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Fredrik Asplund & Elias Flening

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Boundary spanning at work placements: challenges to overcome, and ways to learn in preparation for early career engineering

Fredrik Asplund and Elias Flening
KTH Royal Institute of Technology, Department of Machine Design, Division of Mechatronics, Stockholm, Sweden

ABSTRACT
The transition from engineering student to early career engineer is often difficult as not all skills that constitute effective engineering practice are formally taught. Work placements are suggested as a solution by providing opportunities to learn skills that academia is unable to teach. However, academic requirements for skills such as research proficiency can be overlooked in a work placement environment, since they are often seen as of little value to engineers. Nevertheless, through interviews with master’s students that have conducted their thesis projects at a firm, their experience of boundary spanning to align academic and industrial requirements has been shown to prepare them for an (early) career in engineering by providing opportunities to learn informal professional skills. As the effect is moderated by the motivation of the individual firm for offering work placements, teachers need to consider this motivation when planning and preparing a student for such a work placement.

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Boundary spanning; master’s education; professional engineering skills; research–teaching nexus; work placement

1. Introduction
Increasing the use of learning environments other than laboratories is a way of improving the breadth of engineering skills taught at Higher Education Institutions (HEI) without expanding formal curricula (Jamieson and Lohmann 2012). Swedish engineering education thus frequently employs cooperative education with industry (Törngren et al. 2019), a learning environment that provides students with hands-on experience of what it is like to be an early career engineer. A prominent example of this is the Swedish HEI policy to allow master’s thesis projects to be conducted at firms. In fact, in Sweden this is the norm rather than the exception, even though the research component of master’s programs is now emphasised in the same manner as in other European countries (Davies 2009). The assumption is that cooperation centred on master’s thesis projects will allow engineering students to span the boundary between researchers and engineers (The Ministry of Education and Research 1993), learning the practice required at the Research & Development (R&D) firms where master’s students are expected to spend their careers. Rather than only acquiring the latest knowledge on technology, students should learn to gather, assess, analyse, create and share this knowledge during engineering design (The Ministry of Education and Research 1993). Previous work suggests that engineering students thus acquire research proficiency when writing their master’s theses, but with an engineering perspective (Asplund and Grimheden 2019).

However, traditional research often solves problems that are disparate from those of engineering design and without business requirement constraints. Researchers can thus be oblivious...
to the limitations that engineering practice imposes on R&D (Dym et al. 2005). Similarly, the attitude among engineering faculty and practicing engineers towards research proficiency can be dismissive (Griffiths 2004). It is thus a considerable effort to bridge the expectations of both academia and industry on a Swedish engineering master’s thesis project. This is a cause for concern, especially as the effect on learning outcomes by placing engineering students in firms for a prolonged time is understudied (Hadgraft and Kolmos 2020). In the worst case the academic requirements on showing research proficiency would not only be left unfulfilled, but may even interfere with the other learning that should come from being placed in an industrial context.

To explore this problem we focus on the students’ boundary spanning between academia and industry during practice-focused master’s thesis projects conducted at engineering firms. Boundary spanning is a generic concept, used to describe people spanning organisational boundaries to relate organisations to external elements (Haas 2015). The associated challenge is that the boundary spanner has to relate to several contexts that might be fundamentally different, e.g. organisations that have different goals, emphasise different knowledge, and reward different outcomes. This is very much the case for master’s students conducting master’s thesis projects, who enter work placements at firms with the intention to return after fulfilling certain academic requirements. Most obviously, these academic requirements might be in conflict with the outcomes sought by the firms. As an example, the academic institution might stress the rigour of the conducted research, while the firm might want to see a working prototype. If the academic institution and firm involved in a master’s thesis project do not know each other well, such differences might be aggravated as both sides take precautions to ensure outcomes in line with their wishes. As a master’s thesis project is an independent endeavour, the abilities and motives of the individual student will play a part in mitigating or aggravating any challenges due to differences between academia and industry. Even failing to grasp certain subtle differences between research and engineering might have an adverse effect. A student’s plans might for instance allocate too little time to understanding the causal relationships to be proven, leading to the engineering of prototypes unsuitable to answer the research questions. In fact, the situation is even more complex than the organisations and students involved in this boundary spanning suggest, as the definition of the primary outcome of this boundary spanning – what the students should learn – is open to dispute. At the very least students should proceed from research questions to conclusions according to academic standards. However, research at firms with a focus on engineering systems will face other limitations and requirements than those most frequently encountered in academia. As an example, finishing a prototype critical to experimentation might be less related to missing knowledge than being able to persuade management and other engineers to provide necessary resources and expertise. If students gain such insights, or even learn associated informal professional skills during their master’s thesis projects, it will be valuable to their continued work as early career engineers. However, this opportunity is not necessarily well understood by either academia or industry.

The focus of this study – to understand the antecedents to enabling boundary spanning during a master’s thesis project to facilitate the transition of engineering students into early career engineers – is thus a broad topic. However, by focusing either on the challenges to fulfilling academic requirements under engineering constraints, or the difficulty in maximising the opportunities to learn from an engineering practice that involves research, the issues discussed thus far can be divided into two categories. On the one hand, the relationship between this boundary spanning and the challenges of conducting a master’s thesis project, and, on the other hand, the relationship between this boundary spanning and the learning of engineering practice.

The next section provides a theoretical framework for our exploratory study and points at key concepts that are important to investigate. This is followed by our methodology section, describing the case we have chosen to explore. The results and analysis sections describe the outcome of our interviews, which is then discussed and summarised into conclusions.
2. Theoretical framework

This section describes the theoretical framework of the paper, which is based on the discourses on the research–teaching nexus and boundary spanning. Firstly, this exposition of literature suggests that no single discourse contains the theory necessary to allow a complete analysis of our results. Secondly, it exposes a paucity of extant literature at the intersection of the discourses on boundary spanning, engineering practice and engineering education. However, even if strong hypotheses cannot be defined, a perspective on how relevant concepts might fit together can be tentatively put forward.

