A structured approach to Evidence-based software engineering in empirical software engineering research.

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Abstract. TBD -> in the structured style we propose.

Keywords: TBD

1 Introduction

motivation

1.1 Fundamental Principles

short introduction to EBSE,..

- adopted from medicine (EBM), starting point: decisions in SE often not based on evidence for suitability, quality.., thus increasing the risk of poor decisions in motivation?
- **Evidence-based approach**: integrate all available research (evidence) in decision making process
- **Aim**: "EBSE aims to improve decision making related to software development and maintenance by integrating current best evidence from research with practical experience and human values." [9]
- **Five steps** of practising EBSE [14]:
  1. Ask an answerable question.
  2. Find the best evidence that answers that question.
  3. Critically appraise this evidence.
  4. Apply the evidence (and critical appraisal).
  5. Evaluate the performance in previous steps.

  → important tool: Systematic Literature Review (SLR)
- **SLR** [12]: identify and interpret all available literature regarding a research question → papers should be written for synthesis (TODO requirements for this, common mistakes/problems?)
- Problems inherent to SE[14]:
  1. Skill factor: performing SE methods and techniques often require skilled practitioners. This prevents blinding and can therefor cause problems related to subect and experimenter bias. (2 approaches to reduce these effects in [14])
  2. lifecycle issue: prediction of behaviour (long time?) of deployed technology difficult, hard to isolate efffects because of interaction with other methods/technologies (also 2 approaches to cope with these effects in [14])
- Step 2: SLR in SE: lack of systematic reviews (still correct? source?), lack of replication studies (source?), problems regarding SLR TODO

1.2 Related Work

SEED, "a preliminary empirical investigation of the use of EBSE by undergraduate students"

2 Knowledge Management

TODO

2.1 Search Methods

- ccs
- google scholar?
- SEED

2.2 Structured Abstract

TODO: importance of abstracts: Abstracts, together with the title, are used to identify relevant research, not only in SLRs. Often the abstract is the only part of the paper that can be accessed for free. Therefore abstract and title should contain all necessary information to decide whether a paper (in case of SLR: primary study) is relevant in this context. (source: "Lessons from applying the systematic literature review process within the software engineering domain") → quality of abstract crucial for research, how to support researcher in writing useful abstracts? Structured Abstracts provide guidance for writer and reader. end TODO

In their guidelines for reporting experiments in software engineering Jedlitschka et al. [11] propose the use of *structured abstracts*. They adopted the idea from medicine and psychology, where structured abstracts were introduced to increase the quality of abstracts. Although a variety of different elements is used (see for example "Adoption of structured abstracts by general medical journals and format for a structured abstract "), the most common elements of structured abstracts are *Background* (*or Context*), *Objective* (or *Aim*), *Methods*, *Results* and *Conclusion* (or *Discussion*). Jedlitschka et al. [11] suggest the use of a 6th (TODO: or sixth? heading called *limitations*. This additional information is necessary to decide whether a result can be transfered to another context. Others TODO: often? mostly? (e.g. Kitchenham et al. [13]) include this information in the *conclusion* section.

The list and description of elements below closely follows the suggestion of Jedlitschka et al.[11].

1. **Background** or **Context**: Explain briefly what the motivation for conducting the study was and refers to previous research.
2. **Objective** or **Aim**: Describes the purpose of the study, including the object that is studied as well as focus and perspective. TODO: research question/hypothese?
3. **Methods**: Sums up which research methods were used, for example experimental design, setting, participants and selection criteria, intervention and measurement and analyzing technique.

4. **Results**: The key findings are described here (Do not include interpretations here!).
5. **Limitations**: Describes the scope of the study to point out the limits of generalization (This element might be incorporated in the *conclusion*-element).
6. **Conclusion**: Contains the interpretation of results and puts them into context.

