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Researching together in academic engagement in engineering: a study of dual affiliated graduate students in Sweden

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Abstract: This article explores dual affiliated graduate students that conduct research involving both universities and firms, which we conceptualise as a form of academic engagement, e.g., knowledge networks. We explore what they do during their studies, and their perceptions about their contributions to the firm's capacities for technology and innovation. So far, university-industry interactions in engineering are less researched than other fields, and this qualitative study focuses upon one department of Electrical Engineering in Sweden. First, we define and describe how the partner firms and universities organise this research collaboration as a form of academic engagement. Secondly, we propose a conceptual framework specifying how graduate students act as boundary-spanners between universities and firms. This framework is used for the empirical analysis, when exploring their perceptions of impact. Our results reveal that they primarily engage in problem-solving activities in technology, which augment particularly the early stages of absorptive capacities in firms.

Keywords: intangible assets; dual affiliated PhD students; academic engagement; engineering; university-industry interactions; collaborative research; boundary spanner; absorptive capacity; technology; innovation.

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1 Introduction

The top global 2,500 companies in terms of research and development (R&D) invested €908.9 billion in R&D in 2020, and these companies have significantly increased their spending for the 11th consecutive year, despite the pandemic [European Commission, (2021), p.54]. Evidence from the USA between 1980 and 2006 suggests a shift in the focus for corporate R&D, where firms continue to use corporate activities to promote commercially relevant technology in terms of patents but have moved away from exploratory science in terms of publications (Arora et al., 2017). However, firms still conduct some collaborative research, and such collaborative R&D in engineering firms is particularly interesting, due to the need to combine both use-orientation and exploration-orientation technology development, also known as 'Pasteur's quadrant' (Stokes, 1997). Collaborative R&D is thus a type of academic engagement, which involves knowledge-related interactions between the universities with external organisations (Perkmann et al., 2013, Perkmann et al., 2021).

This article explores dual affiliated graduate students, which conduct research involving both universities and firms, which we conceptualise as a form of academic engagement, e.g., knowledge networks. We explore what they do during their studies as well as their perceptions about their contributions to the firm's capacities for technology and innovation. Hence, our two objectives are:

1 to define and describe how the partner firms and universities organise this collaboration for academic engagement

2 to propose a conceptual framework to specify how graduate students may act as boundary-spanners between universities and firms.

A main motivation for studying them – despite being a relatively uncommon phenomenon – is because these individuals conduct their doctoral studies, as part of cross-organisational collaborative R&D, which should explicitly combine the aims of both industrial invention and academic science. Dual affiliated graduate students – who

are simultaneously at the firm and the university during their studies – represent a very specific type of human capital as intangible assets. They fall into the category that Grimaldi et al. (2018) denote as intangible assets for the implementation of open innovation (Dahlander and Gann, 2010). We interpret that these individuals can potentially serve as a direct investment in firms' absorptive capacity (Cohen and Levinthal, 1990), as they are firm employees spanning the organisational boarder at the same time as undergoing advanced technical training. In different national and disciplinary contexts, such graduate students which collaborate may work under different institutional regimes and purposes, ranging from internships and scholarship, to commissioned technical development projects to explorative science.

Understanding the details of collaboration across partners is important for being able to use science and research to impact firms and innovation. Rather than focusing upon cost containment, Leitner et al. (2020, p.20) argue that for large multinational, R&D intensive companies, "decisions about R&D investments are based on expected value creation, risk and strategic competence development". This suggests the need to focus upon intangibles, which also chimes well with calls to examine dispersed complementary assets and technologies across an innovation ecosystem (Holgersson et al., 2018). Although many corporate strategies exist to develop technology, if the aim is to design leading technologies, one option is to work directly with universities, which is more likely for companies with extensive R&D (Mansfield, 1995; Laursen and Salter, 2004). Indeed, the most effective form of knowledge transfer from the university appears to be the movement of people (Hughes and Kitson, 2012), and so we need to better understand how and why people-based activities can be designed to positively impact firms' innovations (Moon et al., 2019).

