Teaching innovation to engineer students: a proposal for an operational process model

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Published in:
Proceedings of the 47th SEFI Annual Conference

Publication date:
2019

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):

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TEACHING INNOVATION TO ENGINEER STUDENTS:
A PROPOSAL FOR AN OPERATIONAL PROCESS MODEL

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Conference Key Areas: New Complexity Quest in Engineering Sciences

Keywords: Innovation processes, managing complexity, process models, teaching innovation, boundary objects.

1 ABSTRACT

This paper addresses the future reality of engineer students, facing an accelerating uncertainty, ambiguity and interconnectedness. The dominant models for innovation process lectured at universities, e.g. CDIO (link 1), the Double Diamond (Council 2007), Design Thinking (Brown 2009) implicate a process with defined phases. Experience from practice indicates that the models do not prepare the students for the actual uncertainty and ambiguity. Moreover, the students confuse the concepts of Project and Process. The paper outlines a theoretical basis for an operational model resting on design theory (Jancke 2013, Lawson 2005, Schön 1983/2008), innovation theory (Darsø 2001), process theory (Hernes 2007), and project literature (Larson, Clifford 2014). A distinction between Process and Project is established, and the paper discusses a prominent understanding of the innovation process as divided in divergent and convergent phases, here named The DC Diamond Model. The concept of emergence, that is the becoming of something new, is identified as constituting for the Concept of Process. The paper proposes the Extended Diamond, integrating emergence, as the basis for an operational model for situated process analysis, design, and management of innovation processes. The proposal is the outcome of a participatory innovation process resting on 4 years teaching practice at bachelor level at the Technical University of Denmark (link 2). The framework VINCA is presented as a manifestation of the proposed model. Finally the paper draws perspectives to actual experiences from engineer education and proposes further development of the framework to reflect an Actor Network perspective (Latour 2005/2007)

2 INTRODUCTION

2.1 Context, background and rationale

In autumn 2013, while teaching innovation to engineers in the bachelor program “Process and Innovation” at the Technical University of Denmark, my fellow teachers and I realized that it can be difficult to communicate the difference between the concepts of Process and Project. The students find the Concept of Process problematic and intangible. Both processes and projects aim to carry out activities to make a change. The Concept of Project offers the idea that a defined objective can
be achieved through planning and control. Contrary to this, in literature about innovation (Darsø 2001, Lawson 2005) it is claimed that in a process neither problem nor outcome is known in advance. Furthermore, the quality of the outcome depends on the participant’s ability to avoid premature closure, that is, when participants decide on a problem definition early in a process (Keiding, Gish, 2018). This is not easy; students must endure uncertainty and ambiguity, which can cause frustrations. Students need methods which support a process-oriented practice. Scholars need means to communicate the Concept of Process to students. This made us ask how an operational framework should be, which helps the student and the practitioner to orientate themselves in a complex reality? (Keiding, Ulrich 2014, authors translation)

The question initiated an ongoing process. One outcome is the VINCA framework, a visual alphabet for innovation and learning processes, utilized in 2014 as learning material (figure 1). VINCA is explained later in this paper.

![Figure 1: An example of a learning design modelled with VINCA. The example shows an internal process outcome intended to be further processed in order to be communicated to third parties.](image)

VINCA has emerged in a practice oriented participatory design process (Simonsen, Robertsen 2012) Students, scholars, and external partners have participated. Innovation and process theory have informed the development as well as the author’s reflections on the experiments.

Students have used the VINCA concept on several courses in the period from 2014 to 2019 as a means for reflection on their own learning process and for their design of innovation processes.

3 THEORETICAL OUTLINE

3.1 Scope of the work

The aim of this paper is to outline a distinction between Process and Project, to present a theoretical basis for the innovation process, and on this basis propose VINCA as an operational model for innovation processes.

3.2 The concepts of Project and Process

In this paragraph the concepts of Project and Process and the relatedness between the two will be outlined.
3.2.1 Project

According to The Project Management Institute (PMI), a project is a temporary endeavor undertaken to create a unique product, service or result (link 3).

Larson and Grey (2014) point out five characteristics for projects:

1. An established objective
2. A defined life span with a beginning and an end
3. Usually, the involvement of several departments and professionals
4. Typically, doing something that has never been done before
5. Specific time, cost, and performance requirements (Larson, Grey, 2014)

3.2.2 Process

The Process perspective is widely accepted in innovation. Ikujiro Nonaka, influential Japanese organization theorist, constitutes innovation as “a process in which the organization creates and defines problems and then actively develops new knowledge to solve them” (Nonaka 1994).

