Received: 10 May 2022 | Revised: 24 January 2023 | Accepted: 20 February 2023

DOI: 10.1002/spe.3200

RESEARCH ARTICLE

WILEY

An industry survey on approaches, success factors, and barriers for technology transfer in software engineering

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Abstract

One central aspect of software engineering research is the transfer of the proposed approaches into industrial practice. In the past, a number of technology transfer approaches and experiences from technology transfer projects in software engineering have already been reported. However, many researchers still struggle to get their research results noticed by practitioners. To investigate what is important to practitioners, we conducted a mixed-methods study that provides us with reliable quantitative data as well as deeper insights from qualitative data. Our results show that there is a mismatch between industry professionals' needs and commonly proposed technology transfer approaches in the software engineering field. For instance, collaboration between industry and academia as well as participation in empirical evaluations is not deemed important from an industry point of view. In contrast, industry professionals emphasize the use of company-specific pilot projects conducted by industry and the need for experts to be available in every phase of technology transfer.

KEYWORDS

industry survey, software engineering, technology transfer

1 | INTRODUCTION

Despite the fast-paced nature of computer science, software engineering research results often take years to catch on in practice. This is not only frustrating to researchers developing novel solutions, but also impedes practitioners' abilities to create reliable software in a cost-effective manner. For decades, software engineering research has developed not only methods, techniques, and tools, but also tried to improve software engineering technology transfer, that is, the transfer of results into practice.

In Reference 1, the authors examined how long it took for several technologies to become widely used in practice. They identified critical factors, inhibitors, and facilitators which influence this time length. Pfleeger[2] summarizes existing research on technology transfer in software engineering as of 1999. Placing particular emphasis on the collaboration between academia and industry, Pfleeger defines different ways of software engineering technology transfer and

Abbreviations: CEO, chief executive officer; CFO, chief financial officer; dF, degrees of freedom; HW, hardware; IT, information technology; K, Cohen's kappa (interrater reliability metric); M, average; n, sample size/number of occurrences; OEM, original equipment manufacturer; p, Type 1 error probability; ROI, return on investment; RQ, research question; SD, standard deviation; Sig., significance level; SME, small and medium sized enterprise; Std., standard; SW, software; vs, versus.

identifies inhibitors and promoters for the transfer of a technology to industry. Ivarsson and Gorschek[3] provide an overview of support for technology transfer in the requirements engineering field. To do so, they examined technology evaluations that had been published in the Requirements Engineering Journal. Geisler[4] proposes terms and definitions for technology transfer derived from existing research. Furthermore, objectives and research directions are defined to build a theory on technology transfer. In an exploratory study, Diebold et al.[5] report on a survey conducted among academia and industry and conclude that software engineering technology transfer is hindered as most technologies developed in research projects are not mature enough, technology transfer process models do not apply from an industrial point of view, and industry organizations mainly rely on their own research to gain new knowledge rather than promoting technology transfer from academia. Similar results are reported by Garousi et al.[6,7] who conducted an opinion survey on the current state of the art regarding industry academia collaboration.

Thus, numerous publications suggest approaches for successful technology transfer[2,4] or report on experiences made during technology transfer.[3,5,8] Furthermore, papers exist that provide empirical results regarding the suitability of different technologies for their introduction in an industrial setting.[9-11] However, only few report what practitioners expect from researchers to adopt their technology.[12] To add to this body of knowledge, this article continues an avenue of research into software engineering technology transfer* previously reported in Reference 13. Therein, we have reported a systematic literature review on approaches, success factors, and barriers for software engineering technology transfer. In this article, we contribute results of a survey conducted among practitioners to gain insights into success factors and barriers from an industry perspective.

To do so, we conducted a mixed-methods study involving industry representatives to answer the following research questions:

- *RQ1: What expectations do practitioners have for software engineering technology transfer*?
- *RQ2: What should the software engineering technology transfer process look like (from the perspective of the industry)?*

To answer these questions, we first analyzed the state of the art and identified commonly suggested approaches to foster technology transfer from academia into industrial practice in the software engineering literature. Additionally, we identified relevant experience reports and opinion papers to gather information on commonly reported success factors and barriers for technology transfer. Based on the information from the current software engineering literature, we defined a survey in which industry professionals rate suggested approaches and success factors to answer RQ1. We also elicited industry professionals' opinions on the ideal technology transfer process to answer RQ2.

Thus, this article contributes:

1. An initial theory on software engineering technology transfer based on the related work on technology transfer approaches, success factors and barriers for technology transfer.
2. An evaluation of this initial theory on software engineering technology transfer by surveying industry opinions on the several aspects of the theory.
3. Recommendations for successful software engineering technology transfer synthesized from qualitative and quantitative insights gained by surveying industry professionals.

This article is structured as follows: Section 2 describes the study design and the procedure used. In a first step, literature was analyzed to define an initial theory to be evaluated later on. Based on this analysis, we define an initial theory of technology transfer in Section 3 to derive a questionnaire to be used in our evaluation. In Section 4, we discuss the design of the industry survey to evaluate the industry perspective of technology transfer. Section 5 presents quantitative and qualitative results. Section 6 discusses the findings of the study and identifies success factors, barriers, and derives recommendations for an archetypal technology transfer approach. Afterward, in Section 7, we close the loop by presenting additional insights from discussing our findings with our industry partners in order to work towards an improved alignment of academic and industrial approaches to technology transfer. Finally, Section 8 concludes the article.

2 | METHOD

We aim to investigate what is considered important for software engineering technology transfer from an industry perspective and thereby complement our theoretical findings published in Reference 13. Therefore, it is evaluated whether

*By this, we mean transfer of technology from creation into application, not adoption of off-the-shelf components like in the field of supply chain risk management.

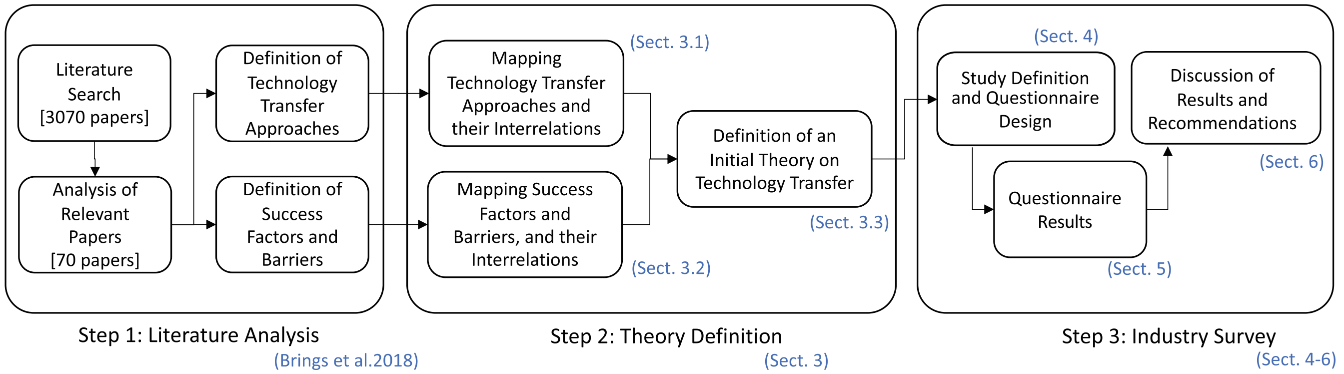

FIGURE 1 Procedure.

the findings from Reference 13 hold for the interviewed industry professionals. To define a study setup for investigating industry professionals' opinions towards technology transfer approaches, a prerequisite is the existence of a testable theory. To achieve this, we re-analyzed the literature identified in Reference 13 with the aim to derive an initial theory that highlights aspects of technology transfer that we can use in an industry survey.

Figure 1 gives an overview of the entire procedure of our study. The study consists of three major steps:

- Step 1: We conducted a literature analysis to identify approaches for technology transfer in software engineering and commonly reported success factors and barriers for technology transfer. Therefore, we conducted a systematic literature review. We used a combination of three complementary search methods (i.e., database search, manual search, snowball search) to ensure for reliable results. More details on the search method can be found in Reference 13. During the search we investigated, 3070 potentially relevant papers. In the end, we included 70 relevant papers as the basis for our analysis. Based on these papers, we investigate technology transfer approaches used in software engineering research and success factors and barriers reported.
- Step 2: We derive two conceptual maps on technology transfer: the first map illustrates the proposed approaches to foster technology transfer and their interrelations (see Section 3.1), the second map shows reported success factors and barriers for technology transfer and how each aspect is related to the others (see Section 3.2). Doing so allows us to formulate an initial theory of technology transfer. This theory is based on the related work and developed by abstraction based on commonalities from the two conceptual maps. Section 3.3 introduces the resulting initial theory on technology transfer.
- Step 3: The initial theory from Step 2 serves as the basis for the design of a survey study to investigate industry's perception on technology transfer in software engineering (see Section 4). Therefore, this theory, was subsequently transferred into a questionnaire taking existing approaches and experiences into account. This questionnaire included open questions, to give the industry participants room for expressing new ideas and particularly to ask practitioners what they imagine an ideal technology transfer approach would look like. Section 5.1 reports the quantitative results of the study and Section 5.2 the qualitative results of the study. Based on our findings, we were able to summarize success factors and barriers for technology transfer in Section 6.3. These constitute a consolidated and expanded view of our initial theory and a refined view on how technology transfer approaches are perceived by industry professionals. Thus, Section 6.3 also gives recommendations for technology transfer based on our results.

In Section 7, we present insights from discussing our findings with our industry partners.

3 | THEORETICAL FUNDAMENT

An initial theory on technology transfer in software engineering is derived from the literature. Therefore, we classified the existing approaches in a conceptual model on how technology is transferred in software engineering, explaining the interrelations of technology transfer approaches. We elaborate on this in Section 3.1. In addition, we conceptualized the reported success factors and barriers from the experience reports, explaining their interrelations as well (see Section 3.2). Based on these conceptualizations, we derived an initial theory of technology transfer in software engineering in Section 3.3, which, in accordance with Reference 14, we subject to empirical investigation.