In Section 2, we present our conceptual framework to specify how graduate students may act as boundary-spanners between universities and firms. Section 3 discusses our research design and methodology. Our qualitative study is about dual affiliated graduate students, who are enrolled into a PhD program at one department of electrical engineering in Sweden and employed in large and medium-sized technology firms. The host firms are active in machine learning, telecommunication, and the transportation industry including construction equipment and automobiles. Our findings relative to the two research objectives are presented in Section 4. Our analysis reveals the details of how they primarily engage in indirect pathways – e.g., specifically related to problem-solving activities in technology – which augment particularly the early stages of absorptive capacities in the firm. We conclude in Section 5 with implications for managing such dual affiliated researchers and for future research.

2 Conceptual framework

The first element is to conceptualise how firms search and develop capabilities for technology and innovation. Cohendet and Simon (2007) argue that creative slack is important for firms and their innovative endeavours, and that day-to-day activities between members of diverse communities is reinforcing the development, improvement, and validation of new ideas. Other modern literature on innovation management has explored how firms search for relevant new knowledge externally, analysed in terms of breadth and depth (Laursen, 2012), and over organisational boundaries (Lakemond et al.,

2016; Lopez-Vega et al., 2016). The concept of absorptive capacity links the individual to the organisation, and specifically suggests that certain individual can bring external knowledge into the firm. In their seminal definition, absorptive capacity refers to the ability to:

1 recognise the value of

2 assimilate

3 exploit new external knowledge (Cohen and Levinthal, 1990).

We conceive that the activities of dual affiliated graduate students can be conceptualised as a position designed to be boundary-spanning from the start (Tushman, 1977; Tushman and Scanlan, 1981; Zahra and George, 2002). By this, we mean they are individuals who have already been selected to be technically competent and well connected, and who are simultaneously members of both partner organisations involved in R&D collaboration. Specifically, as to human capital as intangible assets, these individuals simultaneously pursue their advanced education and also work on research problems of interest to the firms, and hence must resolve conflicting aims in Pasteur's quadrant (Stokes, 1997; Faulkner and Senker, 1995).

The second element is to conceptualise how their activities link into the university. The extensive literature on the people-based activities of university-industry interaction has been conceptualised as 'academic engagement', as contrasted with other academic activities of research, teaching and commercialisation. Academic engagement is defined as knowledge-related interactions of the university with external organisations and including a variety of forms of interaction, such as collaborative research, consulting, and ad hoc advice (Perkmann et al., 2013, 2021). However, that literature has put little emphasis on graduate students, instead finding that academic engagement with firms is primarily driven by male, senior academics like chair professors, who also obtain extensive resources and publish (ibid). Yet literature which specifically addresses the relationship between graduate students and firms tends not to address our issues. This literature focuses primarily upon post-graduation careers in terms of impact of degrees on income and career paths relative to publication strategies (Cruz-Castro and Sanz-Menéndez, 2005; Roach and Sauermann, 2010; Garcia-Quevedo et al., 2011) as well as upon how interaction is related to educational outcomes (Thune, 2009; Borrell-Damian et al., 2010). Hence, most existing literature examines the differing career paths of individuals working within academia or firms (Leten et al., 2014). We study dual affiliated PhD students, who are concurrently researchers and firm employees, making the role of such PhD students in academic engagement particularly relevant to study.

The third element is the interactions between graduate students and firms. Some literature has highlighted the specific role of graduate students in collaboration with firms. By contrasting the strategies of large and small firms in interacting with universities, Thune and Børing (2014) find that 'industry PhD schemes' in both large and small firms were primarily designed to enhance core technologies and innovation capability. In a study of collaborative research centres, McKelvey et al. (2015) find that both master's students and PhD students contribute to research, but that while small firms wanted to access market opportunities through networks with large firms, the large firms wanted to explore technological opportunities inherent in the collaborative research with

universities. We extend this literature but limit our study to subsidiaries and large multinational firms active in R&D in advanced engineering.

Hence, given these three theoretical elements from existing literature, we expect that their activities are reasonable to conceive of as R&D strategic competence development to the firm, in line with Leitner et al. (2020). Moreover, we expect that these graduate students likely enhance the long-term capabilities of the firm through indirect impacts, rather than lead to immediate commercial innovation through direct impacts (McKelvey et al., 2015; Thune and Børing, 2014).

