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Two facets of Innovation

in

Engineering Education

- The interplay of Student Learning and Curricula Design

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Doctoral thesis
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Academic thesis, which with the approval of Kungliga Tekniska Högskolan, will be presented for public review in fulfilment of the requirements for the title of PhD in Engineering in Machine Design. The public review is held at Kungliga Tekniska Högskolan, on Brinellvägen 83, Room B242, on November 29th 2013 at 10:00.

Abstract

This thesis covers two main perspectives of innovation; first, innovation is regarded as an outcome-related mechanism where learning is expressed through artefact presentations at the end of a development process; second, innovation comprises a change mechanism in the process of student learning, influencing educators to reconsider new methods and practices. Building on qualitative data from engineering design courses, the aim has been to explore how learning elements in engineering education influence students during early-phase innovation. By implementing and practicing learning elements, early-phase innovation could strengthen both current and future engineering curricula, courses, and programmes. This thesis put attention to authentic experiences in which learning elements is acted upon by students and targeted, defined, and refined by educators. Introducing learning elements need educators to manifest learning efforts more explicitly to match students' capability to interpret new knowledge. Adopting learning elements that challenge existing paths of action are characterized by diversity, proactivity, openness and motivation. For students to excel in the exploration of early-phase innovation, it is important to identify when, how and to what extent leaning elements can be reinforced. The strengthened understanding by students is mirrored in improved ability to take action and apply relevant knowledge in distinct learning situations. The opportunity to influence student learning provides the design and redesign of curricula, courses and programmes as a prime feature to leaning elements relevant to early-phase innovation. To successfully pursue innovation in engineering education a balance is necessary between responsible actors integrating learning elements and by those determined to learn.

Keywords: *Engineering education, innovation, design, learning elements, student, change*

Sammanfattning

Denna avhandling hanterar innovation i ingenjörsutbildningar utifrån två perspektiv. Dels studeras lärandeelement som är avsedda att tillägna studenter ökad förståelse kring ett specifikt område som är relevant för innovationsprocessen, dvs innovation i utbildning, dels studeras utbildningsinsatser som är menade att påverka och skapa påtagliga förändringar kring studenters lärande, dvs innovation av utbildning. Det senare perspektivet är viktigt för att ompröva och åstadkomma nya metoder och arbetssätt. Forskningen bygger på kvalitativa data där studenters lärande har fokuserats kring autentiska utvecklingsprocesser med förankring i tidig utvecklingsfas. Lärandeelement inom tidig utvecklingsfas visar en förstärkt förmåga bland studenter att tillämpa sina kunskaper i samspel med de utvecklingsinsatser som åstadkoms inom ramarna för nuvarande kursplaner, kurser och program. Studenternas lärande visar att det är viktigt att anta ett öppet förhållningssätt där lärandeelement kan definieras, tillämpas och förbättras. I främjandet av innovation behöver lärandeelement vara flexibla och förändringsbara i sättet de introduceras då en varierad grad av kontroll och supportfunktion behöver anpassas till teknologernas kunskapsnivå. Lärandeelement inom utvecklingsprojekt som denna avhandling studerat visar att de bör kännetecknas av mångfald, proaktivitet, öppenhet och motivation. På vilket sätt och när i tiden det är lämpligt att införa lärandeelement behöver avvägas noggrant för att på bästa sätt stärka studenternas lärande. Studenternas förstärkta kunskaper avspeglar sig i en ökad kunskapsbas och förmåga i tillämpning och reflektion av realistiska gemensamma lärandesituationer. Möjligheten till att bättre anpassa läroplaner, kurser och program till specifika behov inom enskilda och ämnesövergripande lärandemiljöer behöver ses över för att bättre tillvarata potentialen bland lärare och studenter. Att införa innovation i utbildningen kräver en balans mellan hur lärare aktivt kan använda lärandeelement och studenternas egen förmåga att själv fatta beslut och agera proaktivt.

Sökord: *Ingenjörsutbildning, innovation, design, lärandeelement, student, förändring*

Acknowledgements

In his introductory speech as honorary doctor at Stanford University, the late and legendary Steve Jobs brought up a thoughtful point, citing ‘connecting the dots’ as one of his most vital ingredients for success - in life and in business. Bordogna, Fromm, and Ernst (1993) go back to Plato and the birth of academia to sum up different ways of expressing connections between individuals and ways of perceiving learning.

Connections of this nature concern the freedom to learn, question, and challenge what is known. Without a desire to explore this freedom, creativity itself and the birth of all new innovations would be lost. This thesis has been a journey covering exploration and faith - a journey that has made me realise that joining the dots is far more vital than trying solving a single puzzle, although depending on the puzzle, this is also important at times. This section is dedicated to those who have helped brighten my darkest hours and to those who have shown faith in me as a researcher, lecturer, person, friend, father, and son.

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Stockholm, October 2013

Anders Berglund

Act like a bug. Bugs are determined, efficient and proactive in their actions. Bam! The bug has got nowhere to go. Bam! Bam! Now there is no more bug. Why is it that we so often state "I hate bugs"? Is it that we simply do not understand them; we have neither their drive nor their passion? Some of us are simply more provoked by their nature and without hesitating, always try to fend these unpleasant bugs away.

In a brief encounter with literature in the field of bugs, it was striking how interaction and commitment was something that cut across all living organisms, bugs included. Interaction is crucial for establishing successful accomplishments beyond what we see or take partly for granted with our human eyes…

"Like that human social register, the insect social register includes the well-established examples, with a nod to newcomers."

Matthews and Matthews, 2010: 408.

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Appended papers

1 Berglund, A. & Ritzén, S. (2009). Towards Individual Innovation Capability—The Assessment of Idea-Generating Methods and Creativity in a Capstone Design Course. In *Proceedings of the 6th Symposium on International Design and Design Education ASME'09*, San Diego.

2 Berglund, A. & Ritzén, S. (2012). Prototyping—The Collaborative Mediator. In *Proceedings of the International Conference on Engineering and Product Design Education EPDE'12*, Antwerp.

3 Berglund, A. Proactive Student Learning—Towards Innovation in Engineering Education. *Submitted to journal*.

4 Berglund, A. (2012). Do we facilitate an innovative learning environment? Student efficacy in two engineering design projects. *Global Journal of Engineering Education, 14*(1), 26–31.

5 Berglund, A. (2012). Moving Beyond Traditions: Bachelor Thesis Redesign. *International Journal of Quality Assurance in Engineering and Technology Education, 2*(1), 31–45.

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*Awarded outstanding paper award

Berglund, A., Lindh Karlsson, M. & Ritzén, S. (2010). Allowing Playfulness: Examining Innovativeness. In *Proceedings of the 12th International Conference on Engineering and Product Design Education EPDE'10,* Trondheim, Norway.

Grimheden, M. & Berglund, A. (2009). Creating a Better World by Collaboration in Product Innovation Engineering: The PIEp Way. In *Proceedings of the 11th International Conference on Engineering and Product Design Education EPDE'09*, Brighton, UK.

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1. Introduction

Tomorrow's innovations will need engineers who thoroughly understand how to apply their knowledge and skills to designing products and processes that did not exist before (Dym et al., 2005; de Graaff & Ravesteijn, 2001). This thesis concerns engineering students' learning in courses where they have the chance to test their design skills. In conducting the research, the researcher has carried a dual role of both lecturer and researcher. The role of researcher involved no intention to blur or weaken the intended student learning; rather, playing both roles acknowledged a symbiosis to be developed of the two over time. The continuous need for updates that characterizes today's society in general and the engineering profession in particular has pushed accredited engineering programmes to repeatedly call for reform in the pedagogical approach to engineering education (Crawley et al., 2007; Percy & Cramer, 2011). National agencies (NAS, 2007; HSV, 2010) and scholars have called for an innovative and creative workforce; key characteristics of future engineers include innovativeness and advanced technological fluency (NAE, 2005). The challenge of providing the industry with engineers who know how to engineer is considered a foundational mechanism in academia (Borrego & Bernhard, 2011; Crawley et al., 2007).

Engineering education provides an academic learning ground for industrial and technological pressures faced by future engineers that aims to influence technological advances and enhance the quality of life in society (e.g., de Graaff & Ravesteijn, 2001; Berggren et al., 2003; Grimson, 2002). Engineering education has long made efforts to improve ways of learning and educating future engineers (Sheppard, Pellegrino, & Olds, 2008). Today the disciplinary evolvement of a separate field that emphasizes research and educational methods is blossoming and connects peers concerned with engineering education (Borrego & Bernhard, 2011). To support a broad spectra of student learning many universities have successfully established faculty enhancement programmes that aim to strengthen relevant teaching skills (Crawely et al., 2007). In recent decades, engineering faculties have gradually increased the publications ratio among engineering educators and thereby allowed increased transparency in working processes and best practices (Peercy & Cramer, 2011). Research concerning engineering education has come to be understood as a separate entity and a research domain dedicated to reassuring and fostering learning among tomorrow's students (Baillie & Bernhard, 2009).

Engineering education supports students in learning how to synthesize new knowledge with what they already know, allowing them to put together artefacts through learning and relearning knowledge and practice (e.g., Sheppard, Pellegrino & Olds, 2008; Crawley et al., 2011). Learning through problem solving and process improvement, is also present for innovation, were the problem itself many times need time for exploration and definition (Badran, 2007; Dym et al., 2005). Innovation in engineering education covers interruptions of patterns that allows not only specific artefact establishments but for those surrounding and influencing the direct learning experiences, the systematic level in what is cited as transformational innovation (Burton, Schlemer & Vanasupa, 2012). Somewhat overlapping but with a notion on the operational level of transformations in distinct educational purposes has also been labelled 'curricular innovation' (Haggis, 2009; Sheppard et al., 2009; Borrego, Froyd & Hall, 2010). This thesis draws attention to current research in engineering education and engineering design education in particular. Engineering design education is concerned with creation of artefacts and the processes that support such learning. Engineering design education provides courses and programmes in which innovation is present as part of the names, but rather characterized from an output-derived attention (e.g., Dym et al., 2005; Sheppard, Pellegrino, & Olds, 2008). Innovation has become synonym to what is produced throughout a given time frame, i.e. normally course duration, with a final prototype on display by the end of the course (Dym & Little, 2003).

This thesis covers two main perspectives of innovation; first, innovation is regarded as an outcome related mechanism where learning is expressed through artefact presentations at the end of a development process; secondly, learning comprises a change mechanism in the process of student learning, influencing educators to reconsider new methods and practices, known as curricular innovations. Learning concerns the interpretation of 'what' (content) in relation to 'how' (context) as a basis for educators to improve the way they convey learning objectives.

The setting in which design involves 'newness' is considered crucial to early product and process innovations in engineering education (e.g., Crawley et al., 2007; Dym et al., 2005). However, the effectiveness of outcome-based education has been debated, and particularly whether output-derived project achievements best reflect a requested learning achievement by students (Mills & Treagust, 2003). Research from the learning sciences shows that prior knowledge plays a critical role in how students progress through a problem, as well as in what they learn and what they produce (Adams, Kaczmarczyk, Picton, & Demian, 2010; NRC, 2003). Learning in this thesis base curricular innovations (Haggis, 2009; Sheppard et al., 2009; Borrego, Froyd & Hall, 2010), both as a policy-making, institution-wide systematic concern, and its individual support for learning. In the support for individual learning teaching methods' has become focal point namely as change mechanisms behind efforts to promote student learning with learning experiences that lasts (Haggis, 2009). More distinctly teaching methods that concern change imperatives have been clustered in a set of areas that strive to support learning in different forms; e.g. self-directed student learning, collaborative learning and problem-based learning.

Innovation in education has, until recently, been omitted or regarded as a side track in course- or programme-design templates. The international initiative of the CDIO syllabus (Crawley et al., 2007) is set to change perspectives on innovative aspects, given that such factors are part of the extended version—the recently updated v2.0 (Crawley, Malmqvist, Lucas, & Brodeur, 2011). The syllabus advocates for pioneers to test, implement or in other ways contribute with examples that enhance learning. Engineering education research has a tendency to transfer learning experiences through cases that allow descriptive evidence of the ways design challenges are apprehended (Litzinger, Lattuca, Hadgraft & Newstetter, 2011).

From an educational point of view, student learning has evolved from a tradition in which lecturers communicated in a unidirectional format, especially in intense, theory-based subjects (Biggs & Tang, 2007). Whether innovation in engineering education resides strictly in a more theoretical or a more practical approach or in a mixture of the two depends upon existing lecturing traditions, existing curricula, and existing programme outlines. This research pursues innovation as the process of establishing a valuable output that corresponds to or exceeds existing or latent user needs. The value build-up involves internal progression through student learning; the focus is on experiencing this emerging build-up, also cited as 'experiential learning' (Kolb, 1984); 'pragmatic knowledge' (Crawley et al., 2007), and 'functional knowledge' (Biggs & Tang, 2007).

Provided with an educational perspective engineers are perceived to integrate and synthesize new knowledge as something logically structured and possible to be acted upon. From this perspective, what has been addressed as early indications to product innovations is frequently situated in ideas that shape cognitive beliefs in communication and social interplay (Dym et al., 2005; de Graaff & Ravesteijn, 2001). In parallel with idea-generating methods, prototyping defines lateral thinking as present wherever divergence and systematic thinking are unified (von Hippel, 1988). The benefits of prototyping as part of early product innovation exploration have been researched very little, especially considering prototyping's design importance (Carleton & Cockayne, 2009).

Past research has addressed students approach to learning as being related to different type of styles and preferences (Kolb, 1984; Felder and Silverman, 1988). By tradition information has been transferred through visual or verbal demonstrations and explanations with risk of making students passive recipients to new knowledge (Biggs and Tang, 2007). Kolb (1984) has presented this in a scale of active and reflective sensory. Bergsteiner, Avery and Neumann (2010) address an active learning approach as a step that concerns interaction, discussion and a basis for reflection on performed and not performed activities. Early stages of innovation are regarded as informal and ambiguous, which for the teaching and learning of innovation provides no exact positioning of specific content or principles to be applied (Badran, 2007). Rather the promotion of skills, approaches and methods of thinking has come to guide and embrace innovation as a learning phenomenon in engineering education (Crawley, Edström and Stanko, 2013). Individual abilities to achieve in-depth technical expertise and to communicate laterally—as the ingredients required to establish value and novelty.

1.1 Problem framing

According to scholars, society is changing in terms of the areas in which requests for new skills emerge, and this needs to be matched with relevant ways of approaching such new learning (e.g., Adams, Kaczmarczyk, Picton, & Demian, 2010; Graham & Crawley, 2010). A profession such as engineering embodies a set of tenets that are crucial for learning its founding principles (Schulman, 1999; Sheppard et al., 2006). A trained engineer must do the following:

- possess fundamental knowledge and skills (especially academic knowledge and research skills)

- develop the capacity to engage in complex forms of professional practice
- make judgements under conditions of uncertainty
- learn from experience
- create and participate in a responsible and effective professional community

Individuals face an escalating challenge in equipping themselves with skills that are rooted in these tenets and that aim at application in real-life engineering practice. Learning that allow students to develop the ability to test their technical and professional skills fluently by engaging in authentic engineering projects have been considered a vital mechanism for dissemination (Litzinger, Lattuca, Hadgraft & Newstetter, 2011). Education is thus an inevitable element that allows individuals to acquire valuable skills that can be applied to the industry of today and tomorrow. Educators take on active roles as scaffolders, coaches, and mediators in the process of guiding students towards creating divergent and self-regulating performances (Chen, 2001). Several researchers (e.g., Sheppard et al., 2006, 2008; Eris & Leifer, 2003; Dym & Little, 2003; Graham, 2010; de Graaff & Kolmos, 2007) have indicated that collaborative learning and practically oriented learning provide an authentic project challenge for approaching complex problem solving. Considering the way in which learning is learned places an emphasis on the educators and on subtle aspects of the knowledge being transferred, since what works in one context does not necessarily work in the next (Baillie, Ko, Newstetter, & Radcliffe, 2011).

1.2 Scope

The innovation process' early stage activities are stated to have impact, both in relation to the whole process and the end result (Koen et al., 2001; Koen, Bertels & Kleinschmidt, 2012). Due to the influence of input ideas and design, the early stage is the least structured part of the innovation process, both in theory and in practice. This early stage is still ill-defined, with several similar terms and models discussed in the literature that add to the vagueness of this phrase. Innovation literature outside the education domain describes early stage activities of innovation as 'predevelopment' (Cooper, 1988), 'pre-project activities' (Verganti, 1997), 'Fuzzy Front End' (Cooper, 1999) or 'Front End of Innovation' (Martinsuo & Poskela, 2011; Koen et al., 2001).

This research relates to the need for exploration that precedes aggregations of ideas and more formal processes of integrated product development. Learning about the less structured processes and the subsequent more formalized processes of early stages (Koen et al., 2001) requires identification of relevant activities to be targeted, practiced and acted upon. The need recognition and approval for development or its termination is considered typical for this less structured early stage (Koen, Bertels & Kleinschmidt, 2012). It is also argued that this stage is largely about iterative information search, exploration, evoking ideas, testing and initial analysis (Poskela & Martinsuo, 2009). An understanding of innovation would therefore need to be widened to include a set of deliveries that goes beyond the 'analytical' limit. The student learning is also to prepare them to function in the anticipated formal process of the product development cycle. Consequently, what is stipulated as early-phase innovation from hereon is a process that covers both the less formalized actions (i.e. intangibles) and the establishment of testing and functional prototypes (i.e. tangibles).

According to Barton, Schlemer, and Vanasupa (2012), innovation transformation is relevant to highlight since it influences both existing context, e.g., a curriculum, course, or programme, and the individuals involved. Therefore, transformation functions as a concern for educators in how to systematically approach innovation. This is elevating the implications of innovation efforts in courses to a system's level concerning approach to learning. Courses that provide accessibility and easily interaction with students without interfering with any of the intended learning objectives. The literature building the founding arguments for this thesis is influenced by a sense of doing, application of knowledge and a learning approach that promotes active learning and reflective introspection (Kolb, 1984). Founding learning principles related to this activity-based perspective together with innovation literature has been applied in order to frame the phenomenon of innovation in engineering education. In literature, the use of disciplinary 'engineering education' phrasing is interchangeably used for purposes of describing subject-matter learning that relate to engineering design. This thesis uses literature that relates to both the disciplinary level and the subject-matter learning level; 'engineering design' literature in arguments, yet in terms of contribution—the subject-matter learning level is addressed.

