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From Invention to Innovation: Teaching Business Models to Manufacturing Researchers

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Abstract

The competence and skills required to bring technological advancements to the market are increasingly perceived as a key element in the engineering researchers' toolbox. Nevertheless, business modelling is rarely taught in technical engineering programs. This paper presents the design and implementation of a course called "Business Driven Production Development" for manufacturing PhD students at KTH Royal Institute of Technology in Stockholm, Sweden.

Introduction

When describing the *innovation process* as the successful *application* of an *invention,* a common assumption is that the role of engineers is one of mere inventors. Engineering work is perceived as a short-term oriented process that translates requirement specifications into new designs. Accordingly, most engineering programs include tools and methods that equip students to solve a clearly defined problem. Although partially valid, this conception must be expanded to account for the important role that engineers have in multidisciplinary research efforts that solve broader challenges such as sustainable development or system design.

This work considers the three possible application patterns of new technology in the domain of production technology: The first pattern is a *pull* mechanism based on current problems emerging in industrial environments. This mechanism is named "*invention loop*" as the focus of the researcher is on solving the given problem in order to improve an already existing application. The other two patterns are *push* mechanisms where the focal invention is addressing a specific industry challenge but without an immediate application on current shop floors. The difference between these two patterns lies in the way technology tackles

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the underlying challenge: When the invention is an improvement of existing practices, it is viable to refer to "*incremental innovation loops*". When, instead, the technological solution is completely different from current practices one refers to "*radical innovation loops*" (Ettlie, Bridges and O'keefe, 1984; Dewar and Dutton, 1986). Technical engineering programs are traditionally good at preparing learners for the invention and incremental innovation loop. However, they often fall short of providing a wider picture that can support future engineers in coming up with radical innovation.

Business Model (BM) knowledge is an important element here because it helps to describe and account for the multiple, non-technical elements connected to the application of a technology. As radical innovation usually offers higher potential benefit for industries, it becomes important for higher educational institutions in the technical field to address this educational requirement and provide graduate students with knowledge about the full spectrum how technical results can be applied. Among engineers, especially researchers are in need of such knowledge because agencies and companies that provide funds for research increasingly stress the importance of producing results that serve to tackle societal challenges rather than day to day problems.

In view of the above, the department of production engineering at KTH Royal Institute of Technology in Stockholm (KTH) has taken the initiative, back in 2015, to redesign an old educational unit from 2001 named *Business Driven Production Development*. This course, open to all doctoral students, is based on the modern embodiment of the concept of BM and its pivotal role in the innovation process. The aim of the course is to equip future engineers with the basic knowledge to understand the nature of technical research, and trigger reflection about positioning their interests and contributions accordingly.

Approach

The name of the new educational unit (or course), Business-driven production development, is inspired by *business-driven development:* a meta-methodology for developing IT solutions that directly satisfy business requirements. The principle in business-driven development is to adopt a model-driven approach that starts with business strategy, requirements, and goals to subsequently transform these requirements into IT solutions by aligning the business and IT layers. This allows the IT system to automatically follow the business evolution. This course aims at establishing Business driven production development (BDPD) as a systematic approach to aligning the business layer with the production layer. In the production context, this means designing and deploying manufacturing equipment and processes according to the requirements coming from relevant business areas and not only considering the traditional objective of delivering a functional product. As such, the manufacturing system becomes a strategic asset to pursue sustainable, long-term growth. In practice, this translates into designing a manufacturing strategy through the analysis of all the elements of a firm's BM and their influence on the production requirements. This is then synthetized in specific production solutions that match current and future needs of the firm's internal organization, market, network, and supply chain.

In order to fulfil this purpose the course has been developed using the Constructive Alignment approach (CA) (Biggs and Tang, 2011), around a set of three Intended Learning Outcomes (ILO). At the end of the course, the learners should be able to:

- ILO1. Position technological research activities in either the "invention loop", "incremental innovation loop" or "radical innovation loop" and highlight the character of engineering research as "technology push" or "application pull" effort.
- ILO2. Reflect on the complex nature of BMs and discuss the need to use the correct epistemological approach, positivism vs. interpretivism, for different components.
- ILO3. Reflect on a possible pattern to successful application of the given technology: design a BM that could support such a process by choosing one of the methods suggested in the course.

In Constructive Alignment the verbs suggested in the ILO are an important input to defining suitable Teaching and Learning Activities (TLA) and Assessment Tasks (AT). With reference to the well-known Blooms Taxonomy (Bloom *et al.*, 1956), we aligned ILO, TLA, and AT in the BDPD course. Table 1 summarizes the course design.

ILO	Teaching and Learning Activities	Assessment Task
1	• Lectures based on flipped classroom scheme, • Tutorial and example for the suggested tools, • Group discussions based on relevant literature suggested by the course coordinator and presented by the students.	• Formative: Presentation of one selected piece of literature (one for each student), • Personal essay positioning own work in relation to new knowledge.
2	• Lectures, • Group discussion based on relevant literature suggested by the course coordinator.	• Formative: Group work (whole class): Mind map of main concepts in BMs with indication of preferred research approach.
3	• Group discussion based on relevant literature suggested and presented by the students.	• Scientific paper, possibly to be submitted to a conference, regarding the applicability aspect of own research.