The Concept of Process refers to the basic idea of philosophy that the world is moving and constantly changing. It relates closely to the concept of emergence that describes the becoming of something new. In a process, something is "constant in the making [and] the future is to be considered an open field" (Hernes, 2007). In a process perspective it requires an effort to stabilize and maintain an order, for example as a thing understood as a social construct (Storni 2012), a structure, a routine, or a narrative. Even when a result has materialized it will only be temporarily stable. This uncertainty is often referred to as “fuzziness” (Brown 2009, Sanders 2001), illustrated by Daimen Newmann with the ‘Squiggle Model’ (figure 2 (left), link 4).

![Figure 2: (left) "The Squiggle" (link 4). (Right) The Brick Model (Lawson 2005)](image)

3.2.3 Emergence

Design theory (Shôen, Jancke, Lawson and others) discusses the emergent nature of the Design Process.

Bryan Lawson, architect and psychologist, criticizes a linear perception of the design process and identifies three distinct kinds of activities: Analysis, synthesis, and evaluation. Lawson argues that you should neither expect the activities to take place in a given order, nor to be able to distinguish between them. The process as such is
a web of the tree kind of activities as illustrated with the Brick-model, (figure 2 (right)) and consistent with the “Squiggle Model” (figure 2 (left)).

According to Lawson the activities are wobbling around an axis with the problem and the solution as pivots. Over time, the understanding of the problem as well as the solution is refined and the pivotal points stabilizes. The Brick model illustrates a reflective practice (Schön 1983/2007) and Lawson refers directly to Schön who argues that the design process is not about problem solving. Rather the designer enters problematic situations associated with uncertainty, disorder and indeterminacy (Schön 1983/2007). According to Lawson, it’s more likely that problem and solution emerge together (Lawson, 2005).

3.3 A Matter of Concern

To initiate a process something problematic must be present (Schön 1983/2007, Lawson, 2005) and an intention must exist. According to Bruno Latour, co-originator of Actor Network Theory (ANT), processes of knowledge creation take place in chains of translations performed by actors. A matter of concern (Latour 2005/2007) is present in the origin. The outcome of a process emerges through numerous translations where the matter is temporarily articulated and stabilized as proposals and then re-translated. Figure 4 illustrates this in a two-dimensional model for hermeneutic innovation (Keiding, Lauritsen 2011). In the VDI model the matter of concern is represented as a unity of a question mark (?) and an exclamation mark (!). This is compliant with the Brick Model (figure 2 (right)) where the matter emerges as a unity of problem and solution. The stepwise emerging articulations of the matter (“?!”), numbered 1, 2, 3, 4, are shown at the lower part of the vertical axis.

Figure 3: The VDI model (Vision Driven Innovation) (Keiding & Lauritzen 2011)

In the VDI model the question mark represents the presence of something problematic and the exclamation mark represents the intended outcome. Since the outcome not is known in advance (Lawson) the intention should not be confused with an objective. Rather it has the character of a vision (Lerdahl 2004); an indented future state.
3.4 Projects and Processes are interrelated

One outset for this paper is that engineer students confuse projects and processes. Future engineers will work in organizational contexts where they will experience both. A modern organization is a project based environment where resources are allocated and managed to meet objectives. A lot of work is organized and named as projects. At the other hand, ambiguity and uncertainty are inherent parts of modern work life, not least because innovation and creativity are imperative. Many activities, like workshops, brief meetings, ongoing dialogue about matters, interaction with customers and activities related to management, have the characteristics of processes. Processes, whether they are short and simple or complex and ongoing, are embedded in projects and also often founded by projects. To deliver newness, projects depend on the emergence of the process.

3.5 Prominent models

Innovation processes are closely associated with design processes. Design Thinking (Brown 2009) is a widely spread example, and also The Double Diamond (Council 2007, figure 3 right) is rooted in design. In CDIO (link 1), a framework for engineer education applied at DTU and many other universities, the D stands for ‘Design’.

3.5.1 The Diverge - Converge Diamond

Authors to the innovation models Design Thinking and The Double Diamond describe creative practice and innovation processes as organized in divergent and convergent phases (Brown 2009, Council, 2007), illustrated as diamonds, hence the name Diverge – Converge Diamonds or in short DC Diamonds (figure 3 (left)). Divergence is about unfolding, expanding a space, creating choices, producing and explicating more of something, typically information, material or ideas. This refers to the analytic activities in Lawson’s brick model (figure 2 right). Convergence is reduction and decision-making and can be associated with the evaluation of a materialized outcome in the brick model (Lawson). The Double Diamond, mapped out by Design Council (Council 2007) is a four-phase innovations model where the innovation process is represented by two DC Diamonds, one following the other. See figure 3 (right).