1.3 Purpose

This thesis aims to explore how learning elements in engineering education influence students in early-phase innovation and to propose ways that such elements can be used to support early-phase-innovation learning in current and future engineering curricula, courses, and programmes.

1.4 Outline

This thesis is covers six chapters. The first introduces the field of innovation in engineering education; the next chapter revisits relevant literature that (a) seeks to further outline and motivate innovation as an important ingredient of what today's engineering education should be, (b) examines in greater detail learning and how elements for enabling a greater understanding could incorporate innovation, and (c) allows the articulation of research questions that guide the efforts made in later sections. Chapter 3 draws out the methodological considerations that show how the studies have been set up and executed, along with their individual contributions to the thesis as a whole. This section also deals with considerations that arose from the dual nature of my position as both researcher and lecturer. The fourth chapter outlines key contributions of the results collected and presented as evidence under the section of appended papers. Chapter 5 discusses the findings by scrutinizing them in relation to the stated research questions and allows for a thorough and detailed analysis of the investigated phenomena. Chapter 6 sums up the conducted research, drawing attention to the purpose and to ways that new knowledge can promote a new position for future challenges. This final section also presents the implications of this study for educational professionals, contributes to theory, and presents recommendations for proceeding with further research in the field. The six chapters are shown schematically in figure 1.1 on a step-based incline that demonstrates the reader's gain in understanding and the challenging of beliefs that accompany early-phase innovation in engineering education.

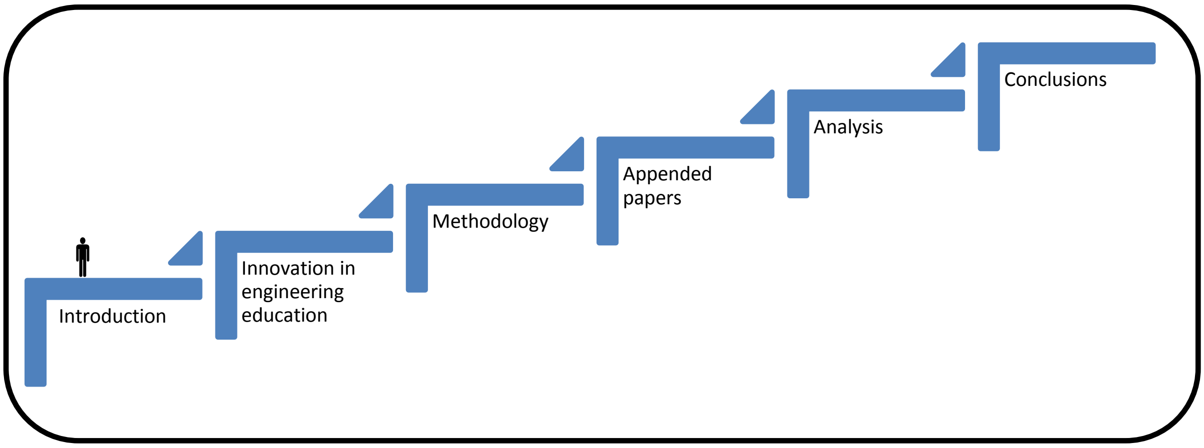

Figure 1.1 Thesis outline.

2. Innovation in engineering education

"Science is the process of discovering and creating knowledge. Engineers share this process but they are also responsible for applying new knowledge to create what has never been: the innovative integration of ideas, devices and systems to implement change." (Bordogna, Fromm & Ernst, 1993: 4)

2.1 What is innovation?

As the title for this thesis suggests, innovation can be portrayed from various perspectives, stemming from multiple facets and bases for interpretation. Crossan and Apaydin (2010) have drawn attention to the way innovation's many facets have fragmented and loosened the connectivity of related research areas. This thesis takes up two of these facets, which are considered in greater detail throughout this chapter and beyond. To approach innovation in an educational context, it is vital to grasp the underlying definition and accepted understanding of the phenomenon innovation itself. Broadly speaking, there are two ways of looking at innovation: either as a final output (Zaltman et al., 1973: 7) or as "a process" (Marquis & Mayers, 1969: 1). In Schumpeter's three-stage process, which originated in 1942, the innovation process behind commercializing an idea opened up a new field of innovation literature. As the literature on innovation has evolved, so too has the number of different explanations of the term *innovation* itself. Therefore, going back to square one, *innovation* in its broadest sense stems from the Latin word *innovare*, meaning 'to make something new' (Amidon, 2003).

Different descriptions of innovation extend beyond the creation of an idea to encompass the whole process of bringing an idea to a commercial application (Doyle, 2002). From another perspective, Tidd, Bessant and Pavitt (2002) state that innovation is essentially about change, in terms of either a product offering or the way it is created and delivered—or both. Innovation involves new ways of identifying the needs of new and existing customers (O'Regan, Ghobadian, & Sims, 2006). Jobber (2001: 338) describes innovation as something that "occurs when an invention is commercialized by bringing it to market." Kuhn (1985) has suggested that creativity forms something from nothing and that innovation shapes that something into products and services. Innovation is intangible, a state of mind (Kuczmarski, 1995) that is developed by early creative propositions in a setting that is open for divergence (Amabile, 1996). Innovation as a concept originated as a synonym to new ways of combining production system outputs in order to increase efficiency (Schumpeter, 1934). Wolpert (2002) describes innovation as the pursuit of radical new business opportunities, exploiting new or potentially disruptive technologies, and introducing change into the core concept of the business. The term *innovation* can be understood as a new or innovative idea applied to initiating or improving a product, process, or services (Wolfe, 1994). According to Kuczmarski (2003) innovation is all of these things and more as it is rooted in an influential way of thinking, a mind-set that for organizations can play a dominant role in their operations. In terms of innovation as a continuum, the phenomenon is characterized as a dynamic process that evolves from identification of needs and idea generation to commercialization (e.g., Cooper, 1998; Tidd, Bessant & Pavitt, 2002; Berglund, 2007). Past research shares the process stance (e.g., Marquis & Mayers, 1969; von Hippel, 1988; Porter, 1990; Tidd, Bessant & Pavitt, 2002; Doyle, 2002; Amidon, 2003), in which development work and progression act as key determinants for what has become synonymous with innovation. Crossan and Apaydin (2010) use the organizational sphere as basis for dividing innovation into three sequential components—process, outcome, and leadership—that permeate all parts and allow innovative processes and outcomes to progress. Innovation has a strong focus on outcomes and effects of innovations rather than for understanding how it is manifested through the actions involved (Cruickshank, 2010). This thesis addresses innovation from the stance that it concerns a process of value-added activities leading to a valuable output for others. Consequently, examining early-phase innovation provides an understanding of exploring needs, of using creativity in different forms, of organizing and sharing knowledge, and of facilitating these contexts.

2.2 Innovation and learning

Innovation from a process-oriented perspective concerns the accumulation of knowledge and experiences that also provide a basis for learning and re-learning to be involved. Kolb (1984) has indicated that learning as a basis for creating experiential knowledge has been conceived as a process rather than in terms of delivered outcomes. From this viewpoint, milestone deliveries and performance based on such deliveries constitute evidence of achieved learning, not prime objectives and aims. Rather, learning is what connects experiences and the site where new knowledge is adopted and reformulated. Past research has indicated that student empowerment provides an underlying intrinsic motivator that affects the quality of learning (Felder, 2007). Sharing and contributing to the quality of ideas by others stem to combine a social level of joint understanding (Cross, 2011). The literature on engineering education has been heavily influenced by the learning involved in functional knowledge (Argyris & Schön, 1978; Biggs & Tang, 2007) and the essence of attaining pragmatic skills (Crawley et al., 2007). Acquiring in-depth engineering skills corresponds well with what been called 'procedural knowledge' (Billet, 1996), in which knowing *how* provides a basis for cognitive development.

During the students' learning process, each learning loop should open up new opportunities in which surprising elements can appear. To optimize knowledge transitions between the learner and the facilitator is to embrace a repertoire of learners' actions: reframing, listening, reflecting, engaging in dialogue, and trying again (Schön, 1983). The guidance- and curriculum-based measurements for supporting a systematic approach to what is known as constructive alignment involve intervening actions, objectives, and examination in a fundamental and balanced learning situation (Biggs & Tang, 2007). One key to achieving greater awareness and reflective learning is engaging in activities that align learning objectives with examination requirements. Bordogna, Fromm, and Earnst (1993) expressed a concern two decades ago about whether the content of existing courses truly provided enough value to the students. This concern is today putting integration as a main feature in trying to bundle existing curricula with people, knowledge, and learning (Arlett et al., 2010; Biggs and Tang, 2007; 2011).

2.3 Innovation as a requested skill

There are concerns in many of today's educational programmes that the traditional learning methods and practices of the past are inaccurate, obsolete, and provide an incomplete way to manage students' needs and expectations (Sheppard, Pellegrino, & Olds, 2008; Crawley et al., 2007; Dym et al., 2005). Creative thinking forms an input basis for innovation insofar as it is a cognitive process; as such, it is one of the most necessary skills for future engineers to have (HSV, 2010; FEANI, 2000). The Employers Skill Survey (SEMTA, 2003) states that 95% of the manufacturing and engineering companies questioned had difficulties recruiting suitable graduate engineers because of skill shortages; this negatively affected their businesses. According to past research (e.g., Biggs & Tang, 2011; Dym et al., 2005), engineering design activities are linked to problem solving and other cognitive activities. The transparency of skills directed at innovation is unclear, and detailed analysis is needed to define and single out issues. In the first CDIO syllabus (Crawley et al., 2007), innovation was not explicitly mentioned, even among the inventive personal skills, but instead was referred to as a vague professional skill (section 2.5.4: 261): "staying current on the world of engineering: describing the social and technical impact of new technologies and innovations."

According to research, (e.g. Cooper, 1999; Amidon, 2003) innovation is one of the more desirable skills an organisation can cultivate; still what makes up for these skills among single individuals is less categorised. Over the last few decades, increased attention has been given to the proficiency and skill levels in engineering programme graduates (Sheppard et al., 2006; Crawley, 2007; Biggs & Tang, 2007). A genre that explicitly questions the authenticity of current educational programmes concerns the capability of a skill-driven curriculum (Bowden & Marton, 1998). It is important to address authenticity as such concern question the founding principle behind what constitutes a graduate engineer. In other words, on what grounds is one an engineer? Active learning has strategically become a way to establish an 'apprenticeship' of knowledge (Sheppard et al., 2006), to gain 'functional knowledge' (Biggs & Tang, 2007), and to bridge potential gaps in the existing programme design (Sheppard et al., 2006; Biggs & Tang, 2007; Crawley et al., 2007).

2.4 Innovation in engineering education

Engineering education is set to educate students so that they develop technical skills and personal, interpersonal, and system-building skills (Dym & Little, 2003: Crawley et al., 2011). Criticism of a fragmented and abstract science-based engineering has brought depth but loosened the grip on the practice-oriented aspects of engineering and on the necessary integration of skills (Bankel et al., 2005). Innovation in engineering education has gained increased attention in recent years both as design ingredient of the educational framework CDIO (Crawley et al., 2007; 2011) and by adopting practices inspired by design thinking (Kelley, 2001; Dym et al., 2005; Dunn & Martin, 2006).

Crawley et al. (2007) state that the basic, core concepts of engineering are encapsulated in the field's founding principles and that innovation is present in at least eleven sections of the

CDIO syllabus[1]. The CDIO syllabus presents innovation as an embedded and integrated part of the learning environment e.g. project, size, and length, faculty responsibilities, external presence and facilitating resources (ibid). Innovation has been classified as "an emerging contemporary theme" in engineering education literature (Crawley et al., 2007: 60). Along with sustainability and sustainable development, innovation is discussed indirectly as a concept that "includes a deep conceptual understanding of fundamentals, the skills to exploit ideas, and a sense of self-empowerment from learning" (Crawley et al, 2007: 62). Engineering education need to address existing curriculum in order for disciplinary knowledge to increase the potential in the creative efforts being made (Badran, 2007).

Design thinking provides a mindset that encapsulates the design of new products in creative and innovative ways (Kelley, 2001). Design thinking could also be portrayed as a framework that is founded in human-centered actions and cognition, concerning how to understand (the user and the system); observe, point of view; ideate; prototype and test (Rowe, 1987). Design thinking provides a wide array of interpretations, in order to relate to an engineer's perspective the definition by Dunn and Martin (2006: 517) is used: "the way designers think: the mental processes they use to design objects, services or systems, as distinct from the end result of elegant and useful products. Design thinking results from the nature of design work: a project based work flow around 'wicked' problems."

Planning, guiding, assessing, and facilitating students are aspects that provide a basis for change efforts in curriculum (Sheppard et al., 2006); innovations in regards to curricula redesign corresponds to new and creative implementations made by faculty in courses and programmes. Curricular innovations concern improvements that lecturers undergo as they evolve in their role—an internal self-regenerating innovation process (Haggis, 2009). Barton, Schlemer, and Vanasupa (2012) expand the phenomenon of innovation in engineering education by differentiating it into three domains, each with its own practices and process.

1. *Problem solving* — The first domain captures innovation within the bounds of a process or set of processes. Problem solving looks at what is already being done, with perhaps additional efficiency, resources, speed, or scale. Problem solving usually results in incremental changes to existing designs.
2. *Process improvement* — The second domain views innovation as a phenomenon arising from examining the process of problem solving. Process improvement has the potential for designs of greater impact, since the boundaries of consideration now include incremental and systemic improvements.
3. *Transformation* — The third domain regards innovation as a transformation that inspires a fundamental identity shift in the surrounding system and the people. This domain addresses deep structures and patterns of thought, habit, and behaviour. Transformational innovation is also considered a context for profound change in the other two domains and as such is an emergent influencer. (Barton, Schlemer and Vanasupa, 2012: 276)

The context that handles emerging problems is also the basis for refining and improving the problem-solving skills applied. The third domain concerns a greater systematic shift whereby

[1] CDIO stands for *Conceive, Design, Implement, and Operate*; eleven of the syllabus's sections involve themes related to innovation: 4.3.1–2; 3.1–3; 2.4.1–3; 4.2.2–4.

transformational innovation or curricula innovation (Haggis, 2009; Sheppard, et al, 2006). A foundational tenet of this thesis is that innovation in engineering education is diverse in nature; one should approach it as such in order to understand its complexity.

2.5 Innovation in engineering design

Research in engineering education propose design artefacts to function as distinct supporting mechanisms to student learning by providing authentic experiences of both explicit and tacit character (Bernhard, 2010). Education in issues as complex as product development and early-phase innovation has, over the decades, evolved to the point that today it is considered one of the most foundational principles there is; students must be active in their learning processes while facing recurring issues and reflecting on actions taken and not taken (Sheppard, Pellegrino, & Olds, 2008; Crawley et al., 2011). 'How-to' procedures for engineers are rooted in creating an embedded understanding that allows one to approach a given problem, regardless of disciplinary skill. Product design development relates to phases and progressions that are difficult to separate from what is referred to as product innovation (Ulrich & Eppinger, 2008; Dym et al., 2005). Student learning are built on parallel activities, cross-functionality and founded in challenges and problems that are ill-defined, ill-structured, or presented as wicked problems (Simon, 1974; Rittel & Webber, 1973; Cross, 2007). With problem statements providing an incomplete set of information design problem comprises a multitude of possible solutions, and no clear-cut solution (Ullman, 2002).

Analysis and the problem-finding process often culminate in a reasonable solution, not in a correct answer; this in turn requires skill to define, redefine, and change the problem-as-given (Cross, 2007). Ideas are renegotiated through a spiral of reaching new knowledge in order to identify the actual problem and to find new solutions to a defined problem. However, to overcome difficulties or constraints in a problem, creativity alone is not sufficient. From an engineer's perspective, ill-defined problems involve the exploration of needs while moving across vague, fuzzy, incomplete, and at times imaginary scenarios (Cross, 2008; Jonassen, 2000).

Early-phase innovation concerns several factors that could influence engineering students' learning process. Altering existing curricula, changing specific activities, or redesigning new ones can trigger student learning about aspects of innovation in engineering education. But curriculum innovation can hardly be successful unless teachers' conceptions and beliefs about teaching and learning are taken into account (van Driel, Verloop, van Werven & Dekkers, 1997). Enabling operational autonomy stresses a rigid understanding of the context so that facilitation or manipulation—that is, alteration—of the facilitation mode can be put into practice. Consequently, an array of elements influences students in their situational practice context and should therefore be handled with sensitive ethical consideration. Engineering design presents activities that precede output considerations in terms of usefulness and applicability (Dym et al., 2005; Eris & Leifer, 2003; Berglund 2012, 2008).

2.6 Learning theories and educational approaches

From the perspective of modern education, three main categories of learning theories dominate: behaviourism, cognitivism, and constructivism (Kolb, 1984; Gibbs, 1992). Each involves unique distinctions: behaviourism concerns learning in a form that aims to single out objectively observable aspects; cognitive learning relates to patterns of thinking and to the way memories are established in the human brain; and constructivism addresses the process in which the learner actively builds his or her own set of ideas, concepts, and beliefs. The categorization of learning theories provides a basis for an educator to act upon when addressing students and subjects. This thesis is best related to the constructivist learning theory due to the build-up and accumulation of authentic and purposely adequate engineering design knowledge that is pursued.

There are doubts among educators about the effectiveness of the approaches related to instructional design, in particular as it applies to the development of instructional courses for novices (Mayer, 2004; Kirschner, Sweller, & Clark, 2006). While some constructivists argue that 'learning by doing' strengthens knowledge, critics of this instructional strategy argue that little empirical evidence exists to support this statement about novice learners (ibid.). Lacking sufficient in-depth knowledge, past research states, novices cannot possess the underlying mental models necessary for learning by doing (e.g., Kirschner, Sweller, & Clark, 2006; Sweller, 1994).