3.1 | Mapping technology transfer approaches and their interrelations

Based on the findings from the related work outlined in Reference 13, we identified technology transfer approaches, whose important aspects and interrelations have been conceptualized in Figure 2. We identified four major categories for technology transfer approaches in addition to miscellaneous approaches:

- *Technology transfer models*. Many technology transfer models have been proposed. We investigated different phase models, which have been proposed by Punter et al.,[15,16] Schuh et al.,[17] Gibson and Harlan,[18] and Aschauer et al.[19] Furthermore, we included models for the maturity of technology by Fowler[20] and Redwine and Riddle,[1] a framework for tailoring technology transfer methodologies by Kalinowski and Travassos[21] and generic models for technology transfer proposed by Rombach and Achatz,[22] Buxton and Malcolm,[20,23] and Fowler.[20]
- *Collaboration approaches*. Collaboration approaches include exchanges between industry and academia, forming strategic alliances, or working in companies alongside their studies. Included approaches are proposed or investigated by Freedman et al.,[24] Redford and Price,[25] Abercrombie,[26] and Bass[27] as well as Reference 28.
- *Education approaches*. For education approaches, we found a wide variety of different applications. First, we have approaches that address several aspects of improving industrial training (cf. References 24,29-32) or conducting workshops with industry professionals (cf. References 33 and 24). Second, there are approaches aiming at empowering students to support industry upon graduation as technology agents (cf. References 34-36). Therefore, improvements are suggested, for example, to the curriculum (cf. References 37 and 24), to improve industry readiness (cf. Reference 37), and to include projects during studies (cf. References 36-40). Third, approaches propose joint training programs involving industry in academic settings and vice versa (cf. References 26,38,40, and 36).
- *Approaches proposing the use of media*. Technology transfer by media is commonly suggested by means of standards, guidelines, or online media. We investigated approaches proposed or mentioned by Abernethy et al.,[41] Heuer et al.,[42] Iyer et al.,[43] Duarte,[44] and Schuh et al.[45]
- *Further approaches*. Further approaches include the proposal of research sponsors[27,36] and software research infusion teams.[46]

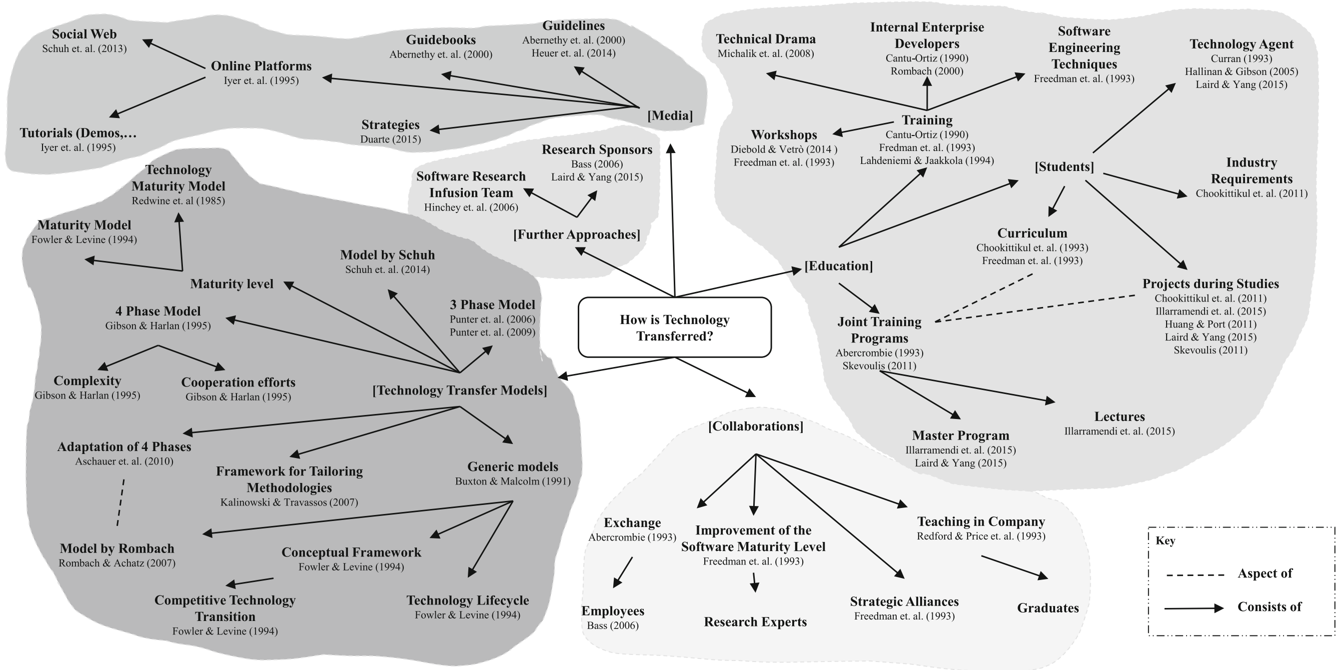

FIGURE 2 Technology transfer approaches and their interrelations.

3.2 | Mapping factors influencing successful technology transfer

In Reference 13, we also identified success factors and barriers for technology transfer and how each aspect is related with the others. In this article, we conceptualize these findings in Figure 3.

A variety of factors influence the outcome of technology transfer.[1,47] These include organization, communication, and social factors[19] as well as the maturity level of the technology to be transferred[34,44] and media and sources used.[33,48] There are issues and challenges[49,50] as well as success factors[22,35,50,51] when it comes to technology transfer.

Issues and challenges can be further divided into three aspects: barriers,[44,52] failures and problem. Barriers[44,52] include things like lack of awareness,[23] the lack of knowledge,[53] the inability to assimilate,[23] cultural[53] and social aspects,[53] which is related to social factors.[19] Failures include lack of quality[54] and the iceberg effect.[54] Problems include restrictions of academic publications[24,36] and protection of confidential information.[24]

Further issues and challenges include lack of knowledge/experience of students when students are used for technology transfer,[35] technology that does not meet requirements,[34] cultural differences,[55] longevity of partnerships[40] and too many persons involved[24] involved in technology transfer which is related to organization. Another important relation is that between cultural aspects[53] and cultural differences.[55]

Success factors for technology transfer include the push and pull effects described by Curtis[56] and Fowler,[20] communication of potential benefits,[47] the involvement of stakeholders,[57] and the involvement of partners directly in defining the problem.[47] Requirements for technology transfer must be analyzed[30] agreed upon in cooperation[47] and comprehended,[47] to be fulfilled successfully,[16,58] since as we have seen not meeting the requirements is a major issue in technology transfer. Furthermore, advocates[19,47] are considered crucial in technology transfer.

What is needed for successful technology transfer is a repack and lightweight approach[59] that can be tailored and adapted[47,56] and a plan for experimental measurement[60] that is able to measure effectiveness and technology performance.[60] The ability to adapt is strongly related to the organization itself in which a technology is introduced.

3.3 | Initial theory of technology transfer

Based on the identified literature, we defined two conceptual maps for structuring the field. Figure 2 shows existing technology transfer approaches and their relations, Figure 3 visualizes known factors influencing successful technology transfer and how these are related. We use these conceptual maps to define an initial theory of technology transfer. This theory is based on the related work and developed by abstraction based on commonalities from the two conceptual maps. Figure 4 shows the resulting initial theory on technology transfer.

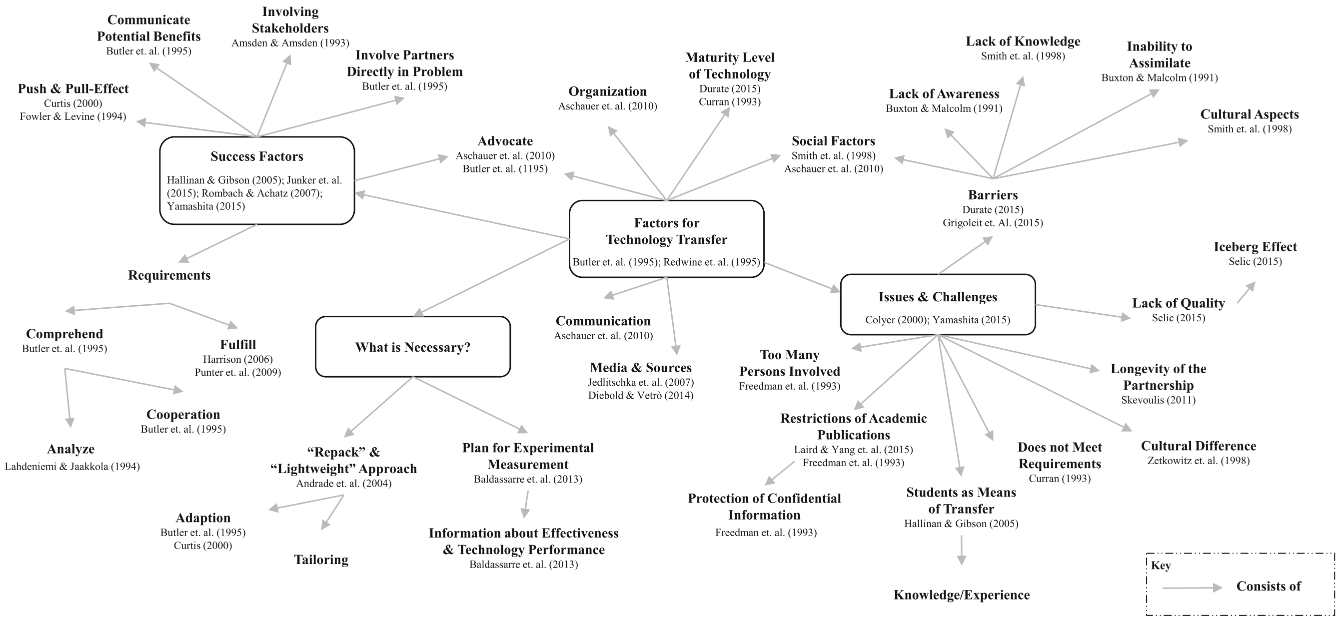

FIGURE 3 Factors influencing successful technology transfer.

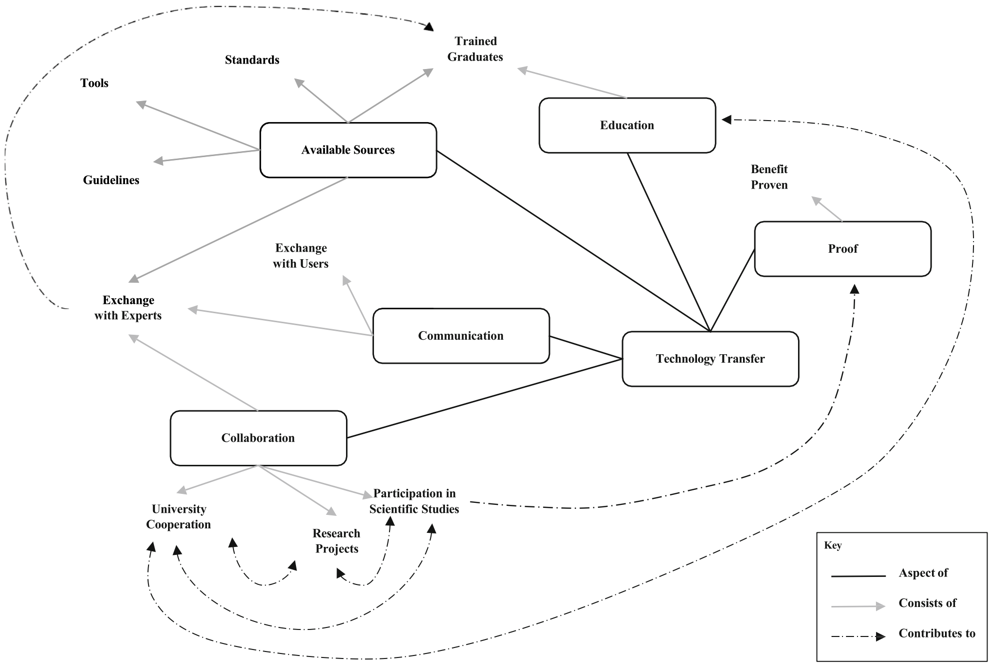

FIGURE 4 An initial theory of technology transfer derived from the related work.