2.1. The research–teaching nexus

The idea of whether the relationship between research and teaching (the research–teaching nexus) is positive or negative has been debated for decades, even centuries (Hattie and Marsh 1996). While often equated to the discussion on whether active involvement in research affects teaching ability, the discourse includes both the inverse influence of teaching on research and the wider perspectives on, for instance, the role of universities (Tight 2016). More specifically, it includes studies on the combination of teaching and research by involving students in research (Prince, Felder, and Brent 2007) or utilizing inductive teaching (Prince and Felder 2006). Swedish engineering master’s thesis projects are examples of one or both of these, as they combine the independent solving of a complex, real-world engineering problem with a scientific study. The applied base means that they are examples of the most common types of inquiry-based learning in engineering programs (Aditomo et al. 2013).

However, they are closer to scholarly research than usually is the case, as the students are largely independent in regard to choosing research questions, gathering data and performing data analysis. The Swedish master’s thesis project is thus an introduction to the independent handling of research as part of the type of engineering that engineers in R&D firms are expected to carry out.

This type of learning is student-centred, meaning that students are required take on a large responsibility for their own learning (Prince and Felder 2006). On the one hand this can be an advantage, as inquiry-based learning provides an opportunity for students to improve their critical thinking, problem-solving skills, planning and motivation (Warnock and Mohammadi-Aragh 2016). On the other hand, for those students that are not sufficiently strong to begin with, the loose teacher-regulation of learning can lead to destructive friction in cognitive, metacognitive and affective learning activities (Vermunt and Verloop 1999; Wulf 2019). Not all students respond well to inquiry-based learning, but may instead be overwhelmed by it.

In regard to cognitive learning activities we note that Asplund and Grimheden (2019) suggest that an especially useful skill during engineering master’s thesis projects is the ability to think freely and creatively about confounding factors. Being able to discuss the flaws of a research task can allow students to better control the scope of an associated engineering task. If the research and engineering tasks are disjointed, this will be more difficult. In regard to metacognitive learning activities we note that while inquiry-based learning is often highlighted as well suited to developing metacognitive skills, this takes time and depends on placing students in unfamiliar territory (Downing et al. 2009). In other words, having to fuse research and engineering tasks during a master’s thesis project might eventually strengthen metacognitive skills, but success in this regard is not necessarily facilitated by inquiry-based learning. In fact, a failure to fuse research and engineering would likely result in a larger scope and more coordination between tasks, which would further aggravate a lack of metacognitive skills. In regard to affective learning activities we note that these are linked across the research and engineering tasks of a master’s thesis project. They both relate to a student’s current mood and thus influence the whole learning process (Vermunt and Verloop 1999). The ability to handle anxiety related to the uncertainty of the research process can be a large part in enabling a student to make necessary decisions in research situations (Wessels, Gess, and Deicke 2019). Similarly, the motivation of students can be affected by the difficulties in handling too
complex engineering tasks without adequate teacher support (Catz, Sabag, and Gero 2018; Gero, Catz, and Sabag 2018). In other words, the more disjointed the research and engineering tasks of a master’s thesis projects are, the more potential there will be for an affective challenge to surface that influences the whole learning process negatively.

This suggests that students who are able to align the requirements of academia and industry on the associated engineering and research tasks will increase their chances of successfully finishing their master’s thesis projects. It will allow them to control the scope of the associated research and engineering tasks, reduce coordination effort, and limit the chances of negative feelings influencing their work. To achieve such an alignment students are required to span the boundary between academia and industry during negotiations with both.

2.2. Boundary spanning

While inquiry-based learning engenders the competence required to handle typical problems and tasks in professional engineering practice (Jungmann 2019), going beyond the attainment of formal professional skills still relies on informal interactions with peers (Johnson and Ulseth 2016). Unfortunately, curricula do not necessarily include the skills required for such informal interactions or the socio-technical complexity in which they occur in engineering practice (Trevelyan 2019). Attempts to socialise students into their professional identities already during higher education are often confounded by a strong emphasis on ‘academic communicative practices, audiences, and goals’ (Dannels 2000). Early career engineers instead become full participants in their profession foremost by informally engaging with, and learning engineering practice from, their community of practice (Lave and Wenger 1991). These groups provide a social context – both internally and between firms – that allows for knowledge sharing and thus reproduce (engineering) practice (Brown and Duguid 2001; Leonard and Sensiper 1998; Lesser and Prusak 2000).

However, elements of contextual, practice-related learning that enable engineering students to glean knowledge from their communities of practice have increased in engineering curricula (Hadjgraft and Kolmos 2020). Although it is still more common in undergraduate than in graduate programs (Jamieson and Lohmann 2012), this could allow engineering students to quicken their transition to professional engineers. Naturally, this also increases the influence on learning by engineering firms, which have their own needs that motivate their engagement in higher education. While academia exposes students to firms to enable learning from real-world problems and technology, firms engage to get access to cutting-edge technology and technological consultancy (Ankrah and Omar 2015; Ozman 2009). Short-term projects allow firms to leverage students’ engineering skills, state-of-the-art knowledge and research proficiency to solve their current engineering problems (Hasanefendic, Heitor, and Horta 2016). As part of an academic context, engineering students will thus have to reach out to a complex industrial context constrained by real-life business considerations to enable a scientific study. Even when such boundary spanning only involves recombining old ideas in new ways (Hargadon 2002), the complexity of the context can involve a diverse set of services both at an organisational and an individual level: intermediary organisations might have to provide foresight, information processing, gatekeeping, validation and commercialisation (Howells 2006), while individuals must handle information exchange, market access and coordination (Haas 2015). Successful boundary spanning under such conditions often depends on the perception of technical competence, and enough time to cultivate both formal and informal contacts (Nochur and Allen 1992). Indeed, cultural differences regarding openness and time management can require substantial (time for) trust to be developed before academia-industry collaboration can lead to meaningful knowledge transfer (de Wit-de Vries et al. 2019). Firms that have not established this trust to a university are likely to prefer to limit the research activities in any collaboration (Buganza, Colombo, and Landoni 2014), and might choose to involve themselves in projects with students, rather than faculty, for this very reason (de Wit-de Vries et al. 2019).
Therefore, trust should influence the contribution by boundary spanning to the learning of engineering practice through practice-based master’s thesis projects conducted at engineering firms. Even if the paucity of extant literature does not allow for strong hypotheses, one can draw on separate theories to construct three cases with different implications for the associated boundary spanning:

