen 2014; Kairisto-Mertanen, Penttilä & Lappalainen 2012; Kairisto-Mertanen, Penttilä & Nuotio 2011; Kairisto-Mertanen et al. 2012)

CDIO APPROACH – KEY ELEMENTS

The CDIO approach is a worldwide collaborative network of developing engineering education. The CDIO collaboration network is based on a commonly shared premise that engineering graduates should be able to Conceive – Design – Implement – Operate complex value-added engineering systems in a modern team-based engineering environment to create systems and products (Crawley et al. 2014). The CDIO approach has three goals:
- Educate students to master a deeper working knowledge of the technical fundamentals
- Educate engineers to lead in the creation and operation of new products and systems
- Educate future researchers to understand the importance and strategic value of their work.

The CDIO approach provides a numbers of resources that individual programmes can adapt and implement to meet these goals. The two key elements of the CDIO approach are: CDIO standards and CDIO Syllabus. The CDIO standards describe 12 principles to effective education and practice. The basic principle is that the authentic context of engineering education is the conceiving-designing-implementing-operating of products, processes and systems. Knowledge and skills are learned in a cultural surrounding and environment that contributes to understanding (Crawley et al. 2011). The CDIO Standards define the distinguishing features of a CDIO programme. They guide and support educational programme reform and evaluation, and provide a framework for continuous improvement. The standards aim at improved learning results, students learning more and students having a better experience at their HEIs. (Brodeur 2010)

The other key element and effective practice of the CDIO approach – the CDIO syllabus – answers to the challenge that a programme should have set "Specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders". The general objective of the CDIO Syllabus is to describe a set of knowledge, skills and attitudes desired in a future generation of young engineers. It offers rational, complete, universal and generalizable goals for undergraduate engineering education. The syllabus organizes learning outcomes in four high-level categories:
- technical knowledge and reasoning,
- personal and professional skills and attributes,
- interpersonal skills: teamwork and communication
- conceiving, designing, implementing and operating systems in the enterprise, societal and environmental context.

The CDIO syllabus reflects the requirements of modern working life and is constantly under observation. The latest additions based on the working life expectations have been dealing with engineering leadership and entrepreneurship. An extension of the CDIO Syllabus for Leadership and Entrepreneurship has been added, providing competence areas such as innovation, managing a project, business plan development and the innovation systems.

The CDIO approach is not a quality assurance toolkit, but it certainly provides procedures to support quality enhancement (Georsson, Bennedsen, Kontio, 2015). Based on the CDIO

standard 12 CDIO programmes should evaluate their performance against all 12 standards and identify their development needs and areas of education that need to be focused on (Kontio et al. 2012). This procedure is called CDIO self-evaluation and for continuous improvement purposes, the self-evaluation should be repeated on regular basis. For example, at Turku University of Applied Sciences there are programmes that have used CDIO self-evaluation several times over the years (Kontio, 2012).

Finally, the fundamental principle of CDIO is that it is adaptable to all engineering schools. Actually, the basic ideas of the CDIO approach could offer a starting point for a definition of a new approach in other fields of education too, presuming that the most engineering specific parts are adapted to the field in question. Anyway, most of the CDIO standards are quite adaptable in any field of education as such.

RESEARCH DESIGN AND FINDINGS

Turku University of Applied Sciences (TUAS) was reconstructed in 2004 so that multidisciplinary faculties were established. The aim of the new structure was to facilitate cooperation between different disciplines. The new faculties provided natural working environments with several possibilities for crossing borders and this way supporting innovative initials among students and faculty members equally. The empirical evidence of applying innovation pedagogy and the CDIO approach has been collected during the last ten years at TUAS, and especially in its two largest faculties, the Faculty of Technology, Environment and Business (TEB) and the Faculty of Business, ICT and Chemical Engineering, both multidisciplinary, having engineering education as their biggest field of study (Stenroos-Vuorio 2012). When examining the results of the multidisciplinary organizational structure it can be seen that the volume of research, development and innovations has increased. The empirical evidence from TUAS supports that the creation of knowledge-intensive, multidisciplinary organizations in the universities boosts innovation activities. Knowledge sharing prevents the formulation of closed knowledge pools and especially supports innovation creation. (Kettunen 2009)

The research on integration opportunities of innovation pedagogy and the CDIO approach is carried out so that innovation pedagogy is described through the CDIO standards in order to explore the similarities and differences in both initiatives. The shared language provides opportunities for deeper integration in educational development.