First, we conclude from the research literature that five aspects seem particularly important for successful technology transfer in software engineering:

- *Available sources*. The availability of relevant sources describing the technology and supporting its introduction is often found to be a success factor—or lack thereof is seen as a barrier. Commonly, the availability of tools, guidelines, standards, and experts is seen as a precondition for successful technology transfer. In addition, there is a need for sufficiently trained graduates that are able to apply new technology on their jobs.
- *Education*. Education is another major aspect of technology transfer. This includes university education which lays the foundations for trained graduates that can apply a new technology on their job, as well as the training of industry professionals specifically for a certain technology transfer project. Therefore, the availability of experts—which can serve as educators and instructors—is of importance.
- *Collaboration*. Typical forms of collaboration in technology transfer approaches are cooperation in research projects, cooperation between industry and academia, and participation in scientific studies. While these three aspects are commonly addressed independently of each other, they are strongly related, as participation of academia in research projects and in scientific studies is typically mandated. Industry university collaboration also contributes to education and vice versa: Academia can benefit from industry experiences in university education (and thereby improve the industry relevance of studies), furthermore, industry can be trained by academia in industrial training sessions.
- *Communication*. Communication (which is closely related to collaboration) is seen as a major auxiliary means to aid successful technology transfer. Specifically, the communication with experts is considered important to facilitate technology transfer. However, it was also found that the communication with other users can considerably contribute to the success of technology transfer.
- *Proof*. It is often accepted that technology needs to have reached sufficient maturity, which needs to be proven for industry to rely on this new technology. One important aspect of these proofs is, that not only applicability, correctness and so forth must be proven but that for getting industry to introduce new technology the benefits of this technology need to be proven as well. Therefore, scientific studies are needed, which typically stem from collaboration. In addition, it is often stated that the availability of established standards is a prerequisite for industry to accept a technology as proven.

4 | STUDY SETUP

This section reports the study to investigate industry's perception on successful technology transfer. As outlined in Section 2, we aim at gaining an understanding of industry's perception on technology transfer. Namely, we want to contribute to answer the research questions from Section 1:

- *RQ1: What expectations do practitioners have for software engineering technology transfer*?
- *RQ2: What should the software engineering technology transfer process look like (from the perspective of the industry)?*

To guide our investigation, the initial theory from Section 3.3 was transferred into a questionnaire, taking existing aspects of technology transfer reported in Reference 13 into account. This questionnaire was accompanied by open questions, to give the industry participants room for expressing new ideas regarding their expectations and ideal process. Our investigation hence takes a two-pronged approach, consisting of a quantitative part (i.e., closed questionnaire items) and a qualitative part (i.e., responses to open questions). In the following, we first outline the sampling strategy and demographics of participating individuals in Section 4.1. We continue on with discussing our data collection method and instrumentation in Section 4.2 as well as the analysis procedure in Section 4.3. In Section 4.4, we discuss the remaining threats to validity.

4.1 | Case companies and participants

Several industry companies participated in the study, from which individual participants were recruited. The companies participating in the survey are briefly summarized by Table 1. Companies mainly stem from the automotive industry, but healthcare, industry automation, and consulting are also represented.

TABLE 1 Case companies.

Company	Major domain	Description
Company A	Automotive supplier	The company is a large internationally operating group with more than 85,000 employees worldwide. The company is mainly operating as first-tier supplier for automotive industry, industry automation, energy, and other domains. In case of this study our major point of contact is engineering of embedded automotive systems.
Company B	Automotive supplier	The company is a large internationally operating automotive supplier with about 10,000 employees. It is a subsidiary enterprise of Company A but competes globally with Company A and therefore differs in structure and business model from Company A.
Company C	Healthcare	Is an internationally operating SME (small and medium sized enterprise) in the healthcare domain with about 200 employees. The company develops and produces ventricular assist devices.
Company D	Automotive OEM	The company is a multinational corporation operating as original equipment manufacturer (OEM) in the automotive industry. It employs worldwide about 300,000 people.
Company E	Industry automation	Multinational conglomerate company with about 385,000 employees worldwide. The company is operating as supplier and OEM in various markets. Our major point of contact were three company units developing production plants in the industry automation domain.
Company F	Equipment OEM	The company is a multinational engineering and technology company which employs about 400,000 people. Major branches include automotive equipment, where the company operates as one of the world largest first-tier suppliers, as well as manufacturing equipment.
Company G	Software consulting	The company is a worldwide operating computer software and services company with about 6000 employees. The company provides software services and consulting to clients from various branches.

From each company, at least one or more participants were selected by the partaking companies to participate in the survey. To allow for unprejudiced answers, participation was anonymous. The survey was distributed among participants via the project mailing lists. The later discussion rounds were conducted with participants working in the project that most likely also participated in the survey.

From each company, two to four participants took part in the investigation, allowing us to gain a diverse view involving multiple companies. The actual recruitment was conducted via the mailing list of the joint research project. No effort was made to account for gender, age, or nationality, as neither was deemed to have an impact on the participant's attitudes toward technology transfer.

We had 21 participants complete the online survey. We specifically recruited industry representatives instead of academic participants and specifically recruited them from the companies that participated in the technology transfer project. This project was a major, nationally funded research project with the specific aim to investigate and improve technology transfer in software engineering. Involved companies and their representatives constitute a diverse set of experts with a range of views on the software engineering technology transfer, hence rendering a suitable recruitment platform for the study at hand. Albeit we did not exclude representatives from academia, the purpose of this survey is to supplement our academic findings reported in Reference 13 with an industry perspective. In consequence, we recruited predominantly industry representatives; only one participant had a joint industry/university affiliation. Thus, 20 participants from an industrial background of seven different companies participated, which is a common size for empirical investigations involving industry professionals.[61] Nevertheless, in future work, we endeavor to broaden the scope of investigation to a larger, unbounded set of participants. Detailed demographic data for the sample (i.e., the participants' background and their companies' background) are given in Figure 5. As can be seen in Figure 5 most of them are requirements engineers or system architects/engineers. Note that participants acting in multiple roles were able to select all roles that apply.

Figure 5 also gives an overview over the participants' educational background and their work experience in the field. As can be seen, most participants hold master's degrees. One participant had completed an apprenticeship, and two participants held bachelor's degrees. Two participants finished PhD work. Most participants received an education in mechanical engineering, followed by computer science and electrical engineering. One participant held a degree in business studies.

All participants work in embedded software engineering, and stem from the automotive domain, medical engineering, or mechanical engineering. Work experience of participants was pretty evenly spread.

4.2 | Data collection and survey instrument

Our study was conducted as an online survey, allowing participants to participate anonymously and at a convenient time. The survey consisted of a quantitative and qualitative questionnaire. The quantitative part asked participants to rate the importance of the different aspects for successful technology transfer identified in Section 3.3 on a 5-point semantic differential scale.

For the qualitative part, we collected responses to open-ended questions from the participants after they completed the quantitative part of the survey. The open-ended questions were structured according to the survey response options to identify not only the degree to which aspects of technology transfer are important according to the participants, but also how these aspects should operationally manifest themselves in their view of an ideal technology transfer process.

Open-ended questions took the form of prompting the participant to explain their expectations for software engineering technology transfer (RQ1) and the software engineering technology transfer process (RQ2) regarding the respective survey item:

1. What are your **expectations** to facilitate technology transfer?
2. What are your thoughts on an **ideal**[†] **process** to facilitate technology transfer?

This yielded two open-ended questions in addition to the survey items. Participants were not compelled to respond nor limited in statements per response, hence allowing multiple possible open-ended answers per participant for either question. In the following, we use the word "answer" to refer to individual response statements.

[†]We explicitly decided to ask participants for a vague term to encourage responses notwithstanding organizational constraints.

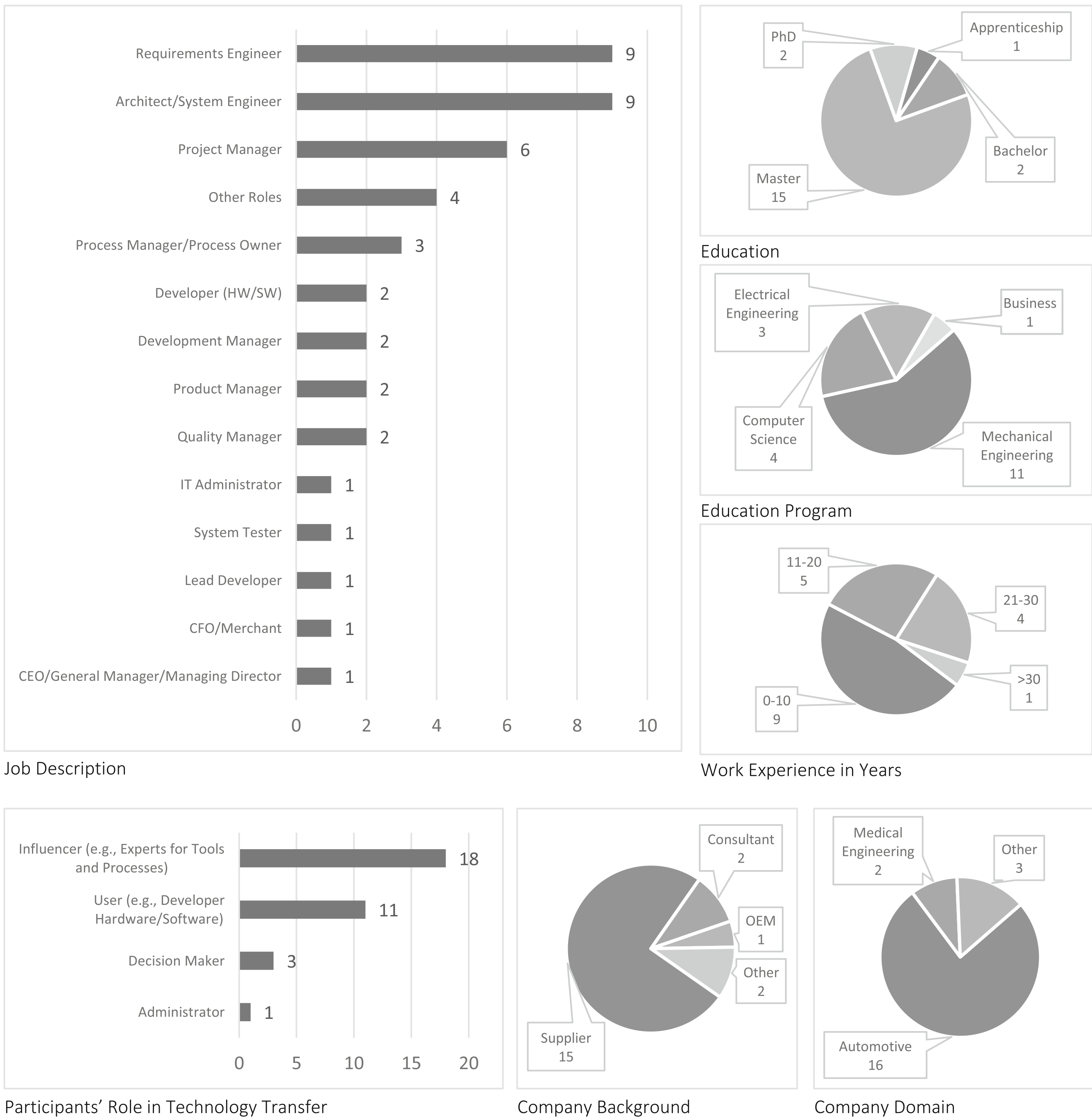

FIGURE 5 Summary of participants' demographics.