- **Cases where the targeted problems are of immediate relevance to the firm’s current business.**
  - In the first type of case, trust does not exist. In this case, firms will want to emphasise problem-solving based on well-formed requirements using best practice engineering and technology. Effort will go towards limiting the uncertainty introduced by research activities. Firms will most likely want to treat the engineering and research activities of the master’s thesis project as separately as possible. Although there will be a need for boundary spanning, it will be strictly controlled, much like in professional project-based engineering capstone courses. The discourse on engineering education then offers several important insights, suggesting that students will be exposed more to formal project management (Bastarrica, Perovich, and Samary 2017), written communication (Fries et al. 2017) and technical (Howe et al. 2018) skills, than skills in negotiation (Bastarrica, Perovich, and Samary 2017), verbal communication (Fries et al. 2017) and budgeting (Howe et al. 2018). Any contribution to the learning of engineering practice by boundary spanning activities is thus likely to be related to formal engineering skills.
  - In the second type of case, trust exists. In this case the state-of-the-art knowledge held by engineering students can have a powerful impact by enabling the design of novel solutions. Arguably, this can be the reason a firm is willing to bear the costs of hosting a master’s thesis project. The discourse on boundary spanning then provides several relevant insights. Students will most likely have to interact with the firms’ gatekeepers, i.e. boundary spanners that bring knowledge from external sources into the firm and ensure that it is both understood and used (Paul and Whittam 2010). They will be asked to repackage and communicate knowledge (Cillo 2005), an aspect of gatekeeping that has become increasingly important over time as information technology has made pure knowledge transfer less valuable (Whelan, Donnellan, and Golden 2009). This is a substantial part of engineering boundary spanning, and is usually more informal than the communication skills taught in engineering curricula (Jesiek et al. 2018). As the tasks are of immediate relevance to the firm’s engineering activities, the boundary spanning is also likely to require coordination of (and with) engineers within the firm to co-create common ground and build more trust. The uncertainty brought on by the research is likely to force the students to go beyond formal specifications, making such coordination more informal and akin to the informal technical coordination of engineering practice (Jesiek et al. 2018). Boundary spanning activities might thus contribute to the learning of engineering practice not only through the learning of formal engineering skills, but also by bringing about the need for associated informal activities.
  - In the last type of case, the targeted problems are not of immediate relevance to the firm’s current business. This can for instance be because the task is artificial, has a deadline set far into the future, or is of minor or no economic importance. On the one hand, trust is then unlikely to be as important, which suggests that students should have an easier time accessing engineers at the firm than in the first type of case. On the other hand, as the problems are of less relevance, these engineers might have less time, interest or useful expertise than in the second type of case. Whether boundary spanning provides opportunities for learning formal or informal engineering practices is more open to chance.

### 3. Research design and methods

This section provides a case description, positions the research as an exploratory case study, and details the data collection, data analysis and validation of the study.
3.1. Case description

This study is based on the Mechatronics track of the Engineering Design master’s program at KTH Royal Institute of Technology. The last six months of this track consist of a master’s thesis course, which assesses the students’ research proficiency and individual mastery of engineering. Higher education in Sweden adapted to the European Bologna process more than a decade ago (Lindberg-Sand 2012). This meant that existing 5-year professional engineering programs were divided in two: bachelor’s (3 years) and master’s (2 years). The master’s thesis course then came to replace what had previously been an engineering project course, usually carried out as an internship. Therefore, it still remains the expectation by most of those involved that the master’s thesis course should be organised at a company and as a project that contains both research and engineering tasks.

Historically the engineering tasks of Swedish master’s thesis projects have thus mostly been provided by industry, with students physically located at industrial premises. Recent examples of such engineering tasks include real-time local wave forecasting for power maximisation of wave energy converters, the design of novel control strategies for pin-on-disc tribometers, and the optimisation of sensor placement for training a neural network to detect anomalies in jet printing.

As for the research tasks of master’s thesis projects, Swedish firms typically do not provide these as part of their master’s thesis project offering. The research tasks, even the identification of research questions, are instead left for the students to manage. Therefore, students usually identify research questions that benefit from the output of the engineering tasks. When Swedish engineering firms provide a master’s thesis project, it would thus be more correct to say that they provide a topic to study. This topic can be a problem that is difficult to solve by contemporary engineering, or a novel solution or method. It is then up to the student to identify something related to this topic that would be valuable to study according to the academic state-of-the-art.

Sixty-four students conducted their master’s thesis projects during the studied semester. Of these, eight projects were provided by professors at the Mechatronics division, six were provided by professors at other divisions at KTH, and two were defined by students. The remaining 48 projects originated from different firms located across Scandinavia. We note that the high number of projects provided by academia during the studied semester was unusual, but that they did not affect the projects provided by industry.

The master’s thesis course process is light-weight, as students are supposed to show independence throughout the course. However, they are allocated an academic supervisor, who – in the case of projects provided by industry or other academic divisions – primarily supports by answering administrative questions. When a project nears its completion, the student will hand in a master’s thesis to their supervisor that describes everything that can be expected from a scientific study – from research questions to conclusions. If the master’s thesis contains all the expected parts, then the supervisor hands it over to one of the professors at the division. This professor then assesses the master’s thesis according to learning goals ultimately established by the Swedish Ministry of Education and Research (The Ministry of Education and Research 1993). This assessment is based both on a reading of the thesis and a presentation of it (at which another master’s student serves as an opponent).

3.2. An exploratory case study

Three months prior to a new iteration of the master’s thesis course the two authors started thematising and designing an interview study. The resulting interview script focused on how the students had planned for their thesis projects, how well prepared they felt, and which challenges they had encountered.

During the first three months of the master’s thesis course a first round of interviews were then conducted, in which the authors interviewed all 64 students. Naturally, many of the concepts that make up the theoretical framework informed our thinking, but the interview script centred on the
students themselves. Most importantly, we did not lead the students along by explicitly asking about the motives of, or relationships between, other actors. These interviews took half an hour to complete on average, but in some instances took a full hour. There were of course differences between the students, but overall their largest problem was with the boundary spanning between industry and academia. The different expectations by these two stakeholders often required considerable effort to handle. However, although perhaps largely lost on the students, the boundary spanning also came across as one of the largest learning opportunities in regard to understanding engineering practice. Although the first round of interviews was not immediately transcribed, we met once a week during the subsequent two months to discuss our impressions. This allowed further refinements to the theoretical framework described in Section 2. The available literature was still not enough to define hypotheses, but a more focused, second interview script could be designed. This interview script focused on challenges to industry-academia boundary spanning, and the relationship between the student and the provider of the master’s thesis project.