Our final element is to specify how the three elements of absorptive capacity can be conceptualised as activities which promote two pathways of impact upon the firm. Based on a review and empirical study, we use the proposed McKelvey and Ljungberg (2017) model consisting of a direct and indirect pathway. We define that the direct pathway is research conducted will fairly immediately and directly lead to product and process innovations in the firm. Through existing literature, we have categorised certain activities from university-industry interactions as linked to direct innovation outcomes: assisting in problem solving (Bishop et al., 2011), engaging in product and process development (Broström, 2010; Gustavsson et al., 2016) and identifying direct business opportunities (Broström, 2010). We define that the indirect pathway for research is to develop technological knowledge, which serves a variety of purposes to the firm, and later has a positive impact upon the firm's capabilities to innovate.

This indirect impact is likely more related to knowledge-related interactions of academic engagement and includes knowledge transfer and learning; network development and signalling effects (McKelvey and Ljungberg, 2017). More precisely, we have identified activities for each of these three elements in which dual affiliated PhD students may partake in through searching existing relevant literature. For knowledge transfer and learning, this may entail human capital management (such as recruitment of young researchers, influencing undergraduate education and securing research partners for the firm (Broström, 2010; Bishop et al., 2011), academics can serve as 'windows' on new technology (Perkmann and Walsh, 2008) and generate patents (Bishop et al., 2011), access to scientific knowledge (Thune, 2009), developing technological competences (Thune and Børing, 2014; Gustavsson et al., 2016) and developing internal R&D activities (Gustavsson et al., 2016). For networks, the key idea is that the firm gets value in gaining access to networks. There is a broad literature showing that knowledge networks in general are important for innovation (Ahuja, 2000a, 2000b; Lam, 2007; Nerkar and Paruchuri, 2005). Finally, signalling effects may be similar to legitimacy. Gustavsson et al. (2016) find that increased legitimacy for a product or process (through for example scientific articles or dissertation) enabled firms to strengthen their ties to clients and business partners (see also Hicks, 1995).

In their conceptual framework, McKelvey and Ljungberg (2017) argue that the indirect pathway may influence firms' capability for innovation: "conceptually, these three categories are intangible outcomes through which research collaboration can stimulate firms' capabilities for innovation" [McKelvey and Ljungberg, (2017), p.541]. More specifically, they propose that knowledge transfer and learning, network and signalling effects stimulate firms' capabilities for innovation through an increased knowledgebase, increased capacity to search for and access external knowledge, and marketing abilities.

In this paper, we further develop the above propositions that such outcomes can stimulate firm's capabilities for innovation. We do so by explicitly conceptualising that:

1 the direct pathway also require firms to have capabilities for innovation

2 the firm's capabilities for innovation require absorptive capacity

3 activities related to the direct and indirect pathway may influence the three phases of absorptive capacity (recognising, assimilating and exploiting new external knowledge) in different ways.

Table 1 summarises our interpretation of how the activities that these boundary spanners conduct can either be related to the direct or indirect pathway to innovation, which may both affect firms' absorptive capacity.

Table 1 Theoretical conceptualisation

	Absorptive capacity		
	Recognise the value of new extern knowledge	*Assimilate new external knowledge*	*Exploit new external knowledge*
Direct pathway to innovation			• Assisting in problem solving • Engaging in product and process development • Identifying direct business opportunities
Indirect pathway to innovation	*Knowledge transfer and learning:* • Human capital management • 'Windows' on new technology • Access to scientific knowledge • Developing technological competences • Developing internal R&D activities *Network effects:* • Develop networks	*Knowledge transfer and learning:* • Generate patents	*Signalling effects:* • Legitimacy

3 Research design and methodology

We provide a qualitative study of one phenomenon, to explore a complex empirical setting (Yin, 2014), although we use a process description and coding following Gioia et al. (2012) rather than a multi-case approach of Eisenhardt (1989). This research is part of a larger four-year research program that focuses on the engineering discipline with the

aim of investigating academic engagement in relation to innovation. We selected dual affiliated graduate students as a rather unusual phenomenon, representing extreme case selection from a theoretical perspective, applying the above conceptual framework. We have used the Goffin et al. (2019) framework of CASET evaluation template to guide and improve our research process.