Table 1: Summary of BDPD Course design

The achievement of the ILOs requires students to work in two consecutive phases: (1) acquiring and consolidating specific domain knowledge, and (2) reflecting on the own work from this new perspective. Consequently, the course is structured in two parts: Part 1 provides the theoretical background. It aims at promoting a systematic thinking about BM design that "is of crucial importance to generate viable BMs for new technologies", as shown by experience in (Snihur, Lamine and Wright, 2018, page 9). Part 2 then features practical examples and self-reflection. This is a part where students are asked to construct their knowledge with guidance from the teacher and it is specifically designed for the field of manufacturing.

The following Table 2 summarizes the course's practical implementation:

Part 1 Duration: 2.5 months Reference ILO: ILO1	Total no. of meetings: 4, roughly one every third week. Duration of each meeting: 3 hours Content of the meetings: • Lectures • Student´s presentation of suggested literature (see table 1): also valid as formative assessment • Tutorial • Group discussion on literature Assessment: the positioning essay has two cycles of feedback, firstly done by peers and secondly by course leader
Part 2 Duration: 2.5 months Reference ILO: ILO2 and ILO3	Total no. of meetings: 6, roughly one every second week. Duration of each meeting: 3 hours Content of the meetings: • Lectures based on suggested literature • Group work: drawing of a mind map with main concepts in BMs and the related research approach; also valid as formative assessment • Student´s presentation of identified literature • Group discussion on literature Assessment: the scientific paper has two cycles of feedback, the first done jointly by the students' main supervisor and course leader and the second as a result of a submission to a relevant conference in the field.

Table 2: Summary of BDPD Course implementation

With reference to Part 1, there are 4 areas where the students are required to develop new knowledge for establishing BDPD:

1. Innovation as composed by invention and successful application
   a. Incremental vs radical innovation
   b. Sustaining vs disruptive innovation
2. Application of technology as a BM design exercise
3. History, definition, components and current methods to work with BMs
4. BM as a complex concept with unforeseeable results

These areas are addressed in 4 separate, yet related meetings. In all these meetings the most important constructs are presented and discussed with the students using a flipped classroom approach. The learners are required to read literature before class. Every week, the students read a few suggested papers and write a single-page analysis as input for the discussion. One of the learners is selected to present the literature to the class during the following meeting as a means to start the discussion. The course leader has two roles: (1) contextualizing the discussion with specific short lectures where necessary, and (2) moderating the discussion to ensure all important concepts are covered. The literature list used in this phase is available upon request.

The students "construct" their knowledge by maintaining an active role during the learning process. They are required to present the literature assigned for their peers as well as work with the proposed tool CANVAS (Osterwalder *et al.*, 2010), and the integrated BM framework (Wirtz *et al.*, 2016; Wirtz and Daiser, 2017). As a result of this process, students should be able to place their research within the newly established body of knowledge and document it with an essay that is shared with colleagues and the course leader.

Part 2 of the BDPD course consists of showing the students applications of this new knowledge in their field and stimulate them to reflect on how it impacts their work. This requires a brief introduction to the philosophical approach to scientific studies known as interpretivism, which is executed through the usual flipped classroom scheme based on specifically designed course handouts and lectures. After that, the learners are required to look at existing literature in their field to highlight good and bad examples of how other researchers in their area have dealt with the applicability of research results. The results of such literature reviews are then presented and discussed in class: this allows learners to discuss differences and similarities between applications of different technologies. The identification of such patterns is fundamental for an effective learning process and may lead students to derive their own, personal methodology.

At this point, students are able to produce a personal contribution related to the applicability of their own research results. The final assessment for the course is thus based on an original conference paper in which the student analyzes his/her own specific research results and positions them in an integrated BM context, which discusses how to come from invention to innovation. The paper is reviewed internally and approved by the course responsible, in addition to normal reviews from the scientific committee of the conference selected. The paper is a useful addition to the PhD dissertation of the students and can be included as supplementary reading in the impact section. For this reason, the course often also requires active involvement of the doctoral student´s main supervisor.

Key Insight

The course was run for the first time in 2017 with a group of 6 PhD students. It was not a new course but an update of a course with the same name run at KTH since 2001, which had been based solely on literature analysis and subsequent discussions. This old course focused only on the applicability of research results: Every week, the course responsible had picked a recently published scientific article or book chapter on the process of bringing a novel technology to the market. The sole ILO of this course could be formulated as follows: *Describe and discuss the main trends of current leading edge literature in the domain of application of new production technology.* The experience in this course was relevant to endow the student with background and learning of requirements, as formulated in the ILO presented above. At the time of writing this paper, the new course has been run only once. Yet, student reactions have been positive, especially on the content learned and the insights acquired for the own research work.