Fifty of the students accepted to be interviewed a second time. Using the updated interview script, these students were interviewed during the subsequent six months after their theses had been accepted by one of the course examiners. Thirty-seven of these 50 students were placed at firms during their master’s thesis project. These interviews took 20 min to complete on average, but in some instances took a full hour. Most of the interviews were conducted face-to-face, but when circumstances did not allow for it they were conducted over the phone.

All interviews from both rounds were recorded and transcribed. Twenty-four of the interviews from the first round were transcribed by the authors, while 40 were transcribed by a professional transcription service for the sake of convenience. Similarly, 24 of the interviews from the second round were transcribed by us, while 26 were transcribed by a professional transcription service. This transcription ran in parallel to the interviews, starting two months after the first interview and ending two months after the last interview.

The analysis and verification started one month after the last interview and took seven months to conclude. The interviews from the first round were analysed to ensure that our impressions were indeed well founded. The interviews from the second round were analysed to arrive at the results presented in Section 4. We met bi-weekly to discuss, merge and refer codes back to the transcripts and recordings. As the codes solidified, these bi-weekly meeting eventually included discussions regarding the results.

The writing up of the study started slowly during the analysis stage. However, most of the writing was performed during the two months after the analysis had concluded.

This study, performed as an explorative case study informed by interviews, thus took about 24 months from start to finish.

3.3. Data gathering

The interviews were designed as semi-structured interviews according to the procedure defined by Brinkmann and Kvale (2015).

We wanted to capture the students’ experiences from boundary spanning across their entire master’s thesis projects. Furthermore, the largest threat to internal validity was thought to be students self-censoring their critique due to concerns about their grading. Therefore, the students were not asked for a second interview until they had finished their thesis projects. This meant that most of the students were interviewed after they had already been hired and transitioned into early career engineers, providing them with further insights into the strengths and weaknesses of their engineering education.

Both interview scripts were designed to explicitly include several follow-up questions, which allowed interviewers to ‘push forward’ (Brinkmann and Kvale 2015). This also ensured that we were reminded to clarify the meaning of ambiguous statements.
To promote active listening and avoid researcher bias, both authors were present for 11 of the early interviews. During these interviews, we took turns either ensuring that the interview script was followed or focusing on the interviewee’s responses. The other interviews were conducted by the author who had the earliest opportunity to conduct the interview.

To ensure the reliability of the data the professional transcribers were instructed to leave parts that were difficult to transcribe to the authors. Although interviews were performed both in Swedish and in English, to minimise mistakes only those performed in Swedish were referred to the transcription service. These two precautions ensured that the data analysis could identify ambiguities and refer back to the recordings in order to handle them. Similarly, all quotes presented in Section 4 were verified against the recordings and, when necessary, translated by us.

As the aim was solely to capture the meaning of the interviewees’ comments, we had to decide on a reasonable level of detail in the transcripts to avoid confounding the subsequent analysis (Brinkmann and Kvale 2015). Therefore, transcripts only included details such as pauses, repetitions and emotional expressions when it was deemed to have a bearing on the interpretation of an interviewee’s statements.

3.4. Data analysis

All interviews were initially coded with descriptive codes (Saldaña 2009a). The code book eventually included 61 codes. The codes’ consistency in regard to meaning and application was ensured by discussions between the authors. To avoid misinterpretations these codes were based on explicit comments by the students. When in doubt, we referred back to the audio recordings to avoid misunderstanding interviewees due to detail that is difficult to convey when transcribing. This ensured that internal validity was not affected by unreliability of the coder or coding. The initial analysis was followed by a recoding of the descriptive codes to identify patterns (Saldaña 2009b), i.e. so-called ‘Pattern Coding’. The resulting secondary coding aimed at interpreting the meaning of the interviews in light of the analytical framework (Brinkmann and Kvale 2015). The patterns, or groups of descriptive codes, thus iteratively identified, are reported in Section 4. The iterations ensured that the final interpretation was free of contradiction, and the traceability between codes ensured that it could be tested against its parts and available literature – an important part of analysing the meaning of interviews (Brinkmann and Kvale 2015).

3.5. Validation

As outlined in the previous subsections several actions were taken to ensure the internal validity, construct validity and reliability of the study: the initial interview ensured that the focus of the study was on a substantial factor in the studied context; the interview script and the use of several interviewers removed ambiguity; the large response rate ensured a complete coverage of student perspectives; to delay interviews to after the associated thesis projects were finished minimised the risk of false, biased or incomplete information; utilising several interviewers decreased the chance of interviewer bias; following up on uncertain transcriptions increased the reliability of data for analysis; analysing and coding as a group meant coder bias was minimised and coding reliable; and testing interpretations against each other and the available literature ensured consistency.

Despite these precautions, we were concerned that the 14 students we could not interview in the second round held unique perspectives on the concepts we explored. However, we could not get to these perspectives through triangulating with other sets of data or performing traditional member checks involving these students (Creswell and Miller 2000). Therefore, we instead asked the supervisors for these students whether they, based on their continuous interactions with the students, believed we had missed any relevant findings. None of the supervisors indicated that they thought this was the case.
Not all of our students had to engage with firms, and the diversity of HEI means that this is the default for the engineering students in some countries and master’s programs (Davies 2009). Differences might also arise due to factors linked to geography, engineering disciplines, business domains, etc. However, there are also more subtle limitations in regard to the external validity of this study. These are addressed by a discussion in Subsection 5.3.

4. Results and analysis

This section starts by providing generic observations. This is followed by results and analysis related both to the relationship between boundary spanning and the challenges of writing a master’s thesis, and to the relationship between boundary spanning and the learning of engineering practice. Throughout this section the firms that provided master’s thesis projects are referred to as (industrial) thesis project providers.