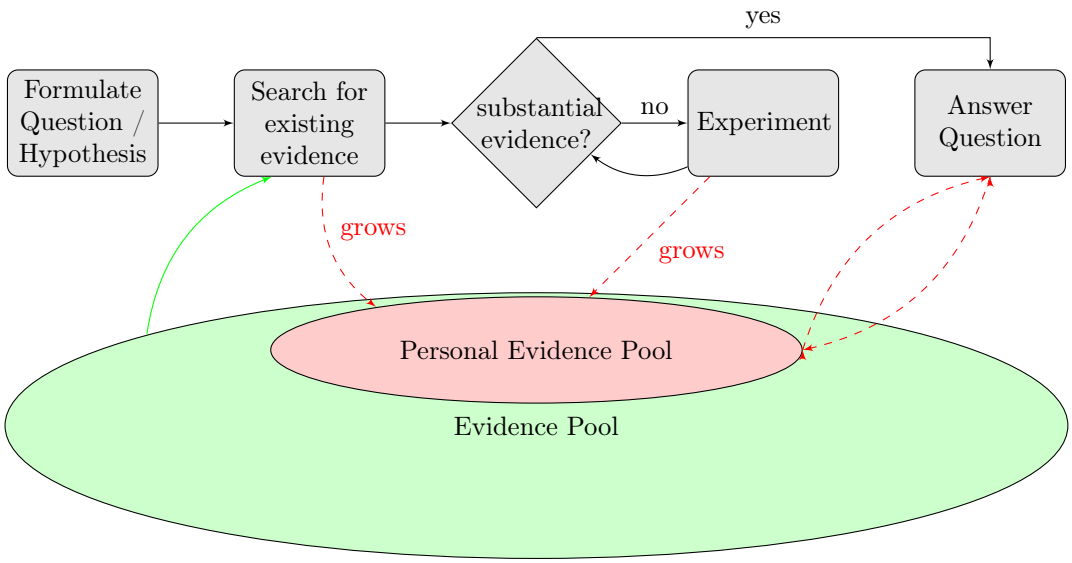
TODO: examples? keywords as part of abstract?
Elements similar to "IMRAD"-structure (see paper "Adoption of structured abstracts by general medical journals and format for a structured abstract")

- About completeness and clarity of structured abstracts:

  1. Structured abstracts include more relevant information and are easier to read than conventional abstracts. [6] [5]
  2. Inexperienced authors are likely to produce clearer and more complete abstracts when using a structured form.[4]
  3. On average structured abstracts are longer (limitations in conclusion is a good idea to prevent lengthy abstracts) and have better readability than unstructured abstracts. [13]
  4. these findings are in accordance with the ones in other disciplines (source: "Current findings from research on structured abstracts[: an update]")

- guidelines for construcing structured abstract (from unstructered ones) in [13]
- Guide with examples (psychology): "how to write a good abstract for scientigic paper.", C. Andrade
  ANSI/NISO Z39.14.1997 (R2015) Guidelines for Abstracts
- use standard terminology (commonly used industry terms) [11], no abbreviations [13]
- structured abstracts are longer and often size is limited (journals): prioritize traditional elements, still structured: background (one sentence), objective, method, results, and conclusion [11]
  unstructured abstracts should still contain the elements

3 Workflow Checklist



TODO:
Add numbers to each node, explain each node
Missing node: "Make Decision" at the end?
Layout/Style/Color

3.1 Checklist

(make notes/documentation of the following points)

1. Formulate Question/Hypothesis
   (a) TODO: reference to PICOT and FINER
2. Search for existing evidence
   (a) rough understanding/overview
   (b) deep understanding
   (c) critical appraisal TODO: reference to ebse for practitioniers: p. 62 checklist
   (d) incremental refinement of search question [using sys. reviews and ebse with master students]
   (e) General search tips:
      i. quoted by...
      ii. systematic literature review
      iii. ccs
      iv. autocomplete "x vs ..."
      v. note search strings for more structured search approach
3. Design, Conduct and Evaluate Experiment
   (a) might be recursive by refining question
   (b) use briefing form
4. Answer Question
   (a) Does the answer match the question?
   (b) Verify/Falsify hypothesis
   (c) Reasoning
   (d) Scope of generalization
5. Discussion
   (a) discuss Experiment
   (b) propose future approaches
   (c) discuss scope/limits
6. Eval Process
   (a) AAR/PA as in [16]

3.2 Formulating Research Question and Hypothesis

For researchers to produce relevant results and understand their research domain fully, the step of developing a good research question, with a supporting hypothesis and sometimes objectives is integral [10]. These components should be carefully designed *before* conducting the study that tries to answer the question. Otherwise it is more likely to produce questions that are already answered, or *"could potentially lead to spuriously positive findings of association through chance alone."* [10, p. 280]