Standard 1. Innovation pedagogy as context
Innovation pedagogy is considered the *context* for all education in that it is the cultural framework, or environment, in which knowledge, skills and attitudes are taught, practiced and learned. The principle is *adopted* by the education when there is explicit agreement of the university or the faculty to initiate innovation pedagogy, a plan to transition to it, and support from the management to sustain reform initiatives.

Standard 2. Innovation pedagogy syllabus outcomes
The knowledge, skills, and attitudes intended as a result of education, *i.e.,* the *learning outcomes*, also called learning objectives, detail what students should know and be able to do at the conclusion of their studies. In addition to learning outcomes for study field specific (e.g. technical disciplinary in engineering studies) competences, innovation pedagogy specifies learning outcomes as innovation competences, divided in individual, interpersonal, and networking competences. The *individual level* includes independent thinking and decision-

making, target-oriented and tenacious actions, creative problem-solving and development of working methods as well as self-assessment and development of one's own skills and learning methods. The *interpersonal level* focuses on the abilities to co-operate in a diversified team or working community, to take the initiative and to work responsibly according to the targets of the community, to work in research and development projects by applying and combining knowledge and methods of different fields, to work along the principles of ethics and social responsibility as well as to work in interactive communication situations. Finally, the *networking level* covers the abilities to create and maintain working connections, to work in networks, to co-operate in a multidisciplinary and multicultural environment as well as to communicate and interact in an international environment. They are consistent with educational objectives' goals and validated by stakeholders, i.e. primarily working life.

Standard 3. Integrated and flexible curriculum
A curriculum according to innovation pedagogy is *integrated and flexible*. An integrated curriculum includes learning experiences that lead to the acquisition of individual, interpersonal, and networking competences (Standard 2)*,* integrated with the learning of study-field specific competences. An explicit plan identifies in CDIO the ways in which the integration of CDIO skills and multidisciplinary connections are to be made; in innovation pedagogy the competences are also integrated, i.e. innovation competences are mapped to study field competences and co-curricular activities that make up the curriculum (e.g. tutoring and personal study plans). However, a very explicit and detailed curriculum is not an objective, because the curriculum has to flexible, providing the students with more opportunities to tailor their own professional paths, and answering better to the needs of the constantly changing working life.

Standard 4. Introduction to innovation pedagogy
The 4th CDIO standard emphasizes the need for an introduction to engineering course providing a framework for the practice of engineering. The course includes personal and interpersonal knowledge, skills, and attitudes and prepares students for more advanced product and system building experiences. In innovation pedagogy, a specific introductory course is not typical, but all studies, from the very beginning, aim to provide the students with a broad understanding of needs and expectations of the current and future working life, emphasizing the development of innovation competences in the context of all studies. Therefore the first study units often aim to enhance e.g. team-working in multidisciplinary teams, an entrepreneurial attitude and project working skills, interconnected also with study field specific competences.

Standard 5. Constructivist approach to studies
The 5th CDIO standard denotes a range of central engineering activities considered basic or advanced in terms of their scope, complexity, and sequence. Innovation pedagogy, being targeted for all educational areas and aiming to develop students' generic innovation competences in every study field, diverges from CDIO approach here, not focusing on one study field such as engineering, business or design. However, learning experiences are also considered as basic or advanced in innovation pedagogy in terms of their scope, complexity, and sequence in the studies. For example, simpler tasks and learning experiences are included earlier in the studies, while more complex applications appear in later studies designed to help students integrate knowledge and skills acquired in preceding study units and learning activities.

Standard 6. Innovative learning environments

The CDIO standards highlight the physical learning environment in order to support the learning of disciplinary knowledge, and in addition practical hands-on learning is emphasized in physical workspaces. The physical learning environment is crucial in innovation pedagogy as well, making active learning methods possible by providing opportunities for practical applications and real problem-solving in authentic environments. The CDIO approach mentions also *social learning*, that is, settings where students can learn from each other and interact with several groups. This is emphasized in innovation pedagogy even further; the social learning environment forms the essential element for all learning.