4.1. Initial observations

The existence of trust between the industrial thesis project providers and the faculty at KTH’s Mechatronics division were obvious to the students. They readily identified longstanding cooperation between the organisations, and found graduates from the Mechatronics track working at their industrial thesis project providers. (We note that these observations matched statements from the faculty on which firms they knew well.) Furthermore, in some cases the thesis project providers had come to trust the students themselves through previous internships. This meant that three out of four students that conducted their master’s thesis project at a company did so in the context of a relationship based on trust. There was also evidence that this trust had been valuable to the firms. Students had for instance bypassed ingrained conceptions to identify novel technical solutions (Table 1).

Table 1. Examples of relationships based on trust.

| Type of Trust                     | Example                                                                 |
|-----------------------------------|-------------------------------------------------------------------------|
| Trusted academia                  | ‘I: So, did [the industrial thesis project provider] have any connections to the Mechatronics division that you know of?  
A1: Yes, I think [industrial supervisor] and [academic supervisor] has a connection. [Other industrial supervisors] did all that work with him a few times. Yes, definitely, yes, exactly. So, they have a good relationship with each other.’  
‘I: Do you know if [industrial thesis project provider] had any earlier contact with the Mechatronics division?  
A2: Yes, what is his name … [Manager at Mechatronics Division] has a very good relationship with [industrial supervisor] as they collaborated on setting up the Engineering Design master’s program.’ |
| Trusted through previous students | ‘I: Did anyone at [the industrial provider] know someone at the Mechatronics division?  
A3: Yes. My colleagues had been to certain courses in Mechatronics and they know a few of the faculty members.’ |
| Trusted through previous internship| ‘A4: Actually, I also did my summer work there last year. That was a project, which … called … I forgot the name of that, but that is summer work plus master’s thesis. So, last winter I did not apply for any master’s thesis opportunities. They just gave me a list of the tasks this year, and I just found one of them …  
I: Did they just give you [emphasis on you] this list?  
A4: A number of others, but as I had the summer internship last year they gave me the priority to choose first.’ |
| Reciprocated trust                | ‘A5: Well, how should I put it? They were very much aware that what they suggested was not [academically] acceptable. Furthermore, I had been clear from my side that to get it accepted it would possibly have to be changed. Then it was not accepted [by KTH]. [Engineers at the firm] were very easy to discuss with, but at the same time there were requirements and wishes that I had to … Well, to get some value out of it … They had an inkling about that the new suggestion I was working on, the [topic of master thesis project], was something they should look at, but they thought other process parameters were more relevant for health data, which I then early in the project showed was not connected to the health of the machine …  
I: So, you showed them the right thing to focus on?  
A5: Yes, I did.’ |
Most students were also keenly aware that the thesis project providers had one, or a combination of several, reasons for offering master’s thesis projects. Naturally, they often wanted a prototype of a new product or an improved version of an old one. There was the intent to ‘test’ the skills and personality of students before offering them employment. There were also several industrial thesis project providers that explicitly used master’s thesis projects to span the boundary into unfamiliar knowledge areas. This involved relying on students to gather knowledge on, and explain the opportunities of, state-of-the-art research, or have them integrate novel technology into an existing product (Table 2).

4.2. Overcoming the challenges of writing a master’s thesis

The first subsection provides results related to the secondary (pattern) coding concerning the challenges of writing a master’s thesis in our context. The second subsection provides an analysis of these patterns. Parts of the patterns that have already been described are not repeatedly exemplified, but the associated code is given in parentheses.

4.2.1. Patterns

Many students felt stressed when writing their master’s thesis, as they perceived different obstacles to completing their project. Those who offered an overall explanation for their stress specifically pointed to the feeling that they were carrying out two projects – one academic and one industrial. These students had all been offered a thesis project by an industrial thesis project provider that wanted to learn from unknown knowledge areas (Reason spanning the boundary into an unknown knowledge area). As the topics for the master’s thesis projects were unfamiliar to the industrial thesis project provider, they were often initially unsure about the size of the scope (Table 3).

Two active strategies for dealing with stress were mentioned by the students. One way was to limit the requirements by the thesis project provider that were to be addressed. The other was to continuously align the requirements by both industry and academia in an attempt to satisfy the demands of both parties. Some students felt that this second approach was, at times, probably just as stressful as addressing the demands from both industry and academia separately. More specifically, it was time-consuming, required unstructured, informal technical discussions and relied on the students’ ability to keep themselves motivated (Table 4).

Table 2. Examples of reasons for offering a master’s thesis project.

| Reason prototype | Quote | Reason employment | Quote |
|------------------|-------|-------------------|-------|
| B1: Yes, it was all very open. We could, to a great extent, handle it as we wanted. We could shape it, but the demand they had was that it would end with a prototype. Or, I think they saw the master thesis as a way to get a physical prototype delivered in exactly this new field.’ | B3: I talked to the boss, who graduated from the Mechatronics track perhaps three years ago. And she said that yes, this is kind of a recruitment … this time, or … it is a way to see … if I fit at [industrial thesis project provider], if I have that consultancy mind-set or whatever it can be called. The personality …’ | B2: [The industrial thesis project provider] was more interested in getting that kind of [technical component] … to only focus on building a physical [technical component] and try to measure and get an efficiency that matched what they had simulated. That was what they really wanted to get at, and wanted to do.’ | B4: … honestly speaking the demands were not that great, they were rather more interested in finding people to employ in the end.’ |
| B5: And it was above all another way of future-proofing them, because they see the industry moving in this direction. This is knowledge they feel they need, and which they are not experts in, because it is not in their traditional working area, but the boundaries are getting more and more blurry, what they are doing in ten years and need to interact with … So … No, it has been a clear information gathering effort in this area.’ |
4.2.2. Analysis

