Contextualizing Research Evidence through Knowledge Translation in Software Engineering

Deepika Badampudi
Blekinge Institute of Technology
Karlskrona, Sweden
deepika.badampudi@bth.se

Claes Wohlin
Blekinge Institute of Technology
Karlskrona, Sweden
claes.wohlin@bth.se

Tony Gorschek
Blekinge Institute of Technology
Karlskrona, Sweden
tony.gorschek@bth.se

ABSTRACT

Usage of software engineering research in industrial practice is a well-known challenge. Synthesis of knowledge from multiple research studies is needed to provide evidence-based decision-support for industry. The objective of this paper is to present a vision of how a knowledge translation framework may look like in software engineering research, in particular how to translate research evidence into practice by combining contextualized expert opinions with research evidence. We adopted the framework of knowledge translation from health care research, adapted and combined it with a Bayesian synthesis method. The framework provided in this paper includes a description of each step of knowledge translation in software engineering. Knowledge translation using Bayesian synthesis intends to provide a systematic approach towards contextualized, collaborative and consensus-driven application of research results. In conclusion, this paper contributes towards the application of knowledge translation in software engineering through the presented framework.

CCS CONCEPTS

• **Software and its engineering** → *Software design techniques*;

KEYWORDS

Knowledge translation, Bayesian synthesis, Decision-making.

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1 INTRODUCTION

It is important that knowledge produced by researchers for practice is also applied in practice [6, 17], or at least evaluated in practice. Budgen et al. [6] suggest that knowledge should be presented in the form of recommendations that enable and support evidence-informed decision-making in software engineering (SE) practice. This is reflected in the fourth step of the five-step process for adapting the practices of evidence-based software engineering (EBSE) which is referred to as knowledge translation (KT) [6, 17]. Devanbu and Zimmerman indicate that the developers rely on and are more influenced by their "personal experience" than evidence from research [11]. Therefore, greater efforts should be made to translate knowledge so that practitioners are informed and rely on verified evidence and that the evidence is integrated with contextual knowledge of the practitioners, rather than solely based on preconceived opinions which may be "*biased, error-prone and spotty*" [11].

Based on the above, it is here argued that both knowledge from research studies in other contexts and practitioners' opinions that are subjective and personal to their context need to be considered jointly for adoption of research results in practice. Thus, our vision is that knowledge translation should be an integration of research evidence and practitioners' opinions based on experiences from a specific context. *Kitchenham et al. consider KT as a research activity involving researchers, subjective opinions of practitioners and policy-makers/decision-makers to make evidence-informed decisions [17].*

KT in SE is defined as "the exchange, synthesis and ethically sound application of knowledge - within a complex system of interactions between researchers and users - to accelerate the capture of the benefits of research through better quality software and software development processes" [17]. The three main aspects of KT are "exchange", "synthesis" and "application". The use of Bayesian synthesis in SE is proposed in [1] and summarized in Section 2. Bayesian synthesis supports KT as it synthesizes data and provides interpretation of the research outcome in the specific context by incorporating knowledge from research studies and experience of the intended users.

Based on the classic two-community theory, academia and practice are not always synchronized due to differences in perspectives and cultures [14]. Devanbu and Zimmerman identify that developers' knowledge is formed based on personal experience and opinion and far less on research results [11]. As a result, knowledge produced in research is too rarely used in practice. This is even more problematic if the studies do not provide explicit recommendations or guidelines to practice. Unfortunately, very few secondary studies in SE provide recommendations for practitioners [5, 6].

The need to transform evidence to the local context [22] and the need to put more effort and systematize the dissemination of research findings is identified [11]. Budgen et al. [6] state that KT in SE is done in an ad hoc manner and lacks adequate documentation. The need to develop guidelines and support for undertaking KT in SE has been identified [6].

The objective is to present a vision of how a KT framework from health care (not to be mixed up with medicine) research may be

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adopted, adapted and complemented with Bayesian synthesis to enable contextualization of research evidence to practice.

The remainder of the paper is structured as follows. Section 2 describes the background and the related work. We then provide the description of the KT framework using Bayesian synthesis in the context of SE in Section 3. An initial evaluation is summarized in Section 4. Finally, we present some conclusions and point to further work in Section 5.

