Using Evidence-Based Paradigm to Iteratively Acquire the Overall Picture of Primary Research Question

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***Abstract*—Formulating a well-established research question is a key step to a PhD student. In this paper, evidence-based paradigm is applied to iteratively acquire the overall picture of primary research question based on the analysis of data in practice. A PhD student's experience, centering on her chosen area-regression test selection, is conducted as a case study to open up the process. Sub-research questions are given and solutions of the correspondent questions are presented. The difficulty to understand the systematic reviews of the particular topic and how to conduct the literature review when the existing systematic review methodology is not suitable are discussed. At last findings are summarized and future work is proposed.**

***Index Terms*—Evidence-based paradigm; systematic review; primary research; research process; regression test selection**

I. Introduction

Research is often a lonely business, except in disciplines where group activity is more common, and PhD is just a preparation for a career in it. A research question is a good first step to map out your research strategy. And formulating a problem properly is half the research done. As a novice researcher, especially to a PhD student, a well-established and probably efficacious research question is the key to open his or her research door. The research question formulation process is not a single activity, but an iterative evolved process accompanying with the adjustment and refinement under the guidance of the emerging sound evidence, until the overall picture of the research question is formulated. To identify the research problem requires a good knowledge of the recent developments in the area, and the ability to create a bigger picture and see how the different work fit and what might be missing [1]. In fact, it is not an easy task to master the ability of formulating a proper research problem, and much time is spent on defining clear problems of the specific phenomenon during the research process.

When I am a software testing engineer at the secondary artillery software testing center, I meet with many puzzles, such as, Is there an approach to use kinds of data emerged during software testing, and how to select test cases in a cost-effective way during regression testing etc. Motivated by the puzzles met with during my two years' experience, my chosen area is naturally regression test selection (RTS). Being a PhD student, I have faced with the same headache problem, how to develop a proper research question and is there a rigorous approach to help me, when I start my PhD research.

As Briony J Oates et al. suggest in [2], that the evidence-based software engineering guidance should be modified for students and novice researchers to incorporate the process of developing a well-defined research question. This paper is focused on an iterative process of acquiring the overall picture of primary research by evidence-based paradigm. A PhD student's experience is chosen as a case study. The main steps are as follows: Start by approaching Regression test selection (RTS), then based on the information elicited from the collected evidence in a systematic approach, we observe that that she has a better understand about the characteristics of the studied phenomenon (i.e., the uncertainty factor and the human-related factor). After thorough understanding about the two factors and gathering sufficient evidence, we find that she acquires the overall picture of the primary research question in regression test selection. During the whole process, firstly we get a map of RTS in virtue of systematic review. Then to the uncertainty factor, the AgenaRisk tool is used to build a Bayesian Networks model; to the human-related factor, the ATLAS.ti tool is used to distill the casual relationship of the studied phenomenon. The main contribution of this paper is therefore, a firsthand experience report of conducting the evidence-based paradigm to iteratively acquire overall picture of primary research question in regression test selection. We discuss the difficulty for a novice researcher to understand the existed systematic review of a particular topic. Besides, we explore how to conduct a qualitative research review under the condition that the present systematic review methodology doesn't provide practical recommendations for it.

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The remainder of this paper is organized as follows: section 2 briefly presents the evidence-based paradigm; section 3 reports the process of using evidence-based paradigm in acquiring the overall picture of primary research; a discussion based on the analysis of the process and the difficulties met with during the process is given in section 4; finally conclusions are presented in Section 5.

II. The Evidence-Based Paradigm

A. The Evidence-based Paradigm

The essence of the evidence-based paradigm, defined by Evidence-Based Software Engineering(EBSE) website, is "*that of systematically collecting and analyzing all of the available empirical data about a given phenomenon in order to obtain a much wider and more complete perspective than would be obtained from an individual study, not least because each study takes place within a particular context and involves a specific set of participants*" [3]. The approach of evidence-based practices employed for Software Engineering is by virtue of Systematic Literature Review (SLR), the core tool of the evidence-based paradigm. In general SLR is divided into three types, systematic review, systematic mapping studies and tertiary reviews [4]. Many SLRs have been published since the idea of adapting this paradigm to Software Engineering was first mooted in 2004 [3].