Students typically want to satisfy the wishes of both academia and industry during a master’s thesis project. An antecedent to this is to understand the requirements on the associated research and engineering tasks. This is often not a problem when an industrial thesis project provider knows the scope of the engineering tasks well (Reason prototype), or when these are not as important as having the student on one’s premises (Reason employment). However, establishing this understanding is difficult when the topic of the master’s thesis project is unfamiliar to the industrial thesis project provider (Reason spanning the boundary into an unknown knowledge area). A student

| Table 3. Examples from the two projects pattern. |
|-----------------------------------|
| **Two projects**                  |                           |
| C1: In the end it was good because both the department and the company agreed on something. I felt that they … of course the initial requirements were fulfilled. The second part that was added to comply with KTH requirements felt a bit forced in the end … I felt that the project could have been better … aimed at something useful to them.’ |
| C2: As they had an idea about what they wanted done, I could not shape the master thesis freely, but at the same time they had … it was not a problem [for the industrial thesis project provider] that I did their engineering task and then also answered a research question afterwards: |
| **Unknown scope**                 | C1: They were really, really, like super enthusiastic about this first subject they suggested to add that was [unknown knowledge area]. But, when we when we started looking at it, it was huge. So even the CEO said: “No, this isn’t like a Master’s, it is more like a doctoral thesis, so you can’t do this.” |

| Table 4. Examples of dealing with separate requirements from industry and academia. |
|---------------------------------|
| **Handling stress by limiting industrial requirements** | B5: Then, what I could add in regard to building a prototype, I think what it was a very smart move to limit the actual master thesis to more analytical verification of the system … it was a bit tactical to appraise the opportunities for keeping it … well, to keep the scope for the actual master thesis clear. To set a time limit for each task. |
| **Handling stress by boundary spanning** | D1: It was the actual implementation, that I did not know what I would have time to finish and how much and how large part of the algorithm I have to implement? How much one should demonstrate? That was what stressed me all the time. Because I wanted to finish everything that KTH required, and what the company required … I always tried to align both sides … But I was, well … I was very clear on that I wanted a lot of meetings to align with all the [industrial and academic supervisors] to see: ‘Is this what is required? Is this everything that needs to be done to satisfy everyone?’ So, I always ran these alignment meetings, with [academic supervisor]: ‘Are you sure this is good enough?’ And then I for instance got a result I did not expect, and then I had to align again: ‘Do you think … is it better to discuss this result that was not expected? Or should I change direction? Change the research question, or what? What is good enough? And then at the company I tried to also align more at the end, as I got more time for the demonstration, to ask: ‘What are the expectations and what should I achieve for the master thesis to be finished?’ |
| **Time required for handling stress** | A1: The communications aspect worked in favour of the thesis. Once the [student’s] plan was communicated, once KTH’s plan was communicated, once [industrial thesis project provider’s] plan was communicated, once all of those were on the table with clear information about the requirements there were no problems. |
| **Informal discussions to understand requirements** | D2: Tried getting help. There was a lot of good help by [academic supervisor] and then … talking to some other [employees at the industrial thesis project provider]. Yes, really good help from the first group. They were really like: “Why don’t you try this angle, let’s talk to this guy or try this angle or that angle.” Then there was this discussion over lunch with [the industrial supervisor] where he came with some good ideas. Yes, he said a sentence that really got the penny to drop. Then you got it: “Yes, this is what they want.” |
| **Personal motivation** | ‘L: Did you think it was stressful at any point when juggling the requirements from academia and industry? |
| C2: It was … during the start … when I talked to [academic supervisor] about the suggestion and then … it was though getting started I would say. |
| ‘L: And how did you handle that? |
| C2: Well, looking back, I think I … it was a bit mañana, mañana sometimes [laughs], but eventually I sorted it out.’ |
with strong negotiation skills and enough disregard for the wishes of the industrial thesis project provider can handle this uncertainty by limiting the requirements from industry. This boundary spanning could still amount to a large effort, but the alternative could easily be more arduous. In contrast, if the student is not able to convince the industrial thesis project provider to accept a limited scope up front, then continuous boundary spanning between academia and industry becomes necessary. This is typically a large effort that requires time, opportunities for informal discussions and a highly motivated student.

4.3. The contribution of boundary spanning to the learning of engineering practice

The first subsection provides results related to the secondary (pattern) coding concerning the relationship between boundary spanning and the learning of engineering practice in our context. The second subsection provides an analysis of these patterns.

4.3.1. Patterns

Opportunities for practicing professional engineering skills were mentioned by several of the students. These opportunities were structured according to four different patterns.

(1) A pattern of students having opportunities to reach out and influence the tasks conducted by different employees of the industrial thesis project provider. These cases occurred at industrial thesis project providers with a trusting relationship to the Mechatronics division or student. The thesis projects were strongly tied to the engineering at the firm, either through the reason for the thesis project (Reason prototype) or because the thesis project was a continuation of earlier internships (Trusted through previous internship). In all these cases the reason that the students had the opportunity to practice their ability to collaborate with other engineers was the need to boundary span to e.g. align requirements or elicit support for their scientific studies, an effort they were all successful at (Table 5).

(2) A pattern of students being immersed in an engineering team at their industrial thesis project provider. This did not involve opportunities to actively influence the engineers in these teams, more that students had a chance to observe their work and seek help from them. These cases almost exclusively occurred at industrial thesis project providers with a trusting relationship to the Mechatronics division. There was one exception, which involved a company with an explicit – and rare – policy of integrating their master’s thesis students into their engineering teams. The reasons for the thesis projects were either recruitment (Reason employment) or unknown knowledge areas (Reason spanning the boundary into an unknown knowledge area). There was little boundary spanning although the students explicitly managed to balance the workload between industry and academia. It is worth noting that there were different reasons for the lack of boundary spanning – some industrial thesis

| Collaboration skill opportunity | 'E1: Don’t do emails, just call people.  
I: And why was that so efficient in comparison?  
E1: Because you can get to the point straight away. Like, this is what I want, this is what you want. Ok. How do we meet in the middle?’  
‘E2: And the thing is, I am meeting these experts, and you kind of get only one shot with them … So, I did two iterations in my thesis, but then that was more or less plan, so I could book two slots with them.’

| Successful academia-industry boundary spanning | 'E2: What made me persist? I don’t know … I mean I really enjoyed … what system architects do, and I had some experience working with a team at KTH. So, I started doing system architecting with them, and that seemed kind of cool. But what I was doing was more hobby level, and this was more professional level. So, I had to bridge that gap, which was good, because now I know.’

Table 5. Examples from the collaboration skill pattern.
project providers did not insist on their requirements being fulfilled, while others left the fulfillment of the academic requirements entirely up to the student (Table 6).

(3) A pattern of the students being pushed by their industrial thesis project providers to develop their own problem-solving skills. These cases occurred at industrial thesis project providers where a trusting relationship to the Mechatronics division or student did not exist, and where the reason for the thesis project was the development of a prototype (Reason prototype). Furthermore, although the industrial thesis project providers wanted to keep their own and any additional academic requirements separate, the students successfully brought together the firms and faculty from the Mechatronics division to create a shared aim for their thesis projects (Successful academia-industry boundary spanning) (Table 7).