4.3 | Data analysis procedure

We analyzed the quantitative data by determining descriptive measurements. Furthermore, we conducted single sample *t*-tests[62] to determine which aspects were rated to have a significant impact on successful technology transfer.

We analyzed the qualitative responses for expectations and ideal processes using the "constant comparison" technique.[63] This technique entails reading every answer and categorizing the answers according to constant concepts mentioned therein. This was done by counting the number of answers for each participant and survey item. We counted a response as containing multiple answers when a participant used conjunctions such as "and" or "furthermore" or when multiple answers were given (e.g., separated into bullets). If an answer included phrases such as "don't know," "just guessed," or other indications that the participant did not provide an answer, this was seen as invalid and not counted. In one case, two participants gave identical answers to the open-ended question regarding the *ideal process*, while declining to provide answers to *expectations*, and giving differing responses (from each other) in the remainder of the survey. This suggests that these participants coordinated their answers for this one question. To not skew the results, we treated the answer as one by discarding the response to this one question from the participant who submitted the survey later than their colleague.

We coded participants' answers according to the constant comparison technique using the following process:

1. Researcher A translated all non-English responses to English and submitted results to Researcher B in a spreadsheet.
2. Researcher B double-checked the translation for meaning and accuracy. Researcher B then counted each answer in each response according to the rubric outlined above and sent the results back to Researcher A.
3. Researcher A checked the quantification of answers. No discrepancies were detected during this step. We identified a total of 21 answers from 11 participants for the question pertaining to *expectations*. For the other question regarding *ideal process*, we identified 53 answers from 13 participants.
4. Researcher B then coded each answer by categorizing them into categories pertaining to survey items, and subsequently by extracting more specific emerging themes across participants. For example, the answer "change management involving senior personnel" was categorized pertaining to the survey item "education," and specifically pertains to "staff training." This coding was documented by entering "staff training" in the spreadsheet row intersecting this answer and the column "education." This was done for all answers. Columns were previously derived from survey items, which in turn pertain to technology transfer aspects identified in the initial theory presented in Section 3.3. In cases where an answer could be categorized into multiple columns, this was allowed. Furthermore, for any answer that could not be categorized into a survey item, the answer was amended to an additional category "miscellaneous."
5. Researcher A then repeated the same process as Researcher B, using the same columns, and attempting to find agreeing or differing emerging concepts. Afterward, Researcher A compared their findings to those from Researcher B, making note of differences in coding that exceeds word-level differences (e.g., often, Researcher A would find synonyms to what Researcher B said). We identified a total of four differences for the *expectations* question and *ideal process* question, respectively. This yielded an inter-rater agreement of 80.29% ($\kappa = 0.7588$) for *expectations* and 92.19% ($\kappa = 0.7661$) for *ideal process*. This is considered "substantial agreement."
6. The eight answers where Research A and B differed were resolved by Researcher C acting as a tie-breaker, who mediated between Researcher A's and B's reasons for categorization. During this step, all three researchers also agreed to use which ever wording for the same categorization was more elegant.

4.4 | Threats to validity

4.4.1 | Internal validity

The survey and, hence, the generalizability of the findings have several limitations, which are discussed in this section. First, we designed the quantitative parts of the questionnaire on the basis of the current state of the art in software engineering literature. Thus, limitations apply as are common for literature surveys (i.e., relevant approaches erroneously excluded or not found). In addition, it must be mentioned that only software engineering literature from academic publications has been considered. Hence, aspects typically discussed in industry-oriented magazines might not have been included in the questionnaire. However, participants were given the opportunity to include such aspects by answering open questions and giving comments.

Additionally, limitations also result from the study setup, particularly by choosing a questionnaire-style survey format instead of interviews. While the latter would have allowed us to gain an even better understanding of the reasons behind the answers, we chose the questionnaire as this ensured that quantitative and qualitative data stems from the same persons and allowed anonymity of participants. Particularly, anonymity was an important matter, as otherwise participants might tend to give sugarcoated answers or to answer according to company policy and along company guidelines.

4.4.2 | External validity

Regarding the participants, restrictions regarding generalizability apply. The participating companies do not represent software engineering companies in general, but have a strong focus on embedded systems engineering. Consequently, the results might have looked differently if companies from the information systems domain, for instance, had participated.

Besides the focus on embedded systems, we must take into account that although we recruited participants from international companies, we predominantly recruited from their German corporate offices, to which we had convenient access through their mutual participation in a joint research project. The conclusions we draw regarding technology transfer may therefore reflect their corporate culture as typical in Germany, which although internationally relevant may not be representative of their exact technology transfer approach in other countries, given cultural differences. Furthermore, as these companies are mostly large internationally operating companies with several thousands employees, the findings might not be transferable to small and medium-sized enterprises (SME). Although the participants working for a SME did not differ in their answers considerably from other participants, we assume that technology transfer needs to take the peculiarities of company size and cultural context into account, which goes beyond the scope of this research.

A further factor regarding generalizability is the rather small size of participants. Particularly, it is unlikely that 21 selected participants are a representative selection for the entire software engineering field. However, we believe they are a good sample for representing the partaking companies. Which—as we have outlined above—do represent international companies in the embedded systems' domain. Thus, results might differ when enacting more aggressive recruiting across public mailing lists and so forth. However, we explicitly wanted to focus on participants representative for their respective companies. Thus, we relied on the recruitment strategy via the employers. This also typically leads to more reliable answers, as participants take the questionnaire serious. However, it clearly leads to a restricted collection of views, probably excluding different opinions due to the narrow recruiting. Therefore, future investigation whether our findings also hold for other domains, specific regions, or companies of different size are desirable.

5 | RESULTS

5.1 | Quantitative results

In the quantitative part of the study, participants were asked to rate the importance of several aspects for adopting new technologies on a 5-point semantic differential scale. Figure 6 shows that the availability of experts familiar with the new technology was rated as the most important. Almost similarly important is the availability of sufficient tool support for introducing new software engineering technologies. Furthermore, face-to-face communication with other users, education, and existing information sources about the new technology were rated as more important for adopting a new technology than the need for the technology to already have proven itself beneficial.

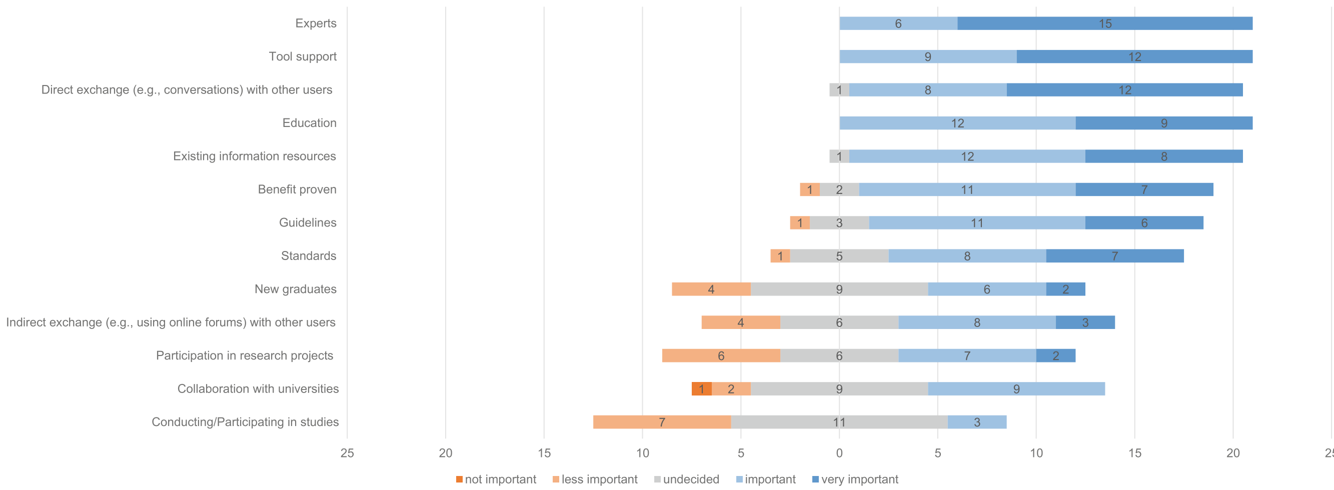

FIGURE 6 Importance of aspects for technology transfer.

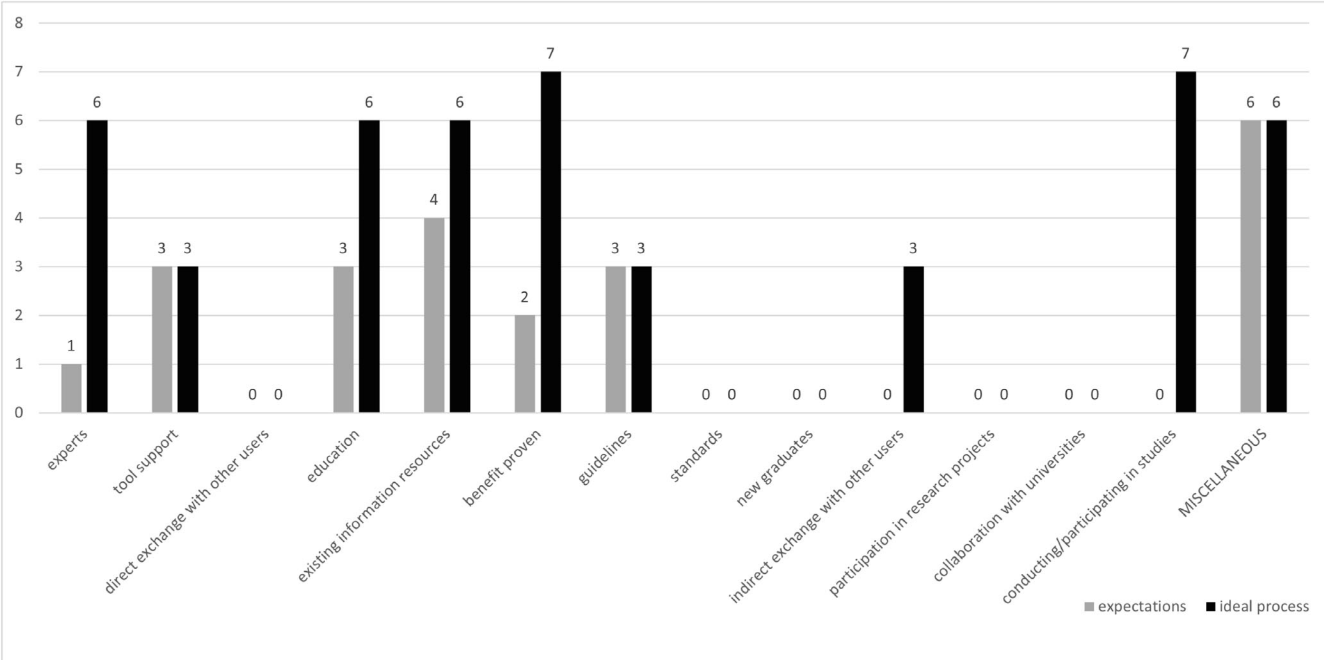

FIGURE 7 Number of answers pertaining expectations and ideal process regarding survey items.