Evidence-based software engineering (EBSE) describes a process of identifying, understanding and evaluating findings from research and practice-based experience, aiming at improving software engineering decisions [5]. The first step used in EBSE [6] is to convert a relevant problem or need for information into an answerable question. Suggestion about the composition of a well-formulated research question is clear and explicit (detail in section2.2), but the guidance of formulating a proper research question process is very little. Rainer et al report that students find it difficult to do [7]. To a novice researcher, it is very important to formulate a right research question of his/her chosen area before conducting the actual primary research.

B. A Well-formulated Research Question

David Sackett et al.[4,5,6] suggests that a well-formulated question has three parts:

- The study factor (e.g., software method, tool, technology, or procedure).
- The population (e.g., a specific software engineering role, a category of software engineer, an application area, an industry group affected by the study factor).
- The outcomes (e.g., Impact of technology in terms relevant to practitioners).

Based on the experience of formulating the research question in regression test selection, we emphasize that the research question formulation process is not a one-time activity, but an iterative evolved process accompanying with adjustment and refinement under the guidance of the emerging sound evidence, until the overall picture of the research question is formulated. In the next section, detail description will be reported.

III. The Process Of Using Evidence-Based Paradigm In Acquiring The Overall Picture Of Primary Research Question

Our vision is depicted in Figure 1. The start point is regression test selection topic. When the rich evidence is gathered through traditional survey and systematic review about the special topic, the further understanding about it is acquired and the interesting research points (i.e., the uncertainty factor and the human-related factor) are identified. The understanding ability is tested by several approaches (e.g., the understanding about the studied phenomenon, the discussion among the research group and with the supervisor). The information elicited is served as a proof for the next step to approach further, with the purpose of making the research question clear and definite. At last after the iterative research process, both the overall picture of the research question and the chosen research solution method are acquired.

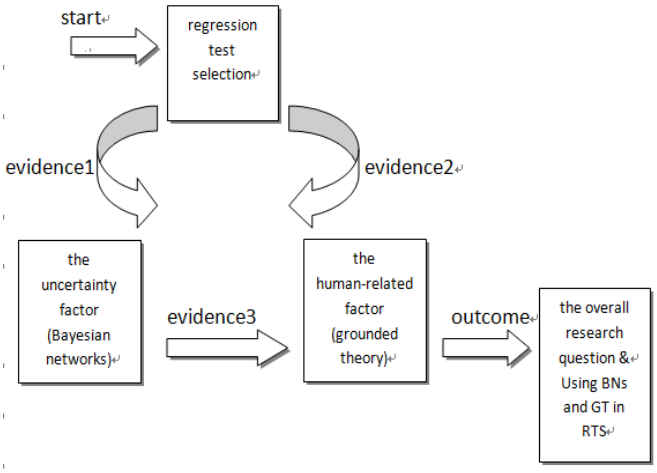

Figure 1. The process of using evidence-based paradigm in acquiring the overall picture of primary research question.

We describe the process phase and outcome listed in Table I. The table is organized by four parts, beginning with phase, moving to researcher state, evidence gathered, indicator, and research tool. The phase is classified into initial phase, temp phase and final phase. During each phase, first the researcher's state is described, then the evidence gathered by the research tool is identified, next in each phase the evidence gathered is verified and revised through group discussion, research question is evolving based on the aforementioned evidence and finally formulated.

A. Beginning With Regression Test Selection

In the initial phase, the researcher's state is as follows: *be interested in regression test selection for the reason of two years' software testing engineer experience; knowing little about the state of RTS research (e.g., the significant researcher and research group, the important conference*

and journal, etc.); knowing little about how to approach it. the research question is obscure, only about how to find an effective and efficient approach to solve the test case selection problem during the regression testing.