Studying them should help us explore how the challenges of research collaboration using individuals as boundary-spanners in these ways. They do activities for both research and academic engagement goals. Setting up projects and hiring these individuals represents intent from the firm and the university to conduct collaborative research. Moreover, the phenomenon is of empirical interest due to growth, because since 2002 when the first dual affiliated PhD students was statistically registered in Sweden, there has been a steady increase of this form of employment, from 189 individuals in 2006 to 979 individuals in 2018 in Sweden (UKÄ, 2019). Engineering has a long tradition in this context.

3.1 Data collection

Information about all PhD students enrolled in 2017 at an engineering department at a single university was obtained. In total, the department had 23 PhD students enrolled at the time, of which all was approached and invited to partake in this study. Two of the students declined to be part of this interview study due to time restrictions, while ten individuals agreed to participate for the specific questions of this paper. The other 11 students did not respond to the invite even after receiving multiple reminders. Thus, although the authors have tried to include all 23 PhD students in this study, it was ten PhD students that accepted the invite and thereby become part of this research.

The main data source is interviews. One author conducted all the interviews and represented the overviews and coding to discuss with the second author, over a three-year period. The interview guide was distributed to the informants on beforehand by e-mail, including:

1 the interview was to be recorded

2 anonymous.

The first interview round followed a semi-structured interview guideline, based on an early version of the conceptual framework in Section 2. A pilot interview was conducted in June 2017, leading to refinements of the questions and triggering the development of a check-box slip of different activities, which the informants filled in during the interview. The final interview guide focused on the background for becoming dual affiliated PhD students, what activities they did during the collaboration and their thought about how they contributed to the firm in terms of innovation. This was followed by the first round of 1st interviews with ten more students in September 2017. A summary of each interview was sent to the informant to assure respondent validation.

The second round of interviews was conducted with eight informants, to specifically focus upon their reflections of how they perceived they contribution to firm innovation during their studies. For Niklas and Olof, this topic was covered in the first interview. The interview started out with open-ended questions regarding innovation outcomes and towards the end the informants was shown the extended theoretical framework. All

interviews were transcribed and used for extended analysis in connection to data gathered from the first round of interviews.

An overview of the collection of primary data is presented in Table 2.

Table 2 Collection of primary data

*Dual affiliated PhD student**	*1st interview*		*2nd interview*	
	Date	*Length of interview (recording)*	*Date*	*Length of interview (recording)*
Adrian	September 2017	01:02:02	November 2018	01:11:10
Christian	September 2017	00:39:55	October 2018	00:58:32
David	October 2017**	01:01:29	November 2018	00:53:11
Emil	October 2017	01:05:43	April 2019	01:02:37
Fredrik	October 2017	01:02:14	June 2018	00:54:46
Gabriel	October 2017	01:21:47	June 2018	01:16:53
Henrik	November 2017	00:46:59	June 2018	00:46:53
Karl	June 2018	00:49:59	November 2018	01:33:15
Niklas	October 2018	1:02:42	-	-
Olof	November 2018	2:14:04	-	-

Notes: *Names are fictive.
**This interview was conducted via Skype (all other interviews were conducted face-to-face).

3.2 Data analysis

The data analysis has followed a two-step procedure, relative to the conceptual framework, and involving rounds of iteration between the authors, and between the conceptual framework and the results, following recommendations from both (Gioia et al., 2012; Goffin et al., 2019). The transcribed texts were imported into the software tool Nvivo. Each individual interview was first analysed separately. Each interview was coded with first-order codes, which were purely derived from the empirical material and without any theoretical links. In this stage, the first order codes were assigned to sentences or chucks of text, thereby lengthier than when using line-by-line coding. Once the first-order codes were identified and agreed upon by the authors, they were grouped in to second-order codes. The first-order codes were of more detailed nature, specifying a specific experience of the dual affiliated PhD student, while the second-order code were on a more aggregated level, where several first-order codes was assigned into one second-order code. After coding the individual interviews with first and second-ordered codes, the analysis of the data proceeds by combining all the information in all interviews (Eisenhardt, 1989). Once the empirical material was organised in this way, the second-order codes was compared to the activities of the direct and indirect pathway to innovation that had been identified in existing literature (for example assisting in problem solving (Bishop et al., 2011), generate patents (Bishop et al., 2011) and access to scientific knowledge (Thune, 2009). Once this stage of the analysis was done, we developed third-order codes, or themes, which represented the three stages of firm absorptive capacity (the ability to recognise the value of, assimilate and exploit new

external knowledge). Thus, the codes and themes have explicitly referred back to those used in our conceptual framework. For the direct pathway of innovation, we did not find support for two of the activities, namely direct business opportunities as proposed by Broström (2010) and engaging in product or process development (McKelvey and Ljungberg, 2017; Broström, 2010; Gustavsson et al., 2016). However, a new activity emerged from our empirical analysis, which is referred to as 'firm-specific activities'. For the indirect pathway, we found support for all activities we had identified through searching relevant exiting literature. One new activity emerged from the empirical analysis, which is referred to as 'legitimacy'.