![Diverge – Converge in Design Thinking](Brown 2009) (Right): “Double Diamond” (Council 2007)

Yet simple, both models are also abstract and generalized. The DC Diamond model serves mostly as a metaphor for the innovative mindset (Brown 2009). Double Diamond is based on empirical studies and introduces the idea that more diamonds
(and hereby sub-processes) can be combined and nested into more complex process visualizations.

### 3.5.2 The Extended Diamond

As mentioned above, the concept of emergence is a constituting factor for a process, but emergence is not explicitly included in the DC diamond models. With the words of design theorist Marcus Jancke, the aim of a divergent Process phase is not to create *options* but rather to create a *mess* of material or nodes, (Grey et.al. 2010) representing the actual matter of concern. Jancke uses the term *the necessary messiness* (Jancke 2013). *The newness* is a translation of the matter, and emerges as a new order and a new meaning recognized as a pattern in the mess. This refers to *synthesis* in the hermeneutic Brick Model (Lawson 2005, figure 2 (right))

There is compliance between hermeneutic innovation processes explicated for instance with the VDI or the Brick Model, and the diamond extended to a 3-phase model, where the phases are

- the divergent phase - compliant with *analysis*
- the emergent phase - compliant with *synthesis*
- the convergent phase - compliant with *evaluation*.

The idea that simple elements, like activities, can be combined or nested into more complex systems is supported by the Double Diamond but also well known from Gantt diagrams in project management. When visualized as combined and nested sub-processes, a high level of details and complexity can be represented.

### 3.6 Shared terms but different meanings

The Concepts of Project and Process share some terms and attributes, but their meaning are different. Some of the differences are summarized in table 1:

<table>
<thead>
<tr>
<th></th>
<th>Process</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intention</td>
<td>Someone wants something to change, wants to crack a wicked problem or to see a vision come true.</td>
<td>An objective is established</td>
</tr>
<tr>
<td>Initiation</td>
<td>A question is raised or a matter of concern is articulated</td>
<td>A management decision is made and time, cost and performance requirements are specified, and resources are allocated</td>
</tr>
<tr>
<td>Objective</td>
<td>Not known in advance but an intention (above) with the character of a question and/ or a vision is articulated</td>
<td>Benchmarks and deliveries has been decided</td>
</tr>
<tr>
<td>Ambiguity and uncertainty</td>
<td>Fundamental conditions for emergence, creativity and the</td>
<td>Risks that must be tamed and reduced</td>
</tr>
</tbody>
</table>
becoming of newness

| Outcome | The most actual articulation of a matter of concern, only temporarily stable | A solution, a delivery |

Table 1: Terms and attributes and their meanings in the context of Process and Project

4 THE VINCA FRAMEWORK – A PROPOSAL FOR AN OPERATIONAL MODEL

The following is a description of the VINCA framework: VINCA has the form of an alphabet built from 8 symbols, organized by a syntax. The concept is available for students as image-files and symbols printed at carton and magnetic foil.

VINCA is a model that encapsulates the constituting elements of the Concept of Process described above: The VINCA process icon (figure 5 (left)) shows the three phases of the extended diamond. The matter of concern is represented by the question mark on the left side of the icon and the exclamation mark on the right side. The 8 symbols can be nested and combined to build detailed representations of complex processes.

In the teaching material a process is explained as a web of interacting activities that lead to emergence: Something new is coming into being. A Process starts with a question or a problem. It is explorative, guided by a vision and controlled by feedback. Processes have ‘fuzzy’ goals. You do not know the outcome in advance, but you can specify which form it should have.

Processes have 3 phases:

- **The divergent phase** where the process opens and the participants gain a deeper understanding of the problem
- **The emergent phase** where the participants explore and do experiments
- **The convergent phase** where the process is closed and the results take a form that makes sense to others” (Keiding & Ulrich 2014, author’s translation).

The black brackets (figure 5, right) represent the project and indicates that a process will always take place in the context of a project (Keiding & Ulrich 2014, author’s translation).

The process icon is a container: Sub-processes and activities can be nested hierarchically inside. A process can be expanded and nested activities and other processes inside can be described and arranged. See figure 7. An activity (the green icon) is the lowest level hierarchically and cannot be further expanded. An activity has most of the attributes of a process, for instance is it constituted by a question
and an expected outcome. An activity will sometimes be guided by a method (the yellow icon) (figure 7, 8, 10).

Figure 7: Left: A process containing 3 activities. Right: A process is built from one activity guided by a method (the yellow square) and one not-expanded sub-process.

