Information and Software Technology 79 (2016) 106–127

Contents lists available at ScienceDirect

Information and Software Technology

journal homepage: www.elsevier.com/locate/infsof

Challenges and best practices in industry-academia collaborations in software engineering: A systematic literature review

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ARTICLE INFO

Article history:
Received 31 December 2015
Revised 5 May 2016
Accepted 23 July 2016
Available online 30 July 2016

Keywords:
Software engineering
Industry-academia collaborations
Industry
Universities
Challenges
Success patterns
Best practices
Systematic literature review

ABSTRACT

Context: The global software industry and the software engineering (SE) academia are two large communities. However, unfortunately, the level of joint industry-academia collaborations in SE is still relatively very low, compared to the amount of activity in each of the two communities. It seems that the two 'camps' show only limited interest/motivation to collaborate with one other. Many researchers and practitioners have written about the challenges, success patterns (what to do, i.e., how to collaborate) and anti-patterns (what not do do) for industry-academia collaborations.

Objective: To identify (a) the challenges to avoid risks to the collaboration by being aware of the challenges, (b) the best practices to provide an inventory of practices (patterns) allowing for an informed choice of practices to use when planning and conducting collaborative projects.

Method: A systematic review has been conducted. Synthesis has been done using grounded-theory based coding procedures.

Results: Through thematic analysis we identified 10 challenge themes and 17 best practice themes. A key outcome was the inventory of best practices, the most common ones recommended in different contexts were to hold regular workshops and seminars with industry, assure continuous learning from industry and academic sides, ensure management engagement, the need for a champion, basing research on real-world problems, showing explicit benefits to the industry partner, be agile during the collaboration, and the co-location of the researcher on the industry side.

Conclusion: Given the importance of industry-academia collaboration to conduct research of high practical relevance we provide a synthesis of challenges and best practices, which can be used by researchers and practitioners to make informed decisions on how to structure their collaborations.

1. Introduction

Industry-Academia Collaboration (IAC) in Software Engineering (SE) has been an important topic since the early years of SE (around 1969). In an applied field such as SE, industrial impact of research is of utmost importance. For example, there are projects such as the ACM SIGSOFT Impact project (www.sigsoft.org/impact) which have measured and analyzed the impact of software engineering research on practice. To highlight the importance of IACs in SE, and to discuss success stories and how to bridge the gap between industry and academia, various workshops and panels are regularly organized at international research conferences, such as a panel called *"What Industry wants from research"* at the ICSE 2011 conference in which ideas from companies such as Toshiba, Google and IBM were presented. More recently an international workshop on the topic of long-term industrial collaborations on software engineering (called WISE) was organized in September 2014 in Sweden which hosted several talks on the subject.

In his classic book *"Software Creativity2.0"* [1], Glass and DeMarco dedicated two chapters to *"theory versus practice"* and *"industry versus academe"* and have presented several examples (which they believe are "*disturbing*") on the mismatch of theory and practice.

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http://dx.doi.org/10.1016/j.infsof.2016.07.006
0950-5849/

In a keynote talk entitled *"Useful software engineering research: leading a double-agent life"* in the IEEE International Conference on Software Maintenance (ICSM) in 2011, Lionel Briand mentioned that: *"Though in essence an engineering discipline, software engineering research has always been struggling to demonstrate impact. This is reflected in part by the funding challenges that the discipline faces in many countries, the difficulties we have to attract industrial participants to our conferences, and the scarcity of papers reporting industrial case studies"*.

To bridge the gap between industry and academia and to foster IAC, a number of researchers from academia and also practitioners from industry have systematically studied and reported challenges, best practices (patterns for successful collaborations) and anti-patterns. As the SE field matures, to ensure the relevance and impact of academic research activities, there is a major need for further IACs in this area. As the number of studies focusing on the IAC in SE has increased, it is important to systematically synthesize the state-of-the-art in this area [2–4]. Such a synthesis would provide many benefits to the broader community of researchers and practitioners, to be better aware of the challenges in collaborations and what (not) to do to ensure success. In other words, researchers and practitioners may use the results presented in this work to identify the potential risks by being aware of potential challenges, make informed decisions about what practices to utilize to ensure successful IACs.

In this work, we utilize a Systematic Literature Review (SLR) and systematic mapping (SM) process [2,5] to select the relevant studies, extract data and then synthesize the above aspects in IAC in SE.

After a careful and systematic paper selection process, our study pool included a set of 33 studies (from the set of 49 identified candidate studies) published in the area of between 1995 and 2014. The full version of our systematic mapping data is available through a publicly-accessible online repository [6]. We utilized grounded-theory-based qualitative synthesis to derive the list of challenges and best practices (success patterns) in IACs.

The remainder of the article is organized as follows. Section 2 discusses related work. Section 3 describes our research goal and research method. Sections 4 presents the results of the study. Section 5 discusses the results, and presents implications of the SLR results for researchers and practitioners, and presents the potential threats to validity of our study. Finally, Section 6 concludes this study and states the future work directions.

2. Context and related work

The context of our study is in the scope of experiences and lessons learnt about IACs as reported by SE practitioners and researchers. Since our goal is not to review nor synthesize the technical aspects of IACs reported in the literature, but instead to review and synthesize the challenges, best practices and anti-patterns of IACs, we have thus narrowed our focus to only "experience" papers reported by SE practitioners and researchers, and not the regular technical papers which have reported (empirical) applications of theoretical approaches in industrial contexts. We, as the SE community, are observing more and more papers on industrial case studies as the result IACs in recent years. There are even specific venues for such papers, e.g., the Software Engineering in Practice (SEIP) track of the ICSE (International Conference on Software Engineering), the industry track of the ICST (IEEE International Conference on Software Testing, Verification and Validation), and several recent special issues of the international SE journals on IACs.

Getting the exact statistics of technical papers in the scope of IACs in not straightforward since different keywords are used by authors in paper titles and abstracts, e.g., "industrial" case studies, "commercial". However, based on our recent experience in conducting a few bibliometric studies in SE, e.g., [7–10], we used a heuristic-based keyword to search for and get coarse statistics on the number of technical papers in the scope of IACs from the Scopus database, as shown in Fig. 1. As discussed above, we acknowledge that this simplistic heuristic-based approach is not the best way to precisely count the annual rate of papers on industrial case studies and IAC in SE, but it is a quick and rough approach to get some coarse statistics. Based on experience in our recent bibliometric studies in SE, e.g., [7–10], we searched for the word "software" in "source titles" (venues) and the phrase "industrial case" in title, abstract and keywords of papers. Given the above search query, the Scopus database returned 1577 records, which after we randomly analyzed, were a rough acceptable set of industrial case studies and IAC in SE. Fig. 2 shows the annual number of these papers and, as we can see, there has been an increase in the number of technical IAC papers in recent years.

As discussed above, since our goal in this work is to review and synthesize the challenges, best practices and anti-patterns of IACs, our focus in this work will be only on "experience" papers reported by SE practitioners and researchers, which we searched for and populated as the pool of primary studies (more details in Section 3.3.3).

Since this work is a secondary study about IAC in SE, as to the related work, we searched for secondary studies about IAC in SE, but we did not find any. A remotely-related work is [11] which is a SLR of experimental studies conducted in software industry. However, it covers no aspect of IAC.

We found only two secondary studies [12,13] about IAC in all broad areas of science. The study reported in [12] is a review of the literature on university-industry relations with respect to academic engagement and commercialization, which has been authored by a team of 13 researchers from across Europe. The study presents a SLR of research on academic scientists involvement in collaborative research, contract research, consulting and informal relationships for university-industry knowledge transfer, which the authors refer to as "academic engagement". The study reported in [13] is another more recent (published in 2015) SLR on collaborations between universities and industry. The review resulted in identifying the following five key aspects, which underpin the theory of IAC: necessity, reciprocity, efficiency, stability and legitimacy. The authors then integrated these key aspects into an overarching process framework shown in Fig. 3 which we partially utilize in the current work when we want to classify challenges and patterns over the phases of the collaboration life-cycle (from project inception to conclusion).

Overall, the related work shows that there are only limited synthesized experiences of IACs in general, and we did not identify any in the area of software engineering.

3. Method

3.1. Overview of the research method used

Our literature review was carried out in two phases. In the first phase, a systematic mapping study was performed following the guidelines by Petersen et al. [5]. The systematic mapping aimed at giving an overview of which SE topics (sub-areas) and other aspects (e.g. use of research methods) have been covered in this area. Thereafter, we conducted on the systematic review based on the guidelines by Kitchenham and Charters [2] focusing on research synthesis of the findings of individual studies to derive the challenges and patterns.

After identifying the need for the review, we specified the research questions (RQs), which are explained in Section 3.2. The

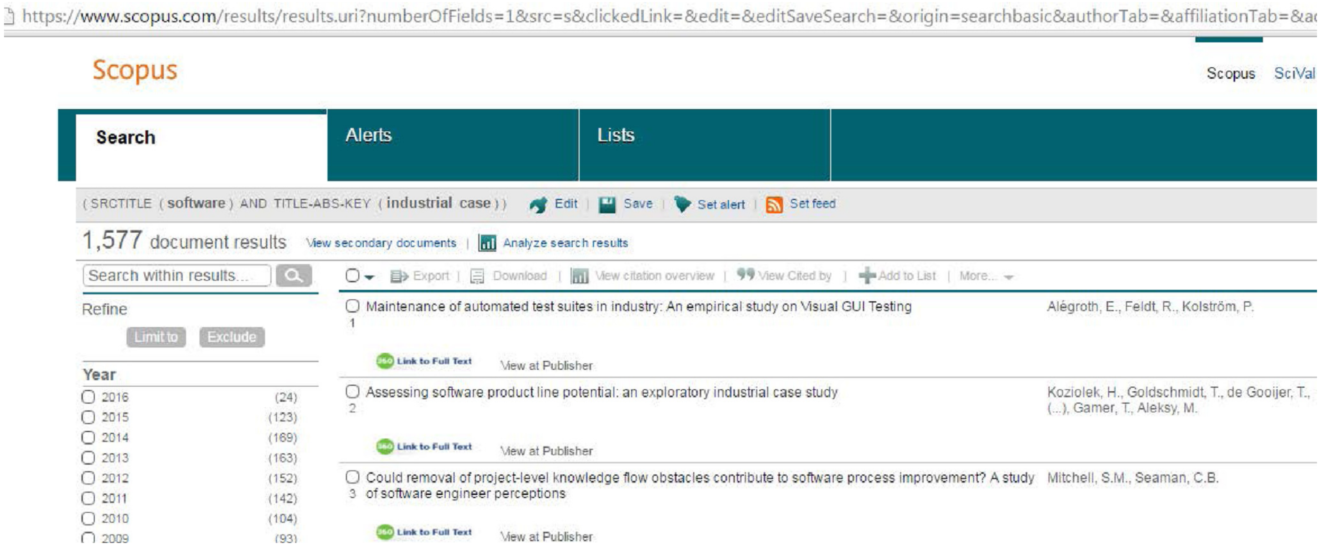

Fig. 1. A heuristic-based search approach to get coarse statistics on the number of "technical" industrial case study (IAC) papers from the Scopus database.

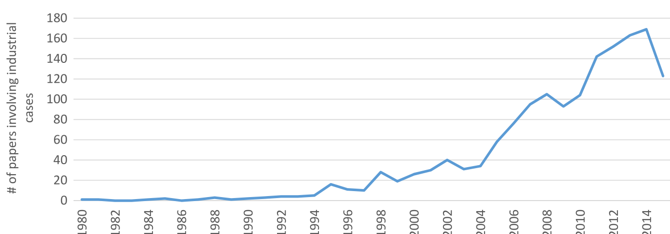

Fig. 2. The annual number of "technical" IAC papers in the Scopus database, based on the data in Fig. 1.

process (review protocol) that we developed in the planning phase and then used to conduct this SLR study is outlined in Fig. 4. The process starts with paper identification and selection (discussed in detail in Section 3.3). Then, we characterized the demographics of the included primary studies using the systematic mapping approach (detailed to be discussed in Section 3.4.1). Afterwards, we conducted the qualitative synthesis (details to be discussed in Section 3.4.2).

To further put this study in context, Fig. 5 positions this study with respect to the literature and IAC in which practitioners and researchers have been involved and reported their experiences from.

3.2. Goals and research questions

The goal of this study is to systematically review the state-of-the-art and practice in the area of IAC. The following research questions (RQs) are raised.

- **RQ1 - Collaboration models:** What type of IAC models have been proposed?
- **RQ2 - Challenges/ impediments:** Which challenges or impediments for IACs have been raised by the papers?
- **RQ3 - Patterns (best practices):** What patterns have been proposed for IACs?