4 Findings

4.1 Defining our phenomenon in the context of electrical engineering in Sweden

This section addresses our first research objective, to define and describe how the partner firms and universities have organised the work of these graduate students.[1] Because of lack of previous research on dual affiliated PhD students as well as the variety of types, (Thune, 2009; Borrell-Damian et al., 2010), this section empirical setting provides details.

In the Swedish context, most PhD students and especially in engineering are employees, of either the university or the firm, while enrolled as PhD students. They are enrolled into a four-year education program as a PhD student, with requirements to take course credits and write an independent thesis. Universities employ 71% of all doctoral students in Sweden (Statistics Sweden, 2017), and these are denoted as academic PhD students here. Another 23% of all PhD students have various employment arrangements such as stipends, medical doctors, and employment in organisations others than universities and firms, which are not addressed here. 6% of the doctoral students in Sweden are employed by a firm and conduct PhD studies within the employment (Statistics Sweden, 2017), which we here call dual affiliated. In the Swedish context, they are most common in engineering disciplines, constituting 14% of all new PhD students in 2016 (Statistics Sweden, 2017). They may also be called firm-employed PhD students and industrial PhD students.

The chosen university is specialised in engineering disciplines. Of all PhD students at this large technically oriented university in Sweden, called the university, 19% were employed by firms while PhD students. To be enrolled as PhD students, they need to meet certain conditions related to study pace (>50%), supervision criteria (two or more researchers at the university) and teaching demands (max 20%, which can be replaced with work at the firm).

All the firms are multinationals, as chosen for this study, as follows: six of the informants employed at firm A, which is a subsidiary, joint spin-off firm within the field of machine learning. Except for Henrik, these informants started doing their PhD studies within other firms and were later transferred to Firm A in recent years. Firms C, D and G are all large and global firms, the first within telecommunications, the second within the transportation and construction equipment industry while the latter is in the automotive industry. Hence, the firms both represent specialised subsidiaries for advanced technology on machine learning, as well as engineering-intensive large firms. The topic of the dual affiliated PhD students' dissertations is considered to be new to the firm, as it

focusses on areas that are in the outskirts of firms' knowledgebase and product development.

Table 3 provides an overview of financing and the division of labour amongst tasks for each of the informants.

Table 3 Financing and division of work of dual affiliated PhD students

Graduate student	*Firm*	*Financing of PhD project*			*Division of work*		
					Academic work		*Firm work*
		External Grants	*Firm*	*The university*	*PhD education*	*Teaching*	
Adrian	Firm A	Yes, public A	Yes	0%	90%	10%	0%
Christian	Firm A	50%, public A	50%	0%	90%	10%	0%
David	Firm C	50%, public B	50%	0%	90%	10%	0%
Emil	Firm D	50%, public A	50%	0%	90%	10%	0%
Fredrik	Firm A	50%, public A	50%	0%	95%	5%	0%
Gabriel	Firm A	50%, foundation F	50%	0%	80%	10%	10%
Henrik	Firm A	Yes (unknown)	Yes	0%	80%	10%	10%
Karl	Firm A	100%, combining foundation F and public C	0%	0%	90%	10%	0%
Niklas	Firm D	30–40%, public A	60–70%	0%	80%	0%	20%
Olof	Firm G	50%, public A	50%	0%	80%	10%	10%

In terms of funding, all ten receive their salary from the firms, but the firms may in turn fund their position through involvement in collaborative research projects with the university. In other words, these positions do often depend upon external competitive grants, which are given from external organisations (e.g., external to both the firm and the university). The firm and the university apply jointly for grants for each of the individual PhD student positions, and the grants are specifically designated to support their employment and education, within larger collaborative projects. They are funded by three public initiatives (labelled as public A, B and C) and one foundation initiative (labelled as foundation F).