Guidelines and standards on how to use the technology were seen as almost equally important. Less important were indirect exchanges with other users (e.g., via online forums) and new graduates that bring knowledge about new technologies they have learned into the company. As least important of all aspects were participation in research projects rated, collaboration with universities, and conducting/participating in studies. A single sample t test[‡] was conducted to determine which aspect were seen as significantly important for successful transfer of technologies. The results can be seen in Table 1. The availability of experts $(M = 4.714, SD = 0.4629), t(20) = 16.971, p < 0.001)$, tool support $(M = 4.571 SD = 0.5071), t(20) = 14.201, p < 0.001)$, direct exchange with other users $(M = 4.524, SD = 0.6016), t(20) = 11.608, p < 0.001)$, education $(M = 4.429, SD = 0.5071), t(20) = 12.910, p < 0.001)$, existing information resources $(M = 4.333, SD = 0.5774), t(20) = 10.583, p < 0.001)$, proven benefits of the technology $(M = 4.143, SD = 0.7928), t(20) = 6.606, p < 0.001)$, guidelines $(M = 4.048, SD = 0.8047), t(20) = 5.966, p < 0.001)$ and standards $(M = 4000, SD = 0.8944), t(20) = 5.123, p < 0.001)$ on how to use the technology, as well as the transfer of new technology via recently graduated employees that introduce technology $(M = 3.762, SD = 0.9437), t(20) = 3.700, p < 0.01)$, they learned about during their studies were all rated highly statistically significantly as important for successful technology transfer compared to the expectation value. Also rated as statistically significantly important was indirect exchange with other users $(M = 3.476, SD = 0.9808), t(20) = 2.225, p < 0.05)$.

Not rated as statistically significantly important were participation in research projects $(M = 3.238, SD = 0.9952), t(20) = 1.096, p > 0.05)$, collaboration with universities $(M = 3.238, SD = 0.8309), t(20) = 1.313, p > 0.05)$, and conducting/participating in studies $(M = 2.810, SD = 0.6796), t(20) = -1.284, p > 0.05)$.

5.2 | Qualitative results

Figure 7 shows the number of answers that pertain to the survey items. The survey items are sorted from left to right, indicating the most to the least important aspects identified in Table 2. We furthermore added "miscellaneous" for aspects that were mentioned by the participants but could not clearly be added to any category.

[‡]There is a long-standing debate in the statistics community regarding the use of parametric and non-parametric test for analyzing semantic differential scale data.[64] Recent studies indicate that in most cases, results from parametric and non-parametric tests do not differ significantly.[65] While we report the results from the parametric test, we also ran a single sample Wilcoxon signed rank test that did yield very similar p-values to the t test and the same results regarding significance.

TABLE 2 Quantitative results for the importance of aspects for technology transfer.

					Test value = 3					
									95% Confidence interval of the difference	
	N	Mean	Std. deviation	Std. error mean	t	df	Sig. (2-tailed)	Mean difference	Lower	Upper
Experts	21	4.714	0.4629	0.1010	16.971	20	0.000	1.7143	1.504	1.925
Tool support	21	4.571	0.5071	0.1107	14.201	20	0.000	1.5714	1.341	1.802
Direct exchange (e.g., conversations) with other users	21	4.524	0.6016	0.1313	11.608	20	0.000	1.5238	1.250	1.798
Education	21	4.429	0.5071	0.1107	12.910	20	0.000	1.4286	1.198	1.659
Existing information resources	21	4.333	0.5774	0.1260	10.583	20	0.000	1.3333	1.071	1.596
Benefit proven	21	4.143	0.7928	0.1730	6.606	20	0.000	1.1429	0.782	1.504
Guidelines	21	4.048	0.8047	0.1756	5.966	20	0.000	1.0476	0.681	1.414
Standards	21	4.000	0.8944	0.1952	5.123	20	0.000	1.0000	0.593	1.407
New graduates	21	3.762	0.9437	0.2059	3.700	20	0.001	0.7619	0.332	1.191
Indirect exchange (e.g., using online forums) with other users	21	3.476	0.9808	0.2140	2.225	20	0.038	0.4762	0.030	0.923
Participation in research projects	21	3.238	0.9952	0.2172	1.096	20	0.286	0.2381	−0.215	0.691
Collaboration with universities	21	3.238	0.8309	0.1813	1.313	20	0.204	0.2381	−0.140	0.616
Conducting/Participating in studies	21	2.810	0.6796	0.1483	−1.284	20	0.214	−0.1905	−0.500	0.119

As outlined in Section 4.3, we received substantially more answers pertaining to *ideal process* (53 answers from 13 participants) and comparatively few *expectations* (21 answers from 11 participants). We anticipated that the aspects would roughly match the trend outlined in Table 2 such that aspects rated as more important also receive more answers. As can be seen in Figure 7, this is not consistently the case. The aspect "direct exchange with other users" was rated as the third most important aspect, yet received no answers pertaining to either research question. By contrast, "indirect exchange with other users" was ranked as the fourth least important aspect, yet received three answers pertaining to participants' *ideal process*. Surprisingly, "conducting studies" was rated as least important through survey responses, yet received seven answers that can clearly be categorized as describing the role of scientific inquiry in the *ideal process* of technology transfer.

In the following, we discuss commonalities and emerging themes for each of these answers for each research question.

5.2.1 | RQ1: Expectations regarding technology transfer

Table 3 shows the answers from the 11 responding participants, categorized into the aspects for which frequencies were given in Figure 7. Non-responding participants and empty categories have been omitted.

According to the participants' expectations, key success factors in enabling technology transfer essentially surround the idea of limiting risk through failed technology introduction. As one participant noted, the "willingness to change" must be present not only on the management level, but also on the operative level. As without clear directives on the adoption of technology, adoption will be slow and employees may evade new concepts and tools in favor of continuing established, proven-to-work approaches. However, and likely more substantially, the financial risk must be ascertainable, for example by being able to ascertain the cost of introduction against the financial benefit the introduction will entail, or the degree to which the company would make themselves dependent on specific vendors. Clear goals and systematic processes are required to manage this risk. It is hence not surprising that participants mainly expect a clear road map for introduction and proven benefits to be communicated to staff. Moreover, multiple participants noted that employees must be appropriately trained, ideally in small groups and repeatedly made aware that the new technology has a provable benefit. Similarly, availability of resources is a key concern to participants, but what these resources look like depends largely on the company. Some participants prefer written resources or available tutorials employees can use on their own, while others prefer training in small groups. An interesting divide between participants who predominantly work in management positions and participants who are operationally involved becomes apparent: while managers have a much clearer focus on goals and costs and therefore list items pertaining thereto as clear *expectations*, operationally involved participants see the technology transfer process, available support resources, as well as access to training as a key expectation. Both types of participants, however, share the common expectation of clear goals for introduction.

In summary, responding participants expect technology transfer to be successful mainly when hinged on a systematic process of introduction, with goals, success milestones, training, and supporting documentation to ensure technology transfer is financially feasible. The necessity of managing the financial risk is hardly surprising in a corporate structure. Yet, the difference in relative importance between management and operational employees of training resources as well as their joint focus on goals and systematic process highlight that technology transfer must center more on the way *how* methods and tools are introduced, rather than what the purpose of introduction is.

5.2.2 | RQ2: Ideal technology transfer process

Our findings for RQ1 above highlight the special importance the technology transfer process has. Like for RQ1, staff training, coaching, and availability of resources play a major role in the ideal technology transfer process, according to the participant answers shown in Table 4. Yet, from the answers, another clear theme emerges, specifically the importance of pilot projects. Seven out of 13 responding participants indicated that "conducting studies" regarding the feasibility and procedure of introducing a new technology must incorporate pilot studies. This is insofar surprising as according to the survey we conducted (see Section 5.1), "conducting studies" was considered not important by the participants. The value

TABLE 3 Categorized qualitative answers for RQ1.

ID	# answers	Experts	Tool support	Education	Existing information resources	Benefit proven	Guidelines	Miscellaneous
17	3					Transparency of cost	Roadmap for introduction	Awareness of success factors
						Transparency of risk		
18	3			Staff training	Availability of resources			Vendor dependency
21	1			Staff training				
25	4		Integration into tool chain				Roadmap for introduction	
			Usability of tools					
			Availability of tools					
29	3				Availability of resources		Roadmap for introduction	Communicating introduction roadmap
31	2							Management goals
								Vendor dependency
32	1							Willingness to change
35	1			Staff training	Availability of resources			
38	1							Management goals
40	1	Consultants						
41	1				Create a foundation	Prove foundation works		
Total	21	1	3	3	4	2	3	6

of using pilot studies, especially in small teams with low-stakes projects, seems to be a prevailing desire of both management and operationally involved employees. According to the participants, pilot projects lay a foundation for assessment, as a majority of responses indicate that continuously monitoring introduction goals is a critical component of the introduction process (similarly to, but different from, the assessment before the introduction occurs and after the technology has been adopted). The need for pilot studies is further highlighted as it allows participants to draw conclusions about the roll-out process, for example, through lessons learned. This was an emerging theme in three participants' answers, who closely related pilot projects with assessment, roll-out support, and the need to tailor roll-out expectations based on lessons learned from small projects. Interestingly, there seems to be no clear consensus on what the nature of the pilot project should be. For example, while participant 17 said that "selection of use case and team in the company [for a pilot project] needs to be relevant from the get-go" and that there is "no time/no money for pure experimentation," participant 21 indicated that a pilot project would be ideal if "one team uses the technology productively but without time pressure" (see Appendix).