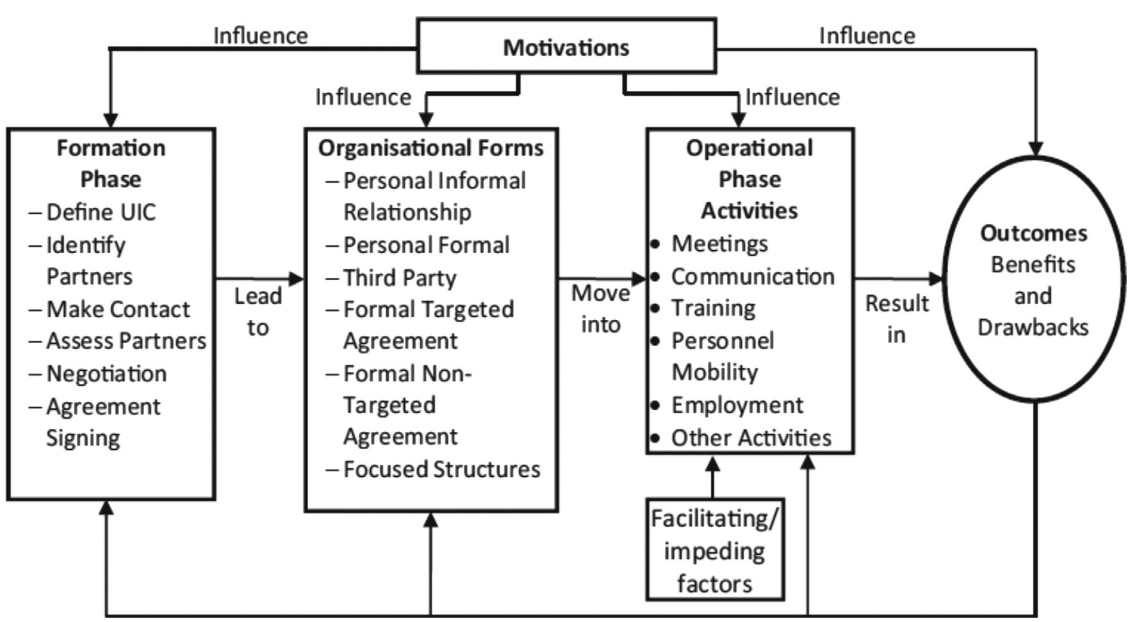

Fig. 3. A conceptual process framework for IAC (adopted from [13]).

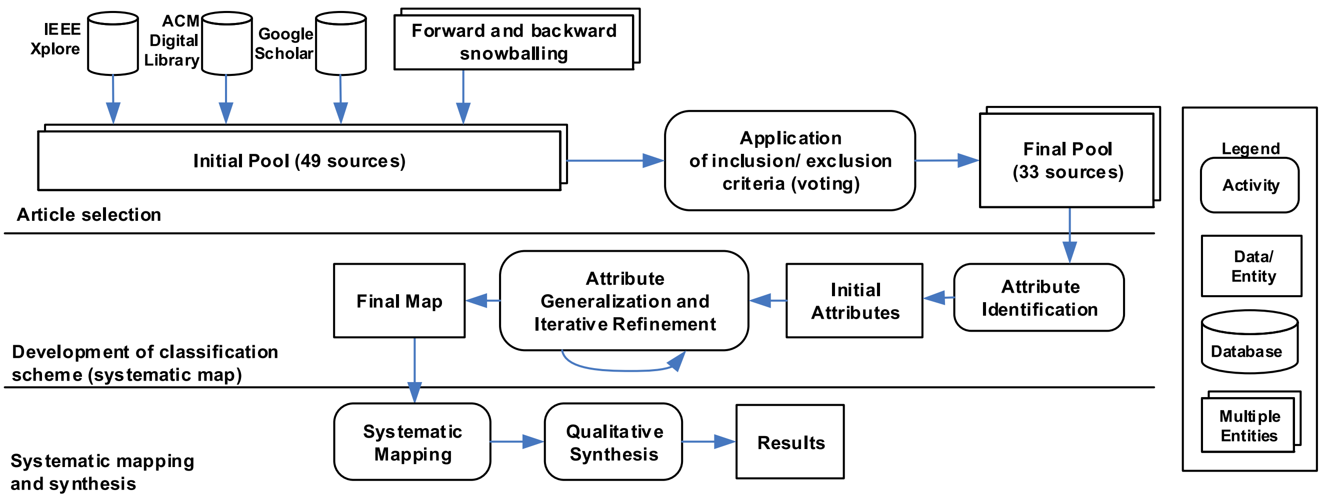

Fig. 4. The review protocol used in this SLR study.

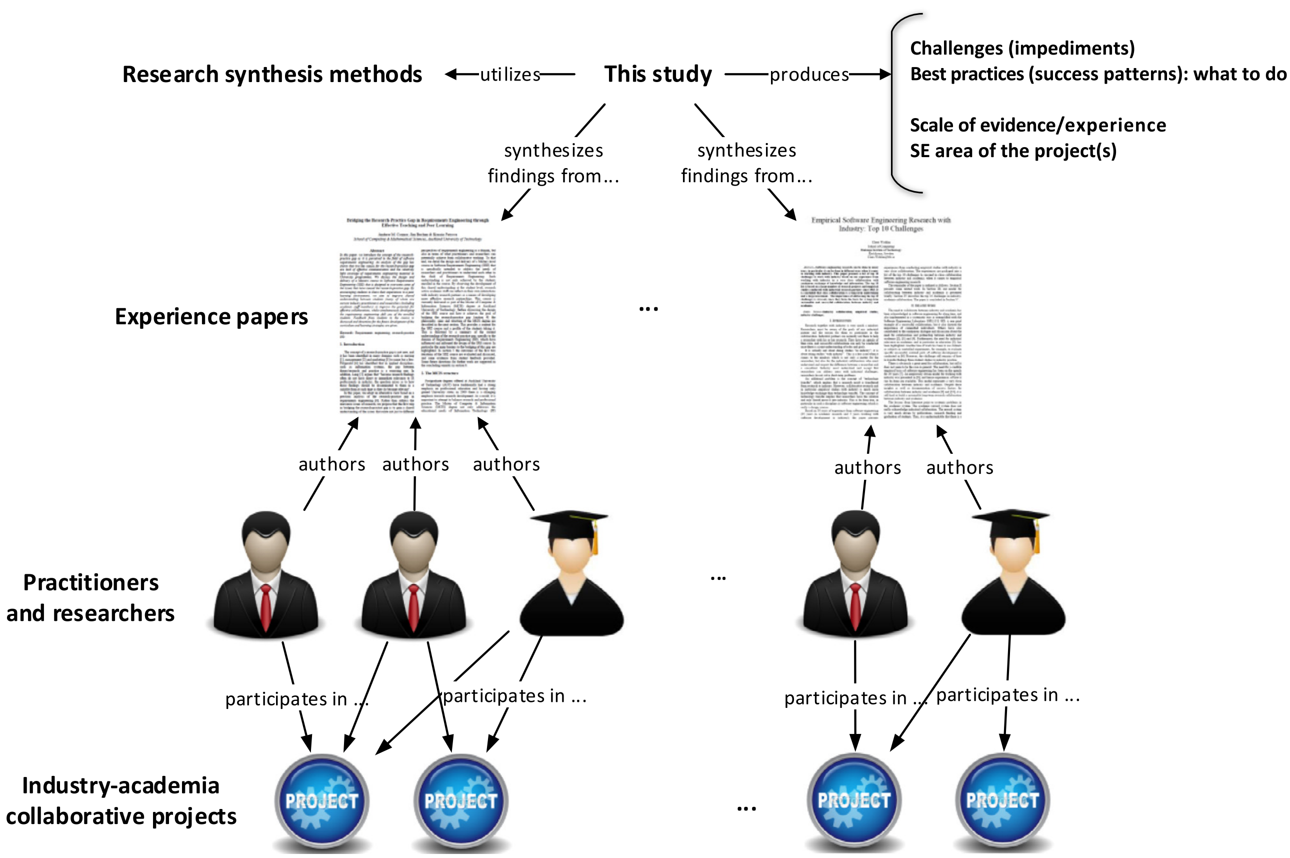

Fig. 5. Position of this study with respect to the literature and IAC in which practitioners and researchers have been involved and reported their experiences from.

3.3. Study identification

Let us recall from our SLR process (Fig. 4) that the first phase of our study is article selection. For this phase, we followed the following steps in order:

- Source selection and search keywords
- Application of inclusion and exclusion criteria
- Finalizing the pool of articles and the online repository

3.3.1. Search

Based on the SM and SLR guidelines [2,4,5], to find relevant studies, we searched the following three major online search academic article search engines: (1) IEEE Xplore, (2) ACM Digital Library, and (3) Google Scholar. In addition to the formal published literature, the authors actually wanted to include the grey literature too, and to conduct a multi-vocal literature review (MLR), e.g., [14,15]. But they were not able to find a minimum number of reasonable blog entries, or other grey sources on this subject. It seems that practitioners have not written much (or anything) on this topic.

Table 1
List of search keywords.

Listing 1	Listing 2	LIsting 3	Listing 4
Industry	Academia	Collaboration	Software engineering
Practice	Theory	Relationship	Software
University		Relation	IT

In order to ensure that we included as many relevant studies as possible in the pool of selected studies, we identified potential search keywords regarding the focus of each of our RQs. Using an iterative improvement process, we extracted four lists of search keywords as shown in Table 1.

The first and second groups were about industry and academia. The third group is synonym terms conveying the concept of "collaboration". The last term is about the "software engineering" domain. The Cartesian product of the four sets resulted in $3 * 2 * 3 * 3 = 54$ combinations which we searched for. In terms of the search time-window, the searches were conducted in January-February 2015 and thus only studies available in the above search engines by that time were included in our pool.

To decrease the risk of missing relevant studies, similar to previous SM and SLR studies, our search strategy also included forward and backward snowballing using the guidelines from [16,17]. For snowballing, we randomly picked five of the articles already in the pool and we randomly searched the articles citing them (forward snowballing) and cited from them (backward snowballing) to ensure that the relevant ones were also in our pool.

With the above search strings and search in specific venues, we found 49 studies which we considered as our initial pool of potentially-relevant primary studies (also depicted in Fig. 4). At this stage, studies in the initial pool were ready for application of inclusion/exclusion criteria described next.

3.3.2. Inclusion and exclusion

In our study, the following inclusion criterion was considered: Does a given study present findings relevant for IAC in SE? The response to be picked by each of the three authors could be: 0='exclude', 1='uncertain', and 2='include'. Only studies written in English language and only the ones which were electronically available were included. If a conference study had a more recent journal version, only the latter was included. If multiple studies with the same title by the same author(s) were found, the most recent one was included and the rest were excluded.

To apply the inclusion/exclusion criteria to the initial pool, all three authors inspected the studies in the initial pool and assigned a vote based on the above scale to each study. We decided to use a threshold of four marks for the decision on study exclusion, i.e., studies with cumulative votes of less than four marks were excluded. To vote on each study, we reviewed its title, abstract and keywords. If not enough information could be found in those sources, a more in-depth evaluation inside the paper text was conducted. Based on the results of the joint voting, the size of the pool of selected studies decreased from 49 to 33. We discuss a few examples of the excluded papers. The study [18] was in our initial paper but was excluded since its focus was not on industry-academia "collaborations", but rather on evaluating rigor and industrial relevance of industrial evaluations of SE techniques and approaches. Although the study reported in [19] had a related title "Industry academia collaboration model: The design challenges", after reading and voting, it was excluded since its focus was not on "research collaborations" but rather on "employability" of graduates, as the study was motived by the following need: "a need for industry-academia partnership has been strongly felt to enhance the employability of engineering graduate workforce and make them industry ready." Finally, as the third example, the study [20] was excluded since it provides messages and recommendations to Researchers active in the Requirements engineering community to connect to industry and it is not on industry-academia "collaborations" per se.

3.3.3. Final pool of primary studies and online repository

After the initial search and the follow-up analysis for exclusion of unrelated and inclusion of additional studies, the pool of selected studies was finalized with 33 studies. The final pool of selected studies has also been published in an online repository using the Google Docs system, and is publicly accessible online (see [6]). The classifications of each selected publication according to the classification scheme described in Section 3.4.1 are also available in the online repository.

3.4. Extraction and analysis

3.4.1. Systematic mapping

To develop our systematic map, as shown in Fig. 4, we analyzed the studies in the pool and identified the initial list of attributes. We then used attribute generalization and iterative refinement to derive the final map.

As studies were identified as relevant to our research project, we recorded them in a shared spreadsheet (hosted in the online Google Docs spreadsheet [6]) to facilitate further analysis. The following information was recorded for each study: (1) study title, (2) year of publication, (3) affiliation countries, and (4) types of the authors affiliations (academic or industry).

With the relevant studies identified and recorded, our next goal was to categorize the studies in order to begin building a complete picture of the subject area. Although we did not a-priori develop a categorization scheme for this project, we wanted to answer each of the study's RQs using the data to be stored in the systematic map.

We refined these broad interests into a systematic map using an iterative approach. The authors conducted an initial pass over the data, and based on (at least) the title, abstract and introduction of the studies, created a set of initial categories and assigned studies to those categories. When the assignment of studies to categories could not be clearly determined just based on the title, abstract and introduction, more of the study was considered. In this process, both the categories and the assignment of studies to categories were further refined.