(4) There was a pattern of opportunities for learning certain skills that was found in all types of providers and contexts. These involved presenting engineering results and planning engineering work (Table 8).

4.3.2. Analysis
As expected based on the literature discussed in Subsection 2.2, opportunities for learning informal professional skills occurred at industrial thesis project providers with a trusting relationship to the Mechatronics division or student. As expected, these opportunities did not always depend on the master’s thesis project being of immediate relevance to the firm’s current business: this was a pre-requisite when the skill involved actively influencing engineers, but not when the skill related to more passively existing in a team.

However, contrary to the discussion in Subsection 2.2, opportunities for learning informal professional skills related to problem-solving did occur when trust was not established, despite the associated master’s thesis projects being of immediate business relevance. These opportunities occurred in this context as long as the students, despite the firms’ wishes, successfully negotiated an alignment between industry and academia.

This implies that both a trusting relationship between industry and academia, and a master’s thesis project of relevance to a firm’s current business, can separately bring about opportunities for learning informal professional skills. However, realising some of these opportunities will depend on the student being an active boundary spanner.

A trusting relationship can provide opportunities to learn informal engineering skills for both active and passive students. Active students can set up a mutual cooperation on engineering tasks of joint interest, which are established by their successful spanning of the boundary between industry and academia. Passive students do not establish such mutual cooperation, but the trusting relationship at least provides opportunities to observe and get occasional support.

### Table 6. Examples from the teamwork skill pattern.

| Teamwork skill opportunity | F1: But next to them there is the [industrial thesis project provider team] and we perhaps had more to do with them. And they were very happy about the data set we generated, and stuff like that… |
|----------------------------|--------------------------------------------------------------------------------------------------|
| Student balanced industrial and academic workload | F2: And I had colleagues around me at [industrial thesis project provider] who could help with technical problems, which I had to solve to not get stuck for too long. So I thought… yes, that is what I, mean… I had people around me who could help me. |
|                            | F3: Yes, I understand. Yes, no, I have… at one stage I decided to trim down the scope to be finished by summer… or just before summer. It was not much of a negotiation, rather it was like I said that, and then the others said: “Ok, then that is how it is.” |
|                            | F4: … Or we had regular meetings with [industrial supervisor]… but it was important that we felt that the work was feasible for us to carry out and… what one could achieve in that time. And then we discussed that, or more analysed it together…’ |
from engineers – also providing training in informal professional skills. A master’s thesis project’s relevance to a firm’s current business can also, by itself, provide opportunities for active boundary spanners. This most likely comes about as it forces engineers to adopt an informal mentoring approach in situations: the relevance of the engineering tasks forces their active interest, but the influence by academic requirements and knowledge means that they do not possess all the answers.

Boundary spanning thus provides, but is not a necessary antecedent to, opportunities for informal learning of engineering practice.

It is also worth noting that, as suggested by Subsection 2.2, opportunities for learning formal professional skills do seem to occur in most contexts – regardless of whether a trusting relationship has been established or the engineering task of a master’s thesis project is of immediate business relevance.

5. Discussion
This section discusses the study’s contribution to theory, contribution to practice and the most important limitations.

5.1. Contribution to theory
There is a dearth of literature on the transition from engineering education to early career engineer (Trevelyan 2019) and the outcome of placing engineering students in firms during e.g. internships (Hadgraft and Kolmos 2020). This study contributes to these discourses by investigating the boundary spanning between academia and industry during practice-focused master’s thesis projects conducted at engineering firms.
The associated theoretical contribution of this study is threefold. Firstly, that the motivation of the individual firm for participating in these master’s thesis projects is an important, overlooked antecedent for enabling opportunities for learning informal engineering skills. Secondly, that different types of motivation lead to opportunities for learning qualitatively different informal engineering skills. Thirdly, that these opportunities require different amounts of effort to grasp, as they require more or less boundary spanning between industry and academia to realise.

It is worth stressing informal, rather than formal, engineering skills in this theoretical contribution, as academia typically struggles to teach students these skills. This implies that the increased use of learning environments is motivated in this case, and that the assumption that students can learn the practice required at R&D firms during these work placements is well-founded also from an engineering perspective. As an example, we know that mentoring relationships with senior engineers are not straight-forward to achieve, but that it is important for early career engineers to work efficiently (Davis, Vinson, and Stevens 2017). Active mentoring is most frequent in situations with little hierarchy and shared responsibility (Davis, Vinson, and Stevens 2017). This matches the only readily apparent cases of mentoring in this study, which involved students and senior engineers who both had a real world stake in the outcome and did not have an established relationship. Arguably, without awareness of this possibility for mentoring this situation would probably not be considered ideal by academic faculty. However, with this awareness the focus can shift to realising this learning opportunity by combining it with a student with good enough boundary spanning capabilities.

Regarding the theory in the theoretical framework, this study primarily has implications for the discourse on the research–teaching nexus. Firstly, different papers have arrived at different conclusions on whether there is any well-formed causal relationships between research and teaching at HEI (Asplund and Grimheden 2019). This study adds another aspect to this relationship, as it shows how the existence of requirements on research can be one of the necessary antecedents to teaching certain engineering skills. Secondly, this study is yet another example in which this relationship can be implicit, and the positive outcome not even actively sought by those involved. It would for instance seem rational to a HEI to only involve firms that are very positive to research in their master’s thesis projects, but this study suggests that this might not always be optimal.

5.2. Contribution to practice

It is well known that both academia and industry need to think through why and how students are placed in an industrial context for a prolonged time to ensure academia, industry and students benefit from the experience (Edwards et al. 2015c). However, usually both students and academic faculty see professional skill development during work (placements) as mostly independent from academic control and assessment (Bennett, Richardson, and MacKinnon 2016; Edwards et al. 2015a). Many of the suggested reasons for this are centred on academia, students or uncontrollable factors, such as the importance of students taking ownership of their own professional skills development, that academic faculty lacks knowledge about the industrial context, and the uncertainty surrounding the engineering skill set in the future job market (Amiet et al. 2020). In contrast, we know that companies have different motivations for offering long term placements or internships, such as the wish to recruit, get access to additional resources, or tap into state-of-the-art knowledge (Edwards et al. 2015b). This motivation might not be possible to change, but this study suggests that being aware of its influence can allow us to control its implications.