2 BACKGROUND AND RELATED WORK

Opinions based on personal experience might be biased, subjective and error-prone [22] and [11]. Therefore, relying just on personal opinions and experience might not be the best approach for improving software development. In most situations, research is not transferred to industrial practice by itself. Thus, the importance of interaction between researchers and practitioners to integrate evidence from research results (knowledge) and practitioners' opinion and experience has been identified in the evidence-based software engineering guidelines [17]. Different approaches to provide knowledge to practice have been proposed in the literature which we discuss in this section.

Academia and industry collaborations are important for better utilization of research results and for guiding future research directions [20]. Regular and continuous collaboration among researchers and practitioners regarding research evidence/contribution leads to better use of research results in practice [20].

Technology transfer in software engineering is recognized as an important activity. Over the years it has been improved and refined to make it more collaborative and a technology pull rather than a technology push activity [13]. Gorschek et al. [13] proposed a model with close collaboration between industry and academia to validate a candidate solution in academia followed by a static and dynamic validation in practice before releasing as a solution. A need to make the technology transfer activity more efficient and effective has been identified [19]. Mikkonen et al. [19] emphasize the importance of co-creation and co-learning instead of a one-way transfer from research to practice. The KT framework proposed in this paper is a complementary solution to the technology transfer model proposed in [19]. The KT framework focuses on adaptation and translation of research results in general and not only transfer of a technology or a candidate solution.

To aid the use of research results in practice, an approach to capture and share the tacit knowledge to make it explicit and widely available has been proposed by Cartaxo et al. [8]. They present and evaluate a template called evidence briefings to be used to summarize findings from systematic literature reviews. Evidence briefings transfer the research results in an attractive format for practitioners. However, it does not translate the knowledge into the context and does not focus on application of the knowledge in practice. Evidence briefings can be used to facilitate knowledge translation. The use of knowledge transfer (evidence briefings) in knowledge translation is illustrated in Figure 1.

Systematic literature reviews (SLR) are shown at the top and KT at the bottom of Figure 1. The key difference between knowledge translation and an SLR is that a KT relevance jury discusses the relevance of the primary studies to the context in which the knowledge

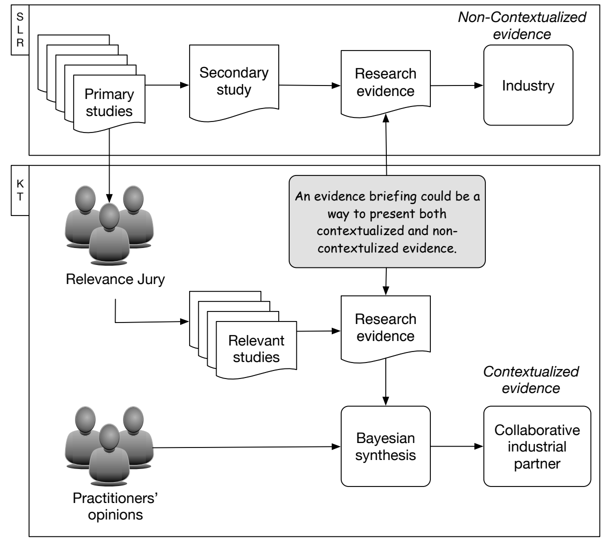

Figure 1: The use of knowledge transfer (evidence briefings) in knowledge translation.

is translated. The relevance ought to be conducted jointly by those knowing the research evidence (researchers) and those well-versed in the context of where the research evidence is intended to be used (local champion). Thus, the findings from these relevant studies becomes more aligned to the local context than if looking at an SLR as it is published.

The Bayesian synthesis depicted in Figure 1 includes three main steps related to gathering the opinions of practitioners: prior probability, likelihood and posterior probability. In a health care study [23], the subjective opinions of experts and qualitative evidence from research studies form the prior probability. The quantitative evidence is used to form likelihood and finally, the prior opinions are revised in the light of quantitative evidence to form posterior probabilities. In health care, Bayesian approaches are used for synthesizing evidence [21] and [24]. However, it has not been integrated into the KT framework for implementing knowledge in practice. The Bayesian approach has also been applied in some other health care studies [9] and [26]. However, subjective opinions are not considered in the prior probability. In [9] and [26], the posterior probability is formed based on qualitative (prior) and quantitative (likelihood) evidence.