Table 2 shows the final data extraction form (classification scheme) that we developed after applying the process described above. In the table, column 1 specifies whether the information to be extracted is for the purpose of characterizing the demographics of the included primary studies using the systematic mapping (SM) approach or to answer the study RQs (1, 2, 3). Column 2 is the corresponding attribute/aspect. Column 3 is the set of all possible values for the attribute. Finally, column 4 indicates for an attribute whether multiple selections can be applied. For example, for the first row (Contribution type), the corresponding value in the last column is "M" (Multiple). It indicates that one study can contribute more than one type of options (e.g., method, tool, etc.). In contrast, for the row corresponding to research type, the corresponding value in the last column is "S" (Single), denoting that each primary study could only be mapped under one of the given types.

We utilized the following techniques to derive the list of categories for each attribute: attribute generalization, clustering and aggregation. If there were several items under the "Other" category which were the same and more than five instances, we grouped them to create new categories. We believe all of the categories in

Table 2
Data extraction form.

SM/RQ	Attribute	Categories	Multiple/Single
SM	SE topic areas	Knowledge areas (KAs) proposed in the Software Engineering Body of Knowledge (SWEBOK) version 3.0 [49]: Generic (not mentioned), Requirements, Design, Construction, Testing, Maintenance, Configuration, (Project) Management, Process, Models and methods, Quality, Professional practice, SE economics, Other	M
SM	Contribution type	Guidelines / recommendations / patterns / success factors, Collaboration model, Method / technique, Process, Empirical (Case) study only, Other	M
SM	Research type	Solution proposal (example), Empirical study, Experience paper, Opinion paper, Philosophical paper, Other	S
SM	Scale of evidence/ experience	No. of example project(s), No. of industry partners, time duration (in years)	M
RQ1	Collaboration models	Names of the collaboration models	M
RQ2	Challenges / impediments	Qualitative phrases from the paper	M
RQ3	Best practices (success patterns)	Qualitative phrases from the paper	M

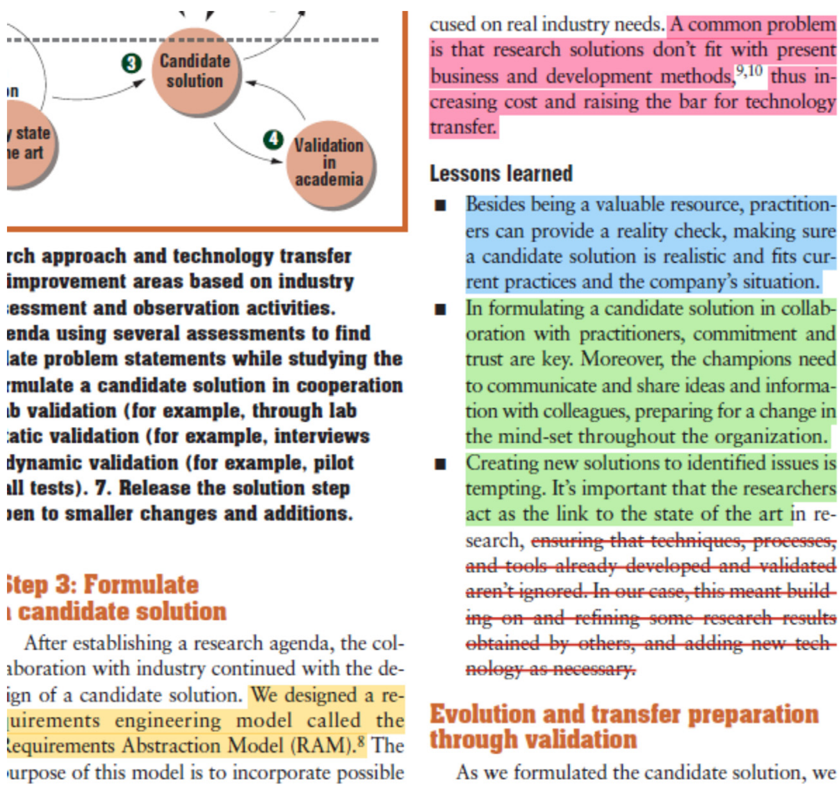

Fig. 6. Color-coding of the phrases in the primary studies according to our RQs to ensure explicit traceability. The example screen-shot is from the primary study [21], Pink = challenges, Green = success criteria/best practices, Strike-through = anti-patterns, Yellow = SE topic areas and projects observed. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 2 are self-explanatory and thus we do not discuss them one by one in the text.

To extract data, the studies in our pool were reviewed with the focus of each RQ and the required information was extracted. The data extraction phase was conducted collaboratively among the authors and data were recorded in the online spreadsheet [6]. The data extracted by one author was peer reviewed by at least one other.

To justify why a given mapping was done for a given primary study, we incorporated as much explicit "traceability" links between our mapping and the primary studies as possible, by explicit color-coding inside the paper PDF file, and also by placing comments inside the cells of the online repository [6]. Fig. 6 shows the screen-shot of color-coding according to our RQs inside the PDF file of one of the primary studies [21]. Such a color-coding scheme especially helped us in the peer review process by ensuring easy locating of the phrases.

3.4.2. Synthesis and coding (SLR)

For the RQs regarding collaboration challenges, and best practices (success patterns), our data extraction process yielded a large set of qualitative data for each of the above aspects. For example, for the "challenges" RQ, we extracted 209 single phrases (challenges) from the primary studies, e.g., *"A common problem is that research solutions don't fit with present business and development methods"* from the primary study [21]. On the other hand, for best practices, our data pool included 430 single phrases, e.g., *"Doing your homework [targeting researchers] and learning the domain es-*

Table 3
An example coding process for the "'challenges" aspect.

Example of phrase in primary studies	Open codes	Axial codes
"there is a lack of well-trained requirements engineers" [5]	Lack of well-trained software engineers	Lack of SE training and technical skills
"Lack of RE (requirements engineering) education" from [22]	Lack of SE education	

tablishes a common understanding and vocabulary" from the primary study [21]. We had to choose suitable qualitative synthesis methods to synthesize such aspects, worded differently but meaning the same concept semantically, to ensure that our study would provide digestible and aggregated findings for the readers. For example, in our data collection for "challenges", our pool included the following two phrases: *"there is a lack of well-trained requirements engineers"* from the primary study [22] and *"Lack of RE (requirements engineering) Education"* from [23].

By reviewing the qualitative data analysis literature, the best methods we chose for this context was "coding" (from grounded theory) of the aspects in two abstraction levels, i.e., open codes and axial codes [24]. We decided to not conduct 'selective' coding since it was at a high level of abstraction in our case, i.e., for "challenges", if we had to do selective coding, the code would be "challenges" itself (refer to a well-documented example by a social scientist in [25]).

Coding is a widely-used approach in qualitative data analysis in social sciences and related disciplines. Glaser [26] described substantive (open) coding as a way to *"generate an emergent set of categories and their properties which fit, work and are relevant for integrating into a theory"*. Strauss and Corbin [27] defined open coding as *"the process of breaking down, examining, comparing, conceptualizing, and categorizing data"*. Focusing in the qualitative SE literature, we reviewed several highly-cited papers and also a good guideline [28–30]. Our synthesis method of choice related to coding was "thematic analysis" which we utilized in our extraction and synthesis process.

Note that synthesis using the above approach was conducted to derive the aggregated sets of challenges and best practices (success patterns). We discuss next more details and a few examples of how we conducted the synthesis. Let us take the "challenges" as the example again. As discussed in the data extraction phase (the previous sub-section), there were many phrases in the primary studies which were worded differently but meant the same concept semantically. When we did the data extraction, we did one level of coding by applying the open coding. All authors independently conducted the open coding on two included papers [21,31] and thereafter compared and discussed the coding results to align their understanding of the coding process. The remaining papers were coded independently by the authors (Table 3).

Once we had all the open codes, each author conducted axial coding independently. We wanted to see how our team of three SE researchers would perform freely when asked to do axial coding independent from the other two researchers. In particular, the identification of higher level concepts from the open codes depend on the experience and interpretation of the researcher. Thus, conducting the coding independently and thereafter comparing and discussing the results leads to more reliable results, as suggested by [5]. Once the independent axial coding was finished, we then put our extracted codes (cluster) together and cross reviewed them. To our surprise, we noticed quite different levels of abstractions on how each of the researchers had conducted axial coding, as shown in Table 4. Note that, intentionally and knowingly, in the first iteration, the researchers did not want to set (settle on) a uniform abstraction level for codes clustering. The rationale was to observe, in an explanatory fashion, what kind of results such an independent axial coding approach would yield.

As we can see in Table 4, without setting a uniform abstraction level for codes clustering, the three researchers conducted the clustering quite differently in terms of abstraction levels, i.e., while the researcher #1 (labeled anonymously) created 37 clusters for the "challenges" aspect and distributed the papers under those clusters, researcher #2 and #3 developed 24 and 10 clusters, respectively. With no predefined granularity, we made no prior decision regarding the level of detail worth coding. As a result, we produced codes on different levels of detail (e.g., coarse ones such as "communication-related issues" and finer ones such as "Gathering developer opinions"), which were difficult to delineate against one another subsequently. The exact same challenge has been reported in grounded theory in general (e.g., [32]), and in a SE-related qualitative study of pair programming [33], in which the authors used coding and grounded theory for qualitative analysis of pair programming and faced certain challenges when researchers had no predefined granularity for coding.

On the other hand, similar to [33], the other challenge that we also experienced was regarding having no predefined level of acceptable subjectivity. As defined in the grounded theory procedures (e.g., [26,27]), the nature of the chosen codes can be anywhere on the spectrum, ranging from codes that reflect observations that any observer could agree with to codes that interpret the observation to a degree that could be called 'wishful thinking'. Grounded theory as such does not provide a criterion for deciding where "grounded in data" ends and wishful thinking begins. As a consequence, in our first iteration, we noticed that the three researchers mixed objective-descriptive and subjective-evaluative attitudes for selecting codes. This led to codes of different nature (e.g., descriptive ones such as "Stability of the organization" and assumption-bearing ones such as "Resistance to change") existing side-by-side, which made it harder to decide which code to use in a particular case. As a result, after the first round of axial coding, to minimize subjectivity, we decided to set the level of acceptable subjectivity, to be followed by all three researchers, to "objective-descriptive".

In summary, by utilizing the foundations of the grounded theory (e.g., [26,27]) and useful heuristics and the coding-scheme development methodology from the SE-related qualitative study of pair programming [33], we developed our qualitative synthesis and coding approach as reported above.

4. Results

We first present the study demographics. Thereafter, the identified collaboration models are presented (RQ1). The results of RQ2 and RQ3 (challenges and best practices, respectively) are presented thereafter.

4.1. Study demographics (systematic mapping)

Author affiliation: Fig. 7 shows the ratio of authors from academia (employment with a university or research institute), industry (employment with a company), and joint authorships (authors from both industry and academia authoring a paper together). Around half of the papers were written by academia authors only (17 papers). It is positive to see that the other half (15 papers) was written collaboratively with industry practitioners, thus incorporating both perspectives. Only a single study has been reported by authors from industry.

Knowledge areas researched in the collaborations: In order to answer which SE areas have been discussed the most in the pa-

Table 4
Snapshot of the axial codes (clusters) by the three researchers after the independent axial coding was conducted. Different levels of abstractions followed by each researcher are noticeable.

Reviewer 1 (37 themes)	Reviewer 2 (24 themes)	Reviewer 3 (10 themes)
Lack of research relevance **(13)**	Lack of research relevance **(12)**	Lack of research relevance/ research result not useful **(11)**
Lack of SE training **(4)**	Lack of SE knowledge **(8)**	Research method and research data related **(8)**
Differences in perspectives **(2)**	Limited usefulness of pilot evaluations **(1)**	Lack of SE training and technical skills **(8)**
Reluctance to share **(4)**	Lack of responsiveness and access to resources **(3)**	Lack or drop of interest level/commitment **(3)**
Terminology mismatch **(4)**	Lack of research skills/awareness of research from practitioners **(4)**	Mismatch of industry/academia objectives, methodologies, goals, terminology **(14)**
Scalability **(1)**	Too high expectations **(14)**	Communication related issues **(4)**
Effective communication **(3)**	Different time horizons **(17)**	Human and organizational factors (other than communication) **(4)**
Lack of collaboration methods for current challenges **(3)**	Challenges in research validity **(11)**	Management related issues **(6)**
Long term goals **(7)**	Lack of usefulness of traditional collaboration methods **(8)**	Resource related issues **(4)**
Researcher bias **(1)**	Different objectives and priorities **(15)**	Contractual, confidential, and privacy issues **(5)**
Subjectivity **(1)**	Arranging effective meetings **(8)**	
Context dependence **(3)**	Establishing a clear goal/direction **(7)**	
Intellectual property rights issues **(2)**	Difficult to transfer research solution to industry **(7)**	
Lack of research interest **(2)**	Achieving effective communication **(7)**	
Pilot limitations **(1)**	No agreed terminology **(6)**	
High expectations from researchers **(1)**	Lack of tool support for research **(3)**	
Research settings **(1)**	Hard to find and sustain champion **(4)**	
Limited research skills **(2)**	Challenges to choose the right context **(3)**	
Project management **(4)**	Contractual and privacy constraints **(4)**	
Difficulty in transferring knowledge to industry **(1)**	Lack of funding opportunities **(4)**	
Requirements engineering **(1)**	Human/social factors **(3)**	
Industry constraints **(6)**	Lack of academic rewards for IAC **(2)**	
Academy constraints **(1)**	Resistance to change **(2)**	
Recognition of SE **(1)**	Instable organization **(1)**	
Champions **(2)**		
Expertise in the domain **(1)**		
Lack of rewarding mechanisms **(1)**		
Validity threats **(2)**		
Balancing the research rigor **(1)**		
Difficulties in adopting new technologies **(1)**		
Different interests within an organization **(1)**		
Previous success as a success factor **(1)**		
Gathering developer opinions **(1)**		
Resistance to change **(1)**		
Identification of success factors **(1)**		
SE solution awareness **(1)**		
Managing change **(1)**		