Most, if not all, of the master’s students interviewed in this study were satisfied with the opportunity to work with an engineering problem of substantial complexity. Similarly, the examiners of the master’s thesis course had accepted both the students’ attempts at engineering a solution, and their accompanying scientific studies. By all appearances the students’ final leg of the journey towards becoming early career engineers had been successful.

However, only 28 of the students had a substantial opportunity to learn more about any professional skill, and only 10 of these had the opportunity to practice informal professional skills.
Furthermore, some students found it difficult to work with firms that wanted the students to explore knowledge areas on their behalf. As alluded to in the previous subsection, to mitigate these issues requires teachers to:

- Only encourage students who are able and willing to span the boundary between academia and industry to engage with firms that offer master’s thesis projects as a way of exploring unknown knowledge areas.
- Encourage students to engage with firms that offer master’s thesis projects of immediate relevance to their business, regardless of whether they are able or willing to span the boundary between academia and industry. However, teachers should prepare the students by explaining the benefits of active boundary spanning in their context.
- Actively seek a close working relationship with firms that offer master’s thesis projects as a way of recruiting early career engineers. Students who engage with these firms should at least get the opportunity to learn by passively observing engineers at work provided by a trusting relationship between industry and academia.

Arguably, our results also have implications for the hidden curricula (Villanueva et al. 2018) of many higher educational institutions in engineering, as both faculty and engineers often see little value in engineers acquiring research proficiency (Griffiths 2004). We have shown that this attitude can be a barrier to learning informal engineering skills in the studied context, even though these skills are not necessarily related directly to research. Arguably, lowering this barrier could also serve students well in their early engineering career in other ways, as the associated boundary spanning can involve weighing state-of-the-art technology and knowledge against ‘engineering as usual’. We know that firms often invest in certain technology and practices to the extent that they become locked to a specific technological trajectory (Dosi 1982). Attempting to alter this trajectory is difficult and will require students to consider both business and technological limitations. While engineering students typically want to focus solely on technology, this boundary spanning is an opportunity to describe the value of their work in terms of e.g. commercial value and sustainability. Many master’s programs, including the Swedish engineering master’s (The Ministry of Education and Research 1993), intend for this to be a learning outcome. However, there are not always opportunities for it to be learnt. Indeed, many practicing engineers find it difficult to describe their work in such terms (Trevelyan 2019).

5.3. Limitations

This study has two main limitations. Firstly, in regard to theory, practice-focused master’s thesis projects placed at firms create a specific learning environment, as academia will have requirements on the output which are not necessarily solved by the successful engineering of a system. Other motivations for work placements, such as capstone courses, might not have as strong academic requirements. It is entirely conceivable that results might differ under these circumstances. We have worded our discussion and conclusions to take this into account. Secondly, in regard to practice, we focus on the learning of professional skills. There are other factors that need to be considered when placing a student in a work environment. As an example, a firm might force a student to sign a non-disclosure agreement and not allow results to be released until the work has reached a certain (production ready) quality. The suggestions put forward in this paper are thus meant to be only part of a teacher’s assessment of whether a work placement matches a particular student, rather than absolute guidelines.

We also note that among the 14 students that did not take part in the second round of interviews, 5 did not finish their master’s thesis projects. Three of these students were placed at a firm. It is possible that there were unique challenges to the boundary spanning that these students had to perform, which can explain their failure to finish. However, this should not reduce the strength of
the observations reported in this study. Furthermore, the associated discussion with the supervisors at the Mechatronics division, described in the methods section, did not indicate the existence of any such unique challenge.

6. Conclusions

The transition from engineering student to early career engineer is often difficult. On the one hand, academic courses become more arduous by teaching increasingly advanced skills. On the other hand, some of the skills that an early career engineer needs to possess are not taught by HEI. Work placements have been suggested as a solution to this by providing a realistic context with opportunities to learn skills that academia is unable to teach. However, the implications on learning outcomes of placing students in an industrial context are understudied. Academic requirements can easily be overlooked if related to skills such as research proficiency, which are often seen as of little value to engineers.

However, this study has found that boundary spanning to align academic and industrial requirements can be valuable during practice-based master’s thesis projects conducted at firms. This boundary spanning can better prepare students for an (early) career in engineering by providing opportunities to learn informal professional skills, or even be critical to passing such a course at all. This ultimately depends on the motivation of the individual firm for offering the work placement. Specifically, different types of motivation can require a student that is both willing and able to reconcile academic and industrial requirements by actively spanning the boundary between industry and academia. Teachers thus need to consider this motivation carefully when planning and preparing a student for such a work placement. Firstly, to avoid unnecessary difficulties with completing thesis projects, teachers should avoid matching firms interested in investigating new knowledge areas with students that are weak boundary spanners. Secondly, to optimise the opportunities for learning professional engineering skills, especially informal ones, teachers need to explain the need for active boundary spanning in work placements at firms that host master’s thesis projects of immediate business relevance. Thirdly, to avoid missed opportunities for learning informal professional engineering skills, teachers should strive to have a trusting relationship with firms that offer master’s thesis projects as a way of recruiting early career engineers.

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Notes on contributors

Fredrik Asplund received his PhD at the KTH Royal Institute of Technology in 2014, has been a Postdoctoral Researcher within the Mobility for Growth programme, and was employed as an Assistant Professor at KTH Royal Institute of Technology in 2020. Throughout his academic positions he has taught courses in research methodology and supervised students at the master’s level. Research interests include system safety, empirical software engineering and engineering
education in the Cyber-Physical Systems domains. Dr Asplund is a Marie Curie Fellow and a VINNMER Fellow since his postdoctoral research at Rolls-Royce plc in Derby, UK.

**Elias Flening** is currently pursuing his PhD at the Division of Mechatronics at KTH Royal Institute of Technology. He achieved a MSc in Industrial Engineering and Management from KTH in 2014, and has worked as a research assistant at the Stockholm School of Economics. Research interests include engineering design processes, engineering education and project management in the mechatronics domain.

**ORCID**

Fredrik Asplund [http://orcid.org/0000-0001-5704-4504](http://orcid.org/0000-0001-5704-4504)

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