Mayer (2004) argues that not all teaching techniques based on constructivism are efficient or effective for all learners, suggesting that many educators misapply constructivism, using teaching techniques that require learners to be behaviourally active. Mayer (2004: 15) describes the inappropriate use of constructivism as the "constructivist teaching fallacy," which equates active learning with "active teaching" providing insufficient guidelines rather than "cognitively active" students.

Kirschner, Sweller, and Clark (2006) describe constructivist learning as based on unguided methods of instruction where there is an urge to promote more structured learning activities for learners with little or no prior knowledge in a given subject. This learning category lumps several learning theories into a single category, stating that scaffold constructivist methods like problem-based learning are ineffective. However, several research studies have shown a positive and contradictory scenario where problem-based learning provides a vital and useful source for learning (Felder, 2006; de Graaff & Kolmos, 2007), and strengthen soft skills such as collaboration and self-directed learning (Hmelo-Silver, Duncan & Chinn, 2007).

2.6.1 Experiential learning

Experiential learning provides a holistic theoretical model for individual learning, outlining the process of learning; how learning is manifested and developed (Kolb, Boyatzis & Mainemelis, 2001). In respect to Kolb's (1984) model, this thesis concentrate on the way students are classified as having a preference for (a) 'concrete experience' or 'abstract conceptualization' (how they take information in) and for (b) 'active experimentation' or 'reflective observation' (how they process information; Kolb, 1984; Felder & Brent, 2005). The conflicting dualities explain how complex mental processes are perceived and translated into bipolar knowledge dimensions, dividing them on axis of 'active experimentation' and 'reflective observation' and 'concrete experience' and 'abstract conceptualisation' (Kolb, 1984). Based on this reasoning experiential learning juxtaposes fundamental differences in how to learn from experience.

Kolb's (1984) four categories of learning styles are diverging, assimilating, converging, and accommodating. Numerous well-cited alterations have emerged that have the same origin; Lönnheden and Olstedt (2005) slightly modified the categorization of learning to awareness, action, thought, and reflection, confirming that successful learning requires a balance of all four categories. If any of the categories is too weak, the learning process becomes a negative one. Quality in learning is related to how these four elements are processed (Kolb, 1984; Döös, 2004). Within each category of the learning process, there are three distinct ways knowledge can contribute to learning and learning types:

- *Assimilation*: acceptance of new knowledge and integration with earlier knowledge and experience, with confirmation or rejection of existing knowledge and experience
- *Accommodation*: struggling and questioning, followed by acceptance of the new knowledge
- *Homeostasis*: avoidance of new knowledge

By addressing what research has indicated as active rather than reflective learners (Felder & Silverman, 1988); this thesis align with the presumption that engineers could be favoured by adopting an active learning role (Kolb, Boyatzis & Mainemelis, 2001), that emphasise practice and provides the explicit proof of an engineer, which is to craft (Crawley et al., 2007). One key for bringing about a reflective perspective and deepening the learning process for the individual is to rethink and reframe ongoing negotiating design processes. Understanding the learning process and how it works from a practical viewpoint may substantially increase a student's chances of developing and applying these abilities later in life (Eris & Leifer, 2003; Cross, Christiaans, & Dorst, 1994; Felder and Silverman, 1988).

2.6.2 Motivation to learn

The learning cycle can then be described as a hermeneutic reflective process whereby new insight through reflection creates new perspectives and knowledge (Kolb, 1984). Learning in this manner is clearly not easy, and students need to be both motivated and in control of their own learning. Learning in terms of content and the process of realising this content provides the perspective of motivation for both learners and educators. Regardless of the type, character, or place a course is presented, its effectiveness as a learning accelerator depends on the interpretations made by the learner. From this belief the learner must motivate himself or herself to get involved. Studies have focused on distinct objectives set by the students and their efforts in achieving these aims (Bandura, 1977; Dweck, 1986). Students' motivational drive towards achievement is derived from their desire to realise these objectives; this finding corresponds to the self-actualization principal articulated by Maslow (1943) meaning that true motive and strive resides in the individual and that it is the attitude towards this motive to act that is of importance.

This is similar to the rule evident in different fields that guides the way people generally act in certain situations; consider, for instance, 'self-directing independence' (Humphreys, Lo, Chan, & Duggan, 2001). In simple terms, there are people who do not always strive to make the best buy, and there are individuals who do not always strive to challenge themselves and learn new things. This pattern of conversion between extrinsic and intrinsic motivation is based on the willingness to learn without really integrating practice and the bigger picture of what they are setting out to understand and may thereby later accomplish. Researchers regard this as a weak tie, a superficial approach to learning (e.g., Savage, Birch & Noussi, 2011, Gibbs, 1992).

From social learning theory (Bandura, 1977) individuals strengthen their learning by experiencing situations from performed actions. Past studies, (e.g. Turner & Patrick, 2004; Bandura (1997) have shown positive effects from actions that strive to actively develop a motivating learning environment with performance. The student learning environment can provide both local and distributed forms of knowledge exchanges (McGill et al., 2005). Individuals, i.e. students, that are more intrinsically motivated show a tendency to developing oneself towards what Maslow (1943) peak his reasoning about; self-actualization. That has been interpreted as 'a greater self' in response to favourable influences of social character. By bringing forward the potential of individuals, authentic settings allow self-actualization to be a question of attitude towards engagement. Savage, Birch, and Noussi (2011), among others, argue that the use of reliable identification and motivational factors could provide a basis for learning interventions.

2.6.3 Problem- and project-based learning

Problem-based learning is a student-centred educational approach that allows students to both learn strategic approaches and gain new knowledge through disciplinary subject experience (de Graaff & Kolmos, 2007). Problem-based learning allows students to experience knowledge at a greater depth while also providing complementary learning via the conversations involved (Bron & Lönnheden, 2004). Problem- and project-based learning (both using the acronym PBL) are frequently usual in engineering education, presenting recognition to active learning as a way to enable students with proficient skills (Beddoes, Jesiek & Borrego, 2010). Scrutiny of project-based learning practices in engineering educational programmes (Graham, 2010) has uncovered a great variety of applications related to problem-based learning and project-based learning that have led several engineering departments to present their approaches as 'activity-led learning' rather than as anything else (Graham & Crawley, 2010).

Despite problem-based learning is applied across a range of disciplines e.g. medicine, economics and engineering, the approach is not without critics. Sweller (1994) confronted the ideal of problem-based learning by proposing that information overflow—or, more precisely, cognitive load theory—could explain difficulties that novices experience during the early stages of learning. Problem-based learning does not automatically produce success; showing positive effects on the development of students' professional skills the assessment and effects on content knowledge remains unclear (Prince & Felder, 2006). It has been noted that approaches to problem-based learning do not offer readily transferable models, either because they are designed for low student numbers on relatively high per capita budgets or because they rely on specialist in-house expertise or equipment (Graham & Crawley, 2010).

Problem-based learning is not so much a teaching method as it is a learning method aimed at lifelong learning. Students involved in problem-based learning emphasize what they know effectively and apply the products of their reasoning; they have greater self-awareness and self-direction, enjoying the learning experience more and enjoying their peers and teachers, as well (e.g., Barrows, 1986; Biggs & Tang, 2007). The distinction between project- and problem-based learning is considered fluid creating a mixture of blends and overlapping definitions (de Graaff & Kolmos, 2007). Generally project-based learning is characterized as broader in scope than problem-based learning, and is typically directed toward a final product (Prince & Felder, 2006). However, certain communities address and interpret project-based learning differently to better target their learning, e.g. Aalborg's approach (de Graaff & Kolmos, 2007). The development of an output artefact (i.e. final prototype) that is originating from an open-ended and ill-structured problem provides a major basis for this thesis, why it is perceived relevant to relate to project-based learning. Projects of this character are normally completed with a written or oral report summarizing the procedure used (and to disseminate knowledge) to create the product and presenting the outcome (Prince & Felder, 2006).

2.6.4 Learning in context

Some researchers (e.g., de Graaff & Kolmos, 2007; Prince & Felder, 2006) mention project-based learning as an extension of problem-based learning in which more detail is applied to accurately describing context-related aspects. Engineering design projects have a common denominator: support for procedural approaches and collaboration to bring problem finding and a minimum of constrained approaches into focus (Kolmos, 2002). Dym et al. (2005) use design thinking as an integrated founding principle in their engineering programmes, allowing scaffolding for students that undertake complex processes of inquiry, including working collaboratively in teams using problem-based learning.

Project-based learning in engineering design settings provides opportunity to influence the confidence in students' ability to face future challenges (Crawley et al., 2011; Sheppard, Pellegrino, & Olds, 2008). The common feature of these different courses is the centrality of the student team. According to Biggs & Tang (2011), structuring student work around self-managing teams is considered a key leverage point for improving embedded, functional knowledge. The range of transferable personal skills that students address in these learning environments involves skills that concern communication/presentation, problem-solving, organizational, teamwork and leadership (Sheppard et al., 2004). In such settings, engineering design students are incorporated into industry-sponsored projects in order to determine project requirements and benchmark alternatives, as well as to conceive solutions and develop a series of increasingly sophisticated prototypes, followed by analysis and user testing.

Beckman & Barry (2007) have presented a shift from a clear-cut problem-solving process to a problem-formulating process in getting to a collectively acceptable starting point. Activities that reinforce project experiences and learning cover: determining project requirements and benchmarking alternatives; conceiving solutions; designing incrementally more sophisticated prototype modes, analyses, needs-finding preferences, and user-testing methods; building teams; organizing projects; and capturing and reusing domain-specific knowledge (ibid). Academia presents examples (e.g., Berglund & Leifer, 2013; Graham & Crawley, 2010) in which projects are slightly altered to promote a shifted variety of both the diversity and the depth of acquired skills.

2.7 Educational change efforts

Faculty and educational developers are faced with several concerns in order to develop either form of problem- or project-based learning. Key ingredients is to promote educators; stimulating their motivation to practice and approach learning, and by supporting the development of new competences (de Graaff & Kolmos, 2007). A significant part of an educator's responsibility involves moving students from a state of dependence on instruction, in which they are capable of repetition, to independence in learning. Depending on the type of work conducted, students' collaborative efforts concern a shared representation of the problem. Feedback loops allow for the build-up and maintenance of common ground and of an understanding that facilitates coordinated problem-solving efforts. Rugarcia, Felder, Woods, and Stice (2000) state that self-awareness and the ability to reason must be applicable in a context that poses an understanding of applicability across an array of interdisciplinary perspectives. This should encourage educators to challenge learners to develop an interdependent stance: students should be capable of communicating their reasoning to others in different disciplinary domains and work groups.

Attempts to bridge educational practice with engineering education research have gained urgency stating that innovation is established in cyclic loops towards the design of an efficient and prominent learning environment (Jamieson and Lohmann, 2009). Individuals that act to promote transformational processes involve either directly or indirectly changes to the learning environment (de Graaff & Kolmos, 2007) more recently also derived from research (Borrego, Froyd & Hall, 2010) in efforts to promote 'scholarly excellence' (Trigwell & Shale, 2004). Efforts that systematically allow value-added feature to surface and influence change has been addressed as an important feature for the development of engineering education (Bowden, 2004). Recent indications support curricular innovations as being attached with high awareness levels among engineering faculty, yet not through dissemination of research papers but through word of mouth and presentations (Borrego, Froyd & Hall, 2010). Curriculum-level design improvements show that what is portrayed as authentic engineering projects tend to suffer in learning alignment (Arlett et al., 2010; Litzinger et al., 2011).

Change requires both content and the delivery of the curriculum; a move that itself may be difficult context where universities easily resist change as a matter of organizational design and tradition (Crawley et al., 2007). Academic change-agents operate in engineering programmes to develop activities and curriculum, usually only on a small number of committed and highly autonomously working faculties (Graham & Crawley, 2010). The expectation that graduates should take on the role of agents of change has also gained attention (Crawley, Edström, & Stanko, 2013). Implementing change is ultimately in the hands of the individuals responsible for creating, adopting, and adapting a given task (Arlett et al., 2010). Research has, however, presented these enablers as people who do not recognize their own influence in the changes made and who are little recognized by others or rewarded for their work (Hannan, 2005). Employing a champion who nurtures and protects a potential new product (i.e., course or module) from inception of an idea to its launch has been suggested as a more effective approach to addressing resistance to change (Martin & Horne, 1993); in this way, a champion can act as an antithesis to an individual's natural resistance to change (Johne & Snelson, 1988).

2.8 Research questions

The discussion to this point has attempted to deepen the connections between perspectives on innovation from an industrial and an educational view. The theoretical aspects brought up specifically address how students perceive and motivate themselves to establish a greater awareness and to ultimately gain knowledge about the ways elements of early innovation can be established through experiential learning. The first research question deals with how diverging and early converging activities are established through early-phase innovation. With a perspective on how the design process is applied for master's level project students, it mixes a set of intangible and tangible elements (Cross, 2011; Sheppard, Pellegrino, & Olds, 2008): orientation and information gathering, design research, idea generation, concept development, concept detailing and refinement, 3D visualization, and prototype development.

RQ 1: What are the characteristics of elements for learning early-phase innovation in engineering education?

By denoting how a problem is framed and pursued in the learning environment, enabling elements may be understood from a given context. The relevance of context and ways to understand it provides founding principles and possible implications to new learning environments (Borrego & Bernhard, 2011). A learning environment that can nurture innovation is essential to expanding the experiences and practical implications of knowledge application (Hassan, 2011; de Graaff & Kolmos, 2007). The research question intends to investigate the driving forces of students' commitment that characterize students' learning process. In review of what might influence a given context, both a contextual recognition (internal features) and facilitation for on-going work (external influences) is looked upon.

RQ 2: How are elements put into practice and facilitated throughout early-phase innovation in an engineering education setting?

The third research question highlights the unlocking mechanism from an educational perspective and asks how to go about transforming students by imbuing them with a greater awareness of early-phase innovation. Building on the work of research authorities in the field of engineering education (Dym et al., 2005; de Graaff & Kolmos, 2007; Prince, Felder & Brent, 2007; Sheppard, Pellegrino, & Olds, 2008, Crawley et al., 2007, 2011; Peercy & Cramer, 2011), educational efforts must change existing courses and programmes to better address existing and future challenges. Given that these changes are made from the teacher's (i.e., the educator's) perspective, this research question should mirror the learning possibilities that could support such change efforts.

RQ 3: How can the learning elements of early-phase innovation be transferred into curriculum activities, courses, and programmes in engineering education?

To approach the complexity of innovation in engineering education, the research questions provide an emerging path of understanding. Learning elements of outcome-based innovation and problem-solving capabilities could alter approaches and the state of initial problem exploration, and thus motivating curricula re-design efforts (Arlett et al., 2010; Litzinger et al., 2011). Recent research frames deep-level thought and changes in beliefs as emerging influences based on the concerns derived through problem solving and process refinements (e.g., Burton, Schlemer, & Vanasupa, 2012; Sheppard, Pellegrino, & Olds, 2008). By aiming for curriculum transferability, academic change places the attention on power holders and on systematic structures as the means for implementing change.

3. Methodology

3.1 Research perspective

Emphasizing an understanding of how new knowledge has been established and has contributed to research clarifies a stance and sheds light on later interpretations. Precautions have been taken according to a pragmatic structure intended to strengthen the objective nature of the research and to establish guidance (e.g., Yin, 2003; Miles & Hubermann, 1994). Showing concern for such founding perspectives created a starting point that positions the research in relation to belief paradigms. Portraying the way methodological perspectives have been applied interpret distinct perspectives on how the form of knowledge could be addressed both in relation to single contributions, i.e. papers, and thesis as a whole. Arbnor and Bjerke (2009) define two distinct perspectives. These perspectives balance out knowledge assumptions and the fundamental approaches sought by the researcher in qualitative studies (ibid.). The two perspectives are located on separate levels, one a macro level, referred to as a 'systems perspective', and the other a micro, detailed level that encapsulates the actor's view—the 'actor's perspective'. What has been declared an 'actor-observer asymmetry' (Jones & Nisbett, 1971) could well fit this scenario when one is interpreting student perspectives while also filling the role of an observer. More recent studies indicate that asymmetries should not necessarily be treated as bias but, rather, as a consequence of dealing with multiple cognitive and motivational differences that fundamentally exist between actors and observers (Malle, Knobe, & Nelson, 2007). O'Laughlin and Malle (2002) use a supporting belief that for this research interprets students' performed actions as observations built on causal explanations. Here, the research has been addressed from the actors' (i.e., students') attention to frame the elements of early-phase innovation. In a subsequent step, the research examines a holistic perspective on learning that concerns facilitation and learning about innovation.

The perspective on adopted on early-phase innovation is that it relies strongly on an operational capability that is manifested in performances and distinct establishments. There are however embedded knowledge and work practices allowing knowledge to evoke a need recognition that reconcile steps of action with external input. This thesis uses this linear view of innovation but deepens the meaning of each step by looking into social interactions and the interplay of individuals as facilitating creative activity. The social perspective has been strongly argued for and used in previous research, as well as in design (Cross, 2006) and innovation (Schroeder, Van de Ven, Scudder, & Polley, 1989).

The research examine learning whose aim is to portray how actors' understanding can be facilitated so that they better learn and comprehend the innovation-derived situations that they face in their learning scenarios. The learning process aims to enhance student learning, and in doing so, reinforces or adds new knowledge. Distinct student activities are isolated and independent from one another so as to explain how new knowledge is captured and shared among actors. Sharing is especially central to understanding the systematic mechanism behind collaborative learning that is captured and drawn upon as a means of combining innovation and learning in higher education. The captured knowledge about innovation in education transcends a constructivist perspective where the actors portray and display the reality being investigated. Without by any means proposing a unified view of the engineer, the research ambition was to identify individual and joint efforts that project members made. Nevertheless, this allowed the research to propose a holistic understanding of actions taken rather than solely addressing individual recollections.