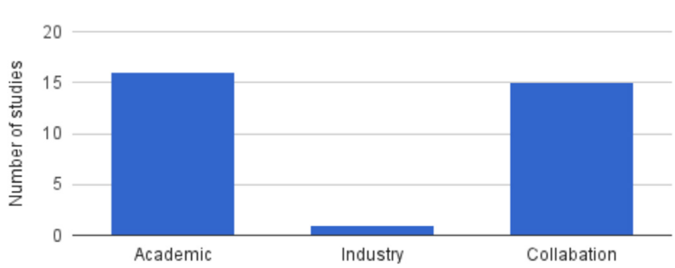

Fig. 7. Author affiliations (industry or academia).

pers, we used the 15 knowledge areas (KAs) proposed in the Software Engineering Body of Knowledge (SWEBOK) version 3.0 [34] as a reference. Topics of the collaboration projects in the papers were identified and classified by one author to the KAs and was peer reviewed by another author. Fig. 8 depicts the SWEBOK KAs covered by the papers and the number of the papers that discuss projects from each KA. Papers discussing collaborative projects related to software testing (7 papers), requirements (6 papers) and models and methods (6 papers) are the majority. The least frequently KAs addressed by the project topics were SE economics (one paper) and maintenance (one paper). There were 13 papers that were generic and did not discuss projects in the context of any of the KAs.

Types of contributions: The frequencies of the number of studies by different contribution facets are shown in Fig. 9. As the frequencies data of Fig. 9 depict, all of the 33 papers reported guidelines (also referred to as recommendations, patterns, and success factors, in this study).

Seven papers contributed collaboration models, to be reviewed in Section 4.3. We defined “collaboration model as a (semi-) formal specification of how practitioners and researchers work together (collaborate) on joint R&D projects. Such a model includes

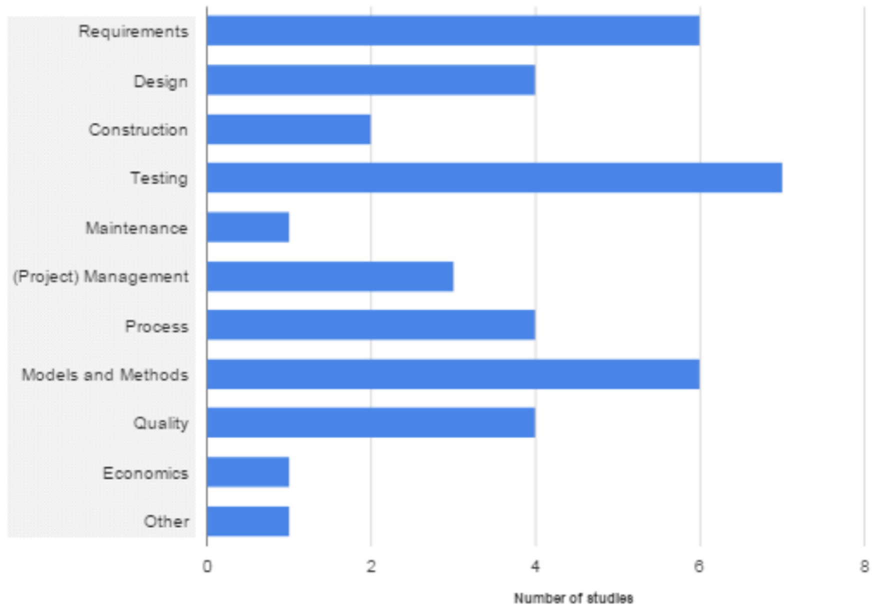

Fig. 8. SE topic areas of the projects studied in the primary studies.

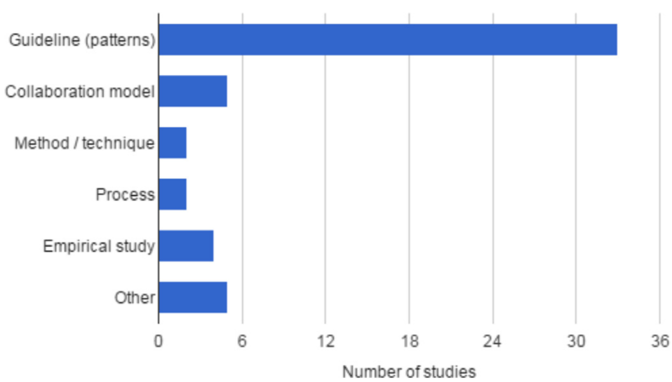

Fig. 9. Frequencies of the number of studies by different contribution facets.

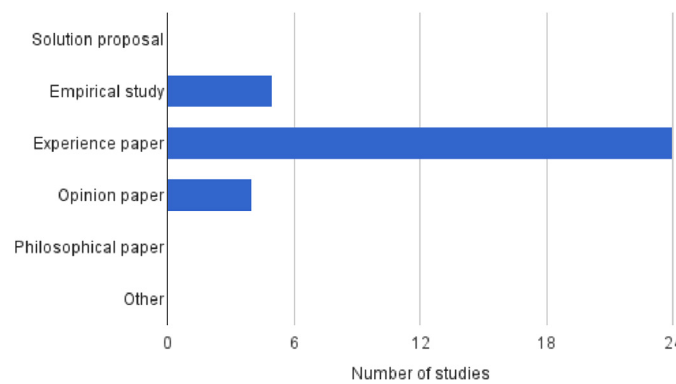

Fig. 10. Frequencies of the number of studies by different research facets.

the collaboration steps, roles and responsibilities. Action research [35,36] is an example of such a model.

Two papers discussed methods (techniques). To bridge the gap among academics and practitioners in non-functional requirements, the authors of [37] recommended using "situational method engineering" [38] to provide customizable solutions and techniques. Kaindl et al. [23] suggested using an approach called "problem frames" [39], which they believe is promising to classifying, analyzing and structuring software development challenges of the industry partners.

Two papers contributed processes. The technology transfer model proposed in [21] was accompanied by a process-driven approach. Kaindl et al. [23] described a process, which evolves research results from "less applied" to "more applied" to "ready for prime time".

Four papers contributed empirical studies in this context. Petersen and Engström [40] used an interview-based study to develop a taxonomy to be used for finding relevant research solutions for practical problems. Rombach et al. [41] follows a systematic case-study approach. Martínez-Fernández and Marques [42] used the "focus group" approach, which is considered a suitable technique to obtain the perception of a group of selected people on a defined area of interest. The authors of [43] reflected on their experiences based on the success factors for IAC in the context of several empirical studies that they had conducted as part of a collaboration with industrial partners in the area of software product lines.

Five other papers made "other" contribution. Connor et al. [22] presented design and delivery of a Masters course in software Requirements Engineering (RE) that was designed to overcome some of the issues that have caused the research-practice gap. Ostweil et al. [44] determined the impact of software engineering research on practice. Wohlin [45] specifically presented the Top 10 challenges of Empirical software engineering research with industry. Petersen and Engström [40] presented a taxonomy and how to use it to bridge the communication gap between industry and academia. Morris et al. [46] presented a dependency chain of research results.

Research types: In a different classification, we mapped studies by their research facet (Table 2). The results are shown in Fig. 10. As can see in the frequencies data, a majority 72% (24 of 33) of the studies are experience reports, i.e., a team of authors being involved in IAC have presented their experience. Apart from the 24 experience reports, in terms of maturity (level) of research approaches, we classified the remaining papers as follows: six papers [23,37,40,41,44,47] under empirical studies, three opinion papers [46,48,49], and no philosophical papers.

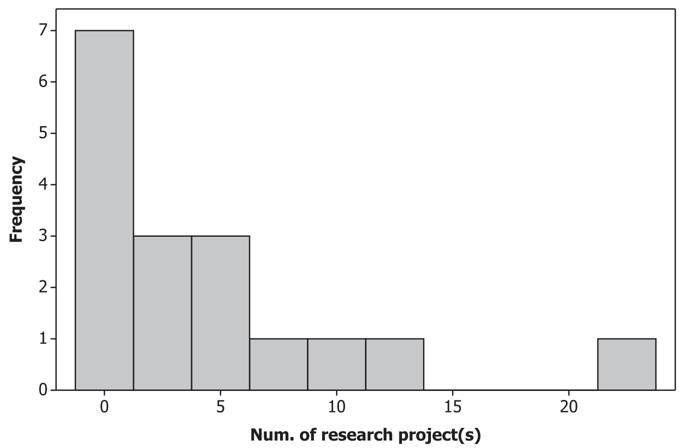

Fig. 11. Number of research projects studied in the primary studies.

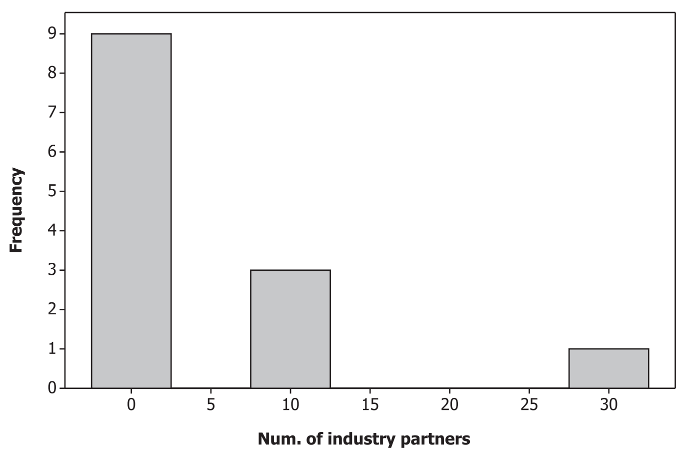

Fig. 12. Number of industrial partners in each primary study.

Here are some examples of how the above classifications were done. [23] was classified under opinion papers since *"The paper summarizes, clarifies and extends the results of two panel discussions, one at the Twelfth Conference on Advanced information Systems Engineering (CAiSE00) and the other at the Fourth IEEE Conference on Requirements Engineering (ICRE00)"*. Only a small ratio (5 out of 33) are rigorous empirical studies on IACs, i.e., [37,40,41,44,47]. For example, Ostweil et al. [44] conducted a narrative (informal) meta-analysis of several studies in SE sub-areas.

4.2. Scale of empirical evidence/experience

With regard to scale/experience of evidence, we captured the number of research projects reported, the number of industry partners involved, and the time duration of the reported experience/results in years. For all three variables, only a subset of papers provided the information.

With regard to the number of research projects (see Fig. 11), it is evident that the majority of papers only reported on a small number of research projects in the range between one and five projects, with the clear majority reporting experiences from only one project (7 of 17 papers providing information about the number of projects).

Only 13 papers reported the number of industry partners involved (see Fig. 12), the figure reports the number of partners at least involved in the research collaboration between industry and academia. For example, in one study [50] the authors mention

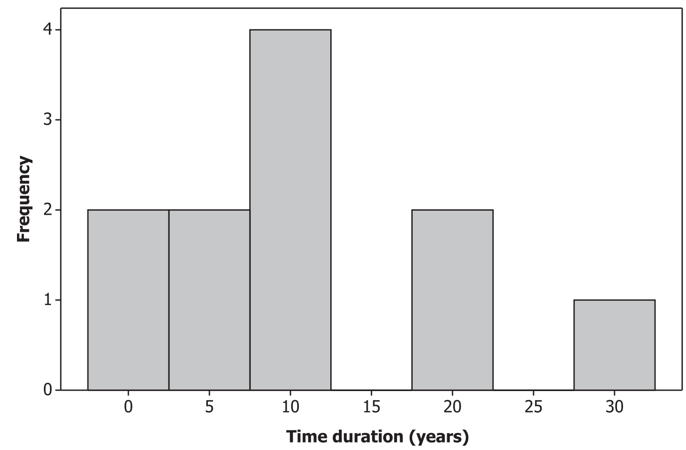

Fig. 13. Time duration of the reported experience/results in years in each primary study.

that 12 large companies and many small have been involved. In most cases only a few industry partners were involved. One case [45] stands out with an involvement of 30 industry partners.

Out of 33 papers, 12 papers reported the length of the collaborations (Fig. 13). It is interesting to observe that several longitudinal experiences have been reported. Seven papers reported experiences from joint research work with industry of at least 10 years.