Moreover, to better understand what they do, we categorise and label their activities into the broad categories of 'academic work' from 'firm work', as found in Table 3. 'Academic work' relates to both PhD education and thesis, specifically the amount of time that the informants should spend on their education and research project, and teaching, which is the amount of time that the informant should spend on teaching activities at the university. Six out of ten informants spend 100% of their time on academic work, for example 90% PhD education and 10% teaching. The remaining four informants dedicate 80-90% of their time on academic work. What we label as 'firm work' refers to the amount of time that the informants are expected (by contract) to participate in firm-specific work. Thus, the tasks that are to be performed are firm specific and can theoretically be anything the firm manager decides. Practically though, they reported that these tasks are usually related to the research project. Moreover, even if the main part of the informants does not have time assigned for firm work in their contracts, the interpretation of the interviews revealed that they still spend time at the

firm and help out their colleagues in different ways. All informants aim to work at the firm office at least once a week, whereas others spend all their time at the firms' office except when they have teaching or other scheduled activities at the university.

Initially surprising, we found that these students did not often report goal conflicts between the two organisations, although they recognise that they have a demanding position. Possibly this acceptance of the demands of the position has to do with self-selecting into it. They do attend scientific conferences and publish papers and report that their activities are similar to the academic PhD students. They do not report that they are 'only' working on technical development projects within the firm, but of course that could be a finding due to the interview method. However, what does come across strongly in the interviews is that in practice the PhD students also spend time on firm-related work tasks and issues, in addition to their PhD studies, which means that the workload can exceed full time employment. They seem to suggest that this intensity and types of interaction are necessary, to meet the demands of being an effective boundary spanning individual as a dual affiliated graduate student. To conclude, the dual affiliated PhD students simultaneously combine academic and firm-related work tasks although they primarily focus on their academic work (80–100%) related to research such as taking PhD coerces and writing their dissertation, as well as teaching duties.

4.2 Reflections of the students

The focus of our second research objective is upon the perceptions of the graduate students on their own contributions – in order to better interpret how they reflect upon their own activities and contributions during doctoral studies which involve courses and independent research projects.

Table 4 presents our interpretation of how students reflect, as related to our conceptual framework. The specific activities are divided into the direct and indirect pathways to impact innovation in firms, through academic engagement.

For direct pathways, our analysis is in line with previous research and thus indicates that, from the perspective of the graduate students, there are few instances where their activities will lead directly and immediately to the market as product or process innovations (McKelvey and Ljungberg, 2017; Broström, 2010; Gustavsson et al., 2016). If the graduate students are involved, then usually they have previously worked at the firm, and therefore have an existing personal network within the firm. We have identified some situations when they do step in and help firm employees with a specific problem they are dealing with or problem-solving more generally, which we consider representing assisting in problem solving, similar to Bishop et al. (2011). Regarding direct business opportunities as proposed by Broström (2010), we do not find this. The closest we find is that they express that their contributions may lead to new product in the future, by for example developing a vision or a technology base. Additionally, from our analysis we have identified firm-specific work activities. Four of the informants have been assigned firm work (10-20%) in their contracts, and others also participate in firm-specific activities as well, usually through different types of technical and group meetings, or personal contacts in the company.

Table 4 PhD students' reflections on activities, categorised by direct and indirect pathways

How the PhD students reported their activities	*How it helps the firm*	*Expected contribution to firm*
	Direct pathway	
	Product development	
"The ones that come from industry are more used to [the process of patenting]"	Not common. Expectation depends on contracts and whether possible to patent, or not, in that technology area	Patenting
"It's very well connected to reality and we take academic help to see and explore if there are other possible control (engineering) structures that we can use"	Not common. A few do use their research to look for alternatives in product development	Being involved in product development
"It's not so far ahead but I don't think the code I write will end up in a product. It is rather code that are based on what I have researched, that might end up in a future product".	Long time delay to product, even in engineering	Influencing future products
"So we identified this gap and that's why we created this project. I was involved pretty early in the phase, we found this gap to be significant and we realized we could work on this with a research interest as well"	Ability to contribute seems to be related to previous work experience	Wide diversity of whether, and how, long the individuals previously worked in a firm
	Problem-solving activities	
"You can suggest new ways of doing the same thing, that's also, or solving the same problem with new solutions"	May be useful to solve problems	Learning new tools and methods
	Indirect pathway	
	Knowledge transfer and learning	
"We can be the first ones to have this kind of solution, and that's a good thing. And as we talked about before, its starting to come up some things that can be developed, based on my models, into like some product or tool that can be used either by the firm or our customers."	Developing methods, algorithms and models	Scientific knowledge Bringing in a wider perspective
"I will be part of a long-term technology road map"	A Focus on technology, but might not result in a specific product or process	Develop a technology base
"Something that happened quite recently is that the firm suddenly wanted to offer a certain product to our customers, and then they started to search for knowledge within the firm and then they found me."	B Developed technology to levels 3–4 on the 'technology readiness level' scale	Develop a technology base