3.2 Research design

A descriptive research design is suitable when a research problem is clearly structured and research aims to explain the characteristics of certain groups (Hair, Money, Samouel & Page, 2006). In addition, a descriptive study can further extend and develop patterns that were derived or generated during an explorative stage. This design facilitates the clarification of complex issues by determining how different factors of possible influence on innovation interact. The research was conducted through a set of six studies and summarized in an elective set of papers (papers 1–6), each of which functions as a solitary piece in relation to the overall purpose. The individual research presented in each paper contributes to answering a specific part of the overall investigative purpose, as well as to addressing individual research questions. Figure 3.1 depicts the relations between the research questions and papers.

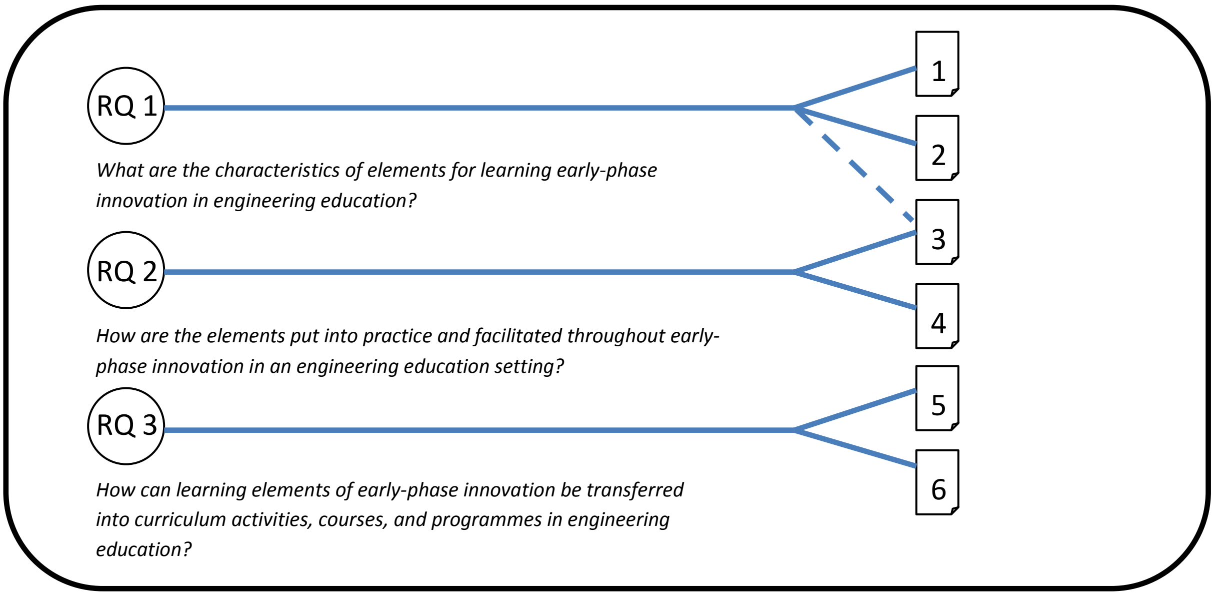

Figure 3.1 The relationship between the research questions and papers 1–6.

Research question 1 connects to papers 1 and 2 and, given that investigated elements are contrasted in practice to some extent, also to paper 3. Research question 2 provides a practice-oriented description of projects in which elements are put into context, thus papers 3 and 4 provide some answers. Finally, research question 3 explores the possibilities of evoking change efforts beyond the existing domains, thereby connecting to papers 5 and 6. The first two papers emphasize divergent and explorative thinking and the practices that design challenges present to students. The third paper focuses on context, placing students' design ambitions in the spotlight, particularly regarding how students executed and reflected upon their early-phase innovation work. The third study also builds on distinct motivational attempts that reinforce the actions of using and activating the already investigated elements, such as idea generation and prototyping. Further, paper 3 focuses on the self-regulated and proactive efforts that the students made while implementing elements of early-phase innovation. The fourth paper covers the facilitation of the student projects' self-perceived efficacy. Paper 5 addresses the question how a collective group, rather than single individual, could strengthen students' learning of the development process. The product in this scenario is not technically originated but still follows the 'stage-gate' (Cooper, 1990) procedures of outlining a finalized prototype—a report. Building on paper 2, in which prototyping captures collaborative mechanisms as a driver for learning and communication, paper 5 presents a complete contextual shift in the systematic approach applied. Finally, the sixth paper proposes a way of integrating student learning with a playful board-game logic approach, while combining a taxonomic learning incline with an innovation process graduation. For this process, the paper aims at an approach that incorporates elements of early-phase innovation in a game format that intertwines recognition, acceptance level, and a willingness to interact. The duration and progress of each study is indicated through a horizontal bar and captured in a concluding research paper, indicated by a flag in figure 3.2.

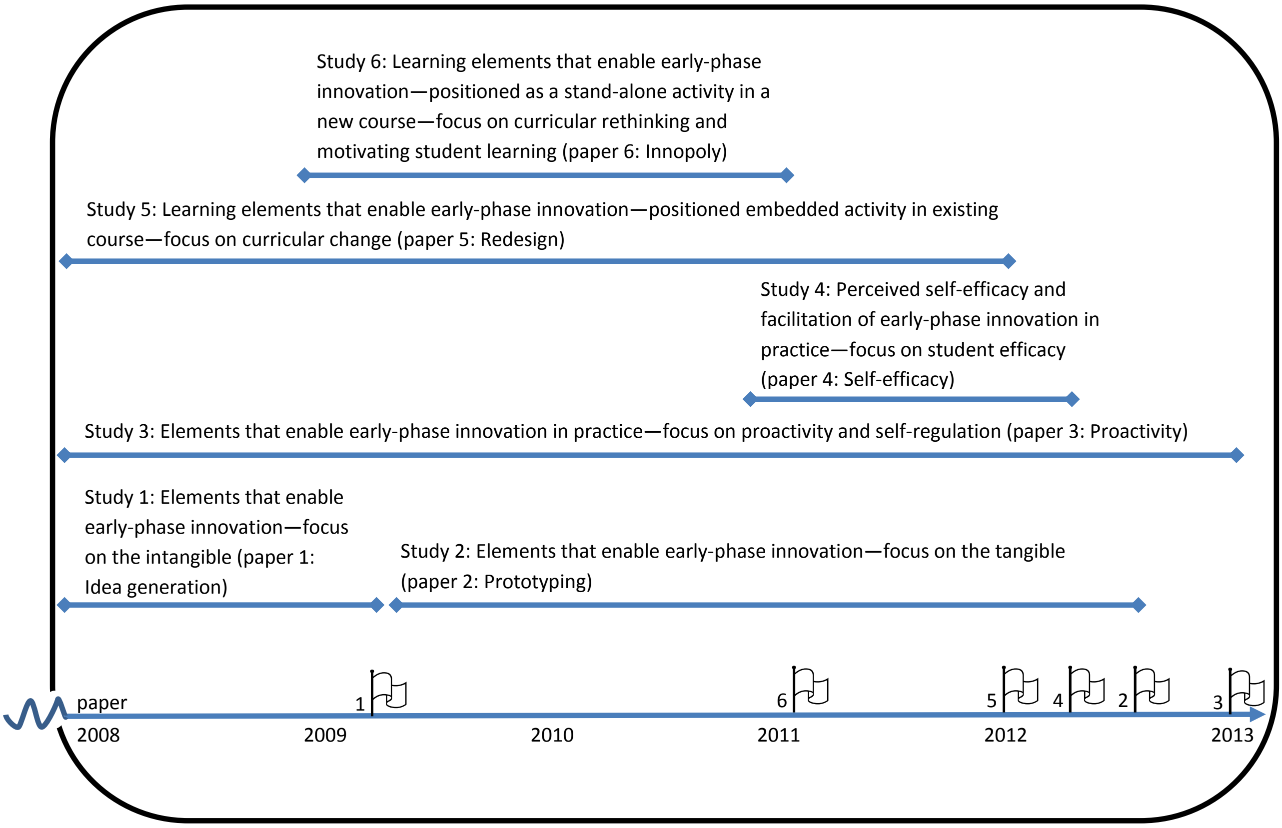

Figure 3.2 The research progression outline.

3.3 Research motivation

Chapter 1 condenses the main investigation to the following research purpose: *This thesis aims to explore how learning elements in engineering education influence students in early-phase innovation and to propose ways that such elements can be used to support early-phase-innovation learning in current and future engineering curricula, courses, and programmes.*

The purpose has been developed based on the method for proceeding in future research argued for by Yin (2003) and Eisenhardt (1991). This research was consequently designed with particular methods and procedures for collecting and analysing data in order to achieve the overall purpose.

There are different ways in which research designs are purposively categorized—namely, exploratory, descriptive, and explanatory (Yin, 2003). Reynolds (1971) uses stages to describe the way different portions of the research might be captured with different aims. The research has been carried out through an evolving cycle in which exploration was helpful in obtaining a foundation of knowledge. The point of origin can be located in the learning elements of innovation; next the study moves towards a more descriptive character by relating the performed exploration to the research questions. In doing so, the research possibly expands on portions of theoretical arguments proposed to frame the existing phenomenon of 'innovation in engineering education.' The arguments presented in relation to engineering education hitherto may interpret that suggestion could still be made to support the subject-matter learning of engineering design in relation to innovation. Consequently, the intended explorative character is appropriate when relations concerning the investigated elements are difficult, new, or unknown (Yin, 2003).

3.4 Setting for student interaction

Designing originates from acts by humans; for purposes of this thesis, the actions are those undertaken by engineering design students. Based on a gap of industrial application in authentic product-development work practices and support methods (Norell, 1998), and inspired by what became known as Design thinking (Kelley, 2001), the Integrated Product Development master's level project course (hereafter referred to as the project course) is a 24 credits (ECTS) half-time course that span cross three quarters of a full year. Before the year 2010 the project course covered a full academic year on half-time, 30 ECTS in total. The course is characterized by ill-defined problems or loosely set criteria and constraints; these are the input variables the students receive. Participants are enrolled master's level students, a combination of Swedish students and fewer international students.

The course's main focus is a practical engineering challenge that captures the attention of the students through three-quarters of a year as a half-time project. The project is carried out in cooperation with an industrial partner and in teams of 10–15 students. As outlined in the course description, students are responsible for project operations; each team receives teacher assistance from an assigned coach. Throughout the project, each project team reports on its progress to a steering committee that comprises both faculty (predominantly the engaged faculty) and industrial representatives whose objective is to guide the project forward and meet the project objectives. The primary aim of the course is to create and provide students with valuable collaborative design experiences, to practise skills that range from user needs, problem definition, idea generation to prototype production. One long-standing description of the course indicates that highly complex technical challenges need to be solved using a complex set of resources under circumstances in which differences in competence and skills are unvalued. The multifaceted set of resources is spun together, creating complexity not only in the challenge but also in the ways of utilizing people, systems, and methods. This includes the task of integrating diverse knowledge and skill sets to provide a well-designed final product. Decisions made are also analysed, discussed, and reflected upon.

Cross (1992) formulized an educational research proposition that focuses on (a) problem formulations, (b) solution generation, and (c) cognitive strategies. Following the situational dynamics and context characterized by student project teams, support is grounded in all three streams, thus supporting the foundation for the methodological approach itself. According to Whyte (1991), these are (a) social research methodology (i.e., students' collaborative communication and interaction), (b) participation in decision making by low-ranking people (i.e., students' self-regulated project work efforts) in organizations, and (c) sociotechnical systems thinking regarding organizational behaviour (i.e., transparency in work practices between work domains and lessons learned that are relevant for other contexts). This setting is the focus of papers 1, 2, 3, and 4. Voluntary participants from the project course were also active in the meetings that contributed to paper 6.

The project course is intended to equip students with practical experience and essential knowledge about how to produce complex products in a complex setting. Complexity in this sense relates to work procedures in dealing with, for instance, stakeholders, competences, people, processes, and support methods to master the ambiguous work that arises soon after project initiation. Students work in large product-development teams comprising approximately 15 students and operate in close relationship with an industrial sponsor (Beskow & Ritzen, 2001; Berglund, 2012). Based on demand-driven changes, continuous improvements in work procedures are mainly organizational; "multi-functional teams working in a project form are significant for industrial product development today" (Beskow & Ritzén, 2001: 173). The project course assessed for this thesis is characterized by the coordination and systematization of parallel development processes and activities covering stages that move from the idea's birth to its manifestation as a functional prototype, a proof of concept.

The project course involves students in a project experience that lasts three-quarters of a year. Each project is set up in a relatively open-ended project description, including a specified set of open and closed (fixed) project requirements. Through hands-on development work, often as the first real industrial encounter for participants, student learning takes place via realistic encounters with early-phase development work. Paper 5 concentrate on bachelor students and how to influence a process redesign in an otherwise strict individual and single-perspective way of working.

3.5 Collection of student data

To mitigate bias in the data collection, student respondents were recruited from many different project cases (episodes) among the annual enrolment in the two main courses that contributed data to this research. This concern the project course and the Bachelor thesis course taken by engineering design students that pursue an undergraduate degree with focus on integrated product development[2]. The variation of sample context provides possible distortion and polarization of views that might follow a sample selection (Eisenhardt &

[2] Spring 2014, attention on subject IPD, course: MF121x – previously, attention to originating programme: MF111x, MF112x and MF114x.

Graebner, 2007). Methods for this design include participatory observation, interviews, focus groups (moderated as workshops with participants providing individually and with peers), and finally, a sample setup including both project course students and external design students.

Throughout this section, participatory observations have been denoted as a source of data, and for this purpose these observations were made through a unilateral process, characterized by little researcher interference in the project groups' autonomy. This research addresses the fact that the development of a designer-oriented skill is best facilitated by giving students practice—not by simply talking about or demonstrating what to do. Observing students' progress and opportunities to understand how an arising problem is approached becomes a key concern and has been central in past studies (Cross, 1993; Whyte, 1991; Adams et al., 2010). Student interaction and engagement in activities have been of great concern in establishing a deeper understanding of student learning. In relation past engineering design research (Larsson, 2005) this thesis concerns methods that put attention on a specific cohort over time, i.e. student groups. Observations of engineering work have allowed identification of key characteristics to the elements of learning early-phase innovation in collaborative design environments. The observations focus on the interactions of, communication among, and actions performed by project members.

The research has been oriented by presence and localism as natural components in the role of both lecturer and researcher. Scholars (e.g. Cross, 1993; Whyte, 1991; Adams et al., 2010) present how qualitative research could shift in details of what, where, and how in relation to traditional methods (e.g., participant observation, broadly constructed and unstructured interviewing). Throughout the papers, the qualitative methods used were selected in order to facilitate better understanding of the motives, reasons, and behaviours of the actors involved.

Whether ideas are gained through any sort of formalized methods, paper 1 was screened and pragmatically adopted within the research context, the student project under investigation. Further, in an attempt to provide students with an enlarged perspective on possible ways to approach initial problem scenarios, the first paper sampled students who were actively involved or had recently been involved in an idea-generation session. Participatory observations were made on several occasions each week, while the most diverging ideas and early converging attempts was processed by the project group. Notes were recorded regarding the ways students combined elements of methods that they knew by heart, forming a purposeful approach new to them and creating new alternatives. These notes were embedded in the screening table that charted a set of 30 different idea-generation methods and outlined how the project students perceived their work via the chosen methods. Probing questions asking 'what' and 'how' supported rich description in the idea-generation methods that students applied.

The second paper conceptually reviews performed prototyping activities performed in the integrated product development project course. This was done through topical research meetings that elaborate and sort out interruptions in the process of conceiving the basic underlying element of prototyping. Artefact data were collected and screened to enable fairness in the partly retrospective approach of establishing perspectives.

In paper 3, observations were made at occasions twice a week, as the project teams met up for work. Subject investigations referred to as cases in the paper were separated in time by two years. Minor adjustments in questioning were made to the second case in order to gain more distinct and targeted scenarios (e.g., data gathering, discussion concerning problem definition, idea generation, presentation of group ideas and prototyping occasions). Observational notes were made during internal project meetings, work-in-progress activities concerning, particularly, idea generation and prototyping efforts, and formal gate meetings. Student perceptions and their instant reflections after completing an activity were ascertained through brief questioning that aimed to understand both what they had been doing, using their own phrasing, and how those activities could influence the project. This idea is similar to that behind applying idea-generation methods (paper 1). When examining the context in which the specific activities had been carried out, different projects were able to show a degree in variation and activity to different learning elements involved. Investigations took place throughout the entire project, and weekly 'captures' framed scattered project activities. Individual reflections were examined, which were part of course assignments, treating them as supporting secondary data sources.

The fourth paper presents data from two parallel projects. To determine self-efficacy levels among participating students, a structured questionnaire was used. Students were asked to provide answers on two separate occasions: before the second gate meeting, which took place before the summer holiday, and after the fourth gate meeting, which took place midautumn. Given the occasions for data collection were separated in time by six months, and took place in presummer and midautumn, attention was paid to explaining the questionnaire details underpinning the design and the categories that determined self-efficacy on both occasions. To retain as much internal validity as possible in the questionnaire, categories similar to those of the original Ambrose et al. (2010) setup were used; however, interpretations had to be somewhat modified to target individual student perceptions instead of reflecting a lecturer-student point of view. The categories with connected interpretations were explained on each testing occasion.