In our previous work, the Bayesian approach is adapted to SE by separating subjective opinions from qualitative evidence for use in SE [1]. The method still consists of three steps: prior probability, likelihood and posterior probability. However, the prior probability is formed based on subjective opinions from practitioners including decision-makers/policy-makers, for example, three out of five people judge factor X to be important for improving a certain software process in a company. In this case, the prior probability becomes 60% (3/5). The likelihood is calculated by considering both qualitative and quantitative evidence in literature, for example, by counting the number of studies viewing factor X to be important for software process improvement as targeted in a company. It is important to note that the frequency of research studies does not necessarily imply practical importance. The posterior probability is obtained by presenting the outcome (preferably both the prior probability and the likelihood) to the people contributing to the prior probabilities. This separation allows tracking of how subjective opinions got revised based on both qualitative and quantitative research evidence. The posterior probabilities for different factors form the basis to decide how to proceed with software process improvement. Through these three steps the research evidence is combined with the opinions of the practitioners. This includes both their first personal opinion (input to the joint prior probability) and their opinion after being presented to both research literature (likelihood) and the joint prior probability (integrated probability based on the participating individuals). Taken altogether, the three steps support alignment among the people involved and combination of research evidence with the opinion of the people. Thus, supporting contextualization of the research evidence.

3 PROPOSED KT FRAMEWORK

The KT framework described here is adopted from health care research [14] and adapted to SE, and complemented with Bayesian synthesis. Since the term EBSE was first coined in 2004, it has gained popularity among researchers. The first three steps of EBSE describe the procedure for SLRs. Several guidelines have been proposed to conduct SLRs [28], [16] and [4] and to synthesize primary studies [10]. An interest in EBSE outcomes is emerging in industry and the need to focus on systematic knowledge translation in SE has been identified [6]. There are no existing guidelines for the fourth step in EBSE i.e. knowledge translation. Guidelines for KT exist for use in health care. The first KT framework adaptation made here is to describe each step of KT in an SE context. Furthermore, the KT steps where mapped to two existing methods (see Figure 2): 1) PDCA (Plan-Do-Check-Act), which is a well-established method for control and continuous improvement and it has been applied in different forms in software engineering [2] and 2) Bayesian synthesis as outlined above and further described in Section 3.2. This resulted in adding new steps to the KT framework (not part of the KT framework in health care [25]), which elicits prior opinions of the practitioners before making the research evidence available. This additional step allows to effectively capture subjective and contextualized opinions, knowledge and experience of the practitioners.

3.1 Overview of the proposed KT framework

The KT framework may be one concrete way of bringing research results from literature systematically into, for example, a case study. Thus, we see the case study as the study carried out, for example, at a company and then the KT framework helps in systematically integrating research literature into the case study. As it stands today, it is often the researchers carrying out the case study that brings in research literature to the study, but they do it through their own personal lenses. The KT framework systematizes the translation of research literature into practice, and in particular through the use of Bayesian synthesis, the voice of the practitioners integrates into any improvement initiative in relation to research.

Figure 2 provides an overview the relationship between knowledge creation and knowledge translation. In particular, the Bayesian synthesis customizes the external knowledge and adapts it to the local context. The use of Bayesian synthesis in the KT framework is discussed in more detail in Section 3.2. The KT framework, in Figure 2, consists of two main parts: knowledge creation (represented as a knowledge creation funnel) and knowledge translation (represented as a knowledge translation cycle). The main focus here is on the knowledge translation cycle.

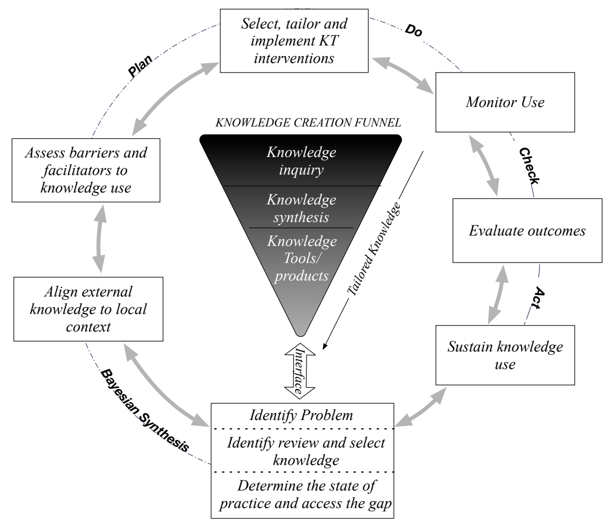

Figure 2: Knowledge translation framework (Adapted from Graham et al. [14]).