Thus, in summary, we highlight once again that the primary studies in our pool are mostly experience reports (24 out of 33) and opinion papers (4 out of 33). Only a small ratio (5 out of 33) are rigorous empirical studies on IACs. Thus, the primary studies have a different strength of evidence associated with them than more traditional academic papers. Hence, it is fair to say that most of the primary studies do not always reflect ground truth that can be validated by rigorous evidence. As a result, their statements need to be taken and synthesized with caution. Thus, in the rest of this SLR, when we extract and synthesize the challenges and best practices, as a critical reflection and assumption, we do not differentiate the level of reported evidence in different studies. Based on the scale of empirical evidence/experience in each paper, as quantified by research facet types, number of research projects, number of industrial partners, and time duration of the reported experience, and as extracted by our SLR, one can assess how strongly the statements in each of the primary studies are supported by evidence.

4.3. RQ1 - Collaboration models

As discussed in Section 4.1 (systematic mapping of studies), five papers contributed collaboration models, which we briefly review next. Gorschek et al. [21] presented a technology transfer model, comprising on the following seven steps:

- Identify potential improvement areas based on industry needs, through process assessment and observation activities.
- Formulate a research agenda using several assessments to find research topics, and formulate problem statements while studying the field and the domain.
- Formulate a candidate solution in cooperation with industry.
- Conduct lab validation (for example, through lab experiments).
- Perform static validation (for example, interviews and seminars).
- Perform dynamic validation (for example, pilot projects and controlled small tests).
- Release the solution step by step, while remaining open to smaller changes and additions.

The work in [51] presented a collaboration model for industry-academia collaborative practice research which includes 10 factors for ensuring success and 10 action principles for collaboration management.

The work in [22] adopted the idea of "Reflective Systems Development (RSD)" [52] from the information systems (IS) community to IAC. The authors mentioned that the sharing of world-views required to ensure that such collaboration is successful is dependent on effective communication and the development of a shared world view, which is realized by using RSD.

The work in [53] discussed a spiral model for innovation-based industrial development developed in and used by the Fraunhofer Institute for Experimental Software Engineering (IESE) in Germany.

Last but not the least, Runeson and Minör [54] presented an "architectural" model for IACs, inspired by Kruchten's software architecture model. The model has four views: time, space, activity and domain, which correspond to the four questions/aspects of IAC: when, where, how and what.

4.4. RQs 2 and 3: challenges and best practices

We present and organize the challenges and best practices of IACs along the lifecycle of IAC. Furthermore, since challenges and best practices are related, i.e., a best practice is utilized to address a given challenge, we present them together and answer both RQs 2 and 3 jointly. The life-cycle has been inspired by the work of Ankrah and Omar [13] (see the conceptual process framework for IAC in Fig. 3). The life-cycle perspective determines where in the collaboration process a given challenge or pattern will have the main impact. This indicates where corrective actions have to be taken. Challenges should be addressed as early as possible. The mapping to the life-cycle is done for each challenge, and pattern. The lifecycle phases are defined as follows:

- **Problem formulation (F):** During the formulation stage, the problem has to be properly discussed and understood by both sides, and a topic should be selected to collaborate on (interesting to both sides), and contracting (agreement of collaboration)-related activities should be conducted.
- **Planning (P)** The planning activity comprises of defining specific research objectives, and time planning.
- **Operationalization (O):** The operationalization comprises of activities where the actual work on the research takes place (conducting case studies, training, etc.).
- **Transfer and Dissemination (T):** In the transfer and dissemination phase, the results developed during and obtained by the research are applied in the organization and paper publications take place. In writing papers, special attention should be made regarding IP protection and confidentiality of industry partners business and technical data.

The complete overview of challenges and best practices identified are provided in Tables A6 and B7. The synthesis resulted in 10 categories/themes of challenges identified through synthesis using open and axial coding. Below each axial code (e.g. mismatch between industry and academia) the list of detailed open codes related to each theme is presented. The number of studies and the related references for each open code are also stated. Which life-cycle phase each open code belongs to is specified (F, P, O, and T). In a few cases more than one phase is concerned. Tables A6 and B7 also show that a variety of codes were related to the end-to-end process, denoting that they are not specific to a particular phase.

4.4.1. Problem formulation

Challenges: With regard to the problem formulation, 12 challenges have been reported (see Table A6): C02, C05, C18, C20, C22, C23, C25, C34, C53, C53, C61 and C63. The challenge of not understanding the industry problems (C02) becomes a hinder for starting the collaboration. As pointed out by Runeson [55], it is not possible to push the solution to the industry as often the solutions do not fit into the industry context [21], or are not scalable [22].

Furthermore, the differences in objectives [51,55,56] (C22), reward systems [23,46,48] (C25), and what is perceived as useful (C23) hinder to establish collaborations. For example, Glass and Hunt [57] point out that only few researchers would be interested in doing the development ("D") of R&D. With regard to rewards, it was pointed out that academia does not value industry impact and that there is no academic reward for industry collaborations and success [45,58]. The perception of what is useful becomes apparent in different ways, for example giving low priority to post-graduate studies from the industry perspective [59] and the lack of consideration of human factors in academic research [58] (e.g., neglecting the fact that software development is conducted by humans). As a consequence, the initiation of IAC projects is usually challenging.

After having decided to collaborate, it is difficult to manage intellectual property rights early on (C60 and C61). Runeson [55] points out that legal departments are not experienced in contracting for research. The consideration of what-if scenarios in contracts also takes a considerable effort [55].

Best practices: During the formulation of the research collaboration, buy-in and support from industry collaborators need to be encouraged and obtained [43,60] (BP20). Different stakeholders need to commit, in particular company management is of importance [42,45,46,48,51,57,60,61]. An important means to gain commitment is the ability to communicate well in early meetings (BP18), the most frequently mentioned best practice.

Further suggestions have been made to get commitment. 'Proper' topic selection (BP19) is of importance early in the process [23,56] and topics need to be prioritized [51]. To choose a topic of interest, the problems of the companies have to be well understood. Kaindl et al. [23] suggests to use a systematic method for this purpose, call the problem frame approach (BP30).

Glass and Hunt [57] suggests to find out why theories succeed or fail in industry projects. Deep investigations of the problem area should be undertaken [61] to understand potential reasons for companies to participate [56].

Additionally, it helps to be able to refer to prior experience [57] (BP9) and present replicated results that were successful across projects [62] as well as success stories [48].

After having been successful to obtain commitment and deciding to collaborate, contractual concerns are apparent, namely intellectual property rights, project management [53,63] and the status/role of the researcher. With regard to property rights, it is recommended to be flexible and have simple management [46] (BP86). It was recommended in multiple sources to employ the researcher (e.g. full employment [31], internships [55,64], or at least part-time [59]) (BP87).

Key findings (most frequently given suggestions):

i) The most common challenges during problem formulation are the differences between industry and academia in terms of time horizons, objectives, reward systems and perceptions of what is useful.
ii) The frequently-mentioned suggestions for addressing the mismatch and to get commitment are proper presentation and communication, and topic selection.

iii) Invest in order to understand the problems of industry to gain their commitment using systematic research approaches (should be done by both sides).

4.4.2. Planning

Challenges: During the planning phase, several challenges have been reported (see Table A6). We discuss the major ones (discussed in more than one papers) below.

With regard to the research method, it is challenging to incorporate change (C07) into and running flexible research projects [65].

The differences in time horizons (C21) make planning and agreeing on a schedule for the research project challenging. Long-term goals of research (solving a challenging research problem) often do not align well with short-term goals of the companies [55,64,66], i.e. industry and academia have different time horizons. Long time investments into research also make the research project a risky endeavor [54]. The overall long time required to transfer may lead to a failure of the research project [62]. With regard to planning, it was observed that, in practice, industry deadlines override academic interest [45].

Besides the planning of the time-line, projects in general require clear goals. Setting goals for research projects with academia and industry was reported as challenging (C48), industry-academia research projects lack clear directions [51] (C26). In research, there is no guarantee for success of improvements [46], while success is a requirement for companies to collaborate [45,53]. That is, there is a conflict in the goal definition between the two sides.

Best practices: With regard to planning, general recommendations are to plan ahead of time (BP102), and to assure careful planning and nurturing of the research project [51,60,62]. A conscious choice for an effective model for research collaboration should be made [66] (see Section 4.3 for the different models proposed).

The goal should be to make long-term commitments (BP17) and funding [43,44,50,63] while applying short-term goals mixed with long-term goals [23]. Long-term commitments imply that a high degree of commitment from the partners are needed [67].

The commitments made shall be based on common objectives between industry and academia [22,42,67] (BP45) and an early agreement on mutual goals and roles in the project shall be achieved [56]. Besides agreeing on common objectives, also the right time for starting the collaboration has to be considered [65] (BP52), in particular both parties have to be aware of their time horizons when agreeing on the planning [50].

When deciding who to involve in the project, the industry partners should be actively [46] involved and provide relevant and best-in-class employees (e.g., best testers) to give input to research [51] (BP54). With regard to the involvement of researchers, it was emphasized that researchers should be involved beyond research activities [63], for example they should be encouraged to also participate in development [57] (BP53).

A part of planning is also to choose the principle research methodology to use (BP66-BP73). The most frequently recommended research method was case study research [46,50,62].

Key findings (most frequently given suggestions):

i) The difference in time horizon is the most generic challenge observed (more than one quarter of all included studies refer to the challenge)

ii) Other common challenges are limitations in planning to achieve high validity of the results and the challenge to achieve clear and realistic ambitions and goals in projects.

iii) To address i) and ii) common objectives and a common understanding have to be achieved, e.g. related to an awareness of different time horizons.

iv) The most common research method suggested to consider in planning was case study.

4.4.3. Operationalization

Challenges: Multiple challenges arise with regard to the research method during the conduct of the research (C06, ... , C10). The challenges reported were context dependence and lack of generalizability [31] (also internally in the company when using pilot studies [21]), lack of control in the industrial environment [31,66], lack of the ability to create repeatable results [42] and bias and subjectivity of the researcher [31]. The technology transfer process itself has been highlighted as a validity threat [67]. This may be explained by the fact that the quality of evidence is not as important to practitioners [40], hence affecting the research and quality of data available to the researcher.

As the goal of research is to lead to practical improvements, practitioners require certain set of skills to work with research solutions (C11, ... , C15). However, this is a hinder as it is difficult and costly to train practitioners [46] (C43). Overall, lack of willingness to high investment in time and effort (C49), and the lack of resources available (C56, ... , C59) have been highlighted, both for operationalization [42,66,67] and transfer [44,53,57]. Companies also have to fight for resources internally [50] hampering the ability to collect data [42]. The shortage of time is not one-sided, also there is a lack of resources on the academic side [23,53].

Confidentiality and privacy are also hinders in publishing due to restrictions in disclosure [67] and were highlighted as too stringent [64]. The access to data is another concern [42,43] (C60).

Confidentiality and privacy are also hinders in publishing due to restrictions in disclosure [67] and were highlighted as too stringent [64]. The access to data is another concern [42,43] (C60).

Best practices: There is a general need to conduct more empirical studies in industry [37] and place more emphasis on evaluating solutions in realistic contexts [58]. In the literature, we identified various practices which were suggested to realize industry-based studies.

An important basis for designing a useful solution for industry practice is to understand industry problems and to have the willingness to base the research on these problems [21,40,43,46,51,56–58,60,61,63,64,67] (BP29). Industry needs and problems have to be actively elicited [21,51] by being in close contact with the industry and to monitor needs [45,64]. As part of the active elicitation is to have practitioners explain their projects and challenges [42]. From a research perspective it is of importance that the problems are non-trivial [65].

When collaborating with industry benefits for the organization have to become visible during the research (operationalization) and the solution transfer to practice [21,50,51,62,65,67]. Stakeholders, such as the developers, have to be satisfied [62]. As pointed out by Raschke et al. [47] early success needs to be delivered for a continued collaboration. When no solution is transferred attractive and interesting knowledge for the practitioners should be produced that is valuable for both parties [37,48,66].

More concretely, the following criteria important for a solution transferred to industry should be demonstrated:

- Sustainability: Solution is valid over a prolonged period of time [41].
- Adaptability/customizability/evolvability: Solution can be tailored and is easy to evolve depending on the contexts [37,41,57,65].
- Scalability: Solution scales to the complexity of problems observed in industry [58].
- Portability: Design alternative scenarios of how to use the solution [42].
- Simplicity: Provide a simple and elegant solution [65].
- Usability: The solution should be simple to use [65].
- Credibility: The solution should be mature and have credibility with regard to its usefulness [46,51].

After having defined the problem, a solution has to be developed. With regard to the solution design, multiple studies suggest to evaluate the solution in the laboratory before taking them to industry practice [21,41,42] (BP118). Thereafter, they should be evaluated in the industry environment (also referred to as dynamic validation) in a controlled setting [21,42], for example, in pilot projects [46] (BP119). For solutions to become useful in industry, tool support (at least prototypes) is often needed [21,37,67] (BP121). During the solution design, the importance of the user interface design was highlighted [37,67]. User interfaces should have a familiar look to practitioners, resembling the look and feel of the interfaces they are used to in their practical work [67]. Such expectations seems to indicate that, in some cases, once an IAC project is finished, industry wants to see an industry-strength product out of the project instead of a research prototype. While such an expectation may not be very realistic given the constraints of the university research teams, we have seen in our own IAC projects that such tools can be developed jointly by both sides [68].