The fifth paper treats the combined bachelor thesis course that is offered to students completing their degree projects in one of the following programmes: Design and Vehicle Engineering (course: MF114x), Design and Product Realization (course: MF112x), and Machine Design (course: MF111x). The sampled population was not fixed throughout the longitudinal four-year encounter. Following student classes that changed annually entailed directing lessons at a systems level. The level of reasoning covered course structures, activities, and outcomes. Data were retrieved using observational studies based on in-class interaction with students, on report deliveries, and on questioning students both in class and after hours via e-mail. Observations were made of weekly course activities and interaction; these varied in focus throughout the thesis-writing process—topics included exploring the purpose, discussing the problem, and considering theories of data collection, analysis, and conclusions. No predetermined template was used for this; rather, such structure was avoided so as to minimize undesirable effects on the role of course lecturer. As researcher, participation in post-course activity, i.e. course analysis, focused on structuring thoughts and writing brief summaries that would be stored for later use in support of the paper as lessons learned. In some course episodes, students were also asked to share reflections in both written and oral form throughout the course. The longitudinal process takes the perspective of the researcher/lecturer and the system (i.e., course) that was captured in relation to 'needs recognition' (year one) to 'radical change' (year two), 'incremental adjustments' (year three), and 'process refinements' (year four).

In preparation for paper 6, learning elements for innovation was targeted to be tested. Two workshops were designed and carried out, three months apart. Four project course students participated in the first workshop, which was organized to test students' beliefs about innovation as a concept for education. They were asked to provide sketches, explanations, and perspectives on how different suggested scenarios could be outlined or would be required. Students were encouraged to think in alternative ways and played with Lego® blocks to illustrate elements of concern. The second workshop scrutinized the collected propositions from the first workshop, which by that time had been fitted into a very early version of what would become paper 6. On this occasion, eight integrated product development master-level students participated, two of whom had been involved in the first workshop. This time, a test version of the paper had been sent out for students to read in advance, and the starting point was testing boundaries and formats for playing the proposed game, Innopoly. Notes were taken throughout the sessions and all material displayed or written became available for allowing post data collection analysis. In addition to data from the two workshops, a final set of written reflections were collected from a dozen industrial designers. The written reflection part was designed to provide conceptions of Innopoly in particular and of innovation in higher education in general. Internal pre-workshops were held for the involved lecturers (i.e., the three paper authors) in which possible ways to approach and test the game ideology was pre-tested.

3.6 Research generalizability

This thesis pursues mainly exploratory research, in which quality assessment is a way of relating conducted efforts to a demanding quality measure (Yin, 2003). With the aims of making this research useful to others and focusing on overall generalizability, this study pays attention to what methodology researchers consider two linked, generalizable distinctions—empirical and theoretical. The empirical concern, also called 'external validity' (Yin, 2003) and 'transferability' (Bryman, 2008), concerns the degree to which findings can be applied in new settings, new contexts, and by new sample representation. The theoretical aspect relates to better understand the phenomenon of innovation in engineering education and how possible theory building arguments and propositions could contribute to the understanding. In a similar way, Barnett and Ceci (2002) present transferability as something multi determined, stating that transfer relies on content and context sensitivity that intercept aspects that are physical, social, and semantic.

Yin (2003) uses a division of four categories to cover validity and reliability from both internal and external dimensions. Screening this research through such a categorical lens would provide more depth in the meanings of and differences between such categories. Bryman (2008), suggest that qualitative research should be screened against a different set of taxonomic statements rooted in the overall trustworthiness of the study undertaken. The question ‘why’ should also be an iterative mantra portraying each word and each activity undertaken when addressing the study’s overall relevance. This research particularly deals with implications, and thus two independent papers (5 and 6) are dedicated to creating depth and considering implications beyond the given context. Relevance in this sense concerns the accuracy of these implications so that they nurture the theoretical domain and its contribution, in details as well as on the whole. This research also follows a stringent approach that touches upon the use of theories, methods, and procedures that have matched and influenced the statements made.

In greater detail, this research has been conducted qualitatively and from its subjective nature presents original thoughts and interpretations. This dependence on subjectivity is difficult to overlook, yet creating room for objectivity would necessarily produce elements of transferability that could render efforts in this research worthwhile in terms of a follow-up and testing in similar academic settings (or in any other settings where they might be considered suitable). Guba’s (1981) evaluation model for research closely scrutinizes studies undertaken from a qualitative perspective. The research should be designed, conducted, and analysed according to a pattern of recognition so that its rigour can be evaluated. A qualitative researcher, however faces a conflict in understanding a phenomenon’s true nature since that understanding is necessarily subjective, based on the researcher’s own perception. However, the addressed views need to be legitimized; otherwise, such an approach implies that everything perceived as a data point is an item for interpretation, allowing less objectivity and discarding the simplest truth. Conducting this research perceived in a reality rooted in the actors’ view provided means of sorting out knowledge about items that were not always easily expressed. In this respect, a qualitative approach provided rich in-depth data to aid interpretation and subsequent quality concerns.

The possibility of replicating performed research is a prime factor in determining the research’s acceptance in scholarly contexts (e.g., Yin, 2003; Bryman & Bell, 2005; Cohen, Manion & Morrison, 2011). Given this research’s explorative purpose the way methodology is outlined determines how well objectives are met. Research’s legitimacy depends on whether it is objective or subjective (Cohen, Manion & Morrison, 2011). This research deals with a subjective nature although the explained efforts have been made to meet a more objective stance. The more objective stance is found in the social constructivist view, which—rather than attaching each individual to a distinctive universal belief of the world—corresponds to a pragmatic view. The social reality behind student interaction addresses objectivity where separate entities collectively are perceived as one. The projects’ collaborative and dynamic pattern of interaction could now be summarized with regard to overall impressions and interpretations of distinct behaviours and actions undertaken.

Still, Yin (2003) tells us that a degree of robustness can be attached to the design of qualitative research. By using detailed context descriptions, this study follows a method that allows in-depth examination of complexity and the specific nature of a distinct phenomenon (e.g., Bryman & Bell, 2005; Miles & Huberman, 1994). Using vivid context descriptions also opens up for opportunity to apply multiple qualitative methods and to strengthen the overall robustness. Specifically, participatory observation and unstructured interviews are both common and well suited to extensive and detailed studies (Bryman & Bell, 2005). To ensure that this series of steps was followed, the research involves as many crucial aspects as possible. Interpretation is inseparable from qualitative research, and with concern for what Bryman (2008) calls 'conformability', the objectivity emphasizes how the researcher's role might have influenced processes and findings.

3.6.1 Role of the researcher

As argued in the introduction, the dual role of the researcher (i.e., as both lecturer and researcher) involves the risk that truth will be distorted and polarized through interpretation, which is not necessarily an objective procedure that produces objective findings. Based on Bryman's (2008) taxonomic reasoning, students exhibit a dependency on the lecturer responsible for grading, while the role of the researcher involves the dependency of establishing fluent communication and gaining access to students' work. This has put the 'credibility' concern in focus; a researcher with less proximity to the investigated cases might gain in objectivity yet lose some of the details. The stipulated reassuring 'conformable' data have been provided by accessing distinct student courses that, over time, followed similar integral procedures. To avoid situations that could result in too much bias in the perceived data, the collection procedure was treated as delicate. As for the informal queries that evolved in my interaction with students primarily as a lecturer, there would be ethical grounds for recording or verifying these statements; in sum, many of the findings and occurrences are based on notes and observations performed when interacting (passively and actively) with students. As a consequence, data interpretation involves the delicate risk of portraying a distorted reality—yet this is the reality, consequently interpretations made should be perceived as such by those scrutinizing the credibility and legitimacy of the statements made. The credibility of investigations focusing on distinct student groups should be handled with caution when stating any 'transferability' opportunities. The conducted studies should be considered in relation to other engineering design–oriented courses, given the uniqueness that characterizes investigations of qualitative studies.

Overall, though this study's trustworthiness and transparency exhibit limitations, its openness is significant, as are the potential to derive wisdom applicable in other contexts and the usefulness of the conducted studies and findings. Feldman (2007) argues that qualitative studies are related not for measurements but rather for describing, interpreting, and creating an enriched understanding of a certain phenomenon. The subjective character of most qualitative research (Yin, 2003) has been taken into consideration here in terms of structure and processing aspects, such as position of the research, the data provided, and the analysis performed. These steps provide a basis for expanding the otherwise one-sided interpretational truth towards greater objectivity, necessary for this research to be considered less subjective.

3.6.2 Subject of investigation

Point of origin—where should one begin the search for evidence, trying to understand the elements investigated? This research carries a biased sampling situation in which the research setting is also, conveniently enough, the courses that the researcher and lecturer's work has concentrated on. Addressing access to the given population of investigation could probably have been performed in numerous other ways; it is important to state that this research concentrates on a particular context where access provides a sense of control—useful when dealing with aspects that are experienced as anything but controllable at times. Access to rich qualitative data is one of the foremost criteria when conducting research (Bryman & Bell, 2005; Miles & Huberman, 1994). With concern for the objectivity, distance, and control that relate to the sampled data and the procedure of the analysis, the data have been treated as objectively as possible, even though they are also qualitative and 'person dependent' and thus subjective by nature. This idea is particularly critical to this research, which concentrates on a fractionalized sample that does not represent either the general engineering population or even that of engineering design.

The analysis of the collected data has been treated as objectively as possible. The research process concerns explorative stages that set out to find answers to questions influenced by what Reynolds (1971), more than four decades ago, called explorative stages—there is not necessarily a need to present a final answer; rather, the idea is to promote insights into further research. Like the final design of student projects, the research process rarely starts from a given description but rather from criteria, considerations, and desirable requirements about performance. Roozenburg (2002) summarizes the key modes of reasoning in design situations that have evolved, via automated reasoning, from the originating purpose.

This line of reason does not automatically reflect the presumption of facts (Roozenburg, 2002). Rather, the purpose is to set up and engage a new set of actuation points that are intended to derive a fresh start, in addition to the initially stated purpose. Based on new knowledge derived by addressing that purpose, an explanatory and secondary descriptive nature is captured (i.e., the 'why'). As a consequence, the findings presented in the last chapter's conclusions should reflect an intended continuation, rooted in iterative reasoning.

4. Appended papers

The appended papers intend to address and provide answer to the stated research questions. In all, the papers present the conducted research results. A schematic view of how the papers interrelate and the key contributions of each are provided in figure 4.1.

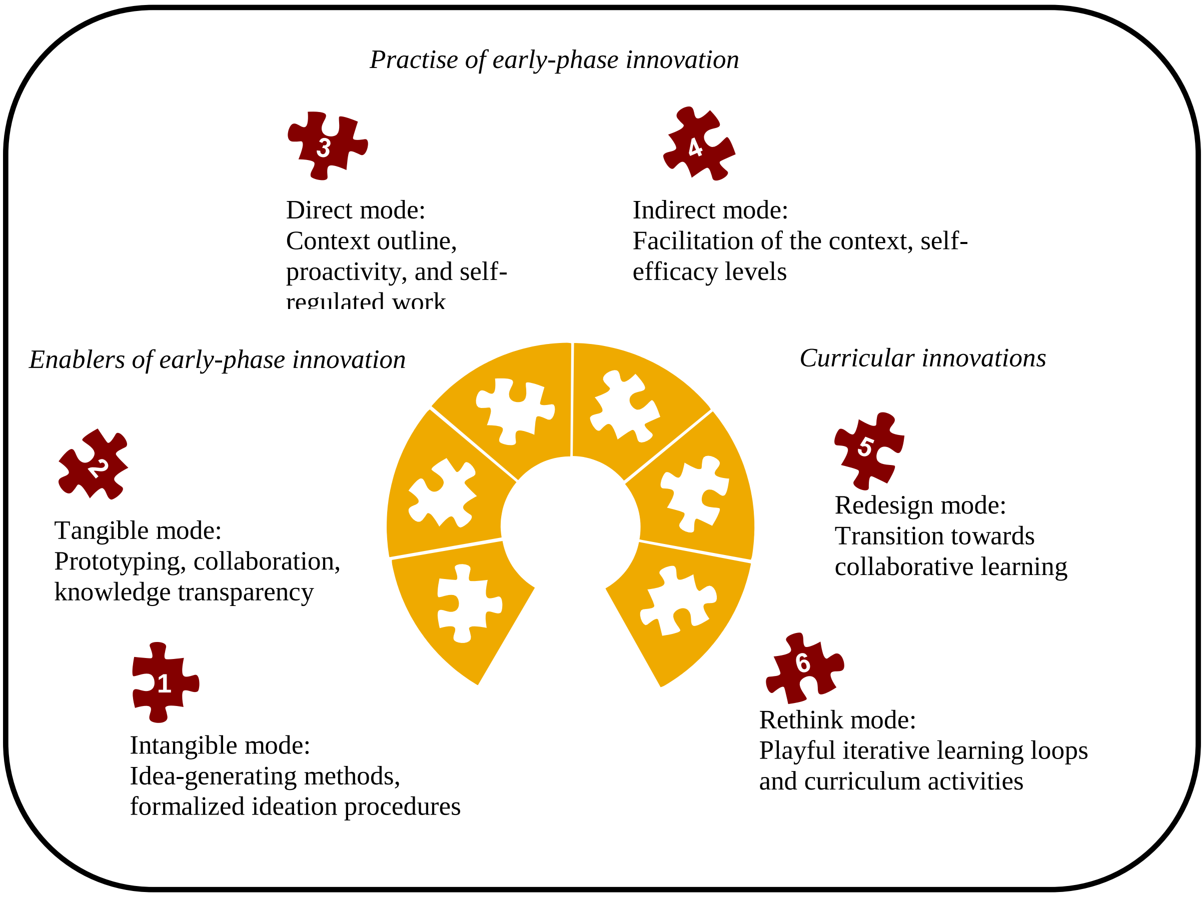

Figure 4.1 Outline and focus of each paper's result section.

Barton, Schlemer, and Vanasupa (2012) use three distinct dimensions to approach innovation in engineering education. Based on the foundation of these dimensions (problem solving, process improvements, and transformation), the results are strongly characterized by their underlying meaning. Elements of early-phase innovation present knowledge through interchangeable embedded and explicit artistry, in either 'intangible' or 'tangible' modes. Process improvements relate to enriching the practise of knowledge either 'direct', which relates to students' acts of doing, or 'indirect' that address the facilitation of students' work. Building a momentum for change, transformation through educators' efforts is perceived to break existing patterns and allow new knowledge and processes to be addressed through actions of 'redesign' and 'rethink'. The appended papers present the captured results independently, yet still interlinked in three categories; 'Enablers of early-phase innovation', 'Practise of early-phase innovation' and 'Curricular innovations'. The first two papers present two distinct modes in establishing early-phase innovation, as well as the ways enablers for learning are captured in the activities of the idea-generation methods and prototyping. The next two papers centre on how performed activities are put into practice, focusing on context and on the facilitation of contexts in which enablers are active. The last two papers concern an elevated thought process, focusing on educational implications to help enablers evolve. The last two papers concern two distinct curricular innovations; the level of change and novelty is expressed through the notions of redesigning and rethinking. In all, these six clustered pieces each addresses a unique portion of the spectrum of modes that summarizes the research: intangible, tangible, direct, indirect, redesign, and rethink. The papers present a progression that integrates founding beliefs of innovation and learning into a common theme.

Paper 1

Berglund, A. & Ritzén, S. (2009) Towards Individual Innovation Capability—The Assessment of Idea-Generating Methods and Creativity in a Capstone Design Course, In *Proceedings of the 6th Symposium on International Design and Design Education*, ASME 09, San Diego.

Innovation per se is based not only on individual problem solving but also on the process that moves a product from new idea to commercialization. In a time with rapid technology shifts and frequently altered customer requirements, idea generation methods have been used to identify ways of invoking creativity. This paper consists of a combined theoretical and empirical approach that aims to study existing tests and propose methods suitable for teaching creativity in higher education for engineers. The authors work with an extensive capstone design course in integrated product development that emphasizes systematic and parallel approaches to product development. The project-based course use idea generation methods to diverge the exploration of feasible ideas and possibilities.

In addition, the course puts a large part of the responsibility for progress on the student. Thus, students' self-regulation and insights into how to work with idea generation methods and exercises are of particular interest, and study of these factors may uncover ways of improving their creative skills management. This paper aims at students' ability to pursue innovation by adopting and use idea generation methods and to the extent influence of formal methods is used in the work. The ambition with the paper is also to assess on what grounds the selections made by student project groups best utilize students' own creative thinking. Idea generation methods are useful only if insight and fluidness in the understanding and application of methods are present. Since methods may restrain the creative efforts, teams show less stringency towards a single 'right' way of working with distinct methods. Rather, an inspirational and inventory-related approach is used that sometimes even merges elements of existing methods into a user-friendly version that students tend to favour. Students display ownership as a motivational aspect in their work of interpreting idea generation methods, establishing their own versions.

Key contributions: Idea generation methods are useful for implementation; achieving deep knowledge of distinct idea generation methods involves having the embedded capability to implement skills in other contexts. Ownership and the application of methods are derived from what has been learned, thus promoting a plethora of alternatives for students to play with.

Paper 2

Berglund, A. & Ritzén, S. (2012) Prototyping—The Collaborative Mediator. In *Proceedings of the International Conference on Engineering and Product Design Education, EPDE 12*, Antwerp.

Prototypes are made and presented and interpreted differently by people according to each individual's understanding and frame of reference. The communicative entity of prototypes has immediate implications beyond the design domain as 'boundary objects' (Carlile, 2002; Boland & Tenkasi, 1995) and 'ambiguous artefacts' (Cross, Christiaans, & Dorst, 1994). Responsible for a plethora of diverging activities, the types of information and specialist knowledge embedded in prototyping require a breadth of perspectives on the concept itself. In ideal terms, prototypes should engage individuals to evoke sensations of new knowledge but how is knowledge shared and interpreted? This paper investigates prototyping as a means of building learning experiences and the way prototypes act as boundary objects. The collaboration involved with prototyping allows individuals to open up and be influenced as they integrate more input from peers into their own subsequent concepts. Conversely, colleagues also appreciate more useful feedback on their creative thinking and prototyping efforts. Thus, prototyping provides a tangible expansion of the generic understanding between interacting peers. Differences between industry and academia in the ways prototypes are interpreted and applied seem more contextually dependent and therefore more difficult to pinpoint. In contrast, past prototyping research is reluctant to show more than scarce pedagogical comparisons at cognitive levels. This paper shows that prototyping is an important mechanism in engineering education, the value of which moves beyond distinctive product-development phases. Prototyping also unlocks cognitive mechanisms where embedded modes (e.g., visualization and communication) enable an expansion of the perception of boundary objects. Prototyping highlights a pragmatic way of approaching innovation. The function of a collaborative mediator is apparent in many different ways as the action of prototyping allows for the expansion of existing knowledge.