In summary, the ideal process of technology transfer in general includes activities before, during, and at the end of company-wide roll-out. Before roll-out, pilot projects should be conducted to assess weaknesses and advantages and scope adoption goals. During the adoption process, these goals need to be continuously assessed, and the process needs to be monitored and possibly tailored, staff needs to be coached, and resourced need to be made available. Finally, at the end of the transfer, goal achievement must be assessed and staff need to be continuously trained to use the adopted technology gainfully.

Having a closer look at participants' responses despite the similarity of answers regarding the aforementioned general remarks, we found two different attitudes towards the process on how to transfer new technology. We call these the *knowledge-centric* technology transfer process and the *pilot-project-centric* technology transfer process. The differences are due to different cultures within the respective company. As we show in the next subsections, the knowledge-centric approach is more traditional, relies more on documents and is a typical top-down process. By contrast, the pilot-project-centric approach is more agile, relies on iterations to optimally fit a technology to a company and is more focused on people.

5.2.3 | Knowledge-centric technology transfer process

The knowledge-centric technology transfer process matches rather traditional work environments. As shown in Figure 8, training materials and documentation of the technology (e.g., manuals, guidelines) are created upfront. Thereafter, employees are trained, and subsequently the new technology is applied. At this phase, the technology documentation is used as the first source of information in case questions arise. For further questions or problems that arise, expert support on short notice is desired. Thus, problems can be solved directly in the work environment.

This transfer process, typically favors very mature technology already fitting the work environment as no need for iterations should arise. Depending on the company and its culture, we noticed slightly different attitudes. Participants either focused on the documentation and thus the technology transfer via media, or focused on training sessions, placing more emphasis on technology transfer via education.

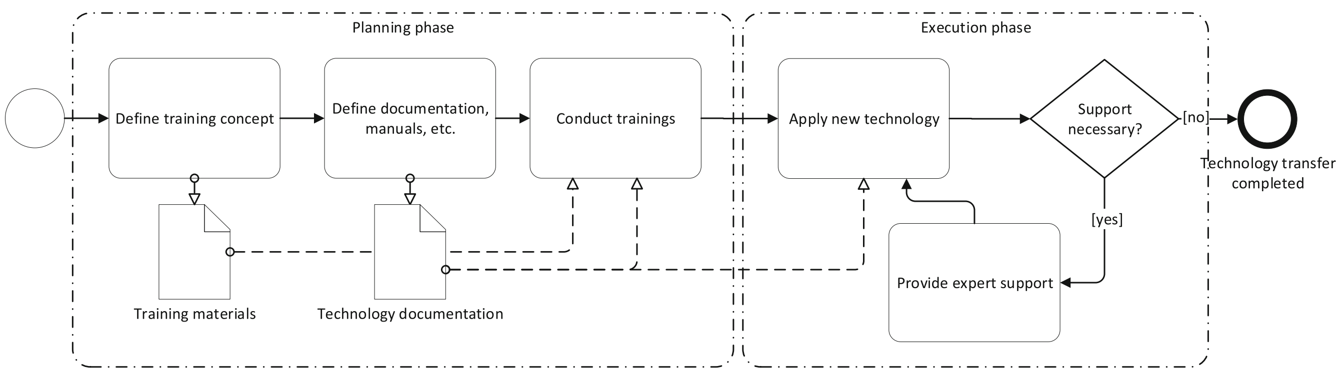

FIGURE 8 Knowledge-centric technology transfer process.

TABLE 4 Categorized qualitative answers for RQ2.

ID	# answers	Experts	Tool support	Education	Existing information resources	Benefit proven	Guidelines	Indirect exchange with other users	Conducting in studies	Miscellaneous
17	5					Assessment (continuous)				
		Coaching			Small examples				Pilot project	
						Risk				
18	5					Ability to compete			Staff performance	
						ROI				
						Cost				
						Risk				
21	6			Staff training	Support during roll-out			Lessons learned	Pilot project	Low-stakes introduction
25	5		Availability of tools	Staff training			Process support		Pilot project	Management goals
29	3				Availability of resources				Pilot project	Intensive change management
31	6	Access to experts	Access to tools	Staff training	Availability of resources		Process support			Binding start date
32	3	Coaching		Staff training		Mature technologies				
35	4			Staff training		Assessment (continuous)		Lessons learned	Pilot project	
38	7	Access to experts	Access to tools		Availability of resources	Assessment (continuous)	Process support			Introduction timeline
40	2	Coaching							Pilot project	
41	5	Coaching		Staff training	Systematic roll-out	Assessment (continuous)		Lessons learned		
49	2					Assessment (before-after)			Pilot project	
Total	53	6	3	6	6	7	3	3	7	6

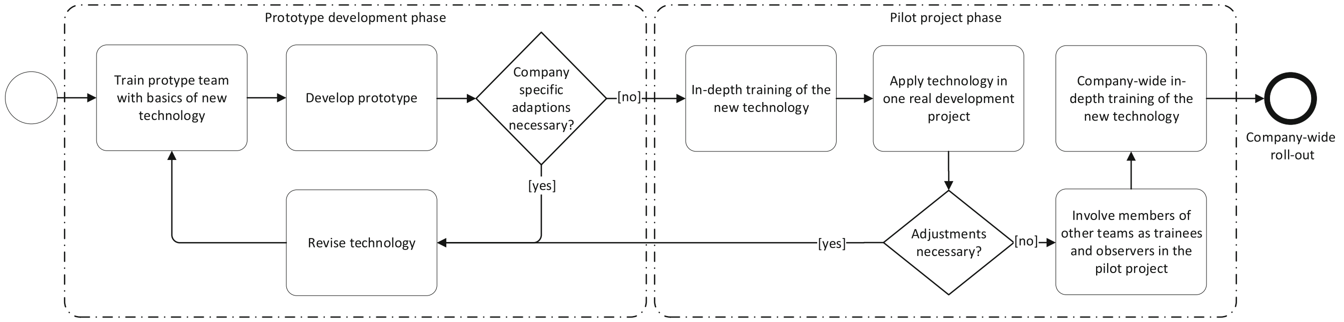

FIGURE 9 Pilot-project-centric technology transfer process.

5.2.4 | Pilot-project-centric technology transfer process

The other technology transfer approach we derived from participants' answers is more agile and relies on iterations. Thus, a pilot-project-centric technology transfer process seems to be more appropriate to introduce new technology that should be specifically tailored to the company or is considered less proven or less mature by the adopting company. As shown in Figure 9 the development process uses exploratory development projects to properly define the technology in the context of the company, to train employees, and allow them getting accustomed to the new technology. The first project is typically a prototype development, rather than a high-stakes development project. Hence, engineers should be allowed to extensively try the new technology and explore its limits. When the prototype team reaches the conclusion that the technology is appropriate for the company, sufficiently tailored and applicable, the technology is introduced in a real development environment. In this pilot project the technology is applied by one team to solve a real problem and develop a real product, whenever the team notices problems with the technology or room for improvement the technology is revised. These changes should first be tested in the prototype environment before finally introduced in the pilot project. When the pilot project team is convinced from the new technology, members from other teams throughout the company should be invited to observe the work of the pilot team and/or join the pilot team for some archetypal tasks. Thus, other employees can also get accustomed to the technology and how it can be used. Thereafter, the technology is rolled out, starting with in-depth training of the new teams to apply the technology.

6 | DISCUSSION

Perhaps the least surprising finding from Section 5 is that the software engineering technology transfer process is as diverse as the people who are involved with it. Expectations and ideals vary as much as the roles of the individuals and the domains they work in. Nevertheless, we were able to show common themes from our findings. In this section, we extend our initial theory of technology transfer from Section 3.3 with success factors and barriers for technology transfer that we extract from the common themes identified above. Finally, we present recommendations for an archetypal technology transfer approach which may serve as a guide for providers and adopters for a new technology transfer project.

6.1 | Success factors of the software engineering technology transfer

From our findings regarding RQ1 and RQ2 in Section 5, we can see that merely providing the technology is insufficient. Most important seems to be also providing experts, who support planning the introduction process, assist with specialty questions during introduction, and are available to directly interact with other users to discuss matters and solve potential problems after introduction. Moreover, in the absence of direct access to experts, suitably detailed information resources are critical.

For non-tool technologies (e.g., approaches or methods), providing tool support that seamlessly integrates into the company's existing tool infrastructure is crucial. Sufficiently educating the intended users of the technology and its tools is critical. Otherwise, operationally involved practitioners are likely to abandon a technology that does not work seamlessly in their industrial context.

Finally, the benefits of the technology must be proven upfront by the technology provider, with minimal interaction required from the adopter. Especially, participants with management roles are unlikely to invest time and effort in technology without proven benefit and are hesitant to commit resources to a technology to assess its value. It is the responsibility of the technology provider to show that their technology works, in which contexts and given which preconditions it will work, and what type of concessions the adopter is expected to make to involve the technology.

6.2 | Barriers of software engineering technology transfer

In addition to the success factors outlined in Section 6.1, there are certain barriers that the technology provider and adopter must overcome. For example, while for consulting agencies, providing access to experts and proof of value are at their core business, especially university researchers typically struggle with providing industry-realistic and generalizable objective data on the applicability of their technology or better than prototypical tool support. This is evidenced by the comparatively low amount of rigorous and repeated validation research in software engineering.[66-68]

In both the quantitative survey and qualitative responses, a company's participation in research projects turned out not to be a strong expectation or desire from participants. Similarly, collaboration with universities and conducting/participating in studies was not seen as important. However, in contrast, most participants emphasized that technology transfer only works if suitable pilot projects can be conducted. This implies that companies place limited value on collaborations, even if they could result in low-stakes pilot projects being conducted within the company.

These findings partly contradict the current state of the art in the software engineering literature. In particular, software engineering research literature has traditionally suggested collaboration as a driver for technology transfer.[20,31,36,60] Specifically, collaboration between universities and companies and participation in projects is commonly suggested in technology transfer approaches.[69,70] Furthermore, literature often discusses that the benefit of a technology is best proven objectively in industrial practice, that is, within the respective company. From the perspective of the industry participants, this is not the case, as the predominant attitude is that the benefit should be proven before technology adoption is even considered.

Most participants emphasized that certain preconditions must be met upfront and then actions shall be in place to ensure successful introduction. The implication here is that without proper preconditions, that is, availability of resources, experts, and sufficient time for the operationally involved participants to concentrate on the transfer process to ensure success, technology transfer will fail. Only few participants found continuous support after introduction worth mentioning. This means that management goals must align with the operational goals of the practitioners who are operationally involved with the transfer process. In other words: the choice to adopt a technology cannot be "dictated" by management, but must be an operational benefit for the involved staff to foster success.

The consequence is that the technology must be sufficiently mature enough for industry introduction and exceed prototypical implementation and proof-of-concept results. Therein, however, lies a dilemma: in order to show objective evidence of technology maturity, application beyond lab conditions, that is, in industry-realistic scenarios are necessary. However, without evidence of maturity and benefit, industry is hesitant to consider adoption. The obvious solution are strategic partnerships and collaborations, which, as we have outlined above, paradoxically is not considered a critical success factor by our participants.