In businesses and organizations, the way of working includes that problems are solved and innovations are created in groups and networks, and there usually are people from many different fields and disciplines who are expected to work effectively together. Equally also the tasks at work often require knowledge and skills which do not belong to the scope of one discipline only. Innovative solutions are created through social learning in diverse surroundings and therefore the social learning environment and boundary crossing/ multidisciplinarity play a key role in workspace solutions according to innovation pedagogy (Penttilä & Kairisto-Mertanen 2012).

Standard 7. Integrated learning experiences
Learning experiences in innovation pedagogy are equally integrated. The curriculum and learning outcomes can be realized only if there are corresponding pedagogical approaches that make dual use of students' learning time. With integrated learning experiences, the students are better prepared to meet the demands of their future profession.

Standard 8. Active learning
Both innovation pedagogy and the CDIO approach emphasize active learning methods, which engage students directly in thinking and problem solving activities. There is less emphasis on passive transmission of information, and more on engaging students in manipulating, applying, analyzing, and evaluating ideas. Active learning is considered *experiential* when students take on roles that simulate professional practice, for example, projects, simulations, and case studies. Innovation pedagogy goes some steps further, including also tacit knowledge and intuition as important in contexts relating to a concrete innovation process (Penttilä & Putkonen 2013). In addition, active learning according to innovation pedagogy includes also the earlier mentioned collaborative learning, where different actors are able to work together in dialogue, in such a manner that their own expertise can be efficiently shared and combined in novel ways, resulting in something more than the sum of its parts.

Standard 9 and 10. Enhancement of faculty competence
The CDIO approach supports the faculty members to improve their own competence in the personal, interpersonal, and product and system building skills, as well as their teaching skills. Innovation pedagogy was originally developed for universities of applied sciences, where it is a prerequisite that the teaching staff has, in addition to the university degree on the teaching field, also a university degree from the field of education (= teacher's education), and third, at least three years' work experience from the teaching field. Thus, deep understanding of teaching and learning has always been the basis for innovation pedagogy. As CDIO, innovation pedagogy encourages the teaching staff for continuous improvement of their own competence. According to innovation pedagogy, learning is a shared process; it's not only the students who learn, but also their teachers and tutors as well as other stakeholders such as businesses and other organizations participating in the learning processes.

Standard 11. Assessment according to innovation pedagogy

The CDIO approach and innovation pedagogy share a parallel goal in assessment; effective learning assessment uses a variety of methods matched appropriately to learning outcomes that address not only study field specific competences but innovation competences as well. In innovation pedagogy there are special challenges for assessment; in the assessment of innovation competencies, the emphasis is more on performance-oriented competences and lies on interpersonal and networking innovation competencies. This sets special demands especially on the number and timing of assessment, assessment criteria and assessment methods. For this purpose, the INCODE barometer, which can be used in self, peer and tutor assessment of behaviour and its development, has been developed in the co-operation between European partner universities (e.g. Watts et al. 2013).

Standard 12. Evaluation of innovation pedagogy
Both in CDIO and innovation pedagogy, the feedback forms the basis of decisions about the programme and its plans for continuous improvement. A key function of evaluation is to determine the effectiveness and efficiency in reaching the intended goals. Evidence collected during the evaluation process also serves as the basis of continuous programme improvement. Moreover, many external evaluators and accreditation bodies require regular and consistent evaluation.

Above, we have described innovation pedagogy through the CDIO standards in order to show the similarities and differences in both initiatives. Our conclusion is that innovation pedagogy can be easily be described using the 'same language' by using the CDIO standards. The findings can be summed up and presented in a similar format as the CDIO standards (Figure 2).

Innovation Pedagogy Standards – Best practices

1. Innovation Pedagogy as Context
Adoption of the principle that Innovation pedagogy is considered the context for all education

2. Innovation Pedagogy Syllabus Outcomes
In addition to learning outcomes for study field specific competences, innovation pedagogy specifies learning outcomes as innovation competences, divided in individual, interpersonal, and networking competences. They are consistent with educational objectives' goals and validated by working life

3. Integrated and Flexible Curriculum
Curriculum that leads to the acquisition of innovation competences integrated with the learning of study-field specific competences, in a flexible way to allow the student to formulate his/her own professional path according to dynamic working life needs.