Research Question The question the later study is designed to answer is called research question [8]. It should be an answerable question and address a relevant issue in the research area [9]. Preceding a research question is the need for a deep understanding of the topics that have already been studied, in order to produce questions which drive knowledge further. The questions that arise during the acquisition of knowledge, and cannot be answered by means of EBSE, are likely appropriate questions for further research [10].
There are two general classes of research questions: qualitative and quantitative questions. Qualitative research states questions which report, describe, or explore a subject [7, p. 139-141]. In computer science as the research field matures these questions become more and more rare TODO: (find source). Therefore focus is on quantitative research questions in this paper. *"Quantitative research questions inquire about the relationships among variables"* [7, p. 143], and from them emerge quantitative hypotheses.
To understand the structure of research questions Shaw provides a model where she categorizes research questions from software engineering papers in five types [19] TODO: (maybe cut out).
To design a good research question Haynes coined the acronym PICO: Population, Intervention, Comparison group, and Outcome [1]. Sometimes Time is added as fifth component, when it is important over what time frame the study is conducted, see Table 1. A research question structured with the PICOT approach supports in restricting the research question and steers thereby hypotheses and study. By restricting the research question researchers can limit bias and increase the internal validity of the study, but a too narrow question may also lead to decreased external validity [10].
Before PICOT Sackett and colleagues suggested that good research questions consist out of three components: Intervention, Context and Outcome [17], which is a more coarse grained decomposition than PICOT. Dybå *et al.* displayed a fitting example for this template in software engineering: *"Does pair programming lead to improved code quality when practiced by professional software developers?"* [9, p. 60] Here the intervention (technology) is pair programming, the context of interest are professional software developers, and the outcome (effect) is improved code quality [9]. To verify the quality of a freshly designed research question Hulley *et al.* suggest the use of the FINER criteria. It highlights key aspects of the question and provides thereby new angles to view the proposed study from. The FINER criteria consists of: Feasible, Interesting, Novel, Ethical, and Relevant [10]. A more detailed view of the FINER criteria can be seen in Table 2. TODO: specify more tips for writing a good question. Creswell2014)

Hypothesis For each quantitative research question there should be a hypothesis - an educated guess about the outcome of the research question [3,10]. A good hypothesis needs to be a testable, prediction of the studies outcome, but it is important that it does not contain any interpretation [15]. A simple template for writing a hypothesis would be:

> If [I do this], then [this] will happen. [3]

P	Population	What specific population are you interested in?
I	Intervention (technology)	What is the investigational technology/ intervention?
C	Comparison group	What is the main alternative/baseline to compare with the intervention
O	Outcome	What do you intend to accomplish, measure, improve or affect?
T	Time	What is the appropriate follow-up time to assess outcome?

Table 1. PICOT criteria adjusted to fit better in computer science research.

F	Feasible	• Adequate number of subjects • Adequate technical expertise • Affordable in time and money • Manageable in scope
I	Interesting	• Getting the answer intrigues investigator, peers and community
N	Novel	• Confirms, refutes or extends previous findings
E	Ethical	• Amendable to a study that institutional review board will approve
R	Relevant	• To scientific knowledge • To clinical and health policy • To future research

Table 2. FINER criteria for a good research question [10]

Vickers *et al.* propose a more refined structure, whereas a good hypothesis needs to include three components: Two or more variables, population/context, and the relationship between the variables [8]. TODO: specify the thing with the variables more. For example a good hypothesis in software engineering research could be:

> Pair programming used by professional software developers improves code quality, in comparison to teams that use conventional techniques. (revise this)

Furthermore, when conducting empirical research - as we propose in this paper - (revise this) the hypothesis should be formulated as a *null hypothesis* H_0, and be accompanied by an *alternative hypothesis* H_1 [10]. The null hypothesis is a theory that is believed to be true but not proven jet. The alternative hypothesis is the opposite prediction of the null hypothesis [15]. At the end of the study the null hypothesis is empirically tested, and only if it is rejected (i.e., there is a significant difference between groups) the alternative hypothesis is taken as true. This confirms that effects did not show by chance alone [10]. A null hypothesis to the example above would be:

> Pair programming used by professional software developers does not affect code quality. (revise this)

To support the validity of the study even more, the hypotheses should be formulated as 2-sided hypothesis. *"A 2-sided hypothesis states that there is a difference between [groups, but without specifying the direction of the outcome]."* [10, p.280] 1-sided hypotheses should only be used when there is a strong justification for one direction of the outcome [10]. A 2-sided revision of the H_1 from above would be:

> Pair programming used by professional software developers does affect code quality. (revise tis)

TODO: specify more tips for writing a good hypothesis. Creswell2014

Objectives Sometimes researchers define objectives to their hypotheses. They are active statements that *"define specific aims of the study and should be clearly stated"* [10, p. 280] at the beginning of research. Objectives help to define the study (e.g. helping to calculate sample size). [10,8] Although we do not include objectives in our briefing sheet we would like to mention them for reasons of completeness.

3.3 Review Existing Evidence

TODO

3.4 Designing, Conducting And Interpreting Experiment

- propose our briefing form that is described later.
- set in context of evidence generation

3.5 Answer Question

TODO

4 Briefing Form

In this section, the *Briefing Form* is introduced. The Briefing Form is a sheet designed for two purposes: Guide users through the design of an experiment and make conducted experiments easier skimmable and searchable.
Experiments are used to obtain scientific evidence. To make the evidence as reliable as possible, the experiment needs to be designed and conducted with minimal flaws. That can be a very difficult task because experiments and their interpretation can be tremendously prone to errors or mistakes. Especially for people new to experimenting, an awareness for common mistakes and best practices can be very benefitial. The Briefing Form is meant to be a supporting framework for a systematic workflow. It is supposed to shift the focus to the important aspects in each step and sensitize for critical errors.
For software practitioners, it is important to find solutions for a problem quickly. Reading through papers can be very time consuming. The Briefing Form can help speed up the search by providing a clear structure for a quick overview for an experiment.

TODO: Move the following text and the table to related work? The briefing form is meant to implicitly guide the user's approach to experimenting. By guiding the user, typical mistakes might be prevented. To create guidelines that help preventing typical users' mistakes, these mistakes first need to be identified. In this section, experiences and guidelines found in related work are discussed. The conclusions are used as basis for design of our guidelines. The first set of guidelines is based on the report of Rainer et al. [16]:

Observation	**Conclusion/Guideline**
"Students had problems constructing well-formulated EBSE questions." (p. 6)	Give examples for good questions to make sure the user understands a good question's scope of information. Also, explicitly list which building blocks should be contained in the question.
"Students used limited criteria for identifying the best or better evidence[...]" (p. 6)	Support decision-making to get a decision as unbiased and suited as possible. Since a decision's quality is highly dependent on the individual case, we only give a very general hint to the user. The idea is to sensitize the user to consciously prevent bias as good as possible.
"Students used a very limited number of search terms." (p. 6)	If users look for something very specific without knowing the technical term, search engines might yield better results when used with more detailed search terms. Also, synonyms or similar words might widen the search's scope to find more related work. Encourage more search terms by providing examples containing enough search terms.
"Students provided poor explanation in their reports of how their searches were conducted." (p. 7)	Recommend users to write down their search terms for a more structured search approach.
"Students varied in their use of the EBSE checklist." (p. 7)	Design the checklist in a way to support the user's workflow instead of hindering it. Keep it as simple as possible and provide enough examples to make the user never guess an item's meaning.
"Some students critically appraise the technologies rather than the publications (evidence) on the technologies" (p. 7)	TODO: link ciritcal appraisal checklist
"But we also think that the kinds of problems students were tackling [...] are not the kinds of problems researchers commonly investigate." (p. 8)	Scientific and practical evidence can have very different requirements regarding content and other aspects such as duration of evaluation. Due to the large differences, we kept the forms and checklists rather general to make the useful for both sides.