During this process, centering on the key words, such as, regression test selection, regression testing, software testing and software engineering, with the purpose of developing the breadth in the discipline, we observe that the important surveys (e.g. , Rothermel[8], Harrold [9], Bertolino [10], Runeson[11] and Yoo [12]) are acquired, at the same time the Harrold's research group and the Rothermel's research group are followed the track for the further study.

TABLE I.

THE PROCESS PHASE AND OUTCOME

Phase	Researcher state	Evidence gathered	Research tool
Initial phase	Know little about RTS in academic research	RTS is an iterative, uncertain and human-related process	Traditional survey& Systematic review
Temporary phase1	Understanding multi-aspect of RTS and focus on the evidence gathered	The uncertainty factor	Systematic review
Temporary phase2	Understanding the uncertainty factor and focus on the above evidence gathered	The human-related factor	Traditional survey
Final phase	Opening report& foundation support	The overall picture of research question	Group discussion

Encountering with the systematic review Based on the evolution techniques, figured in [11], we carry out a further study of safe RTS and construct a framework for classifying safe RTS techniques on the basis of software, data and bug dimensions. The set of conditions required for safety adaptively with the multidimensional viewpoint is emphasized. And several representative approaches based on the proposed classification are assessed, shown in table II [].

We find that researchers have mainly focused on the viewpoint of software under test about safe regression test selection techniques for a long time, especially on the code-based approach. When our eyes are restricted to a variety of code-based approaches, we find that programming paradigm is an important factor to affect many researchers' decision. However, these approaches have the scalability problem, seldom employed in industry. To help bridge the gap between theories and practices of safe regression test selection, more recently there is an emerging trend that the focal point is converted from software to bug and to data. When focused on bug viewpoint, researchers just begin to define safety based on the most fault prone ability. While turned to data viewpoint, researchers begin to catch the fault-revealing properties based on kinds of machine learning models. And we also find the evolving change of Safe Definition. To software dimension, Safe Definition is defined as no modification revealing tests are left unselected; to bug dimension, Safe Definition is defined as test cases related with the most continuously updated fault-prone files are selected; to data dimension, Safe Definition is defined as test cases that are most likely to reveal a fault are selected.

TABLE II.

CLASSIFICATION OF SAFE REGRESSION TEST SELECTION TECHNIQUES

Safe Definition	Dimension		Affected Factors	Approaches
no modification revealing tests are left unselected	Software	Code-based	Modification code	Procedural-based
				Objected-oriented
				Component-based
				Service-oriented
				The others
			Affected code	The firewall
		Model-based	Uml	Activity diagram
				UML class and sequence diagrams
		Exception	Code-or-model -not-available	System requirement
				Considering database state
test cases related with the most continuously updated fault-prone files are selected	Bug		Fix-cache	Catch the fault-prone files
	Data		Data mining	Cluster analysis
test cases that are most likely to reveal a fault are selected			Machine learning	Support vector machine and decision tree

Information elicited from collected evidence during the initial phase After analyzing the collection evidence through several group discussions, we have found: (1) Regression test selection is an iterative, uncertain and human-related process. (2) A big gap exists between academic research and industry practice in RTS topic. (3)Safe RTS, as one of important branches of RTS techniques, needs to be explored further for capturing the research trend.

Evolution of the research question During this phase, centering on the studied phenomenon, after approaching the existed systematic reviews about RTS, the research question becomes clear and is focused on the characteristics of RTS process, along with better understanding about the RTS process in industry practice.

B. Dealing With the Uncertainty Factor

In this phase, we carry out a systematic review about Bayesian networks in software testing [13, 14, 15,39] in order to acquire how to build a BNs model based on the special domain and what difficulty will be met during the modeling process.

Information elicited from collected evidence during the phase After analyzing the collection evidence through several group discussions, we have found: 1. Regression test selection is inherently uncertain in industry practice. 2. Bayesian networks are a suitable approach to model the uncertain property of RTS process for the evidence that BNs have achieved reliable and efficient software testing and program analysis in many domains. 3. We should gain further insights into Fenton and his research group, risk assessment and decision analysis research (RADAR).