4. Introduction to Innovation Pedagogy
that provides the students with broad understanding of needs and expectations of the current and future working life

5. Constructivist approach to studies
The learning experiences are considered as basic or advanced in innovation pedagogy in terms of their scope, complexity, and sequence in the studies'; learners are guided to utilize and process their previous experiences while helping them cumulate new ones via diverse learning environments

6. Innovative Learning Environments Innovative solutions are created through social learning in diverse surroundings and therefore the social learning environment and boundary crossing/ multidisciplinarity play a key role in workspace solutions according to innovation pedagogy.

7. Integrated Learning Experiences
The curriculum and learning outcomes can be realized only if there are corresponding pedagogical approaches that make dual use of students' learning time.

8. Active Learning
Teaching and learning based on active and often experiential learning methods

9.-10. Enhancement of Faculty Competences
Actions that enhance university staff competences in study field specific competences as well as in teaching and learning competences providing integrated learning experiences

11. Assessment according to Innovation Pedagogy
Effective learning assessment uses a variety of methods matched appropriately to learning outcomes that address not only study field specific competences but innovation competences as well.

12. Evaluation of Innovation Pedagogy
The feedback forms the basis of for continuous improvement; a system that provides feedback to students, university, and other stakeholders including working life, for the purposes of continuous improvement

Figure 2. Innovation pedagogy standards

CONCLUSIONS AND FINAL REMARKS

In all, both innovation pedagogy and the CDIO approach face very similar challenges and share parallel goals and objectives. Our conclusion is that innovation pedagogy and the CDIO approach can easily be integrated. Innovation pedagogy is a strategic approach, representing a philosophy that permeates through the entire organization, and is visible in all activities. Innovation pedagogy offers a name to the development of students' competences, enabling them to participate in the processes of creating innovations.

The CDIO approach has a clear focus on engineering education whereas innovation pedagogy tries to bear in mind the broader needs of the entire economy and focuses on producing valid competencies for the future society where special emphasis is put on innovation creation. Innovation pedagogy can be applied to all the disciplines and to all education be it in the university at any programme, but also to other levels of education e.g. to secondary education where the basis for the students' understanding of learning is created. The CDIO syllabus goes to a deep level of detail while defining the necessary competences, but it is good to remember that the CDIO syllabus is also a reference list and all of the features are not meant to be followed in detail. Innovation pedagogy focuses on providing the methods and tools to provide the three categories of innovation competencies: individual, interpersonal and networking innovation competences. Innovation pedagogy states that certain cornerstones or "meta-

innovations" are needed to succeed in this task, for example such as entrepreneurship and internationalization, which also are included in the CDIO syllabus in various parts. Internationalization is mentioned as communication skills in foreign languages, developing a global perspective and working in international organizations. Entrepreneurship is named in the enterprise and business context as well as in the new syllabus addition, engineering entrepreneurship. In all, innovation pedagogy can form an extensive pedagogical strategy for any educational institution providing both objectives and methods and tools in order to reach the desired learning outcomes leading to innovation creation. The integration of the CDIO approach and innovation pedagogy can provide the students with innovation competences in order enable them to participate in the innovation processes in their future working places and develop them. Innovative solutions are created through social learning (~collaborative learning) in diverse surroundings and emphasize the significance of boundary crossing in higher education and its ability to provide the different types of knowledge needed in innovation creation.

Additionally, our conclusion is that innovation pedagogy can be easily described using the 'same language' by using the CDIO standards. The shared language provides better opportunities for deeper integration in educational development. To sum up, on a practical level innovation pedagogy integrated with the CDIO approach means applying existing learning and teaching methods in a creative, value-increasing way. Simultaneously, new methods are developed and put into practice while ensuring that students take responsibility for their learning and that they actively pursue their learning objectives. As a result, graduating students have professional skills and qualifications that are both innovative and development-oriented. The findings of this paper suggest that integrating the CDIO approach and innovation pedagogical approach support the development of students' innovation competences. Innovation pedagogy strengthened with the CDIO approach moves further from traditional theoretical learning to the application of learned skills to practical development challenges. This aims to ensure improved learning processes and learning outcomes in addition to development actions in engineering education and higher education in general.

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BIOGRAPHICAL INFORMATION

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