During the design and evaluation of the solution, it is also important that researchers and practitioners work as a team [31,31,45] (BP51) with the mindset of collaborating to improve a situation rather than transferring a research solution [23,45]. Thereby, multiple stakeholders from industry across department boundaries should be involved [21,65]. During the collaboration, the roles should change (BP53), while in the beginning the researcher drives the application of the solution, the practitioners need to take more active roles over time [31].

Working as a team requires the researchers' on-site presence in the company [21,31,42,43,47,48,53–55,60,61] (BP61). The visibility of the researcher is important [43,60]. Martínez-Fernández and Marques [42] suggests regular presence with one day per week, while Runeson [55] considers this too infrequent, suggesting several days per week. On-site, the practitioners should provide access to employees and managers [42] and assure an easy access to the researcher [41] (BP62). Also, access to real-world data (e.g. defect databases, depending on the research question) needs to be given [42]. The researcher, on the other hand, should actively participate beyond the research projects and discussion [57,63], e.g., social events in the company (BP63).

From the perspective of research method, it is recommended to utilize established data collection methods [31] (e.g. to conduct semi-structured interviews [37]) and to follow scientific guidelines [31] (such as [69] for case studies and [70] for experiments) (BP66-BP73). Data should be collected face-to-face whenever possible [48,61] (e.g. using interviews rather than paper version questionnaires [64]). Different types of data need to be collected (quantitative as well as qualitative, data triangulation) [48,61].

During the interpretation of the research results, it is important to be aware of the influence of context as a confounding factor [31,37,45,54,55,58,60,62]. Thus, it is important to make conscious decisions to tailor research results to the context [62] and to be aware of constraints [58]. To increase the validity and awareness for context influence, it is suggested to switch contexts [31] by leveraging on internal and external units for analysis [64] and to investigate multiple cases [50].

> *Key findings (most frequently given suggestions):*
> i) The most frequently mentioned challenge is the lack of resources available from industry and academia side (25% of all included studies).
> ii) Validity concerns need to be addressed when industry is involved.
> iii) Four recommendations for the operational phase stand out. Approximately 50% of all studies recommend to base solutions based on real-world problems observed in industry. The key benefits need to be shown and demonstrated to the industry partner. The researcher should also be co-located at the company and have regular presence.
> iv) Also, specific quality attributes of a solution have been identified that should be fulfilled, most commonly customizability.

4.4.4. Transfer and dissemination

Challenges: We can notice a lot of challenges categorized under the 'T' phase in Table A6 almost under all the challenge categorizes. For example, the difficulty to work with the research solution will remain a challenge during the transfer and dissemination of findings to the industry partner (C10). Sometimes, results produced by research are not exploitable, since they are too abstract for example (C03). Research (e.g., in pilots) is often limited to scale (C29), and in many cases, 'toy' examples are utilized initially [23]. Also, the complexity of industrial systems and technologies can be quite substantial, which also is a challenge for the transfer [66]. There are of loss of champions in projects, e.g,. due to staff turnover, or that champions may simply leave the company and thus, dissemination will be hard without the initial dedicated champion (C54). Furthermore, to conduct transfer and dissemination, time and effort investments are needed [44,53,57] (C56).

Best practices: The transfer can only be successful if benefits are achieved with regard to the measures discussed for the operationalization earlier (see BP40 and BP41 in Table B7). To determine the overall success of the transfer, a measurement program should be defined [62] (BP112) to be able to objectively measure and compare 'before' and 'after' cases. As an overall measurement, return on investment (ROI) should be captured [41,62] (BP112).

> *Key findings (most frequently given suggestions):*
> i) The main hindrances in transfer are when research results are not demonstrated on an industrial scale, and there is a lack of availability of time to conduct the transfer.
> ii) Practices important during operationalization are also important for technology transfer, in particular the ability to demonstrate benefits and achieving the important quality attributes mentioned earlier.

4.4.5. Complete life-cycle

Challenges: The end-to-end category contains the largest number of challenges (see Table A6). The challenges under category will affect all phase (activities) in the IAC life-cycle (Fig. 3). For example, if research results are not relevant for practice (C01), the companies may reject them early on, or realize at a later stage that a transfer is not possible. On the other hand, if the objectives of academia and industry are different (C22), this will be a major obstacle during the inception of a IAC project.

Furthermore, specific skills and experiences are relevant and a challenge for collaboration [37,67] (C12 and C15). If the researchers have deficiencies in practical software engineering education [23] (C11), it will hamper them to have informed communication with practitioners [22]. Also, if the researcher has deficiencies of the company context [42] (C14), it may be challenging to communicate the relevant information to initiate a project, and to find a research solution fitting the context, and hence benefiting the company.

The differences between industry and academia also become an end-to-end challenge. Communication gaps between industry and academia are a common challenge [22,40,56], while communication has to take place end-to-end and continuously. The difference in terminology (C24) is a reason for communication gaps [40,64]. The lack of a common vocabulary makes a the learning of the context challenging. A root-cause for terminology problems are the lack of standard terminologies [23] and the lack of consensus on terminologies [37,40]. Besides using different terminologies practitioners and researchers also use different communication channels [37] (e.g., industry conferences versus academic conferences and proceedings, as well as journals). Different cultures have been highlighted as another difference [46,48]. A concrete example is the unwillingness to disclose weaknesses and improvements in industry, while this willingness exists, to some extent, in academia [48], for example in the form of discussing validity threats to research. Research and academia value empirical evidence differently [55,64] (C28). In academia, the strength of evidence is valued highly, while industry values local opinions (what works in the company) more than empirical evidence [55]. Consequently, it is challenging to find an acceptable level of rigor in industrial studies [64]. This will manifest itself in the problem formulation and planning (negotiation of commitments from industry to provide access to data to achieve rigor), as well as the operationalization (the actual access and quality of data provided).

The drop of interest in early and late phases of the life-cycle hampers the collaboration (C16, … , C20). Multiple causes for the drop of interest have been reported, strongly related to human and organizational factors, namely the company 'inertia' preventing the use and acceptance of new methods [23,67] (C19), the unwillingness to admit the need for external collaboration to address a challenge [53], and the "Not invented here" syndrome [53]. From an organizational perspective, an inflexible organizational structure hampers to utilize and develop innovative solutions [53].

Whenever collaborating, trust and respect are challenging and take time to establish [53,61] (C62) and once there are issues, they are hard to fix (undo). These have an effect on how to define contractual and privacy concerns regarding access to data.

Best practices: During the whole process of collaboration, it is important for researchers and practitioners to share knowledge [61] (BP6). Various ways of achieving this have been proposed. Overall, it is important to inform companies what is happening in research [53,56]. On an institutional level, authors [23,60,66] suggest to companies to make better use of the competencies of university researchers. Ties between industry and academia can be built by enrolling people from industry in academia, involving industrial lectures, and formulating thesis topics together with industry [59]. With regard to research collaboration, regular meetings and workshops (BP1) aid in knowledge exchange. Different ways of organizing those have been proposed, such as regular meetings and discussions [42,44,45,54,55,60,67], workshops and seminars [21,50,63], communication networks [46], and public presentations as well as posters [51]. Further ways of dissemination are blogs [37], reports and publications, training through tutorials and demo applications, and industry-tailored reports [42], and tool-based collaboration platforms [42].

From a content perspective, researcher should ensure to share research results frequently during the IAC (cf. [51,56]) and also the state of the art (existing techniques and findings) [42]. Petersen and Engström [40] suggest to describe context, objective, desired effect, and scope of challenges and solutions to enable communication and knowledge sharing.

Overall, since communication in IAC is challenging due to a different use of terminologies in industry versus academia (C24), it is important to build a common vocabulary [37,40,47,64] (BP5), e.g. in the form of taxonomies [37,40] and through standards [37]. Another means for improving communication is the use of examples [21,40,49] (BP7) for both challenges and solutions [40]. Knowledge sharing is further facilitated by a good communication ability [51]. The need for communication and social skills (BP4) has been highlighted by various studies [43,45,51,55,61]. To assure effective communication [67], it has been suggested to improve the communication between technical and business people [23].

Knowledge transfer should be complemented by training of researchers and practitioners [21,43,51,56,57] (BP2). A prerequisite for successful collaboration are well-trained software engineers[22,46]. Furthermore, expertise in relation to project and people management is also essential [65]. Here, prior experience of IAC helps to ease the collaboration [43,60].

Collaboration requires commitment across the project life-cycle. Management commitment needs to be ensured [42,43,45,46,46,51,57,61,62], in particular top management needs to be on board [41,42,50]. To achieve management buy-in, convincing success stories are needed [48]. Solutions need to be presented in a way suited for upper management [42]. Also, the developers who should be part of studies need to be committed [62].

To get access, contacts and commitment, a champion is needed (BP16). The importance of an insider committed to the project has been frequently highlighted (cf. [42,45,47,50,55,56,60,61]). A good champion is charismatic [41], has a network within the company [60], and must have a sincere interest in the project and collaboration [50], and discusses the project benefits with project managers in the company [64]. Companies should help in finding a good champion [43,50].

The researcher should take the responsibility for the research life-cycle [65] (BP21) and commit resources to manage the relationship to the company [43].

Researchers and practitioners should have mutual respect and appreciation for each other [61] (BP46) and understand as well as resolve differences in perspectives [40,45]. It is important to interact in a friendly manner [21] appreciating each others' strengths [51] and competencies [45] (BP47 and BP48).

The research project should be managed in an Agile fashion [51,65]. This comprises of multiple ways enabling agility in research projects with industry (sorted by frequency of mention).

- Iterative research process [31,42–45,55]
- Incremental and graduate delivery of results instead of big-bang [43,50,54,60,62]
- Flexibility with regard to the solution [21] (modification based on industry need)
- Flexibility with regard to the researchers' interest [63]
- Define short-term objectives [65]
- Organizational structure in the organization should support agility [65]
- Run smaller projects [50]
- Flexibility for coordination [42]
- Flexibility in research proposals[46]

From a managerial point of view, risks have to be managed (BP56-BP60). The organizational structure should enable flexibility as mentioned above [65], though one should be aware of the risk of a lack of organizational stability [60] (e.g. leading to loss of champions). The lack of resources should be factored in as a risk for achieving rigorous research [66]. Furthermore, management overhead should be avoided by decreasing overhead in administrative activities [51], also referred to as "Lean research" [64]. To support management, it is recommended to establish a measurement program [21] and to formulate concise and measurable objectives [65].

Key findings (most frequently given suggestions):

i) The main challenge from the overall lifecycle perspective is the lack of relevance of research for practice.
ii) The most frequently mentioned practices (at least 25% of all included studies) to be successful in the overall end to end process were to run regular workshops and seminars, ensure management engagement, the need for champions, and to conduct the IAC in an agile way.

4.4.6. Mapping of best practices to challenges

Table 5 shows the mapping of the challenges to the practices illustrating which practice is useful in addressing a challenge. Only in a few instances, the literature made an explicit link stating that a particular challenge leads to a specific benefit of addressing a challenge. If an explicit link was made in the literature, this is indicated by the reference to the study making the link in Table 5.

5. Discussion

We discuss next a summary of the systematic mapping and review results, the implications of those results, and the limitations and potential threats to the validity of the study.

Looking at the demographics of the studies included, multiple research gaps could be identified providing pointers for further work.

Software testing (discussed in 7 papers) and software requirements (in 6 papers) were the most popular, while SE economics (one paper) and maintenance (one paper) were the least mentioned. We suggest the community to initiate and report more IAC projects in the latter topics. There is a need for more processes and techniques to facilitate IAC in SE. While there are a handful number of empirical studies in IAC, there is a need for more work in this area, as the majority of papers were experience reports. The scale of empirical evidence/experience seems reasonable at the current state. However, we encourage further and larger scale IAC's. Given that in many cases individual projects and companies were part of the IAC, retrospective synthesis proved useful given that the findings would otherwise only be considered for a specific context. Five papers contributed collaboration models:

- A 7-step technology transfer model [21]
- An Agile research collaboration model [51]
- Adaptation of the "Reflective Systems Development (RSD)" model from the information systems (IS) community in [22]
- A spiral model for innovation-based industrial development [53]
- An "architectural" model for IAC [54], inspired by a software architecture model

The empirical basis of all the above five models were based on experience papers. It would be interesting to empirically utilize the above models in IAC projects and report evidence, success and challenges in using those models.

It was also noteworthy that, from a reporting perspective, only a sub-set of studies explicitly reported the number of projects, the duration of the collaboration, and the number of industry partners. However, this is of importance to be reported in experience reports so that it can be later used to assess and compare the collaboration approaches.

We synthesized the findings of the literature with regard to challenges and best practices.

Practitioners and researchers can go into the phases of IAC and determine which challenges they are likely to face (risk management) and may utilize the inventory of best practices for the planning of their collaboration. However, the linkage to the success is not yet explicit. That is, we do not know, based on empirical evidence, which best practices contribute strongly to the success of IAC.