As the knowledge from research studies passes through the knowledge creation funnel it gets more tailored to the end-users' needs. The tailoring in the knowledge creation funnel is done by filtering the knowledge that could be applicable to the end-users. For example, the tailoring is done by filtering information that is not relevant to the users such as methodological details. It is different from the tailoring based on the context which is part of knowledge translation. The knowledge created is assessed for quality during knowledge translation. The knowledge can be presented to the practitioners based on the different quality levels so that practitioners can be more informed and weigh the research results accordingly. More details are mentioned in the relevant steps of the KT cycle in Section 3.2.

The knowledge creation funnel not only provides input to the KT cycle, it also accepts input from the KT cycle hence, depicted by the double ended arrow (<==>) and labeled as "interface" between the knowledge creation funnel and KT cycle. This is further elaborated in Section 3.2 and Figure 3. The main objective of the KT cycle is to implement knowledge in practice.

The KT cycle is related to the use of research evidence in practice. In Figure 2, the KT cycle is represented in relation to Bayesian synthesis [1] and the PDCA improvement cycle [2]. The Bayesian synthesis customizes the external knowledge and adapts it to the local context. Bayesian synthesis differs from a Delphi type study as it not only revises the opinion in the light of the others' opinions but also in the light of external knowledge from literature. The customized knowledge is then implemented using the PDCA cycle.

The implementation is done by assessing the current situation and identifying interventions that are necessary for knowledge implementation and then monitor and evaluate before sustaining it as an industrial practice.

3.2 Steps in the KT framework

The steps involved in producing primary and secondary studies or tools (within knowledge creation) are cyclic in nature. Therefore, the knowledge creation funnel in Figure 2 is represented as a cycle together with the knowledge translation cycle in Figure 3.

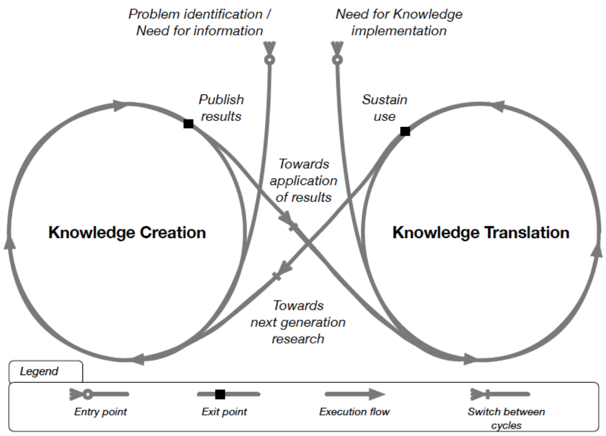

Figure 3: Knowledge creation and translation cycles (Adapted from Straus et al. [25]).

As seen in Figures 2 and 3, knowledge creation and the KT cycle are connected and provide input to each other. The entry point for the cycles depends on the need for knowledge creation or use in practice indicated by an arrow head with a circle and labeled as "entry point". Apart from these entry points the execution of the cycles can continue from the previous cycles as indicated by the arrows with a line and labeled as "switch between cycles". The arrows indicate the execution flow in the knowledge creation cycle and the knowledge translation cycle. Each cycle also has exit points indicated by a "square" which marks the end of the cycle. For example, publishing research is the exit step of the knowledge creation cycle.

Since the focus in this paper is on knowledge translation, the focus is on the KT cycle i.e. Steps 1-9 in Figure 4.

These steps may be viewed as two parts. The first part includes steps 1-4 and is related to the use of Bayesian synthesis and steps 5-9 belong to the second part focusing on knowledge implementation. Step 9 is a switch, which points either towards continued application of knowledge (Step 9a) or towards the creation of the next generation research based on the lessons learned from implementing knowledge in practice (Step 9b).

Figure 4 depicts the detailed working of KT with the use of Bayesian synthesis [1]. The entry point for knowledge translation is denoted "Need for knowledge implementation" in Figure 4. The need for knowledge translation is normally driven by an improvement initiative. To implement evidence in practice, it is useful if there is a local champion and there is support from management

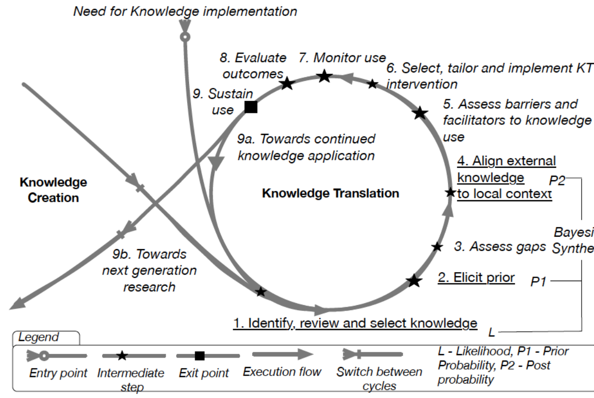

Figure 4: Knowledge translation cycle using Bayesian synthesis (Adapted from Straus et al. [25]).