6.3 | Recommendations for successful software engineering technology transfer

Based on the initial theory from Section 3.3 and our empirical findings from Sections 5.1 and 5.2, we can now derive recommendations for an archetypal technology transfer approach. These recommendations are not meant as strict criteria for the *ideal* technology transfer process, without which the technology transfer will fail. Instead, these recommendation stipulate guidelines for properties a successful technology transfer is likely to have. As many of these as possible should be considered and implemented, depending on the industrial context, the technology to be transferred involved roles. We structure these recommendations along the perspective of the two major roles involved in the technology transfer process: the technology provider and the technology adopter. By "provider," we mean anyone who creates a technology to be used in industrial practice, but who is not per se the user of the technology. This comprises, for example, tool manufacturers, consulting agencies, equipment and parts suppliers, and university researchers who want their tools or approaches applied productively. By "adopter," we mean anyone who seeks to use a technology productively in an industrial context, but who is not per se the technology's creator. Examples include consulting agencies, original equipment manufacturers, and suppliers actively involved in product development.

From the ***technology provider*** perspective, data shows that the following is important:

- Offer access to experts before, during, and after successful technology transfer.
- If applicable, provide tool support alongside the technology to be transferred.
- Foster exchange among users that are involved in the introduction of the new technology, and if possible, with your experts.
- Provide guidelines, documentation, or other available resources to the adopting personnel.
- Only offer mature technology with proven benefits for transfer.
- Offer education and training of the involved personnel at the adopting organization.

We found other commonly proposed aspects to be not that important from the point of view of the ***technology adopter***. However, it is important to:

- Conduct research projects and collaboration with academia in general, specifically to define, plan, and conduct pilot projects.
- Define goals and success criteria for the adoption.
- Ensure that management goals are compatible with the operational reality of involved personnel.
- Before technology transfer starts, define and plan ways to achieve the preconditions for the technology transfer process.
- Establish proper change management.
- Ensure commitment of involved personnel and sufficient resources to concentrate on the process.
- Define a proper technology transfer process. For this, it is important to take the specifics of the respective company (i.e., the company culture into account). In Section 5, we have shown two promising technology transfer processes from the perspective of our industry partners.

"Commitment" in this case refers to all levels of the corporate hierarchy. Thus, it must be ensured that the resources are available and that employees have capacities they can exclusively spend on the introduction (e.g., allotting sufficient time to learn the technology, facilitating direct access to experts and other users). Having commitment for introducing a technology but no exclusive resources limits acceptance among employees, as the new technology is just seen as an additional burden.

"Preconditions" in this sense refers to an objective look if the technology to be adopted is of sufficient maturity (given the individual industrial context). Risks and benefits must be assessed and evidences for the new technology must be collected. Practitioners must be trained in advance and long-term commitment to the new technology must have been established, including concrete goals for the introduction.

7 | TOWARDS ALIGNING INDUSTRY AND ACADEMIC VIEWS

In this section, we seek to align the partly diverging views from the literature (see Section 3) and our survey findings (see Section 5) in order to arrive at conclusions to improve technology transfer between industry and academia.

7.1 | Discussing divergent views

While many findings are in line with the related work and substantiate the usefulness of already proposed technology transfer approaches (see Section 3), some findings are somewhat surprising and therefore of particular interest. Next, we discuss, where our findings differ from the "academic perspective" shown in the published literature or where qualitative and quantitative data show considerable differences.

We discussed findings presented in Section 5 with industry professionals from the participating companies as part of our collaboration in the joint research project.

Findings showed that while tool support was seen as relevant in the questionnaire, participants did not mention a need for tool support in their ideal technology transfer situation. Industry professionals on the one hand assumed that this is such a basic condition in industrial practice that participants did not see a need to mention this aspect. On the other hand, industry professionals stated that a professional tool must not necessarily be already existing before the decision for introduction of a new development methodology is made. This is due to the fact, that the partaking companies have specialized tool chains with tool suppliers typically appointed with long-lasting contracts. Hence, it is commonly the task of the tool manufacturer to implement the needed methods in their tool and provide this tool to the company. Therefore, the tooling part of technology transfer is typically neither under the control of the transferor nor the transferee of technology.

While evidence that the technology to be transferred is beneficial and applicable were seen as necessary by the participants, they also claimed that there is no need for empirical evaluations in the company. However, in contrast to this, they also stressed the need for pilot projects, the purpose of which is to collect evidence within their own company. Discussions showed that most industry partners deem a scientific evaluation of the benefits of a technology in an academic setting as sufficient for trying to introduce this technology. However, before changing the whole company's development processes, pilot projects are needed to learn of the effects the technology has on the company and whether the benefits turn out as expected.

Another aspect we further discussed with industry professionals was the repeatedly stressed need for proper education as precondition. From the point of view of participating non-users (i.e., decision makers and managers) education should be limited to the parts of the technology the respective user will need for the application of the technology in their everyday job. From a user's perspective, it was often stressed, however, that they expect more education than necessary to cope even with unforeseen situations and to be reassured that their capabilities will be sufficient.

Quite possibly, the most significant difference between our findings and the findings gained from the related work is the participants' attitude towards collaboration between industry and academia. This is highly valued from the perspective of academia, which becomes evident in a multitude of explicit collaboration approaches. However, industry participants found research collaborations not important. In contrast, in the qualitative results—while still rejecting academia industry collaborations—some of the aspects that come along with industry academia collaboration such as projects and showing evidence for benefits of the new technology, were regarded as important in the qualitative results of our study. As we sampled participating industry professionals from a joint research project, which per definition aims at collaboration between industry and academia to transfer a certain approach into industrial practice (in this case, the model-based engineering of embedded and cyber-physical systems), it is peculiar that participants claimed that collaboration between industry and academia is not important to foster technology transfer, so our first assumption was that these participants should be more interested in collaboration than others. On the one hand, this finding could indicate that collaboration approaches are seen as really unfavorable by industry, even by those who participate in such collaboration projects. On the other hand, this could also mean that industry participants did not correctly understand what we meant by the term "collaboration." To ascertain this difference, we further discussed this aspect with our industry partners. These discussions revealed that in general, the understanding of the notion of "collaborating on projects" does not differ much between industrial and academic participants. Instead, industry partners' reluctance towards collaboration approaches stems from the assumption, that such collaboration is costly and usually does not yield a return on their investment. In particular, industry professionals are afraid of being distracted from their daily work by researchers and assume collaboration projects rather aid the researchers than industry.

7.2 | Implications for software engineering technology transfer projects between academia and industry

This has different implications for what needs to be considered when aiming at transferring technology from academia to industry. The discrepancies between the related work and the findings of the survey show that the value of collaboration by means of collaboration projects and direct industry academia collaboration is regarded differently by industry and academia. This finding does not necessarily mean that collaboration projects do not work or that they are not beneficial for technology transfer. But if these are to be beneficial, a way needs to be found for coping with industry's reluctance.

Industry's reluctance or industry professionals' unawareness of academia's need for empirical evaluation within a real industrial setting might be a cause of unsuccessful technology transfer. As industry relies on academic evaluations before starting a pilot project on their own and has no interest in thorough evaluations in industry, this hinders academia in learning from the transfer of technology. Also, this raises the problem that academic solution approaches are not properly evaluated in a real setting as industry does not see a need for empirical evaluations in industry, which is a recurring issue in software engineering research.[71] As this aspect was not seen as important for successful technology transfer, this raises the question if a pilot project is seen by practitioners as something that happens without involvement of researchers or if this is simply an issue of different vocabularies used by practitioners and researchers. One indication might be that practitioners clearly asked for guidance in the introduction of a new technology, as can be seen in Section 5. The fact that the involvement of consultants was mentioned suggests that researchers are not seen as someone who can or will provide guidance in the introduction of a new technology, but paid consultants on the other hand are.

Pilot projects are deemed very important by industry professionals. Before rolling out a new technology (e.g., a new development process) across the entire company, it is vital to introduce this technology in a pilot project first. This helps to prove benefits of the technology, increasing acceptance among employees, and adapting the technology to company specific needs that have gone unnoticed so far. Thus, the pilot project allows to further tailor the technology to its specific application context. While we mentioned earlier that industry is reluctant to participate in academic studies, we believe that properly planned and conducted pilot projects can bridge this gap. Thus, it is to further investigate how to conduct such pilot projects in a way that both sides (i.e., industry and academia) gain the benefits they need.

8 | SUMMARY AND CONCLUSION

We investigated practitioners' needs for software engineering technology transfer. To do so, we designed a study on the basis of the current literature on technology transfer approaches and experiences in the software engineering field. Therefore, we first defined an initial theory on technology transfer. Then, we asked participants to rate the importance of certain aspects of software engineering technology transfer and to describe their ideal technology transfer process. Based on the evaluation of the initial theory and additional opinions of the industry professionals, we defined recommendations for better supporting technology transfer.

The participants' answers revealed some discrepancies between approaches suggested in the academic literature and practitioners' actual needs. In particular, industry professionals did not see collaboration approaches as useful, despite the fact that these are most commonly suggested in the software engineering literature. Additionally, industry professionals do not see a need for conducting sound empirical studies in industrial practice.

Industry professionals stressed the need for successful pilot projects in industry and the accessibility of experts before, throughout, and after introduction of a new technology. These aspects, however, are so far only rarely discussed in the software engineering literature.

This study was conducted within the context of an industrial research project that involved a substantial technology transfer effort of a model-based engineering approach with mainly large, international companies. This means that the recruited participants mainly respond from the viewpoint of large, international organizations with several thousand employees. The perspective of small and medium enterprises (SMEs) with at most several hundred employees might differ considerably and may not be adequately reflected in our results, even though we had several participants from Company C (see Table 1). Replication with SME representatives is desirable.

Moreover, future work needs to deal with how to properly address industry needs in pilot projects and how to provide access to experts. Additionally, more research is needed on how to convince industry of the value of empirical investigations in industrial practice and collaboration with academia. However, collaboration needs of academia, the need for experts by industry, the need for experimentation in industry, and for pilot projects by industry might be starting points for better aligning industry's and academia's needs in technology transfer.

AUTHOR CONTRIBUTIONS

Marian Daun acted as project leader and principal author of manuscript draft. Marian Daun and Jennifer Brings conducted interviews. Jennifer Brings and Bastian Tenbergen worked on qualitative data analysis, interpretation, and figures. Patricia Aluko Obe and Jennifer Brings were responsible for statistics and quantitative data analysis. Marian Daun and Bastian Tenbergen were responsible for quantitative data interpretation. Marian Daun and Bastian Tenbergen initially authored Sections 1 and 4. Marian Daun initially authored Sections 2 and 6. Patricia Aluko Obe and Jennifer Brings initially authored Sections 3 and 8. Jennifer Brings was responsible for table layouting. Bastian Tenbergen initially authored Sections 5 and 7. All authors assisted in incremental revisions of all sections.