Technical research papers, as results of IAC, generally do not describe the context of the research project or the history of IAC when reporting the technical results. As an example case of a very small ratio of papers which do describe the context of the research project and IAC, is [72,73] which was a successful empirical IAC research project that provided details on IAC context in their studies. Damm [73] worked in collaboration with industry and succeeded in transferring an outcome of the research (fault-slip through [72]) to industry. In fact, the outcome became an industry-wide standard for Ericsson, which is a Fortune-500 company. This was achieved in the time frame of early 2003 to late 2006. All the mapped best practices were frequently mentioned, which is an early indicator for the importance of these factors for a successful IAC. Though, further research and data points are needed. Thus, future efforts need to be placed on studying the practices utilized in past collaborations, and relating them to success.

With regard to the relationships between challenges and best practices, we found that the link between specific challenges and best practices was not made explicit in many cases. In Table 5 we mapped the challenges to practices only when the link was grounded in the data. Though, one could argue that many more links exist. For example, one may argue that the deficiencies in skills of practitioners to work with research solutions may be addressed by providing examples of challenges and solutions, highlighting the need for continuous learning on both sides, effective communication, creating user documentation, etc. Though, to what degree the issue is addressed is not explicit. Thus, explicitly linking and investigating which challenges can be best addressed by specific practices should be investigated. Given that we do not have sufficient data, many combinations of practice-challenges mappings are possible. The combinations that seem reasonable could be formulated as a research hypotheses to be tested. For example, to address deficiencies in skills of practitioners, examples are more cost-efficient and useful than user documentation, etc.

5.1. Limitations and threats to validity

Potential threats to the validity of our study and the steps that we have taken to minimize or mitigate them are discussed in this section. The potential threats are discussed in the context of the four types of threats to validity based on a standard checklist for validity threats presented in [70]: internal validity, construct validity, conclusion validity and external validity. In dealing and minimizing the potential threats to validity, we have also benefited from our experience in our recent SM and SLR studies [74–77].

Internal validity: Internal validity is a property of scientific studies which reflects the extent to which a causal conclusion based on a study and the extracted data is warranted. The systematic approach that has been utilized for article selection is described in Section 3.3. In order to make sure that this review is repeatable, search engines, search terms and inclusion/exclusion cri-

Table 5
Mapping of challenges to practices.

Challenge ID	Challenge description	Best practices addressing the challenge
	Category: Lack of research relevance	
C01	Results produced through research are not relevant for practice	**BP17**: Make long-term commitments [44]; **BP62**: Provide easy and frequent access for the researchers (makes solutions pragmatic and realistic [42]);
		BP51: Work in (as) a team (collaboration leads to dissemination and transfer [42]); **BP66**: Use case study method (leads to useful generally applicable results [50]); **BP119**: Pilot the solution with industry practitioners [42,46]
C02	Researchers do not understand the relevant problems from an industry point of view	**BP7**: Run workshops and seminars (gives access to industry relevant problems [63]);
	Category: Lack of training, experience, and skills	
C11	Deficiencies in software engineering education	**BP17**: Make long-term commitments (industry becomes willing to get involved in education [63]; **BP51**: Work in (as) a team (collaborative approach transfers knowledge [67]); **BP66**: Use case study method (case studies are useful for spreading knowledge and experience [50]);
C14	Deficiencies of knowledge by the researcher of the company context and technologies used in practice	**BP61**: Researcher should be co-located and be present on the industry site [21];
		BP75: Use established guidelines and data collection methods (here: interviews [37]); **BP87**: Employ the researcher (gains useful industrial experience [59]);
	Category: Lack or drop of interest/commitment	
C16	Lack of commitment to provide access and time	**BP16**: Need for champions and their attitudes [43];
		BP17: Make long-term commitments [45]; **BP18**: Proper presentation and communication by researchers in early meetings [46]; **BP19**: Proper topic selection [56]; **BP40**: Show benefits of the research solution for the industrial partner (gives support by top management [65]); **BP46**: Friendliness and reciprocal respect [21]; **BP61**: Researchers should be co-located and be present on industry side (opens doors at the company [43]); **BP64**: Have frequent interaction through meetings (gives network access [55]); **BP86**: Manage intellectual property rights [71]; **BP119**: Pilot the solution with industry practitioners (time and with that cost savings [53]);
	Category: Mismatch between industry and academia	
C24	Different terminology and ways of communicating	**BP22**: Prior positive experience (facilitates communication [43]);
		BP77: Personally interact with the practitioners during data collection [54]
C26	Different communication channels and directions of information flow	**BP7**: Run workshops and seminars (increases visibility across organizations [63], allows to show relevance, strength and ability [63]) ;
	Category: Human and organizational factors	
C41	Resistance to change and inflexibility	**BP66**: Use the case study method (only exploratory [62]);
C42	Lack of organizational stability and continuity	**BP15**: Ensure management engagement in the industry side (reduces impact of organizational change [55]);
	Category: Management-related issues	
C48	Difficulty to achieve clear and realistic ambitions and goals in projects	**BP18**: Proper presentation and communication by researchers in early meetings [51];
C49	Willingness to put high investment in time/effort	**BP40**: Show benefits of the research solution for the industrial partner (valuable solutions save time [67]);
	Category: Contractual, and privacy concerns	
C62	Missing trust and respect	**BP5**: Establish common and simple terminology (vocabulary) [21]; **BP40**: Show benefits of the research solution for the industrial partner (valuable solutions make the industry open up [67]); **BP51**: Work in (as) a team [when done long enough builds relations and trusts [48]; **BP77**: Personally interact with the practitioners during data collection [54];

teria were carefully defined and reported. Potential problematic issues in selection process could be limitation of search terms and search engines, and bias in applying exclusion/inclusion criteria.

As discussed in Section 5, technical research papers, as results of IAC, generally do not describe the context of the research project or the history of IAC when reporting the technical results. A very small ratio of papers describe those aspects. Our search strings targeted all the candidate papers by searching in "full-text" mode, however no such paper came to our candidate pool. We believe that such a small ratio of papers will not impact our results, i.e., the set of challenges, patterns and anti patterns, since the example technical study that we found [72,73] discussed the aspects already in our synthesized sets.

Limitation of search terms and search engines could lead to incomplete set of primary sources. Different terms were used by the three authors to point to a similar concept. In order to mitigate risk of finding all relevant studies, formal searching using defined keywords was done followed by manual search in references of initial pool (i.e., snowballing) and in web pages of active researchers in our field of study. For controlling threats due to search engines, not only we included comprehensive academic databases such as Google Scholar, but also we have searched special active venues related to the topic, e.g., the international workshop on long-term industrial collaboration on software engineering. Therefore, we believe that adequate and inclusive basis has been collected for this study and if there is any missing publication, the rate should not be high. Applying inclusion/exclusion criteria can suffer from researchers judgment and experience. Personal bias could be introduced during this process. To minimize this type of bias, joint voting was applied in article selection and only articles passing the threshold score were selected for this study.

Construct validity: Construct validities are concerned with whether the objects of study truly represents the theory behind the study. Threats related to this type of validity in this study were suitability of RQs and categorization scheme used for the data extraction.

To limit construct threats in this study, we preserved the tractability between research goal and questions. Research questions were designed to cover our goal and different aspects of the topic. Questions are answered according to a categorization scheme. For designing a good categorization scheme, we adapted a baseline classification from our recent SM and SLR studies [74–77], improved it with the goals of this SLR, and finalized the schema through an iterative improvement process.

Conclusion validity: Conclusion validity of a SLR study is provided when correct conclusions are reached through rigorous and repeatable treatment. In order to ensure reliability of our treatments, acceptable size of primary sources are selected and terminology in defined schema is reviewed by authors to avoid any ambiguity. All primary sources were reviewed by at least two authors to mitigate bias in data extraction. Each disagreement between authors was resolved by consensus among researchers.

Following the systematic approach and described procedure ensured replicability of this study and assured that results of similar study will not have major deviations from our classification decisions.

External validity External validity is concerned with to what extent the results of our SLR study can be generalized. As described in Section 3.3, defined search terms in the article selection approach resulted in having primary sources all written in English language; studies written in other languages were excluded. The issue lies in whether our selected works can represent all types of literature in the area. For these issues, we argue that relevant literature we selected in our pool contained sufficient information to represent the knowledge reported by previous researchers or professionals.

Also, note that our findings in this study are mainly within the field of IAC in SE. Beyond this field, we had no intention to generalize our results. Therefore, few problems with external validity are worthy of substantial attention.

6. Conclusion and future work

By following a systematic literature review (SLR) process, this paper selected a pool of 33 sources (papers and books) in the area of IAC in SE and then classified and synthesized the challenges, success patterns and anti-patterns of IAC in SE. The results presented a snapshot on the above issues with the hope of encouraging researchers and practitioners to be more aware of the challenges and anti-patterns and also apply success patterns to ensure successful IACs. For the SE research community to have a meaningful future, there is a critical need to both industry and academia to collaborate with one another. We believe that our results are an enabler in that direction. This can be achieved in different ways. Challenges may be utilized to assess risks in IAC. This allows to take proactive actions, which can be obtained from the list of best practices. What is particularly important to avoid has been reported through anti-patterns. Based on a case we found early indications that the frequently mentioned patterns may play an important role in successful IAC, though further data is needed given the limited availability of evidence.

Among our future work directions are the followings: (1) to practically apply the success patterns in our current/upcoming projects and evaluate their effectiveness, (2) to quantitatively and qualitatively measure the observed levels and impacts of challenges, success patterns and anti-patterns in our current and upcoming projects, and correlate them with project success measures, and (3) we had also extracted the set of anti-patterns in IACs, but due to space constraints, we could not present them. We plan to publish them in other upcoming papers.

Appendix A. Complete list of challenges

The complete list of challenges is shown in Table A6.

Table A6
Complete list of best practices.

ID	Description	#	References	Phase
	Category: Lack of research relevance			
C01	Results produced through research are not relevant for practice	8	[21,22,31,37,46,49,51,63]	E2E
C02	Researchers do not understand the relevant problems from an industry point of view	4	[22,48,58,66]	F
C03	Results produced by research are not measurable and exploitable (mechanisms for exploiting them are missing)	1	[46]	O/T
C04	University education not focused on industrial relevance	1	[59]	E2E
C05	Research topic selection not driven by relevance	1	[56]	F

(continued on next page)

Table A6 (*continued*)

ID	Description	#	References	Phase
	Category: Research Method Related			
C06	Not properly addressing the validity of the research when industry is involved: Generalizability, control and confounding factors, biases, subjectivity, sample size, and repeatability	6	[31,40,42,64,66,67]	P/O
C07	Running a flexible research project/method is challenging	1	[65]	P/O
C08	Research in its nature is risky	1	[46]	E2E
C09	Difficult to evaluate whether research addresses future needs in practice making it challenging to decide on solutions	1	[46]	O/T
C10	Integrating new and improved solutions in the already existing context	1	[46]	O/T
	Category: Lack of training, experience, and skills			
C11	Deficiencies in software engineering education	4	[22,23,46,66]	E2E
C12	Lack of training, experience, and skills (general)	2	[67,71]	E2E
C13	Deficiencies in skills of practitioners to work with the research solution	2	[41,67]	O/T
C14	Deficiencies of knowledge by the researcher of the company context and technologies used in practice	2	[42,55]	E2E
C15	Deficiencies in research skills from practitioners	1	[64]	E2E
	Category: Lack or drop of interest/commitment			
C16	Lack of commitment to provide access and time	2	[50,64]	O
C17	Lack of commitment to assess research results and forums (such as conferences)	1	[58]	E2E
C18	Lack of commitment to invest money	1	[58]	F/P
C19	Lack of commitment due to human factors (inertia, admit the need for external collaboration, 'not invented here' syndrome)	4	[23,53,57,67]	E2E
C20	Lack of commitment due to competitive business	1	[23]	F/P
	Category: Mismatch between industry and academia			
C21	Different time horizons between industry and academia	9	[23,45,50,54,55,57,62,64,66]	P
C22	Different interests and objectives	6	[45,51,55–57,60]	F
C23	Different perception of what solutions and outcomes are useful	6	[23,43,47,56,58,59]	F
C24	Different terminology (vocabulary) and ways of communicating	5	[23,37,40,42,64]	E2E
C25	Different reward systems	3	[45,58,66]	F
C26	Different communication channels and directions of information flow	3	[37,51,57]	E2E
C27	Different cultures	3	[23,46,48]	E2E
C28	Different expectations on quality of evidence in research	3	[55,55,64]	E2E
C29	Different focus on scale of solutions	2	[23,66]	O/T
C30	Different types of knowledge available (industry vs. academia)	2	[37,67]	E2E
C31	Willingness for technology transfer from academia larger than acceptance of transfer from industry	1	[23]	E2E
C32	Different contexts	1	[53]	E2E
C33	Different business models	1	[55]	E2E
C34	Different perception of challenges	1	[47]	F/P
C35	Different requirements on novelty	1	[23]	E2E
	Category: Communication related			
C36	Communication gaps between researchers and practitioners	3	[22,40,56]	E2E
C37	Difficulty of managing multiple research partners	1	[71]	P/O
C38	Difficulty to elicit information from developers	1	[62]	O
C39	Fulfilling the need of communicating on time-frames, topics, and responsibilities	1	[54]	P
C40	Lack of prior relationships between a company and academia	1	[56]	E2E
	Category: Human and organizational factors			
C41	Resistance to change and inflexibility	3	[46,53,67]	E2E
C42	Lack of organizational stability and continuity	2	[42,53]	E2E
C43	Difficulties in training practitioners due to high training cost and lack availability of time due to market pressure	1	[46]	O/T
C44	Intangible human factors with organization-wide impact	1	[56]	E2E
C45	Competition between industrial and external researchers	1	[66]	I/O
C46	Hard to find champions	1	[55]	P/O
C47	Solution incompatible with organizational culture	1	[46]	O/T
	Category: Management-related issues			
C48	Difficulty to achieve clear and realistic ambitions and goals in projects	4	[45,46,51,53]	P
C49	Lack of willingness to put high investment in time/effort	1	[46]	O/T
C50	Difficult to find the right project infrastructure (management, collaboration environments)	1	[64]	O/T
C51	Difficulty in competence management to integrate external competences	1	[53]	O/T
C52	Time-critical windows of opportunity for product research	1	[71]	O/T
C53	Lack of openness to disclose weaknesses	1	[48]	F/O
C54	Loss of champions in projects	1	[50]	O/T
C55	Unwillingness to disclose weaknesses/improvements	1	[48]	F/O
	Category: Resource-related issues			
C56	Lack of resources due to high investment in terms of resources (people's time and effort) both from industry and academia side	8	[23,42,44,50,53,57,66,67]	O
C57	Financial investment risky from academic side	1	[50]	E2E
C58	Licensing restrictions on tools	1	[63]	O/T