[29]. Close collaboration with industry and discussions with the local champion in identifying the need is important. Once the topic is identified then the required knowledge is identified, reviewed and selected.

The description of Steps 1 to 9 in Figure 4 are as follows:

(1) **Identify, review and select knowledge:** In this step, the knowledge that could be used in practice to address the need for improvement is identified, reviewed and selected (cf. relevance jury in Figure 1). In addition, the quality, strength and applicability of the knowledge is determined so that the knowledge is correctly interpreted. The quality of the research studies can be evaluated using the rigor and relevance criteria [15] and the strength of knowledge/evidence can be determined using the guidelines in [12] or [27]. It is important to determine if the knowledge is based on a general context or a specific context. A simple literature review or a systematic literature review can be conducted to identify, review and select knowledge.

(2) **Elicit prior (Prior probability):** In this step, the current state-of-practice in terms of probabilities are elicited from the relevant stakeholders. It involves the following:
- Selecting individuals - In SE, the subjective opinions of practitioners and decision-makers/policy-makers are relevant [11]. The selection of individuals who will be the users of the knowledge is important. For example, if a decision needs to be made in a software project then, all the practitioner roles that should be involved in making the decision should be selected to elicit their subjective opinions.
- Eliciting opinions - Opinions and experiences are elicited to collect prior probability. Opinions and experiences of practitioners related to the area of improvement should be elicited. Prior probability can be captured in terms of a percentage ranging from 0 to 100 % or in terms of absence/presence (0/1) of a parameter value.

(3) **Assess gaps:** In this step, the size and nature of the gap between the current and desired knowledge, skills, and outcomes are assessed. The desired level of knowledge, skills,

and outcomes depends on each KT study. For example, a current level could be that team members in a project have different or even conflicting understandings about a particular process and the local champion might want all team members to have a common understanding about the process, which would be the desired level. Quality indicators can be used to assess the gap. For example, what is the current and desired level to achieve the goal?

(4) **Align external knowledge to local context:** In this step, individuals or groups of decision-makers go through the knowledge identified in Step 1 and determine the value, usefulness and validity of the knowledge in their context. Before knowledge from research studies is provided to the practitioners, the terminology used in the literature should be adapted to the language and terminology in the company. The local champion could help to adapt the terminology.
The knowledge can be summarized in the form of likelihood calculations. The likelihood is a representation of what is known. In other words, it is a summary of all research studies within a specific research objective. The likelihood is calculated as the percentage of the research studies reporting a finding. For example, the likelihood of 60% indicates that six out of ten research studies are reporting a particular finding. The likelihood calculated from empirical studies can be further divided based on the strength of evidence The likelihood calculation is not always the indication of the importance of a finding. For example, if the likelihood of Finding F1 is 80% and Finding F2 is 70%, it does not mean that F1 is more important. It only means that Finding F1 is more often investigated. Therefore, the likelihood does not always indicate importance. The importance of a research finding needs to be judged by the practitioners, and hence findings from research may be seen as a checklist for contextualizing the knowledge related to different research findings.

(5) **Assess barriers and facilitators to knowledge use:** In this step, the barriers and facilitators that restrict or help implement knowledge are identified. The barriers and facilitators are useful in understanding the intentions of the practitioners. Barriers for knowledge use could be related to knowledge, attitudes, skills, habits or the like of the potential adopters according to Graham et al. [14]. The possible interventions for such barriers could be interactive educational workshops or training and documenting the knowledge in the form of company standards.

(6) **Select, tailor and implement KT intervention:** Based on the identified barriers and facilitators, the KT intervention is determined, for example, training is selected, tailored and implemented.

(7) **Monitor use:** Once the knowledge is in use or has been applied, it should be monitored. Monitoring knowledge use is important to understand if the desired level of knowledge use is attained. If the knowledge use is not adequate then, the barriers and facilitators of knowledge use need to be reassessed to understand the intentions of the practitioners to use the knowledge.