Evolution of the research question When focused on the uncertainty factor of the studied phenomenon, the research question begins to consider kinds of the uncertainties of RTS process and in what way to model them effectively and efficiently.

C. Dealing With the Human-Related Factor

In practice, it is a little difficult for a novice researcher to understand and operate all of the elements of the checklist for qualitative studies provided by "Guidelines for performing Systematic Literature Reviews in Software Engineering" [5]. We adopt the approach to collect the required evidence on the basis of the main steps of conducting a qualitative research in empirical software engineering and summarize the most used approaches of each step [16, 17, 18,19], shown in table III.

TABLE III.

THE MAIN STEPS OF CONDUCTING A QUALITATIVE RESEARCH

The main steps	The most used approaches
Sampling	purposive sampling
	quota sampling
	snowball sampling
Data collection	participant observation
	in-depth interview
	focus group
Data analysis	grounded theory
	case study
	ethnography
Validity verification	triangulation
	negative case analysis
	anomalies in the data
	member checking

Information elicited from collected evidence during the phase After analyzing the collection evidence through several group discussions, we have found: (1) Qualitative research renders empirical software engineering, especially to the human-related situation. (2) Testers are the key factor and should be considered for regression test selection process. (3) Grounded theory is a suitable approach for the reason that we want to hear the real voice from testers and build theory from data. (4) It is possible to combine grounded theory with object-oriented Bayesian networks to identify BNs' variables and network structure.

IV. ACQUIRING THE OVERALL PICTURE OF PRIMARY RESEARCH QUESTION

In the final phase, regression test selection is considered as an iterative, uncertain and human-related process. And then correspondingly research questions for the further empirical study work are formulated. Details are depicted in table IV.

TABLE IV.

THE OVERALL PICTURE OF RESEARCH QUESTION AND THE CHOSEN SOLUTION

How to develop a systematic approach to make full use of different forms of data emerged during regression testing process; and to model regression test selection strategy to benefit for testers' decision making in an effective and efficient way at the third-party software testing center?	
Sub-research question	Chosen approach
SQ1. How to collect and analyze qualitative, quantitative forms of data with the purpose of identifying factors affecting testers' RTS decision?	Grounded theory approach[20,21,38]
SQ2. How to identify and define BNs model's variables and network structure; how to validate?	Combining grounded theory with OOBN[22, 23]; questionnaires[24]
SQ3. How to identify and define the qualitative characteristics of variables in order to acquire node probabilities tables?	Ranked node [31]
SQ4. How to use the model for RTS decision-making and adaptively calibrate it?	Scenario analysis, sensitivity analysis and focus group method[26]

A. Steps of Collecting and Analyzing Data based on Grounded Theory

We choose a grounded theory research method as the appropriate methodological vehicle for SQ1. The grounded theory approach is so named because its ultimate aim is to produce innovative theory that is 'grounded' in data collected from participants on the basis of the complexities of their lived experiences in a social context.

Fig.1 presents steps of Grounded Theory. Details of our use of the GT process are available here [29].

Establishing the data selection protocol At first, the research question of identifying factors affecting testers' RTS decision is posed. Then centering on it, we begin to establish the data selection protocol. The first step is to choose one kind of the sampling approach based on the research objective and the study population. The rules are

as follows: under the condition of preselected criteria relevant to a particular research question, such as, the key case, the typical case, the maximum difference, the extreme or the deviation, etc, choose the purposive sampling, which is suitable when data review and analysis are done in conjunction with data collection; under the condition of having some understanding about the characteristics of the overall sample and ample sampling, choose the quota sampling, which is more specific with respect to sizes and proportions of subsamples, with subgroups chosen to reflect corresponding proportions in the population [30]; under the condition of sampling in low rate or rare overall, choose the snowball sampling, which is often used to find and recruit groups that are not easily accessible to researchers through other sampling strategies.