Key contributions: Prototyping is an active contributor in manifesting inner thoughts and externalizing knowledge, making the implicit tangible. Visualization and communication are the two main criteria that catalyse such a collective appropriation. Participants who share a common understanding of the problem at hand and collaborate are more likely to make use of their colleagues' input, applying it to their own concepts, and to themselves contribute without concern for distinct individual ownership.

Paper 3

Berglund, A. Proactive Student Learning—Towards Innovation in Engineering Education. *Submitted to journal.*

This paper's main contribution is a deeper understanding of what an innovative context in engineering education might look like. In detail, it presents an investigation concerning the proactivity and autonomy level of students actively enrolled in a full-year engineering design graduate course. Rooted in what is traditionally categorized as a project-based learning scenario, the paper presents strategies and experiences that can be used to improve the quality of student learning. In particular the paper looks at activities, e.g. idea generation, prototyping and collaboration, that can support and foster the development of self-discipline that allows a project group to be motivated and excel. The paper describes how two different engineering student projects can produce radical new output when provided with conditions that allow them to operate autonomously. Proactive antecedents are searched for in the student team's work outline. The results indicate that students provided with a design challenge seem to learn by verifying and testing beliefs that they have established through mainly past theoretical knowledge. Proactive behaviour is apparent in the work ambition, time on task, and overall performance achieved. Findings also emphasize that clearly stated learning objectives, in combination with open and flexible coaching, positively influence students' motivation to learn, participate, and understand future work roles and processes.

Key contributions: Proactive student learning is rooted in intrinsic motivation, which by freedom and flexibility in work processes opens up room for creative expression. Self-derived values act to strengthen the motivational experience for project members. Students' systematic approach and engagement in e.g., problem definition, organizational aspects, and the project's realism, foster the development of independent learners.

Paper 4

Berglund, A. (2012) Do we facilitate an innovative learning environment? Student efficacy in two engineering design projects. *Global Journal of Engineering Education, 14*(1), 26–31.

This paper investigates student efficacy and the motivation to work in relation to three distinct forms of interaction were student perceptions is used to support a project's overall efficiency. Based on previous research into student efficacy (Ambrose et al., 2010), this study takes a student-centric point of view: self-efficacy is based on students' intrinsic motivation to work. The paper's principal goal is to investigate how different elements of interaction cause students' beliefs to shift, both individually and in groups. Results show that the internal proximity and joint motivation to work have positive influences. The way feedback was given by external stakeholders (i.e. coach and firm) matched a preferred constructive and valuable approach by students. Reported differences clearly separated the teams with several features, e.g. group cohesiveness, stakeholder proximity, organisation, project management and coaching. Students' perceptions of their own efficacy levels are determined by their group cohesiveness and ease in communication with involved stakeholders and peers. The two groups showed variations in team composition and beliefs, especially regarding the manner in which 'external' parties contributed to the respective group's overall performance and innovative output. Although output results were equally satisfactory between project groups, differences in perceived facilitation were apparent. This suggests that further attention should be paid to requirement expectations and to ensuring that facilitation efforts are part of forthcoming projects. Also, expectations by external parties need to be scrutinized prior to implementation as this may influence variation of interaction and cause minor or major disturbance or 'noise' that could affect the projects overall performance and output.

Key contributions: Facilitation and team composition are key features for establishing a high motivational self-efficacy level among engineering design students. Self-efficacy measurements by students present interaction with peers as influencing to the internal supportive climate. Indications were shown that registered ratings provided higher motivational ratings towards in the end of projects rather than in the beginning.

Paper 5

Berglund, A. (2012) Moving Beyond Traditions: Bachelor Thesis Redesign, *International Journal of Quality Assurance in Engineering and Technology Education*, 2(1), 31–45.

Student learning is built on native ability, preparation, and experience but also on the compatibility of a student's learning style and the instructor's teaching style. Past research (Kolb, 1984; Felder & Silverman, 1988; Baillie & Moore, 2004; Biggs & Tang, 2007; Crawley, Malmqvist, Ostlund, & Brodeur, 2007) indicates mismatches between engineering students' common learning styles and traditional teaching styles. This paper addresses a transition from a teacher-centred approach to a collaborative student-centred approach. A longitudinal study of bachelor thesis redesign is described by following the progression of three parallel courses during four consecutive years. Moving beyond the traditional practices of individual thesis writing, a strict individual assignment has been transformed; now, roughly 50% of theses originate from collective work efforts. Findings support a collective approach when working with bachelor thesis writing as work groups become self-governed and develop a creative disposition, pursuing functional knowledge and key generic skills of industrial relevance and collectively supporting deep-level learning.

Key contributions: 'The research provides a pluralist perspective on student learning where stage-gate procedures are mitigated with distinct individual and collaborative work activities. The paper articulates the need to redesign the bachelor thesis that aids individuals by: enabling functioning knowledge learning; shaping key generic skills of industrial relevance; and creating understanding-seekers rather than knowledge-seekers' (Nair & Keleher, 2012: iii–iv). The paper reflects a change process in which innovation is applied to a course outline so as to favour a collaborative approach rather than an individual one. Injected with product development, the focus on a step-based stage-gate incline is used to ensure quality and deep-level learning.

Paper 6

Berglund, A., Lindh Karlsson, M. & Ritzén, S. (2011) Innopoly, Design Steps Towards Proficiency in Innovative Practices, in *Proceedings of the International Conference on Engineering and Product Design Education, EPDE 11*, London.

Different ways of addressing learning have long been a source for revitalizing existing curricula and programmes. One distinct way to approach learning has been through various forms of games. These have in common that they strive for a dual cause: allowing fun and excitement while paying attention to distinct learning objectives. The research tries to intercept the need for playful attitudes and creative dispositions involved in early-phase-innovation problem solving. This paper presents design steps to bundle innovation skills in an educational model that, as our previous research shows, involves ideas and construct foundations rooted in a game-plan ideology aimed at examining innovativeness (Berglund, Lindh Karlsson, & Ritzén, 2010). In this paper, the ambition is to deepen students' abilities to apply self-governed innovative practices within a team. The paper presents an educational model for embracing design creativity, building on the foundations of a game-plan ideology that explores innovation-driven practices. It also sets out to find a way of communicating coveted and sustainable knowledge and to motivate learning, since it will affect the momentum of a self-driven learning process. Through a series of workshops, focus groups, and course analyses with engineering design students, the paper frames and concretizes the 'Innopoly' educational platform.

The educational prototype Innopoly consists of an inclination model inspired by Bloom's taxonomy (Bloom, 1956; Anderson & Krathwohl, 2001; Anderson, Krathwohl, & Bloom, 2005); it is meant to prepare students for future challenges. The implementation of specific interdisciplinary design elements aims to strengthen students' understanding of the various ways to carry out and practise an innovative process. The ambition of examining innovative practices is fulfilled by incorporating applied skills in order to manifest an autonomous level of performance and integrity. Innopoly follows the outline logic of the innovation process—identification, research, ideation, concept, prototyping, testing, and commercialization—similar to the way increased value can be traced to the original game form. By deriving needs and escalating value-added activities, the proposed Innopoly prototype comprises description on both an operational (i.e., course-activity) level and a strategic (i.e., course-design) one. Both levels are rooted in Bloom's taxonomy with the ambition of leveraging students' innovation-related experiences and knowledge. The paper considers the operational level that, in short, concerns learning the innovation process through the act of addressing game plan logics. Although the model is not fully realised, its accessibility and awareness of elements involved in early-phase innovative are important to later, more thorough explorations.

Key contributions: This paper demonstrates the value of using playful approaches as embedded curriculum activities meant to facilitate the learning of innovation. The intersection of play, the innovation process, and learning taxonomies provides an applicable game format. Promoting creative flexibility, students engaging in various learning elements put possibility to alter and reinforce specific actions and experiences. The game presents an adjustable course format that approaches the innovation process, using both educators and students to define, alter, and stimulate play.

5. Discussion

This thesis initially framed the problem of innovation in engineering education as an attempt to bridge the learning elements of early-phase innovation and ways of practising support for educational implications. The following sections cover the stated research questions, presenting the findings of the investigated papers. Each section begins with a stated question formulation, which is followed by the arguments and interpretations that can be made.

RQ 1: What are the characteristics of elements for learning early-phase innovation in engineering education?

The elements for learning are complex in composition, like the problems and challenges that they are designed for. These enablers exhibit a dichotomy between structure and freedom. The following discussion concerns how elements that allow a balance of structure and freedom are expressed in the research conducted. In relation to how students face the investigated learning scenarios, collective learning is enacted by establishing structure and implementing a systematic approach. The opposite, individual learning, seeks to promote free thought, through which tangible and less tangible modes of innovation are expressed. The goal of this balancing act is to allow the evolution of several distinct features that support learning.

Starting out with 'Enablers of early-phase innovation', the first paper considers idea-generation methods, demonstrating that the level of embedded knowledge in idea-generating methods used is crucial for a systematic supporting structure in creative thinking. The ambition of the study was to discover the learning levels of students who use idea-generation methods in early-phase innovation. Ultimately, the relationship between planned activities, execution of activities, and the perceived value of using various idea-generation methods were scrutinized. Early-phase innovation began from a systematic approach in which ideas were tested and iterated through prototyping attempts. The establishment of deep, applicable disciplinary knowledge is vital here in order to swiftly facilitate the materialization of ideas. The collaborative efforts involved in prototyping, it could be argued, set a common understanding among participants while also enriching the knowledge being used.

The context in which both idea generation and prototyping are carried out also emphasizes students' determination and intrinsic motivation as contributors to project derived establishments. The more the context intervened as a factor in early-phase innovation, the clearer the supposition became that the learning elements involve varying degrees of activity. Consequently, for this paper, the student projects investigated involved a behavioural connection, emphasizing proactivity, self-regulation, and student empowerment. The findings also suggest that early-phase innovation is a phenomenon that evolves in a project setting in which individuals adopt new knowledge through self-awareness, self-directedness, and self-reflection. It was found that diversity and proactivity concern an externalized way of approaching activities. Openness and motivation concern an inner perspective that needs to become embedded in the minds of the participating students in order to affect the more explicit nature of the influencing elements. Since interpretation of these elements may differ depending on context, the following section allows for a description of the way interpretation was done in relation to what paper 1-3 present.

DIVERSITY allows different perspectives and methodical approaches to the same event while also contributing a multitude of either ideas or prototypes. The findings show that diversity helps resolve a given problem; past research has recognized this as a process of identification and the establishment of a varied solution space (Shah & Vargas-Hernandez, 2003). After testing a variety of creative expressions, communication—or rather, ease of communication—emerged as crucial to the characteristics of elements. Allowing multiple perspectives and ideas to flourish, students indicated greater confidence and consequently established more robust and practical approaches for consideration. Multiple input sources also meant multiple ways to bring forward new thinking and interpreting new findings. Though knowledge alternated between divergence and convergence, the application of past knowledge was shown to bring new thinking patterns into play.

PROACTIVITY concerns students' action-oriented determination as they go about gathering, testing, and analysing data. Presumptions and planned actions establish a structure vital to efficiently achieving a project's main objective. In a student-centric learning scenario, students are thus able to act with rigorous seriousness while maintaining a systematic approach. A proactive characteristic displayed efficient execution of planned activities and the greater display of internal appreciation among participants. Allowing formal methods to influence the interplay could, based on the findings, confirm that *instrumenting* design activities had a positive effect on the groups' motivation, cohesiveness, and performance. Research mentions how important understanding students' design skills is, as well as the significance of how they act to enhance potential ideas and reflect on actions taken (Cross, 2006), yet full comprehension of what such understanding entails is very difficult to obtain.

OPENNESS bridges a founding belief for project participants to share and communicate, as equals, relevant sources of information. This particularly emphasizes allowing a climate to develop within the group that unifies a plethora of thought patterns and does not shut out individuals who do not 'merge with the masses.' Establishing high-level thinking patterns is a way of opening up channels for both incoming and outgoing knowledge. This channel of sourced knowledge is allowed to flourish only if most project participants agree to fully share and adopt what is communicated. A minimum of constraints were found; instead, the relatively free work structure that characterized the student projects investigated became a foundation for an understanding of ideas, concepts, and functions. In relation to the way idea-generation methods mostly target inner-directed perspectives, students showed dedication to drawing out these individualized perspectives and to establishing a broad span of thoughts that could be acted upon. New ideas were shown to be critical for project members' on-going sharing process.

MOTIVATION is, by nature, a split phenomenon in which intrinsic and extrinsic values cause certain behaviour. The students' endeavour and passion are actuated through intrinsic motivation where self-awareness and disciplinary knowledge become vital ingredients for internal boosting. External support is an important factor in students' internal processing. A myriad of actions can be taken by educators (e.g. informative communication, up-front planning, time-on-task, pursued interaction, response-time) to strengthen students' to influence students' motivation. This thesis shows that students who engage heavily and invest in their learning are fuelled by intrinsic motivation, allowing them to act and draw inspiration through collective 'ownership.' In terms of intangible (idea generation) and tangible (prototyping) modes of learning innovation, students perceive self-made versions as user-friendly as well as time-saving and teambuilding. Depending on level of idea generation and prototyping activity, minimal prior knowledge, and little complexity is involved in initiating a corresponding activity. Proactive behaviour and self-guided efforts constitute motivational triggers for student activity. Paper 3 and to some extent paper 1 reveal that the regulating switch was balancing student empowerment with a fair amount of challenge. What an appropriate level is depends on the seniority of students and their anticipated level of expertise. It should also be noted that ownership and a sense of control were important for allowing projects to progress smoothly and for intrinsically moving a motion forward.

The way students need to balance collaborative duties that come with establishing a joint and combined complex project, therefore, motivates an inner and an outer level of reasoning. The results indicate that 'diversity', 'proactivity', 'openness', and 'motivation' are distinct characteristics of learning elements for innovation. This research characterizes learning elements as a way to balance systematic procedures and playfulness. Illustrated by idea-generation methods and prototyping, diversity and allowing pre-planned actions to guide student initiatives are vital to exploring the complexity of problem scenarios and their settings. By making revitalizing interpretations through iterative work, design and manufacturing allow early assembly and construction visualizations. Establishing a process whereby this interchange takes place 'automatically' allows rigour to become part of the systematic process, resulting in more concentrated doses and efficient learning in which creativity and design are combined.

Playful approaches in project work open the way for unexpected and possible innovations in engineering design projects. This phase spans the cross-implementation and practice of ideation and idea-generation methods for prototyping attempts. As the findings in paper 1 and 2 indicate, the diverging approach should aim to support a multitude of perspectives, functions, critical domains, and aspects not thought of. Iterative and joyful idea generation exercises were carried out by students, allowing ownership and quality concerns for details. Rather than the mere production of ideas, the collective attachment was provided by the openness among project members that purposefully selected and defined methods to be tested. Consequently, supporting idea-generation techniques and prototyping exercises establishes connectivity and a pattern of recognition between individuals' learning and their intrinsic motivation. Learning through systematic processes tends to establish quantity as a prerequisite to overall quality in ideas and manifestations expressed. Using iterations and fixed deliveries, a given challenge opens up the breadth of knowledge that can be accumulated and enhanced collectively. The ability to test myriad perspectives through thought processes shaped to derive creative ideas and tangible manifestations of prototypes serves as a creative starting point from which outcome-based innovation can grow. Results show that students working with idea-generation methods in particular welcome the diversity of creative proposals produced.

As for the professional aim of creative design, in which functionality is the focus, students need to consider expanding their knowledge and skills related to the design structure and its process. The time spent elaborating designs through different methods enabled divergence in which students acted self-governed and allowed multiple creative dispositions. A gradual increase—to systematically influencing students with ideas and processes—that supports early ideas seems to derive from past experiences and the type of learning context the students find themselves in. To support strength and input from the context in which action takes place both cognitive (e.g. freedom, support, constraints) and physical (e.g. tools, place, people) recognitions should support the creative input being made. These ingredients relate strongly to what has been described as the 'creative climate' (Ekvall, 1990; Ekvall & Ryhammar, 1999).

The results show that performed project activities form a sequential time-on-task template that enables more efficient student work. In situations where project deliveries are scrutinized (i.e., at gate meetings), some cases raised concerns about adhering to a pre-established template. Communicating externally with company experts is seen as vital, although it can also evoke internal concern about increased criticism of students' design and technical considerations. Focusing on divergent approaches that capture growing ideas in both intangible and tangible formats, students showed openness and sincere willingness to test a broad set of both idea generation methods and prototypes. Creating depth of possibility for a potential outcome, such learning examines ways to influence and stimulate self-propagated methods of working that align creative ideas with the systematic considerations needed to avoid becoming bogged down in distinct activities, considering instead what is accomplished through each iteration and work session. Clear and precise communication in particular in the conceptual phase of design, where information gathering and idea generation are present, relates to what past research (Shepard et al., 2008) has found resides in the minds of individual designers and must be communicated to team members before it can be discussed, built upon, refined, and evaluated. Consequently, the communication of a large amount of information occurs.

With regard to RQ 1, *characteristics* are interpreted as vital for both idea generation and prototyping to make a substantial cognitive connection. Adding deep-level knowledge through participatory and interactive patterns of behaviour moves beyond intangible ideas to methods and techniques that nurture the understanding of a targeted issue. Through collaborative sharing, flexibility and openness keep the individual up to date with a multitude of applicable methods and techniques. Procedural knowledge found its roots in collaborative efforts that are common in many of today's engineering design projects (e.g., Dym et al., 2005; Sheppard et al., 2008; Graham & Crawley, 2010). Yet subsequent links to innovation are portrayed merely from either an output-driven or a process-oriented design perspective. The consequence of this has been a generic scenario that filters out core pragmatic activities as generalist learning objectives.