(8) **Evaluate outcomes:** Two types of evaluations are needed:
- **Evaluation of knowledge use outcomes:** The outcome of knowledge use in terms of impact needs to be evaluated and it could be on the process/organization level, practitioner level or customer level.
- **Evaluation of the KT intervention:** The effectiveness of the KT intervention selected in Step 6 could be conducted using quantitative and qualitative evaluation methods. Another important aspect of the KT intervention evaluation is determining the extent to which practitioners were exposed to the intervention [25]. For example, if training is used as the KT intervention, then the number of practitioners that received the training and the duration of training should be considered in the evaluation.

(9) **Sustain use:** Sustainability of knowledge implies continuation of knowledge use after the initial adoption. To sustain knowledge use, sustainability-oriented action plans need to be developed. There should be a consensus on the implementation needs and benefits of the knowledge use.

4 EVALUATION

An initial evaluation of the KT framework for SE has been conducted. The practitioners involved in the evaluation value results from research studies. This is consistent with the study conducted in Microsoft where practitioners were positive towards results from software research studies [18].

The evaluation results indicate that the practitioners have different opinions and knowledge. The practitioners might not always be aware of each others’ opinions and knowledge. This creates misalignment, which might be a problem in cases where alignment and shared knowledge is necessary. This is supporting the problem identified in [22] and [11] that suggest relying solely on practitioners’ opinions and knowledge might be error-prone.

In a previous study, Devanbu et al. mention that practitioners are heavily influenced by their prior beliefs which impacts their response to new evidence [11]. In our evaluation, the practitioners had a broader view through the interactions in the KT interviews and workshops where they discussed the literature results as well as each others’ knowledge. Thus, it is perceived that the practitioners were not biased and heavily influenced by their prior beliefs.

Another finding in the previous study [11] was on the relation between the level of agreement with the strength of evidence. They conclude that “the level of agreement did not always correspond very well with the strength of evidence in regards to the claim” [11]. In the previous study [11], the practitioners were asked to respond to the new evidence through a survey, which might explain why practitioners were more influenced by personal opinions than evidence. However, in our initial evaluation of the KT process, we found that the practitioners did considerably revise their opinions although, only when the results from research studies are valid to their context. Thus, the difference in research approach may at least partially explain the difference in being more or less influenced by research evidence.

5 CONCLUSIONS

KT in software engineering research is an important activity for application of research results in practice. This paper outlines the steps in the KT framework and the initial evaluation results indicate that KT can be valuable in addressing the practice-research gap.

In summary, the KT framework presented has the following positive characteristics:

- **Systematic and repeatable** - Each step followed in the KT cycle may be described in detail in the KT framework steps. The descriptions may include low-level instructions such as selection of interviewees (Step 2) and process for synthesis (Step 4). The sequence of execution also is clearly described (Steps 1 through 9).
- **Collaborative and reflective of the needs of the practitioners** - The main adaptation made to the KT framework for use in SE is by considering input from practitioners in most of the steps in the KT cycle such as Steps 2, 3, 4 and 5 (see Figure 4). For example, in Step 4 the practitioners make decisions about the usefulness, value and relevance of the knowledge from research studies in their context. The need for knowledge implementation is also identified based on the needs of the practitioners as discussed in Section 3.2. Step 2, in the KT cycle, is a new step added and is not part of the KT framework described in health care [25]. Steps 1, 2 and 3 are integrated with the Bayesian synthesis [1], which also is an adaptation made to the KT framework for use in SE.
- **Iterative** - In the last step in the KT cycle, i.e. Step 9, the long-term knowledge use is evaluated. The KT cycle then continues to implement knowledge on a larger scale, for example, in other projects or organization wide.

Beecham et al. [3] identified: accessibility, credibility and relevance as important aspect to address to minimize the gap between research and practice. The KT framework starts by identifying and summarizing the research results (Step 1) to make it accessible to the practitioners. These results are presented to the practitioners by the researchers in Step 4, and hence making it accessible. It incorporates expert opinions of the researchers as well as elicits practitioners' knowledge and opinions (Step 2) thereby making the results more credible for the practitioners who prefer advice from people with "skin in the game" [3]. In addition to making the research results accessible, the KT framework also facilities aligning the external knowledge from research studies to local context, thereby making the research relevant to the context.

The KT framework is modular in nature, we have integrated it with Bayesian synthesis in this paper. The future work is focused on further evaluating the modularity of the KT framework. The plan is to integrate KT with the following two approaches: 1) a transfer medium (evidence briefings [8]) to provide summaries of knowledge from research studies in a systematic way, and 2) rapid reviews [7] for efficient identification and selection of knowledge to be translated.

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