The second step is to construct the data collection method. Structure interview, semi-structure interview and open interview are the most often used data collection method. Among which, structure interview means interview question, interviewee, and track record are designed in a standardization way; semi-structure interview means that researchers have some degree control in interview structure and at the same time the research participant is allowed to actively participant in; open interview means that there are no fixed interview questions and the research participant is allowed to speak freely.

Data collection Data collection includes the primary data collection and the ongoing data collection. The primary data collection is spread out according to the predefined data selection protocol. For example, centering on the research question "what factor can affect regression test selection decision-making at the third-party software testing center", the sampling approach we chosen is the purposive sampling based on the maximum difference criteria. And the primary data collection method we chosen is semi-structure interview.

While to the ongoing data collection, it is guided by theoretical sampling. Theoretical sampling is continued sampling based on the emergent theory constantly being verified and modified, until no new themes, categories, or relationships are being discovered, at which point the properties of, and relationships among, constructs are specified in the form of a substantive theory about the social behavior under investigation [21, 38]. Under the guidance of theoretical sampling, the following condition should be considered: choose a case to fill theoretical categories, to extend the emerging theory; and/or; choose a case to replicate previous case(s) to test the emerging theory, or; choose a case that is a polar opposite to extend the emerging theory [20, 21, 38]. For example, during the primary data collection, we choose the interviewee type, that is, the user, the developer and the tester related to the regression testing activity. After data analysis based on the primary data collection, we find that it is a must that the test specialist and the advanced tester will be chosen in the next round, aiming at acquiring more deep understanding about testers' influence to the selection decision.

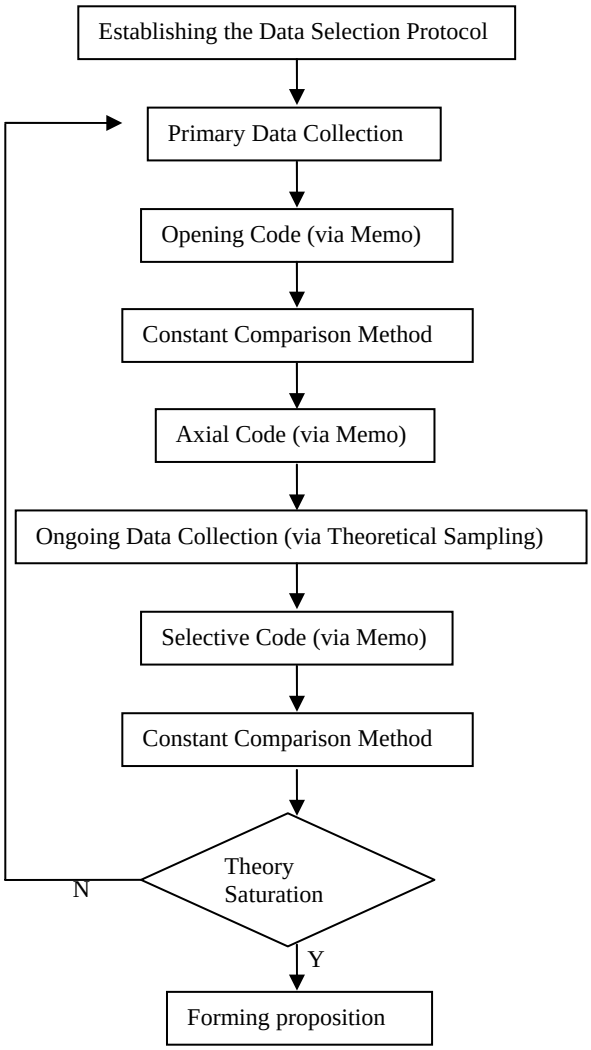

Figure2. Steps of collecting and analyzing data based on grounded theory

Data analysis The researcher employs a constant comparison method of analysis, using cascade coding (e.g. open, axial, and selective) of data garnered through theoretical sampling procedures. Open coding is the process of the analysis concerned with identifying, naming, categorizing and describing phenomena found in the text. Axial coding is the process of relating codes (categories and properties) to each other, via a combination of inductive and deductive thinking. And selective coding is the process of integrating and refining the theory [21]. During the data analysis, constant comparison method is used to group codes from the same interview or/ and the other interview to produce a higher level of abstraction called concepts, and is also used to group concepts arising out of codes to produce another level of abstraction called a category [16]. Memo is very useful tool involved in the formulation and revision of theory during the research process, aiming at capturing