Tasks that reinforce project experiences and learning cover a number of designated work practices: need-finding preferences, determining project requirements, benchmarking alternatives, conceiving solutions and prototypes, user testing, team building, project organization, and the capture and reuse of domain-specific knowledge. Early-phase innovation expresses a dichotomy between enabling thoughts and actions. As students pay attention to user-driven needs, they accumulate understanding of the phenomena at hand. This understanding is expressed differently, although it is by nature less tangible and rigid than what prototyping efforts manifest. Consequently, combining efforts that allow an iterative process to take place interconnects the use of both elements and favours more rapid motion; both intangible and tangible practices are thus challenged and played with early on.

The overall objective is to develop functional literacy, or ‘lateral depth,’ across these core notions. The concept of lateral depth in this attempt to develop integrative capabilities contrasts sharply with the ‘vertical depth’ needed for good research. According to de Bono (2010) vertical thinking digs the same hole deeper; lateral thinking is concerned with digging a hole in another place and by so testing new beliefs. Being and thinking in new ways involves connecting different levels of knowledge in an internal integrative effort. Such an effort relates to lateral depth so as to establish connectivity between embedded knowledge and external knowledge, projecting a saturated image of need difficulty.

RQ 2: How are elements put into practice and facilitated throughout early-phase innovation in an engineering education setting?

Reflection and learning about early-phase innovation should initially be screened from a larger context in which the elements are present. Reflection and action has been practised in a context similar to that addressed in the research (Eris & Leifer, 2003). The empirical findings have noted that the learning environment in which new knowledge is produced and facilitated undergoes cyclic loops of input and dissemination. Further, learning situations made students to operate actively in both the role of actor and recipient. Paper 3 distinguishes students as proactive in their action to prepare and execute routines, including specific reflection exercises that take place throughout the projects. As part of the course delivery, i.e. a learning objective, passive abstract reflections are present as students conduct reflections throughout their work. As the relation a direct experience and impact of their experience is influencing their subsequent actions can be perceived to be ‘concrete abstract’ (Bergsteiner, Avery, & Neumann, 2010).

Paper 4 study students’ self-efficacy and how different domains of interest (e.g. project group, coach and industry partner) influence the learning environment. The facilitating coach must be aware of the two other learning loops in order to coach in a way that maximizes the overall learning experience or output performance. Barton, Schlemer, and Vanasupa (2012) describe process improvement as arising when scrutinizing the way problem solving is conducted. Encouraging students to embrace diversity and behave proactively involves continuous updates whereby routine knowledge (i.e., things known from past experience) is constantly mixed with what is going on presently. This approach emphasizes how students have engaged in their problem-solving activities report an increasing level of self-efficacy towards the realisation of each project. It remains unclear exact reason to why self-efficacy is reported to score higher values in the near completion of the projects investigated.

Papers 3 and 4 provide insight into how innovation outputs are established and facilitated. Findings show that interacting parties, faculty, and industrial partners in these investigations can potentially have a leverage effect on students' existing working knowledge. Consequently, expectations must be matched by those individuals (coaches and firm representatives) who are in direct contact with the students. Coaching includes an array of opportunities as outlined in paper 4; generic aspects (e.g., communication, planning, testing, and design) bring an objective approach to the coaches' roles of facilitation. Coaching in the design of innovative outputs is no longer considered relatively new (Carrillo, Carrizosa, & Leifer, 2003), having progressed from the phase in which this knowledge was captured largely implicitly and anecdotally. The facilitating role throughout the projects relates strongly to what has been labelled the coaching role (Reich, Ullmann, Van der Loos, & Leifer, 2009). The coaching role is characterized by a loose, independent relationship between coach and students (ibid). According to the facilitation interpretation, the coach acts as an independent source of support, the students' work and performance constitute the focus, and the aim is to avoid unnecessary complexity. As each project encounters different coaching needs, students tend to benefit from different types of facilitation—that is, from various coaching styles.

The findings emphasize concern for technical aspects and group process issues; the coach's facilitation should move from an ad hoc function to a supportive function that aims to build a work atmosphere in which students feel at ease and comfortable while working. Functional groups tend to favour strong cohesiveness and interrelatedness, as in the cases investigated in which the reported high level of self-efficacy indicated strength in terms of both the achievement culture and deep learning involvement. The students' project work, furthermore, showed that internal proximity and work intimacy motivated them to express feelings more openly. By showing emotions, appreciation and appraisal of good efforts made each project to inhibit a unique atmosphere involving both joy and at times frustration and anger. The cohesiveness became even more present in the subgroups that were allowed to stay untouched over time, which became evident in how self-efficacy became perceived in relation to project and subgroup settings. The students that addressed the subgroup in combination to the main project group were those that had established less proximity and bundled work relationships within the project group as a whole. Organising the larger project group in to subgroups is a 'natural' and efficient of progressing, however once subgroups become entities that carry distortion to what is trying to be produced overall, the composition, duration and input needs to be addressed. Consequently, reorganizing efforts have more than a triggering effect when loosening up and breaking apart certain formal sub constellations; the learning provides new roles and formations that need to be assimilated. Informal settings may be more difficult to access and influence. The findings have identified differences in openness among student groups. Students' acceptance levels act to legitimise actions by external parties (e.g.

lecturers/coach or nonparticipants) making communication and input flow (to students as recipients) a critical and vulnerable aspect.

Facilitating large or expanding group settings involves the risk of a sense of detachment. Weaker attachments reduce the advantages of multiple perspectives that allow increased breadth of reasoning and thus may constrain emotional identification and the sense of shared commitment, ultimately leading to less-satisfied students. Although this conflicts with the core composition of courses that favour addressing complex problems in large, multifunctional, and complex groups, research states that when size increases, individuals' efforts decline. The way students are put in position to organise and re-organise their project groups, is done according to the principles of constructive alignment (Biggs & Tang, 2007), making them being exposed and learn from complex situations of realistic character. Consequently, the type of course, the way facilitation is conducted, the course structure, and (where possible) the extraction of some sort of legacy may exist, put student motivation on tasks beyond group size related structures.

A somewhat oversimplified assessment procedure when it comes to judging degree of innovation is to deduce existing creative processes from the features of the creative output. As past research has pointed out, the creative output of early innovation attempts could well be categorized according to originality (or newness), appropriateness, elaborateness, and flexibility (e.g. Amabile, 1996; Klavir & Hershkovitz, 2008; Sternberg & Lubart, 1999). Providing a context in which early-phase innovations can be facilitated and nurtured into their prime would dedicate educational efforts to reassuring what Prince, Felder and Brent (2007) mentions as a set of implicit elements related to how the collaborative effort within the team is constituted and organized. The findings reflect these concerns in relation to project members' role attainment, shared responsibilities, resource allocation, internal recognition, and rewards. The facilitation of a project team's context confirms a set of researched aspects common to design projects in engineering education; up-front communication with clear-cut directives, teamwork, and a shared knowledge base (e.g., Peercy & Cramer, 2011; Crawley, 2007; Prince, Felder & Brent, 2007; Dym, 2005; Gibbs, 1992; Berglund, 2008, 2012). By addressing organizing issues, e.g. meetings, decision-making, leadership, delegation of tasks, the sharing and exchange of knowledge internally, and through open channels, from external parties increased the efficiency in the project groups. Hinds and Pfeffer (2003) argue similar the importance of establishing an understandable, mutual language is an inevitable precondition to bridging the gap between experts and the intended knowledge recipients who are involved in the projects.

In order to trigger innovation in engineering education, it is important to align learning objectives with the activities and assessment thereof. Using Biggs and Tang's (2007) constructive alignment learning activities should embrace (a) what is expressed as deviation attempts from routine solutions (originality), (b) relatedness to known solutions (elaborateness), (c) individual reflections that concern the possible creative issues for the produced output (appropriateness), and (d) the overall context and content of output. The ability to transfer ideas and thoughts to areas not considered initially in problem definition or to areas of investigation renders project teams to be dynamic and open. The engineering design projects incorporated into this study exhibit assessment features that varied uncontrollably among interacting peers who determined the value of the innovative output. Industrial partners connected to the investigated design projects support a problem-area description that, depending on the scope of detail, includes minimal constraining factors. Internal assessments have considered how the project group tackled the problem of establishing the finalized output. However, a measuring effect of these four aspects (a–d) could be well suited to individualizing the extent of innovation efforts. This remains a profoundly difficult method to implement owing to the nature of the collaborative mechanisms behind the projects. In parallel to the collective gains of the group, individuals benefit from an assessment procedure that highlights the extraction of individual works (e.g., portfolios, log books, reflections, lessons learned). The findings display transparency to individual learning's in relation to the target of skills used in early-phase innovation.

RQ 3: How can learning elements of early-phase innovation be transferred into curriculum activities, courses, and programmes in engineering education?

The step-based incline of students' achieved understanding of ways to enable elements of learning of early-phase innovation coincides with the proposed 'structure of observed learning outcome' (SOLO) taxonomy introduced by Biggs and Collins (1982), 'constructive alignment' (Biggs & Tang, 2007), and Bloom's revised taxonomy (Bloom, 1956; Anderson & Krathwohl, 2001). Similar to Biggs and Tang's (2007) reasoning, paper 6 set out activities to be designed and aggregated for a given set of learning objectives that converges in the act of playing as part of examine student knowledge. The findings use a playful approach to conceive a link in which the four competence-building dimensions illustrate distinct elements available for testing and learning, evolving from descriptive to procedural knowledge. The proposed playful-learning model highlights actionable learning in which doing becomes essential as a founding principle for learning. In common for the learning taxonomies (e.g. Biggs & Collins, 1982; Bloom, 1956; Anderson & Krathwohl, 2001), is the incline of an increased awareness that allows activities to be tested, new knowledge to be applied, analysed, evaluated, used for design and re-created. Findings emphasize that the selection of relevant topics to be learned should not be content-overloaded but should, rather, focus on establishing an attraction that will motivate students to acquire understanding. Both paper 5 and 6 make distinctions regarding how this transfer of educational changes can be articulated and addressed. Findings put forward collective approaches to learning and to ways peer-to-peer formats may support individual learning while raising concerns about quality and students' learning efficiency.

The findings in paper 5 are inspired by a research-based change towards collaborative learning, and the pursuit of a thesis work that relate processes similar as the design projects. Still, much of what is presented also captures teaching experiences and reflection, which is according to scholars should be looked further beyond, and rather confront changes from a research-based paradigm (Borrego et al., 2008; de Graaff and Lohmann, 2008). In this sense, dependencies to the learning context representing the course and curriculum should guide the operational, and detailed work progression of any innovation made, yet the guiding and direction should be addressed from a research perspective. In cases presented with researched examples if transferability is fairly possible it could be relevant to change initiatives even on a more detailed level.

Papers 5 and 6 address potential changes to be made that initiate elements of early-phase innovation. According to the holistic rethink and redesign image presented by Peercy and Cramer (2011: 625), "engineering education provided to current and future students needs to change significantly in order to prepare our graduates for a world of rapidly accelerating changes." In detail, redesign efforts modifying traditional routines and practices may trigger changes that promote skills of importance for innovation. Situating students as peers relating to one another allows for different learning techniques and collaborative learning. Facilitating this process is presented in paper 5, closely related to the stage-gate procedure as found in industrial product-development processes (Cooper, 1999). The output is tangible, yet in the form of a written report. The characteristics that portray the development process present the need for project organization and resource allocation. Internal acceptance among group participants also guides ways for sharing and production to be made.

Finding inspiration to support a process-oriented attention is rooted in the early innovation claims of Schumpeter (1942), which according to innovation researchers could be summed up as "doing things differently" (Crossan & Apaydin, 2010: 1155). Burton, Schlemer, and Vanasupa (2012: 275) refer to this as a way of "interrupting existing patterns". The challenge to shift and leverage students' learning could be perceived as being rooted in acceptance levels and interpretation of useful new knowledge by students. This emphasizes building blocks that shape key generic skills, e.g. organizational skills, project management, communication and collaboration. Implementing curricular innovation target educators to redesign and rethink selected portions of existing learning. The studies set key principles of good teaching and learning in relation to student learning. Paper 5 derives learning attention from a restricted individual learning setting to a collaborative setup, a peer-learning scenario. Similar to how innovation use collaborative efforts to solve complex problems, peer-learning situations also require complex set of resources and skills.

Paper 6 elaborates ways that innovation could be taught to and inspired in students through a playful game ideology. Allowing playful approaches to elements relevant to product innovation is relevant for providing an increase of students' knowledge. For lecturers, this approach provides a myriad of practices that could be merged on different educational levels and to different extents. The research presents the potential of future course-design considerations; distinct innovation-related activities are presented in order to strengthen the use of skills that could provide a deeper level of applicability. The student-centred approach aims to provide an autonomous level of performance and integrity that would elevate learning potential and better achieve learning objectives. The ambiguous level of innovation requires that distinct elements thereof to be extracted in order to approach and access innovation more openly and direct. Change to existing programmes and courses must be balanced both on behalf of being effective and cost-efficient. The game ideology presented in paper 6 is does not imply faculty time to be redirected away from what researchers regards as highly fundamental, the interactions with students (e.g., Dym et al., 2005; Peercy & Cramer, 2011).

It is rather the type of interaction and on what basis that is brought forward as being different, student being active in peer-learning situations, with a guiding supervising lecturer at hand.

The idea presented in paper 6 use a modular method to allow interaction and efficiency in the learning process. The 'rethink' ideas presented in paper 5 stipulate also changes to how interaction is handled. By allowing change negotiations curricular injections may well be suitable to convey the rationale of the innovation process. Past studies suggest that project-based activities are often developed by staff members operating as lone champions with limited time, resources, and support (Graham & Crawley, 2010). Although many seek approaches that have been tried and tested elsewhere, the engineering education community supports robust models that could establish appropriate levels of particular initiatives. This also means that the responsibility for promoting innovation falls to those who have the authority to make changes over time. The research can be seen as testing change efforts in a local setting in a form of curricula innovation; however, for long-term impact this is not sufficient. Scrutinizing the courses (and programmes) each student is enrolled in should become part of a more embedded approach to incorporating innovation into a more extensive set of course offerings. Efforts that result in lasting change but that do not negatively influence existing engineering skills emphasize redesigning and rethinking the ways that learning elements of innovation can be integrated. Paper 5 supports collaborative learning and a process perspective on producing the outcome. A course design intended to produce output that is perceived as innovative, involving a process that sets students in a screening process of various prototypes, provides artefact recognition only over time, at best. Still, given more paths to recognizing innovation and via alternative ways of dealing with the subject, there is a chance for a longer-lasting change among students.

From the conducted research students' engagement is critical in every aspect of teaching and learning. Therefore, activities based on peer learning, teamwork and student motivation present opportunities that could support elements of early-phase innovation. Student engagement and the self-governed actions that is present in student-centric learning is in this thesis manifested as a variation level of engagement and their respective intent of carrying out subsequent actions. The sixth paper address joy as a key ingredient to induce change and that a rewarding learning environment could work in favour for both learners and educators by supporting clarity, motivation and engagement.

Engineering is far from static; rather, it is essentially a creative profession. It is necessary that educators find a way to address curriculum needs based on the choices and interests of students. Innovation in engineering education poses many challenges; one in particular, is whether a generalist approach or a focus on deep disciplinary-specific engineering skills is to drive the application of skills. Both types are needed, yet with the risk of diluting curricula and programmes comes a drastic refocus: the starting point should be to embed activities, elements that support learning. Attempts to specify the content of an engineering curriculum should be preceded by an understanding of the learning objectives to be fulfilled. These objectives are twofold, based on the technical and social responsibilities that must be accepted by graduates expecting to enter the engineering profession. Results from the research address students to be preparing for a greater lateral set of skills without reducing or interfering with specific technical knowledge. Technology today is rapidly shifting; students across the investigated studies show an overall tendency to welcome and incorporate new technical features that could enable support for organizing work and processes. This stresses that facilitating educators and faculties as a whole should to address change, and actively pursue a critical awareness of new, improved techniques and processes. Ultimately, stating that an engineering graduate should be able to innovate—treating innovation as part of the skill set expected of trained professionals—explicitly draws attention to the learning of innovation. There are indications in the findings that designated roles could support a link between efficiency and creative dispositions. Although roles exist in the investigated projects, it is questionable whether each enacted project role should individually address learning objectives, rather, as this research highlight attention to the value-added support to learning element could be made and reinforced through facilitation, i.e. interaction coaching.

The findings in concern for curricula redesign put the educator in a position that imposes a transformational shift as it involves actions that contribute change. From an external point-of-view this could be looked at as 'an act by a responsible lecturer'. Changes addressed as innovations should carry a clear benefit for the addressed user, i.e. the student, and be made based on quality concerns by those responsible for transformational processes. The most presently active party for change initiatives is similar to what past research has revealed the lecturer in charge (de Graaff & Kolmos, 2007) and in best of cases driven by scholarly excellence (Trigwell & Shale, 2004).

This thesis, proposes that in order for students to learn the actions of early-phase innovation, educators need an established understanding of the both research relevant for the area and the implications to practices that follows. Attention should also be made to embedded thoughts about how interaction with tomorrow's engineers should take place. Routines that address such actions should be made explicit and formalized so that necessary support can be provided in terms of allocated time and resources. Technical and social considerations are learned and fostered through the process of working and iterating with peers in engineering design projects. Elements such as idea generation and prototyping could be applied in order to intensify the learning effects of early-phase innovation. Still, even though students act both individually and collectively in the investigated projects, innovation remains difficult to define for the purpose of being separated in to an individual ability. Bowden and Marton (1998) question the authenticity of existing educational programmes, stating that skills should be validated against distinct capabilities. If it were legitimate to use such a definition, students would be in serious need of distinctly outlined skill requirements for the assessment and examination of their capacity to innovate. Currently, innovation is desired in engineering education, yet how is authenticity established unless direct track records or direct links to learning establishments can be made explicit? Innovation in engineering education has arrived at a crossroads: it is no longer useful for innovation to be central in courses unless there exist processes that allow an outcome-based innovation to emerge.