(*continued on next page*)

Table A6 (*continued*)

ID	Description	#	References	Phase
C59	Lack of resources to provide technical support for research solutions	1	[23]	O/T
	Category: Contractual, and privacy concerns			
C60	Intellectual property rights and privacy limit access to data	6	[42,43,48,64,66,67]	O
C61	Difficulty in managing and handling intellectual property rights (skills, definition of requirements, handling of transfer of rights)	2	[55,71]	F &A
C62	Missing trust and respect	2	[53,61]	E2E
C63	Incorporating new methods and solutions in research contacts	1	[23]	F/P

Appendix B. Complete list of best practices

The complete set of best practices is shown in Table B7.

Table B7
Complete list of best practices.

ID	Description	#	References	Phase
	Category: Knowledge management (communication, terminology, training and skills)			
BP1	Run regular workshops and seminars	16	[21,42–46,50,51,54–56,60,60,61,63,67]	E2E
BP2	Need for continuous learning and for training on both sides	8	[21,22,43,46,51,56,57,65]	E2E
BP3	Improvements to university and research communities	6	[23,44,56,59,60,66]	E2E
BP4	Researchers should tune their social skills	5	[43,45,51,55,61]	E2E
BP5	Establish common and simple terminology (vocabulary)	4	[37,40,47,64]	E2E
BP6	Researchers should better open up knowledge to practitioners	4	[37,40,42,53]	E2E
BP7	Provide examples of challenges and solutions	3	[21,40,49]	E2E
BP8	Use existing works (than just inventing yet other approaches)	3	[21,23,42]	O
BP9	Need for prior expertise	2	[43,60]	E2E
BP10	Effective communication	2	[23,67]	E2E
BP11	Create user documentation for research tools and methods	1	[21]	O/T
BP12	Establish a steering group	1	[31]	E2E
BP13	Effective proprietary data management	1	[48]	E2E
BP14	Promote the solution and its ease of use using evidence	1	[67]	O/T
	Category: Ensure engagement and manage commitment			
BP15	Ensure management engagement in the industry side	15	[41,42,42,43,45,46,46,48,50,51,55,57,60–62]	E2E
BP16	Need for champions and their attitudes	11	[41–43,45,47,50,55,56,60,61,64]	E2E
BP17	Make long-term commitments	8	[23,31,43,44,50,59,63,67]	P
BP18	Proper presentation and communication by researchers in early meetings	9	[23,41,42,54,55,57,63,64,67]	F
BP19	Proper topic selection	3	[23,51,56]	F
BP20	Create and encourage buy-in and support from industry side	2	[43,60]	F
BP21	Researchers shall take responsibility and commit resources for the whole research life-cycle	2	[43,65]	E2E
BP22	Prior positive experience	2	[57,62]	F
BP23	Researchers shall treat industry partners properly (as customers)	1	[63]	E2E
BP24	Keep the team focused during the project	1	[64]	E2E
BP25	Transfer ownership of approach to industry folks	1	[21]	T
BP26	Encourage access to industry systems and data	1	[67]	O/T
BP27	Industry shall acknowledge value of research ideas	1	[65]	E2E
BP28	Pay attention to company needs	1	[61]	E2E
	Category: Consider and understand industry's needs, challenges, goals and problems			
BP29	Base research on real-world problems	16	[21,40,42,43,45,46,51,56–58,60,61,63–65,67]	O
BP30	Use systematic approaches, e.g., problem frames, to classify and analyze software engineering problems	4	[23,56,57,61]	F
BP31	Involve practitioners in problem formulation	1	[21]	F
BP32	Attend to not only industry needs, but also goals	1	[51]	F
BP33	Continued contact of researcher with industrial demands during the project	1	[44]	F
BP34	Find the most problematic pain points (prioritize)	1	[47]	F
BP35	Control formulation of problems to be research	1	[40]	F
BP36	Formulate non-trivial problems	1	[65]	F
BP37	Consider industry's long-term needs	1	[50]	F
BP38	Define coherent sets of challenges	1	[50]	F
BP39	Practitioners should assist researchers in studying and understanding diffusion theory	1	[49]	F
	Category: Ensure giving industry benefits and solving the right problems			
BP40	Show benefits of the research solutions for the industrial partner	10	[21,37,47,48,50,51,62,65–67]	O/T
BP41	Important quality aspects of the solution (e.g., sustainability, adaptability, highly customizable, scalability)	9	[37,41,42,42,46,49,57,58,65]	O/T
BP42	Use industrial data in research	1	[22]	O
BP43	Solution should be cost-efficient (ROI)	2	[37,65]	O/T

(*continued on next page*)

Table B7 (*continued*)

ID	Description	#	References	Phase
	Category: Have mutual respect, understanding and appreciation			
BP44	Establish trust	7	[41,43,45,50,53,60,65]	E2E
BP45	Establish common objectives between industry and academia	4	[22,42,56,67]	P
BP46	Friendliness and reciprocal respect	3	[21,40,61]	E2E
BP47	Appreciate each other's strengths	2	[45,51]	E2E
BP48	Value practitioners experience	1	[57]	E2E
	Category: Be Agile			
BP49	Be Agile (use iterations/increments)	15	[21,31,42–46,50,51,54,55,60,62,63,65]	E2E
BP50	Convert large projects to several smaller ones	1	[63]	P/O
	Category: Work in (as) a team and involving the "right" practitioners			
BP51	Work in (as) a team	5	[23,31,45,65,67]	E2E
BP52	Find the right team and time-scale for collaborations	3	[50,57,65]	P/O
BP53	Change roles over time and involve different people over time	2	[21,31]	P/O
BP54	Involve the "right" practitioners	2	[46,51]	E2E
BP55	Write papers together (joint authorship)	1	[45]	O/T
	Category: Consider and manage risks and limitations		P	
BP56	Consider the organizational stability of the industry partner as a risk factor	2	[60,66]	E2E
BP57	Address risks and weaknesses in the collaboration proactively	1	[51]	E2E
BP58	Realize limitations of the lab experiments	1	[21]	O
BP59	Manage time-related risks	1	[64]	P/O
BP60	Share risk-taking	1	[50]	E2E
	Category: Researcher's on-site presence and access			
BP61	Researchers should be co-located and be present on the industry site	12	[21,31,42–44,47,48,53–55,60,61]	O
BP62	Provide easy and frequent access for the researchers (to data and to practitioners)	2	[41,42]	O
BP63	Participate in activities beyond the research project in the company	2	[57,63]	P/O
BP64	Have frequent interaction through meetings	1	[65]	E2E
BP65	Get access to corporate meeting forums	1	[55]	E2E
	Category: Follow a research/data collection method- Guidelines on the selection of research methods			
BP66	Use the case study method	3	[46,50,62]	O
BP67	Use retrospective analysis of experiments	1	[62]	O
BP68	Use situational method engineering	1	[37]	O
BP69	Use the design science method	1	[61]	O
BP70	Use the reflective systems development approach	1	[22]	O
BP71	Use evidence-based software engineering	1	[40]	O
BP72	Use flexible research designs	1	[43]	O
BP73	Use systematic approaches to build taxonomies supporting communication	1	[40]	E2E
BP74	Investigate different contexts for generalizability	3	[31,50,64]	O
BP75	Use established guidelines and data collection methods (interview, survey, etc.)	2	[31,37]	O
BP76	Collect different kinds of data (quantitative - qualitative, triangulation)	2	[48,61]	O
BP77	Personally interact with the practitioners during data collection	2	[64,64]	O
BP78	Place more emphasis on empirical research in realistic contexts	2	[37,58]	O
BP79	Agree on confidentiality before collecting data	1	[45]	F/P
BP80	Aim for "just enough" rigor	1	[64]	O
BP81	Assure relaxed feeling of participants (e.g. in surveys)	1	[64]	O
BP82	Collect archival data prior to conducting the research project	1	[64]	O
BP83	Discuss and record observations immediately	1	[31]	O
BP84	Evaluate your role as a researcher (Software engineering researchers should stop seeing themselves as computer scientists)	1	[58]	E2E
BP85	Report negative results	1	[40]	O
	Category: Manage funding/recruiting/Partnerships and contracting/privacy			
BP86	Manage intellectual property rights (flexible and simple approach)	4	[46,53,63,71]	F
BP87	"Employ" the researcher (e.g. put in status of intern, part-time leave from university, etc.)	4	[31,55,59,64]	F
BP88	Collaborate with few high-quality external partners	1	[53]	F
BP89	Embrace research negotiations (contractual)	1	[51]	F
BP90	Employ researchers (graduate) with industry background	1	[59]	F
BP91	Establish a partnership/joint project with the industry	1	[59]	F
BP92	Establish a research institute to facilitate collaboration and transfer	1	[50]	F
BP93	Fund small research projects	1	[51]	F
BP94	Involve industry partners in research education (PhD)	1	[66]	F
BP95	Research should not be free	1	[55]	F
BP96	Build joint transfer test labs as a bridge for technology transfer	1	[53]	F
BP97	Choose a partner complementing the innovation process of the company well	1	[53]	F
BP98	Create long term/high cost research and development project proposals	1	[46]	F
	Category: Understand the context, constraints and language			
BP99	Be aware of and identify context factors that influence and constrain the research results	9	[31,37,42,45,54,55,58,58,60,62]	O
BP100	Gain an inside view of the practices used at the company	1	[22]	O
BP101	Learn the domain and vocabulary	1	[21]	F/O
	Category: Efficient research project management			
BP102	Plan the research project (time planning, estimation, collaboration, alignment with project goals)	4	[51,60,62,66]	P
BP103	Decrease overhead and waste in research project administration	2	[51,64]	E2E

(*continued on next page*)

Table B7 (*continued*)

ID	Description	#	References	Phase
BP104	Assure consistent reporting across documentation produced in research (reports, posters, etc.)	1	[51]	O
BP105	Assure the availability of time for adequate roles represented by practitioners to participate in research activities	1	[42]	O
BP106	Design effective reward structures for good practice	1	[23]	P
BP107	Ensure that end research results hit the right trade-offs (e.g., quality and cost)	1	[58]	O/T
BP108	Integrate research into daily work	1	[61]	O/T
BP109	Save time of practitioners participating in research (e.g. in experiments)	1	[64]	O
BP110	Utilize Ph.D. students as resources in projects	1	[55]	O
	Category: Conduct measurement/assessment			
BP111	Establish a measurement program and define measurable objectives	2	[21,65]	E2E
BP112	Measure Return of Investment (ROI)	2	[41,62]	O
BP113	Combine quantitative and qualitative information to evaluate projects	1	[61]	O
BP114	Develop a set of guidelines to evaluate bodies of evidence	1	[49]	O/T
BP115	Evaluation criteria should support the R&D project	1	[46]	O/T
BP116	Measure innovativeness (innovation benchmarking)	1	[53]	O/T
BP117	Measure solution stability as an indicator for applicability	1	[31]	O/T
	Category: Test/pilot solutions before using them in industry			
BP118	Test the solution in the lab/academic environment first	3	[21,41,42]	O
BP119	Pilot the solution with industry practitioners	2	[42,46]	O
BP120	Test the solution through a proof of concept	1	[67]	O
BP121	Build tool support (research prototypes)	1	[53]	O
BP122	Have a separate academic solution branch from an industrial solution branch to further evolve the solution	1	[67]	O
	Category: Provide tool support for solutions			
BP123	Provide technical support and documentation for academic tools	3	[21,37,67]	O
BP124	Assure the usability of the user interface - provide interfaces familiar to practitioners	2	[37,67]	O
BP125	Assure the flexibility of the tools	1	[67]	O
BP126	Agree on the licensing model for the tools produced	1	[67]	F
BP127	Encourage the use of Computer-Aided Software Engineering (CASE) tools	1	[23]	F

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