the conceptual links between categories as the researcher writes theoretical notes to focus on conceptual labeling during opening code, or to focus on paradigm features and indications of process during axial and selective coding, or to focus on directions relating to the evolving research design [27] [28].

Forming proposition During the data analysis, we will estimate when further data collection and analysis on a particular category leads to a point of diminishing results, no new insight into the category is generated. We can then stop collecting data and coding for that category [21] [32]. If not, we will return to continue the data collection and analysis process.

B. Steps of Building Bayesian Networks Model

We choose an object-oriented Bayesian networks (OOBNs) as the appropriate methodological vehicle for SQ2. And we choose ranked node for SQ3. OOBNs combine clear declarative probabilistic semantics with many of the organizational benefits of an object-oriented framework. Idioms are reusable patterns to specific BNs fragments that represent very generic types of uncertain reasoning [23].Cause-consequence idiom is one kind of idioms to model the uncertainty causal process in terms of the relationship between its causes and consequences [22]. Ranked node is based on the doubly truncated Normal distribution with a central tendency that is invariably a type of weighted function of the parent nodes, aiming at modeling casual relationships between many parent nodes and one child node or modeling "indicator" type relationships between many children and one parent using the minimal amount of expert elicitation [23][31].We adopt [25] to build BNs model combining with GT, OOBNs and ranked node, shown in Fig3.

Building a Bayesian networks model is in general classified into three steps. The first step is to identify the variables derived from the collection data in the context of affecting the regression test selection decision making by opening code. The second step is to characterize the relationships between the different variables using the cause-consequence idiom through analysis and coding of the interviews (i.e. axial, selective coding). The third step is to eliciting conditional node probability. Here we focus on the condition that there is only diversity of subjective information sources (e.g. testers' judgment, users' feeling and developers' experience). In such a case, we use the ranked node to elicit conditional node probability.

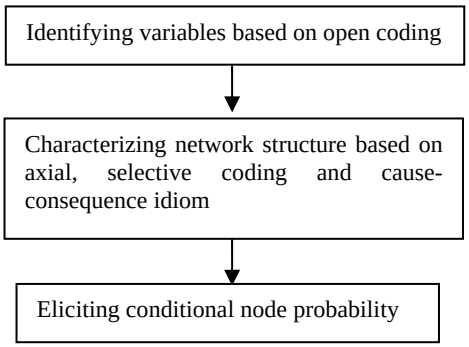

Figure3. Steps of building Bayesian networks model

C. *Using Bayesian Networks Model*

Both scenario analysis and sensitivity analysis are the useful tools for using the Bayesian networks model. Scenario analysis is used to the case that calculates the value of the child/leaf node, given the value of the parent/ root node; or to the case that calculates the most likely conditions of the value of the parent/root node, given the value of the child/leaf node [25]. In this paper, we plan to adopt the two approaches. Sensitivity analysis is uses to identify how sensitive the belief update is to variations in the set of evidence; or to identify how sensitive the results of a belief update are to variation in a parameter value in the model [37].

V. DISCUSSIONS

Although it's important for novice researchers to base their decisions of formulating the research question on the systematic and critical evaluation of the best available evidence, this isn't necessarily easy [6]. In this part, firstly we discuss the calibration and validation of the process phase presented in the above section, then we comment on our harvest of the research process.