Table 4 PhD students' reflections on activities, categorised by direct and indirect pathways (continued)

How the PhD students reported their activities	*How it helps the firm*	*Expected contribution to firm*
Indirect pathway		
Knowledge transfer and learning		
"I see it as there are a vision of doing something, you need to break it down in smaller things and I contribute to one of those things"	Developing a technical vision for future. Fulfil part of firm goals	Act as window on technologies
"The latest news is that a patent we started working on for like 2 or 3 years ago, was accepted this summer."	Filed several patents of which some has been approved	Generate academic patents (with university)
A "Or results, if I can give them anything or sometimes like present to them what we have done kind of […] And then, often I direct them to the article. You know, I put a lot of time into writing them so then I think it is quite well described in there, what they want to know. But if its not in the article, of course you can help them"	A Distributing publications inside own firm lead to new contacts, presentations and introducing new knowledge to the firm	Develop firm R&D
"You can have really critical discussion on what's the best way to do and that has given interesting conversations for us (the firm), to just not be defensive but to be open and to accept criticism where its due"	Valuable to have a more academic and a more global perspective	Develop firm R&D
"It was another team that is located in the other side of the building that said: Hey, we had a thought about using machine learning, can you help us supervise a mater thesis project? So it was another team that has asked me for my expertise and help in supervising a master thesis project together with them, they are the ones getting all output and benefits from the master thesis project but they wanted me involved to push it forward"	Supervising master thesis projects on request of a colleague at the firm	Human capital management
Network development		
"So I think a lot of people knew what I was trying to do already many years ago and now, well now people know what I'm doing so if someone wants to know something (in this area), then they direct them to me"	Positioning in network, internally and externally	Getting access to networks
"[The firm] wants to know what's going on at The University. Who are close to graduation and which of them might be good to hire".	Getting insight into external organisations	Strengthening relationships with university

Table 4 PhD students' reflections on activities, categorised by direct and indirect pathways (continued)

How the PhD students reported their activities	*How it helps the firm*	*Expected contribution to firm*
Indirect pathway		
Network development		
"For example, it was a technical expert from another area at a presentation I had that I had had brief contact with before, when we both worked at an other firm, that started to talk with me and asked about details."	Presentations lead to new contacts and meeting	Develop contact with other companies
"[Foundation A] organize trips, I went to USA on one of those two weeks ago and had the possibility to visit competitors to the company"	Trips abroad and to firms, with graduate students from multiple firms	Develop contact with other companies
Signalling effects of doing science		
"The whole idea is that when we have firms visiting or guests and want to present what the firm does here […] we do excellence, we work on things that no one else is working on, or that no one has solved yet, and its challenges that most have and then they see that we are working on those problems to solve them"	Engage in activities that make it visible that the firm is engaged in research. Examples: expert at industry fair and present Expert Quick Pitch to customers and suppliers to show excellence	Legitimacy
"I think they look at it as a prestige thing, if something is publishable by the section because it brings more valuable to the company as well as the research area so that is them being positive towards publication".	Publishing papers for both individual and corporate prestige	Prestige

When they do impact the firm more directly, then it is through problem-solving activities, usually related to technology, or to the firm's need to move into new technologies, tools, and methods, which are close to their on-going research projects. Thus, we interpret their problem-solving activities as enabling assimilation of knowledge into the existing knowledge structure of the firm (Cohen and Levinthal, 1990), which is similar to the technology-focused activities defined in (Perkmann and Walsh, 2008). This is different from our conceptual framework, as we initially expected the activities related to the direct pathway of innovation to influence the final stage of absorptive capacity, namely exploiting new external knowledge.