Compared to the final part of the course, the first weeks have been quite slow as the students had to step out of their scientific *comfort zone*: This is probably due to the fact that the learners start to see actual benefits for their work only after they have acquired the main concept in part 1 of the course. It was also observed that technical students often lack the economic background that enables them to contextualize the concepts underpinning BM related knowledge. Experience from this course illustrates the importance of integrating these theoretical foundations in the learning process. The following concepts have emerged as challenging and therefore require attention and deeper explanation from the course leader:

- Relation between capital and labor: Definition and examples of labor- and capital-intensive technologies were an important element to clarify that the concept of a BM is linked to market opportunities while the overall firm strategy must account for the environment. A formal introduction through a lecture that covers the relevant literature is advisable to help students understand the impact of minimum salary and import tariffs on manufacturing firms, as well as the importance of having national suppliers of manufacturing technology.
- Game theory: Zero-sum and non-zero-sum games are useful to illustrate the impact on networks when one actors adopts a new technological solution. This is particularly important when talking about value creation. Manufacturing is central in the value creation chain and often the introduction of innovative technology must be evaluated including strategic elements that go beyond costs and technical feasibility. A lecture introducing game theory and a workshop based on case studies is advisable. Also examples from realistic situations are particularly useful here. Examples can, for instance, be that (a) a superior manufacturing technology is not adopted for strategic reasons; (b) a product mix is not optimized to keep market segments that are not profitable but strategically important, and (c) obvious product design improvement are not implemented due to conflicts between production and other functions inside the firm.
- Incentives and Scarcity. Manufacturing can generate value for a firm beyond the simple product realization, yet students needed deep explanations on how this can be achieved. We learned that it is useful to show examples of how manufacturing technology can bring a sustainable competitive advantage to the focal firm. Furthermore, a series of example where the lack of a specific material or tool or a cheap new source of energy can trigger new BMs seems helpful to stress that value does not only lie in new ideas from design or a new need from marketing, because this seemed to be a bias of many students.

One of the challenges in this course has also been that the doctoral students enrolled in manufacturing programs have very different backgrounds. There were mechanical, electrical, management, and industrial engineers among them. This had an impact on the students' capability to follow the lectures. To prevent an uneven learning process among students we decided to change the planned traditional lectures into more interactive presentations including small verification moments, as well as encouraging the active involvement of the learners. One-minute papers[1] and Q&A sessions have been successfully integrated in the course.

In addition to that, this course represented the first time that many of the students were exposed to qualitative research methods and, in general, to a non-positivistic, or interpretivist, epistemology. One of the biggest challenges encountered was the bias that engineers usually have regarding such approaches (often labeled as *not real science)* and it was important to explain validity and the range of application of the presented methods. A suitable approach is to present situations in which, due to complexity of the object studied, it is impossible to obtain meaningful results with traditional scientific

[1] A one-minute paper is a common technique designed to get rapid feedback on whether the teacher´s main idea is correctly perceived by the students. In the basic format, students have 60 seconds to briefly write down on paper anonymous responses to provided questions that reflect a certain aspect of the today´s lecture. For instance, students may be asked to highlight the most important points learned during that lecture. The teacher collects the responses and assesses them.

method or engineering design processes. In this course, due to the background of the learners, examples include different perceptions of manufacturing related concepts such as quality, flexibility, industry 4.0, or manufacturing sustainability. Discussing these helped the students to appreciate how an agreement in these fields emerged, or is emerging through a complex process of assimilating different perspectives, debunking biases and establishing conventions. Other examples include lack of application of superior production technology due to "non-rational" reasons: lobbying, unbalanced bargaining power, loyalty to customer current requirement, or lack of information and competences.

Conclusion

Courses such as ours are filling a very relevant gap in the education of manufacturing engineers: A lack of awareness for the features and mechanics of the innovation process. This gap is common to many other applied research fields where the main focus is on the invention but not on how to bring it to the market. The course blueprint and the lesson learned can thus be a basis to introduce similar educational units in technical curricula. While part 1 of the course could rather easily be adapted to a different audience, part 2 would need to be tailored to the specific subject at hand.

Overall, students' feedback and teacher observations clearly point out that the course is received favorably and deemed an important complement to their education by students. For instance, two students seek to further develop the contribution they produced in the course and include it in their PhD. Particularly appreciated by all students was the presentation of research methodologies not traditionally included in the engineering research education. The participants agreed that it was a valuable addition to their skill set.

Finally, the feedback indicates that the major contribution to the knowledge of the learners after this course is an increased capability to critically appraise the engineering problem: The course triggered students to consider new creative approaches that are based on applicable and quantifiable reasoning, thus enhancing their understanding of the innovation process.

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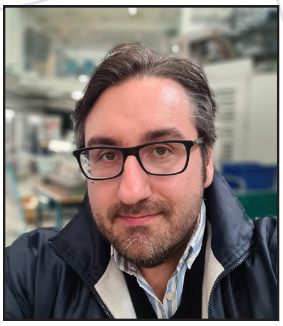

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