FUNDING INFORMATION

The interviews have been conducted in the context of a project funded by the German Ministry for Education and Research (BMBF) under Grant number 01IS15058C.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

ACKNOWLEDGMENT

Open Access funding enabled and organized by Projekt DEAL.

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How to cite this article: Daun M, Brings J, Aluko Obe P, Tenbergen B. An industry survey on approaches, success factors, and barriers for technology transfer in software engineering. *Softw Pract Exper*. 2023;1-29. doi: 10.1002/spe.3200

APPENDIX A

In this section, we provide the participants' raw answers for both research questions. We provide some minor interpretation to complement our results from Section 5.2.

RQ1: What expectations do practitioners have when adopting a new technology? Participants commonly mentioned the existence of a clear road map for the introduction. One comment on this comes from participant No 17, stating that such a road map—in addition to knowledge about success factors, as well as costs and risks—is important.

> Clear road map for introduction; awareness of success factors; transparency regarding costs and risks.
>
> No 17, aged 47, CEO and Project Manager, Automotive Consultant

Participant No 29 also mentions the need for a road map, combined with its clear communication.

> Reliable, clear road map for introduction and intensive communication thereof, as well as confirmation that sufficient resources are available
>
> No 29, 29 years old, Method Developer Systems Engineering, Supplier for various domains (Avionics, Automotive, Industry Automation, Healthcare, Energy, etc.)

The comment of participant No 38, who expects the existence of precisely defined goals for the introduction, is also related to this theme.

> Clear goals for the introduction of a new technology.
>
> No 38 (26), Space and Aero Space Engineer, Requirements Engineer and Architect, Automotive Supplier

Thus, we can conclude that the existence of a clear road map is seen as important by many industry professionals as it was mentioned by participants from different domains (i.e., automotive, healthcare, and no distinct domain), different roles (i.e., project managers, requirements engineers, quality managers, method developers, CEOs), and different company types (i.e., suppliers, OEMs, consultant companies).

Participant No 29 not only commented on the need for a road map, but furthermore the commitment of management for providing the necessary resources. This need for commitment is a recurring topic, as well as other comments also show, such as the one of participant No 31.

> Binding character of the introduction. This means there needs to be a binding statement from leadership that the new technology is important and that from a certain point in time usage thereof is obligatory. Moreover, there must not be any alternative products [i.e., technologies] that can still be used after that point in time.
>
> No 31 (38), Requirements Engineer and Software Architect, Automotive Supplier

Closely related to this is the need for change management that involves executive management, as participant No 21 expresses. It is to note that in case of participant No 21, the comment must not be seen as an employee desiring commitment of the management, but rather that this is also seen as crucial points by members of senior management, as this comment was made by the head of development for an automotive supplier.

> Change management involving senior management.
>
> No 21 (46), Head of Development, Automotive Supplier

Participant No 18 also discusses the need for change management and related questions that arise.

> Sustainability when it comes to support (for how long can I use the technology efficiently?), change management (what consequences do the new technology have regarding training of existing staff and the need for changes to the current staff?) Vendor-lock-in (how dependent do I become?).
>
> No 18 (35), Software Architect, Computer Scientist

Participant No 25, who is a product and project manager from a consulting company, focuses in the comments on the availability and usability of software tools while also pointing out the need for longevity of the technology:

> Sustainable distribution strategy for the technology to achieve good support and longevity. Needs to integrate with existing tool chain. For software tools, usability is highly important beside availability.
>
> No 25, Electrical Engineer, Product and Project Manager, Consulting

Another participant mentioned the need for having consultants as an important aspect of technology transfer. It is to note that No 40 is not working for a consulting company, but a large automotive supplier.

> Consultants.
>
> No 40 (45), Mechanical Engineering, Requirements Engineer and Architect, Automotive Supplier

Other comments relate to the commitment of everyone involved, accompanying training, and the need for the existence of robust foundations that can be relied on. Participant No 32 points out, that not only management commitment is needed, but that sufficient technology transfer depends on an effort to change by everyone.

> Willingness to change for everyone.
>
> No 32 (37), Electrical Engineer, Systems Engineer, Industry Automation Supplier and OEM

Participant No 35 focuses on the education aspect of technology transfer and stresses the need for suitable training concepts.

> Suitable training concepts need to be available.
>
> No 35 (39), Mechanical Engineering, Process Manager, Requirements Engineer, Architect and Tester, Machine Building Industry OEM

As another important factor for technology transfer, Participant No 41 sees that the basic foundations of the technology transfer are comprehensive and have already been proven.

> Creation of comprehensive and proven foundation.
>
> No 41 (28), Mechatronics Engineering, HW/SW Developer, Automotive Supplier

RQ2: What do practitioners imagine should the ideal technology adoption process look like? Regarding the question of what the participants think the ideal technology transfer should look like, we received different kinds of answers. Some participants were eager to define a process consisting of multiple steps, while others just mentioned the most important points, or the points that make a "common" technology transfer process an extraordinary one. You will notice that comments of different participants are related, as they emphasize overlapping points. However, in this section we will not aggregate or abstract the data, but give a clear impression on each participant's answer in its context.

A very brief description of the most basic process steps of an ideal technology transfer process was given by participant No 35:

> Train users, choose pilot project, run pilot project, and assess pilot project. Gather lessons learned and implement changes accordingly.
>
> No 35 (39), Mechanical Engineering, Process Manager, Requirements Engineer, Architect and Tester, Machine Building Industry OEM

Participant No 21, describes a technology transfer process consisting of multiple steps. Emphasis is given to the piloting of the project. Piloting is generally quite often mentioned, participants typically understand that piloting means to define a pilot project. As Participant No 21 outlines, this might also involve training specifically tailored to the pilot and development of prototypes. While some participants encourage the use of pilots also in productive units, participant No 21 stresses the need that employees working on the pilot project must be free to make mistakes to explore what works and what does not. From our subsequent discussions, we gained the understanding that this is a commonly welcomed approach and therefore, piloting most likely should contain two phases: Piloting in the company to make employees accustomed to the new technology and to elaborate ways for using the technology in the company, and piloting in a productive unit testing the new technology in a real project.

> 1. Basic training (motivation, background, and context—no details).
> 2. Build prototype (engineers need to be able to try out the new technology and make mistakes).
> 3. Teach details (theory and details help understand what has been done).
> 4. Pilot project (one team uses the technology productively but without time pressure, members from other teams assist and learn).
> 5. If necessary: further detailed training and lessons learned.
> 6. Broad introduction (further projects with new technology).
>
> No 21 (46), Head of Development, Automotive Supplier

Participant No 25 also focuses on pilot projects (in this case a pilot project in a productive unit, which in case of success should be followed by a company-wide introduction). However, in this case, the use of tools is also explicitly mentioned. The statement was made by a project manager of a consulting company that mainly sells tools, thus, this focus might not be surprising. However, we noticed little mentioning of tool support by other participants. In the discussions it turned out, that the tool support is deemed by industry professionals as absolutely necessary precondition and, thus, was not mentioned for the ideal technology transfer process.

> The ideal technology transfer process looks like
>
> 1. Tool training for 2–3 persons for a new project.
> 2. Installation of tools, definition of new processes.
> 3. Trial in pilot project.
> 4. Company-wide use after successful pilot project.
>
> No 25, Electrical Engineer, Product and Project Manager, Consulting

Another aspect of piloting is seen in providing proof of the usefulness of the technology. Participant No 49 discusses the need of pilot projects to compare new technologies with established approaches to provide proof that the introduction of new technologies will be useful and increase efficiency.

> starting point: "old" technology pilot project for evaluation: "new" vs. "old" technology comparison with "old" technology –> shows benefits and efficiency of the "new" technology.
>
> No 49 (49), Electronic Engineering, Quality Manager, Healthcare OEM

Participant No 41, focuses in their comment on step by step introduction, starting in one small segment of the company to explore, test, and try out the new technology, which can also be classified as piloting.

> First teaching of basics by experts. Then introduction piece by piece into the company. Evaluation of technology. Gather requirements from industrial practice and incorporate them accordingly. Instruction for other teams and finally roll-out.
>
> No 41 (28), Mechatronics Engineering, HW/SW Developer, Automotive Supplier

Regarding the question, how the ideal technology transfer would look like, participant No 17 also says that pilot projects are valuable aspects of technology transfer. And that these also should be used for evaluating the new technology. What is striking in the comment is, that participant No 17, who is a CEO of an automotive consulting company and is working as project manager in technology transfer projects, despite many years of experience, explicitly expresses uncertainty about what an ideal technology transfer process should look like.

> (if only I knew …) maybe like this: presentation of technology including small examples. selection of use case and team in the company (needs to be relevant from the get-go—no time/no money for pure

experimentation); evaluation by project with coaching to minimize risks. Assessment and planning of further introduction.

No 17 (47), CEO and Project Manager, Automotive Consultant

In contrast to the focus on piloting, participant No 31, sees the most important aspects of an ideal technology transfer in education. Therefore, after selection of the process and the method to be transferred, it is intensively discussed that a teaching concept is needed, which needs to be implemented using teaching materials and conducting training.

1. Definition of a strategy.
2. Definition of a process and a method.
3. Selection of a suitable technology that can follow the process and the method.
4. Creation of a training concept.
5. Depending on the complexity, creation of manuals, written documentation and so forth.
6. Training of staff.
7. Definition of a binding start date.
8. Assistance for users by experts in the first months after introduction (depending on the complexity).

No 31 (38), Requirements Engineer and Software Architect, Automotive Supplier

Participant No 31 also claims that there is a need for experts that accompany the introduction of a new technology and are available for several months. This is a recurring topic, which is also mentioned by participant No 32. However, participant No 32 considers it important to have experts in-house.

only mature technologies should be introduced. Training and experts must be available in company before roll-out.

No 32 (37), Electrical Engineer, Systems Engineer, Industry Automation Supplier and OEM

In contrast, participant No 40 prefers to rely on external experts that are seen as consultants.

When introducing new (new for the company) technologies intensive coaching would be ideal. This means for at least two projects, internal staff are counseled by external staff with specialized knowledge. This sounds expensive, but it pays off.

No 40 (45), Mechanical Engineering, Requirements Engineer and Architect, Automotive Supplier

Participant No 29, points out two already mentioned topics: piloting and support by experts. In addition, the need for extensive change management accompanying the introduction is mentioned.

- intensive change management.
- It is important that only intensively tested and piloted technologies are taken over to the productive development units.
- Sustainable user support is provided in productive use, particularly going beyond the roll-out phase.

No 29 (29), Method Developer Systems Engineering, Supplier for various domains (Avionics, Automotive, Industry Automation, Healthcare, Energy, etc.)

Participant No 38 explicitly mentions the need for providing materials that employees can use throughout the introduction, including literature but also room for discussions, which should ideally be moderated by experts.

clear presentation of the problem; introduction of methodological and software tools; availability of further information sources (literature, moderated discussion board)

No 38 (26), Space and Aero Space Engineer, Requirements Engineer and Architect, Automotive Supplier