In terms of the indirect pathways, our analysis reveals several ways in which these graduate students can act as boundary spanners between the two organisations. For knowledge transfer and learning, there are both formal and informal activities in which they bring knowledge from one to the other, for problem solving. Formal activities include industrial supervision at the firm, meetings, presentations, academic papers and conferences, and activities representing more informal interaction include conversations and discussions with firm employees which may lead to assisting in problem solving or scoping new technological areas. We thereby also confirm existing research about dual affiliated PhD students being one way for firms to access scientific knowledge (Thune,

2009; Gustavsson et al., 2016), develop technological competencies (Thune and Børing, 2014; Gustavsson et al., 2016) and can act as 'windows' on new technologies (Perkmann and Walsh, 2008). We interpret that the firms' experience human capital management benefits when collaborating with universities (Broström, 2010), which we interpret as impacting both in terms of recruitment and training of firm employees (Bishop et al., 2011). Our interpretation is that the identified activities of the indirect pathway enable firms to recognise and assimilate new external knowledge (Cohen and Levinthal, 1990) as our conceptual framework predicts. In addition, we also find that dual affiliated PhD students can signal prestige through research excellence of their publications, which we interpret to influence the ability to assimilate new external knowledge into the existing knowledge structure of the firm (Cohen and Levinthal, 1990).

5 Conclusions

Given that the most effective form of knowledge transfer from the university appears to be the movement of people (Hughes and Kitson, 2012), we need to better understand how and why people-based activities can be designed to positively impact firms' innovations (Moon et al., 2019). Hence, we hope that our detailed qualitative study has offered some insights into how these individuals conduct their doctoral studies, as part of cross-organisational collaborative R&D. For the first objective of describe and define the phenomenon, they are clearly well-integrated into academic engagement structures, involving PhD programs and ongoing collaborative research, as almost all are at least partially funded by external public councils and foundations. For the second objective of proposing a conceptual framework to specify how graduate students may act as boundary-spanners between universities and firms, we have chosen to apply and update an existing framework defining direct and indirect pathways. Our results reveal the details of how they primarily engage in problem-solving activities in technology, which augment particularly the early stages of absorptive capacities in the firm.

5.1 Implications for practice

Managing this type of intangible asset requires very high levels of trust, alignment, and goals. Hence, the implications for practise need to consider the boundary-spanning position in both the firm and the university, as part of larger structures. To make these research projects work well, there needs to be alignment in goals, visions, and representations of innovative outcomes (or 'usefulness') amongst the collaborative partners. The partners need to talk and continue to do so throughout the entire project. The partners in the projects we observed had agreed on beforehand that they should collaborate in this specific way, namely by having a joint PhD student project. Thus, the involved university and firms had agreed to devote resources, develop capabilities to collaborate and create denser knowledge networks around much specialised technological knowledge through participating in this form of academic engagement with industry.

5.2 Limitations

We recognise the limitations of our qualitative research. First, it is difficult to produce generalisable results due to the narrow case selection and limited number of interviews.

Our study only investigates dual affiliated PhD students in the electrical engineering department at a single university in Sweden, which implies certain limitations with regards to applicability of our results. Thus, our results would be most applicable for PhD student-firm collaboration within similar research fields and in similar institutional contexts present in Sweden. Thus, the research presented in this paper on dual affiliated PhD students need to be tested further to improve the generalisability of the results. Preferably, future research would include fields other than engineering, such as STEM and the social sciences, and include both higher numbers and diversity of participants, in relation to for example gender and country, to be able to test the findings quantitatively. Second, we are focused upon the perceptions and activities of the graduate students and only include individuals who self-selected in to this research, which might have created a bias with regards to overrepresentation of positive outcomes related to innovation. It would be valuable for future research to also include perspectives from other parties involved in this form of academic engagement, such as academic and industrial supervisors, to strengthen our findings through triangulation (Eisenhardt, 1989). Special attention could also be devoted to failed collaborations between PhD students and firms and to explore related negative effects on firms' innovation outcomes.

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Notes

1 A more detailed description of the activities – but without links to the direct and indirect pathways to innovation – is available in previous work by the authors (Berg and McKelvey, 2020).