The sole elements can be arranged and the attributes can be described in a Power Point slide or similar document formats. The physical instances of the elements can also be used in a more casual manner as design material in a creative dialogue on a whiteboard (figure 1). In 2016, a group of IT-engineer students conceptualized a VINCA app. They treated VINCA as a programming language, analyzed the use of it and formulated the syntax shown in figure 8.

Figure 8: The VINCA syntax

Emergence is a primary distinction between the concepts of Process and Project. In VINCA the bubbles in the process icon represent emergence, but the phenomenon also has its own independent icon called reflection or pause (figure 9 (left)). In the teaching material it is described as an unscheduled activity that connects activities and processes and allows reflection. The Pause is a special activity whose explicit purpose is reflection, incubation or emergence in pure form” (Keiding & Ulrich 2014, author’s translation)

4.1 A generic model

VINCA claim to be a generic model for innovation processes in the sense that it can model other known models. Students can add details reflecting their actual process, and redesign known models or process designs to adapt to the actual context. Figure 9 (right) shows a visualization of The Double Diamond. Each of the four phases in the model is shown as independent processes. Consequently, each process can be expanded and students can decide and organize appropriate activities and methods to be nested inside.
5 APPLICATIONS

Since first introduced 2014, VINCA has been a mandatory element at the courses Innovation and Creativity (link 5) and Innovation and Knowledge Management (link 6). Students primarily use VINCA for process reflection (link 7, p66) and process-design.

5.1 Other Applications

VINCA has been applied for various purposes:

- For course planning in a learning context at DTU and other Danish universities
- In several Danish municipalities as a management tool for process analysis and as a collaborative planning tool
- To facilitate the initiation of several DTU innovation projects with external partners and to maintain the projects.

6 FINDINGS AND PERSPECTIVES

The aim of this paper is to propose an operational framework for an innovation process, not to conduct an in-depth analysis of the use of VINCA.

The effect on the innovation outcome and students’ learning are subjects of further research, which, initially, can make use of 4 years of documented processes and material submitted by students.

6.1 Feedback

The general feedback from students and fellow teachers indicates that VINCA makes the Concept of Process more tangible, offers a common frame of reference, and operationalizes the work with innovation processes. VINCA serves as a
boundary object (Star, Griesemer 1989) in the dialogue between actors at an innovation arena.

6.2 Future research
Feedback also indicates that some factors and some levels of complexity are not represented in VINCA in its actual form.

Most recently VINCA has been applied on the courses Innovation and Knowledge Management (link 6) and Innovation in an Organization Context in the 4th semester at the bachelor program Process and Innovation at DTU. The teaching is case-based, the learning philosophy is design-based and the courses share the same cases (Keiding, Gish 2017). Teams of students’ use hospital departments as cases and co-work with the management and the practitioners to analyze the context, identify a problem, and conduct innovation processes to solve it. Cases are acquired through the project CHI, Copenhagen Healthcare Innovation, a project that aims to create collaboration between the healthcare sector and universities (link 8).

A hospital is a highly complex arena and the innovations processes taking place in the arena are likewise complex. In the spring 2018 Actor Network Theory (ANT) was added to the curriculum to empower the students to capture the complex dynamic of a hospital department. This affected the student’s perception of the innovation process and added new layers to the needed process representation, namely the actors and the network. It made me ask how a process framework (like VINCA) can be further developed to empower the students and the practitioner to facilitate innovation in a complex and interconnected arena with many actors with opposing interests?

Another question to be taken in consideration origin from the interrelatedness between the concepts for Project and Process: How does VINCA differentiate form available flowchart tools? And further: How could the fuzziness and the ambiguity of the process be further operationalized to benefit the value creation of the innovation process?

6.3 Perspectives for the field of Engineering Education
A sense of emergency has been driving the development of the present work. A paradigm shift is taking place in engineering education. Future engineers face a reality of accelerating volatility, uncertainty, complexity, ambiguity and interconnectedness. Problems are no longer given and you cannot rely on a well-defined objective and a good plan. Engineers must be empowered to enter problematic situations (Schön 1983/2007) and to master the emergent process in arenas characterized by high complexity and many opposing interests. It is my hope that this work will support future engineers in this process.
7 REFERENCES


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8 LINKS
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Link 2: https://www.dtu.dk/uddannelsediplomingenior/proces-og-innovation/. Accessed 01052019
Link 3: https://www.pmi.org/. Accessed 01052019
Link 4: https://thedesignsquiggle.com/ Accessed 01052019
Link 5: Creativity and Innovation https://kurser.dtu.dk/course/6200/. Accessed 01052019
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