- in this paper we propose a one page briefing of research study
- supports EBSE and searchability of study
- similar to SEED but more detailed structure to support searchability even more.
- supports researcher in understanding the field of research
- supports researcher in understanding the study itself

- guides researcher through study design and result documentation process
- contains of: research question, hypothesis, experiment/context or deduction, conclusion
- experiment contains: independent and dependent variables (control variables), method, results

Question

Contains ***technology*** in a ***context*** showing an ***effect***. TODO: Kitchenham Quote (practitioners)?

"Does pair programming in professional software development teams increases code quality?"

Hypothesis

Needs to contain a ***prediction*** and needs to be ***testable***.

"If you do x, then y will happen"

Experiment

Context

Dependent Variables

Variables that are ***measured*** during the experiment.

Independent Variables

Variables that are ***changed*** during the experiment.

Control Variables

Controlled to be as constant as possible.
number of participants

Technique

Lab-/Field study, (Double-)Blind, Technique of transcription/logging, ...

Statistical Results

Experiment's outcome. Statistical summary (confidence, variance, etc.)
No interpretation or conclusion!

Conclusion

Interpretation of experiment's results.
Verifying or Falsifying Hypothesis.
Scope of generalization.

TODO: output move conclusion to hypothesis for quicker overview?

4.1 Research Question and Hypothesis

We decided to include both research question and hypothesis in the briefing form. Despite them being rather redundant in many cases. The research question is included due to the method researchers use to search for existing evidence, by entering their question into search engines. On the opposite the hypothesis has its right to exist in the briefing form to support evaluation of validity and relevance of found evidence.
Therefore the fields in the form should be filled in with the research question and hypothesis constructed earlier TODO: (link to research question and hypothesis chapters). The research question in asking form that contains technology, context and effect or is constructed according to the PICOT criteria. And the hypothesis in form of a testable prediction (e.g., *"If [I do this], then [this] will happen."* [3]).

4.2 Experiment

To find cause and effect relationships between variables experiments are conducted [2]. A more detailed view on experiments in our EBSE workflow TODO: (how do we call this?) is given in TODO: (link to experiment chapter in workflow). An experiment consists of: Variables, techniques, and statistical results. These are integral components to describe a study in brief, and enhance the ability to search for, and evaluate the relevance and validity of a given study.

Variables Variables are operationalizations of concepts, and there are usually three kinds of variables: Dependent, independent and controlled variables [2,18]. A good variable must be measurable by any means [2]. Seltman additionally defines several qualities that make a good variable: *"high reliability, absence of bias, low cost, practicability, objectivity, high acceptance, and high concept validity"* [18, p. 10].

TODO: include classification of statistical type. has influence on choise of statistical method in experiment.

We decided to include the different variables in the briefing form to make the decomposition of hypotheses easier while searching for related work. In order to make the search more fertile. Additionally the variables make it easier to evaluate the validity of the evidence.

TODO: maybe put this whole description part of experiment already in workflow and just state here that it is vital for the briefing.

Independent Variables The variables that are changed by the researcher during the experiment are called independent variables. In the pair programming example from above TODO: (link to example above) the independent variable is the technique utilized by the software developers (e.g., pair programming and conventional techniques). Unless there is justifiable evidence that two or more independent variables are not having an effect on the same dependent variable, it is advisable to only measure one independent variable during one experiment [2].

Otherwise it is not clear which of the independent variables caused the observed behavior of the measured dependent variable.

Dependent Variables An experiment focuses on the effect of independent variables on dependent variables. Therefore dependent variables are the variables that are measured. For example the code quality of a software project is the dependent variable used in the pair programming example above TODO: (link to pair programming example).

Controlled Variables The last role a variable can play during an experiment is the role of a controlled variable. These are variable which have or may have an effect on the dependent variables, but are not focus of the study. Therefore they are controlled by the researcher and kept constant throughout the experiment [2]. The test environment of a software, the gender of participants, or the number of trials per group are good examples for controlled variables in software engineering research.

Research Techniques

- different techniques used in this experiment
- give examples
- why is this important in the brief?

Statistic Results

- only statistical key measurements
- no interpretation of data
- which metric was used (crosscorelation, means, etc...)
- orientieren an etablierten kenngroessen damit vergleichbvarkeit gegeben ist.

4.3 Conclusion

- is interpretation of experiment results
- verification or rejection of H_0 and acceptance of H_1
- Scope of generalization.

5 Discussion

propose a digital version

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