Simon's (1974) ill-defined and ill-structured problems is by Cross (2011; 2007) converted to diverging patterns of thinking, and early steps towards designing new elements that ultimately could become innovations. From the perspective of researchers in the field (e.g., Bowden &

Marton, 1998; Dym et al., 2005; Sheppard et al., 2006; Crawley et al., 2007; Graham & Crawley, 2010), the authenticity and contributory grounds for an engineer to be capable of innovation are questionable. The difficulty of transferability places interpretation, practical examples, case studies, and anecdotes about how innovation is treated in engineering education in a position that need greater support. Improving education and university learning involves a high level of knowledge dissemination whereby both internal and external evidence should be examined. Educational professionals need to learn from methods and practices that already exist; these can often be found internally, where there are lower barriers to overcome. Creating support for faculties to strategically implement new learning approaches and methods in favour for improved student learning should be pursued, as existing examples of such function has provided satisfactory support (MIT, 2012).

6. Conclusions

Revisiting this thesis's stated purpose, the concluding remarks present key insights that have emerged from this research.

This thesis aims to explore how learning elements in engineering education influence students in early-phase innovation and to propose ways that such elements can be used to support early-phase-innovation learning in current and future engineering curricula, courses, and programmes.

In what has been mentioned as active experiences and the act of doing, allowing mistakes is commonly cited as a key ingredient for building an understanding of one's actions. Kolb's (1984) view that learning needs to undergo application and reflection corresponds to the proactive nature of iterative testing that is tightly connected to early-phase innovation. This thesis presents ways that elements of learning equip students to engage in early-phase innovation. Directing efforts to enable improvements in student learning puts the impetus on educators to act upon and establish triggering effects among students. The research focuses on two facets in which innovation is perceived either as an embedded element or as a stand-alone element in courses, curricula, and programmes. Integration can be achieved by embedding elements of early-phase innovation in existing engineering education programmes; currently, early-phase innovation is less explicit and difficult to pinpoint. The research presented here focuses on the embedded learning elements that, in early-phase innovation, are given little attention as sole providers and initiators of innovation. This thesis draws attention to an act of perseverance that puts creative, proactive, and collaborative action at the centre. Figure 6.1 schematically elicits the individual, contextual, and educational learning imperatives, moving towards an agenda that highlights innovation in engineering education.

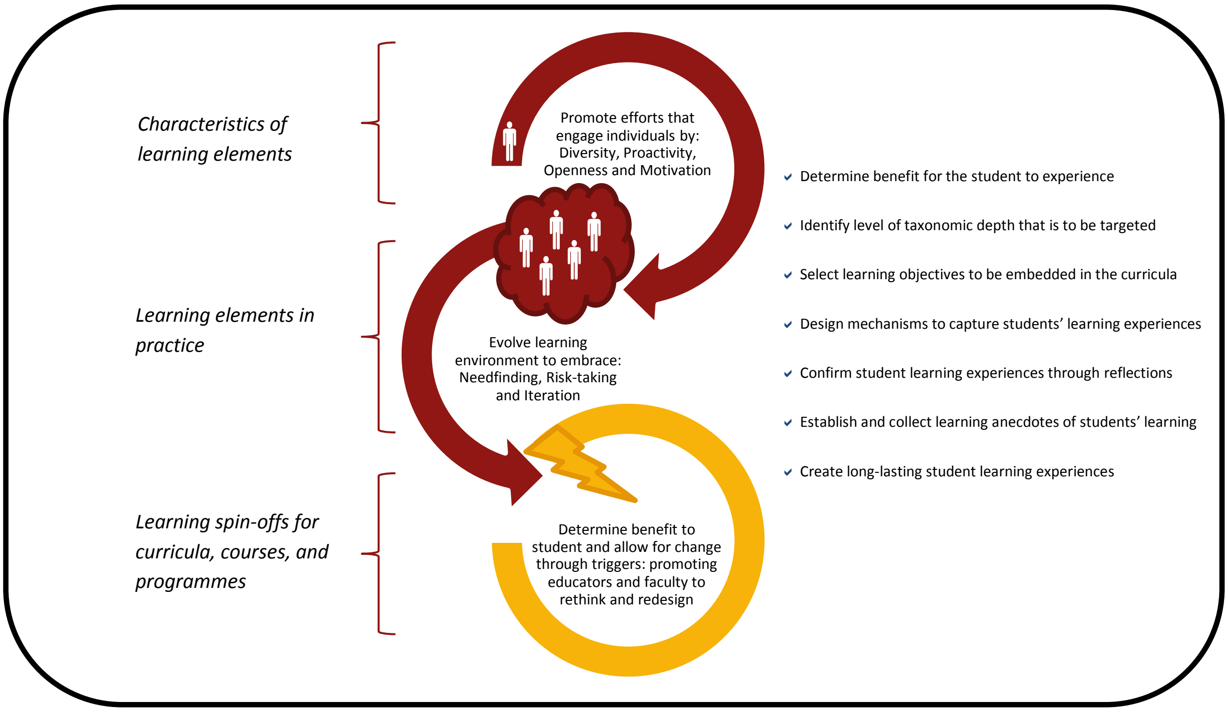

Figure 6.1 An agenda towards innovation in engineering education.

For higher education and for engineering education in particular, mindfulness regarding core skills (those considered fundamental for engineer professionals) is crucial; however, if the aim is to also embed innovation in the curricula, it should not be treated merely as an add-on. There is a need for coherence among discrete learning elements so that from the students' perspective, the bigger, holistic picture tells a story that translates into a distinct path for educators and that informs the selection of appropriate programmes or courses. There is no fixed method for establishing what is perceived by society as innovation; it fluctuates depending heavily on context and content. Ambiguous engineering design challenges have gained legitimacy and accreditation and today serve as learning platforms for both students (participating), educators (facilitating), and researchers (as test beds). The research pointed out that students' conceptual understanding and procedural skills develop through the iterations involved with development work.

Innovation in engineering education does not necessarily need to be extremely complex or difficult. It is important for educators to push forward elements that make abstract concepts pragmatic in nature and possible to act on. This thesis has looked at enabling elements that support learning for innovation through a practice-oriented approach to innovation. This is how innovation, what has been targeted as early-phase innovation concerns a direct and present, and easier to influence and act on. Providing a systems perspective on learning about innovation, the research have given attention to determining in what way learning can be established. Designing environments conducive to learning in which students can discover new ways of thinking and approaching challenges should emphasize team-building and empower students to become independent learners. Learning about innovation in engineering education provides three condensed arguments, which also function as considerations for the continuation of research:

- *Elements (e.g. idea generation and prototyping) that could trigger early-phase innovation need more support in engineering education.*
- *Elements centre on bringing individuals together, and together they generate a greater set of intangible and tangible knowledge relevant to early-phase innovation.*
- *Elements could be integrated into separate curricula and courses and, where appropriate, could be integrated into current curricula to better frame the thought- and practice-oriented nature of an innovation mind-set.*

Apart from the students' personal motivations, educators face the challenge of providing a setting that allows for diversity in, for example, technologies, opportunities, and perspectives. The importance of a systematic approach, planning efforts, and freedom that allows iterative testing and debriefs should be appreciated. The emphasis is on facilitating environmental issues so as to ensure improvements in students' intrinsic and extrinsic motivations while also allowing them to face continual challenges. Acting in such a setting, students will flourish by adopting an open approach to engaging distinct disciplinary challenges, as well as by developing the 'intra,' lateral way that they reason with peers and colleagues. Distinct learning elements constitute a basis for sharing accepted beliefs and new knowledge and for making them functional. The findings suggest a range of inputs in which perspectives and needs are the originating sources governing which piece of knowledge becomes attached to a particular meaning. Initial statements capturing 'to whom' and 'for what' link actions, or at least the thought of actions, to the challenge of ensuring student commitment to learning the existing curriculum. Allowing innovation as a catalyst in the educational approach also entails adjusting existing beliefs and values. Rooted in traditional practices, an act towards innovation allows a first step whereby attitudes are confronted and formed through ongoing experiences. Burton, Schlemer, and Vanasupa (2012) position the challenges to and transformation of beliefs and values as something that needs to occur in practice through new ways of thinking and prioritizing.

This thesis argues that efforts to incorporate innovation at a fundamental level need to aim at a systematic change that moves beyond the direct effects of changed practices. Figure 6.2 presents the interplay between student skills and the way their will to engage is expressed and partly captured through experiences. The lower pyramid captures the learning of a single individual in interaction with peers, interaction that influences whether the context that the educator provides can sufficiently challenge and support learning elements. In each situation the individual student faces an expressed (externalized) 'go' or 'no-go' decision captured in the symbol that entails intent and engagement. The 'no-go' might, however, be a cognitive active choice that results from self-observation, re-framing attention, and reflection. The figure captures what section 4.1 addresses namely, how the research papers correspond and how they centralizes individuals' efforts (papers 1-4) in relation to curricular innovations that alters the learning environment (papers 5-6). Curricular innovation is under the control of the educator, who needs to promote collaboration and shared experiences among peers so as to maintain a learning environment characterized by supportive values, beliefs, traditions and attitudes.

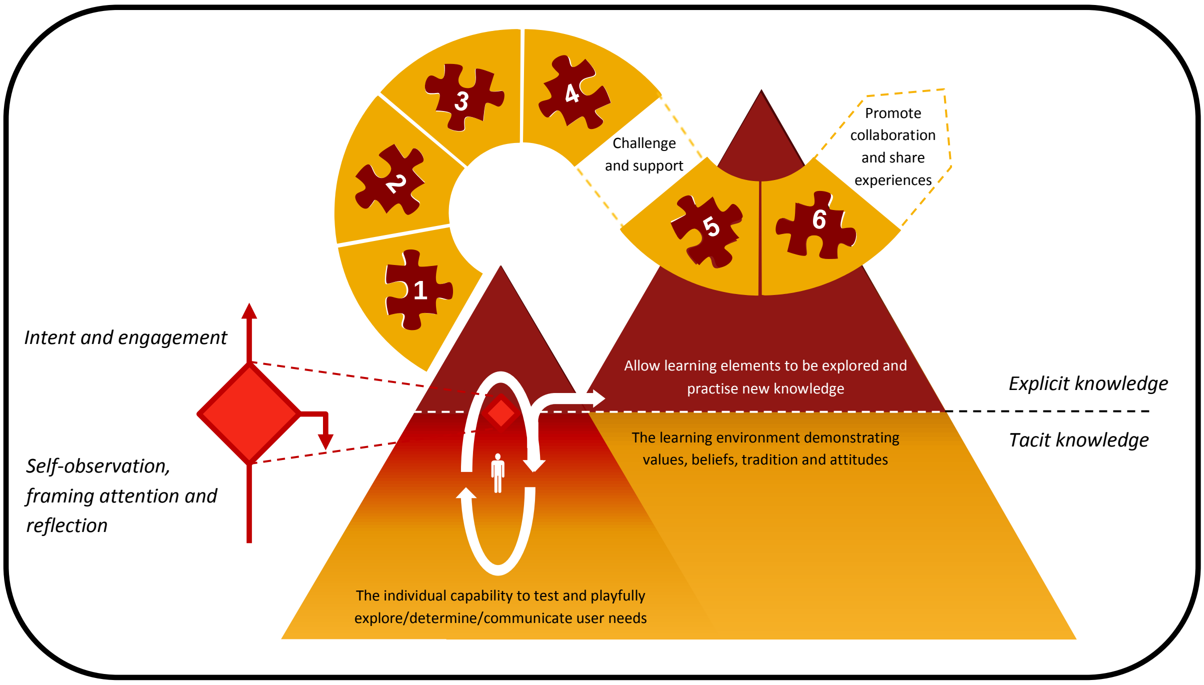

Figure 6.2 Promotion of students' knowledge applicable to early-phase innovation.

This research converges with Kolb's (1984) cyclic looping, according to which student learning is shaped by evolving through stages, such as experiencing, reflecting, thinking, and doing. A student’s conversion of stages also puts him or her in a situation to apply both a concrete, active approach as an actor and an abstract, passive one as a receiver (Svinicki & Dixon, 1987). In terms of distinct activities for learning elements, paper 1 (idea generation) and paper 2 (prototyping) both present knowledge to be translated into explicit and tacit formats. The shifts between explicit and tacit formats cover what Cross (1988) labels reflection-in-action, in which action is concrete and a primary source of knowledge; however, looping distinct anecdotes may trigger the manifestation of new knowledge. This research suggests that contextualizing learning elements could support Kolb’s critics, who argue for a thorough level of detail and the expansion of modes—‘concrete abstraction’ (Bergsteiner, Avery, & Neumann, 2010). Learning by experiencing an abstract occurrence in an activity may consequently translate to what could be covered as something more direct in character than what is presented through reflection-in-action. The modes eligible in this thesis for exploring early-phase innovation are ‘intangible’, ‘tangible’, ‘direct’, ‘indirect’, ‘redesign’, and ‘rethink’; all support the intent and engagement of both an explicit active exploration and an embedded reflecting process.

Learning—or rather, experiencing—innovation in engineering education in relation to explicit and implicit expectations and needs must be given room for conceptualization. Enacting an open approach in which learning elements can be defined, refined, and acted upon is necessary. Tolerance to change is needed from the supporting structure, e.g. faculty, system and organisation. Recognizing and promoting faculty involves allowing engagement by faculty that wish to challenge and revise existing curricula. It concerns follow-up on efforts made and disseminate good examples so that a community of faculty change makers can find a forum for inspiration and sustainability. To build on sharpness, disciplinary knowledge is vital in establishing knowledge that captures both depth and applicability in the specific domain of engineering. This does not conflict with diverging attempts whereby functionality is tested and iterated across a spectrum of alternative domains. Elements need to be flexible in terms of *how* they are introduced, and more or less control will be needed depending on the maturity level of project groups and participants. To sufficiently meet needs and excel in the exploration of early-phase innovation, the timing—that is, *when* to introduce such efforts—should be handled with delicacy. This means that the educator should focus on providing a balance between control and self-regulation, depending on students’ prior knowledge and each enabling activity’s purpose.

It is vital that integrating innovation into existing curricula, courses, and programmes not negatively affect the quality or execution of existing mandatory courses. Disciplinary knowledge must be upheld and strengthened hand in hand with the integration process. Given an integrated opportunity to rethink and redesign current curricula and courses in which it would be suitable to establish a supplement, acknowledging elements of early-phase innovation would carry great value—not only for the individual student but also for the accredited programme and the university as a whole.

6.1 Implications for educational professionals

Change initiatives should combine enabling elements in a mixture that encourages professional enjoyment and best work practices. Implementing an awareness of innovation at different educational levels would require a range of new suggestions, whether in the form of completely new modules, elements integrated into existing curricula, or distinct supplementary courses. Activities should allow an extension into innovation practices that can better meet expectations for innovation-related project work or separate activities; such educational practices would produce engineering graduates who better represent innovative skill as part of their attractiveness to recruiters and who later incorporate innovation into their industrial practices. The ambition of this thesis has been to support engineering education with insights regarding how to address and approach learning about early-phase innovation. It is meant as a step towards providing more distinct recognition of important elements of innovation, the research position's itself as a complement to the arguments members of the engineering education community have presented (e.g. Dym et al., 2005; Peercy & Cramer, 2011; Crawley & Graham, 2010; Crawley et al., 2011; Baillie & Bernhard, 2011). Disciplinary scholars who seek to further explore outcome-based features should endeavour to pinpoint distinct elements that could be showcased to strengthen applicable practices and understandings of innovation in engineering education.

6.2 Implications for theory

This paper's contribution to theory stems from findings related to the stated research questions. Building on past research, this study has produced a series of rich descriptions that provide multiple perspectives on the ways learning elements can be explored through innovation in engineering education. Regarding the phenomenon of innovation in engineering education, there is still little that allows educators to build and follow a clear path. This research attends to the ways that distinct elements can be articulated and acted upon in existing courses, interpreting recent scholarly arguments (e.g., Crawley, Edström & Stanko, 2013; Barton, Schlemer, & Vanasupa, 2012; Sheppard, Pellegrino, & Olds, 2008) to address innovation as a learning establishment that spans knowledge synthesis and culminates in the development of artefacts. The main theoretical contribution is the linkage between student learning via distinct elements that promote early-phase innovation and the ways such practices can be reformulated and tested in other contexts. Learning about how to educate for such challenges has addressed the change and transformation that eliminate obstacles to innovation. Learning solid generic student skills provides a basis from which innovation can evolve. However, skills covering both breadth and depth could be framed more explicitly, promoting the characteristics of diversity, proactivity, openness, and motivation in distinct activities. According to the research, intrinsic motivation also prompts students to engage in situations proactively, since they experience a sense of control over the situation. Educators have the opportunity to increase attention to early-phase innovation in various ways, either through game scenarios, as proposed in paper 6, or by altering the process nature of innovation-related projects (e.g., structure, content, context, and coaching).

6.3 Implications for further research

Future research projects should investigate several potential areas. First, the area as a whole could benefit from more detailed approaches and from the examination of cases in which elements have deliberately been used to support innovation in engineering education. Second, it would be of great benefit to further explore learning attempts and success stories about implementing initiatives into curricula and programmes in order to transfer good practices in the community. Creating a better understanding of how individuals' insights, intuitions, and hunches could be made explicit, i.e. collectively shared and interpreted, would be guiding in the support for learning. Taking into account the deep roots from which early thoughts for a 'new radical' might arise, another approach is to further investigate and trace patterns in students' action, procedures, routines, commitment, ideals, emotions, and values. Various forms of communicative and iterative sharing allow hidden and explicit forms of knowledge to be strengthened, and for subjective learning to receive additional scrutiny thus rendering it more objective. Overall, the change initiatives and proposed arguments involving playfulness provide a basis for further iterative testing and a possible platform for applicability. Comparative studies in which cultural differences and interdisciplinary compositions exist could allow breadth beyond the engineering discipline alone in how to pursue a multifaceted approach to learning worthy further attention.

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