A. Calibration and Validation of the Above-mentioned Proces Phase

In this paper, GT' process is validated by triangulation and negative case analysis (in table III), with the purpose of verifying its validity and reliability. Triangulation is able to solve the weakness of using GT (e.g. biases are caused by group dynamics, samples are short of the representative, and poor quality of the collected data is caused by misunderstanding and misusing the adopted qualitative methods), through multiple sources and methods to acquire a more accurate picture of the studied phenomena [34]. And negative case analysis is also a very important qualitative tool for helping to confirm hypotheses in a rigorous way [35]. When performing negative case analysis, purposely selecting new cases for study will increase representativeness, as well as seeking new sources and types of data to help triangulate the findings [36].

To the BN's process, questionnaires are used to calibrate the model construction and the model behavior is validated in virtue of the focus group method. There are explicit difference between validation of the model behavior and calibration of the model construction. Due to building the model in a systematic approach based on expert knowledge, evaluation should focus on showing that the relationships that are included in the model are appropriate [25] [33]. To calibrate the model construction, questionnaires can determine software testing experts' opinions about the influence of relevant factors on selecting test cases during regression testing process. To validate the model behavior, the focus group method can enable interaction between participants and evaluate the behavior of the models of regression test selection, by focusing on the theme whether or not the model behavior reflects the collective belief of the experts [25] [26].

B. Finds and Lessions

We now comment on our findings and lessons, shown in table V.

CONCLUSIONS

In this paper, we have reported our experiences of using evidence-based paradigm as a power tool to collect and analyze available scientific evidence, aiming at formulating the overall picture of the primary research question and the corresponding chosen solution. As proved, introducing systematic reviews helped the novice researcher conduct the literature search in a structured fashion and enabled the provision of better understanding when the novice researcher is aware of the importance of SRs. Besides, under the condition of lacking SRs (e.g., the qualitative methods), using evidence-based approach can also improve the supply of better feedback.

In one word, conducting evidence-based paradigm for a novice researcher to develop his/her research question is an iterative process. Furthermore, thorough understanding and iterative thinking are very important and can benefit the novice researcher for decision-making. We, therefore, recommend that there is an urgent need for a novice researcher to learn and master the evidence-based paradigm in his research career.

In the future, we will choose more PhD students and conduct more case studies to acquire more evidence and refine our research. We will identify what type of evidence can be regarded as sound and consider how to know evidence is enough and how to evaluate the result of sound evidence in a systematic approach, not only by group discussion.

TABLE V.

FINDS AND LESSONS OF THIS RESEARCH PROCESS

Finds of this research process
Find1: formulating a research question is not one-time activity, but an iterative evolving process.
Find2: systematic reviews benefit to novice researchers, but understanding and learning how to acquire useful information from SRs needs guidance and time to digest.
Find3: under the condition of lacking systematic reviews, such as qualitative research methods, it is important to approach traditional surveys by the evidence-based paradigm.
Find4: when making research decisions based on the evidence-based approach, thorough understanding and iterative thinking are very important for novice researchers to elicit the information as well as SLRs.
Find5: it is necessary to incorporate qualitative evidence into systematic reviews or synthesis qualitative and quantitative evidence if required.
Find6: especially to novice researchers, only when they are aware of the importance of the evidence-based paradigm, they can really benefit from it. So it is an urgent need to popularize evidence-based software engineering in more universities and institutes.
Find7: it is difficult to decide whether the collected evidence is enough or not. And it is difficult to define how long the time needed to understand and master SRs.
Find8: when analyzing the collected evidence, group discussion is important to help novice researchers' decision-making.
Lessons of this research process
Lesson1: it costs a lot of time to collect information from all types of sources, and construct the roadmap of regression test selection before using SLRs.
Lesson2: when encountering SLRs, at first enough attention is not paid until listening to the Yue Tao's report.
Lesson3: when analyzing the collected evidence for further study, subjective thinking prevails and human-related factor, one of characteristics of the studied phenomenon, is omitted and regained attention until participating in the Lionel Briand's controlled experiment.

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