Standards for quality of research in engineering education
A prolegomenon

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Conference Topic: Engineering education research (EER)
Keywords: Research quality, methodology, validity

INTRODUCTION

While preparing this paper, the first author listened to a programme broadcast on Swedish Radio [1]. In some regions of Sweden a co-operation between the fire and rescue service (municipal responsibility) and the ambulance service (county responsibility) has been established, which enables fire brigades to respond to emergency medical calls if an ambulance is not available, or far away. A retired chief of the fire and rescue service in a rural municipality stated to the radio programme host that he had been told that it was impossible to scientifically evaluate whether these co-operations were successful in saving lives since there ‘are too few such emergency calls in Sweden’. This experience reflects the perception we often encounter that only high-N statistical investigations provide reliable “scientific” evidence.

Recent studies into critical factors for research in EER have begun to emerge in Europe and internationally [2, 3]. Borrego and Bernhard [3] consider the emergence of EER as a global field of inquiry and note how EER-researchers from different research traditions can hold (partially) conflicting views about what constitutes research-quality as well as the complications that could arise as a result of this. We suggest that when a thorough discussion is lacking there is a risk that the criteria used tend to be private in that each individual has more or less well-thought ideas about what is ‘good’ and what is ‘bad’. Another risk is that criteria are too specifically bound to a certain research approach or tradition which makes them too narrow and results in the lack of appreciation of the relevance or quality of other approaches. We maintain that a mere unquestioning acceptance of one research paradigm, or epistemology, which is usually the dominant paradigm, can lead to inappropriate matching of research questions to methodologies, confusion between reliability and validity, and a lack of transparency of the criteria being applied with respect to what constitutes research quality.
We think it is time for the EER-community to begin a discussion about what constitutes quality of research in the field of EER, especially in order to avoid privileging some research approaches over others. Such a discussion needs to be thorough and go beyond simple “common-sense” notions about low-N versus high-N studies, “scientific rigour” and quality versus quantity. We need to surpass the notion that rigour is synonymous with quality [4]. We do not pretend to present a definitive and extensive list of criteria for quality in research to be rigorously followed. Instead, we wish to initiate a continuously on-going open and courteous debate and reflection on quality. We do not even think it is possible to settle final criteria “written in stone” since one of the characteristics of science is that it should be open for “professional scrutiny and critique” [4] and revision. We think that the most important contribution in improving the quality of research in EER is not the criteria themselves but the awareness, debate and reflection that result.

1 CRITICAL FEATURES IN THE DEBATE ABOUT CRITERIA FOR QUALITY

1.1 Methodology and epistemology

Epistemology is a branch of philosophy concerned with the theory of knowledge. It attempts to provide answers to the question, ‘How, and what, can we know?’ This involves thinking about the nature of knowledge itself, about its scope and about the validity and reliability of claims to knowledge. Research methods provide ways of approaching, and hopefully answering, our research questions… However, first we need to identify our goal and be able to justify our choice. We need to be clear about the objectives of our research and we need to have a sense of what kinds of things it is possible for us to find out. In other words, we need to adopt an epistemological position. [5, p. 2]

In order to study learning, we need to think about what we mean by the terms ‘learning’ and ‘knowledge’. This will influence the underlying theory we choose to adopt and the way we conduct our research. Epistemology is the term used to describe ways of knowing. In a recent publication about “Gold Standards” and high quality research, the following was pointed out:

Some initial and current interpretations of the Gold Standard have privileged a single research approach and type of evidence regardless of the development of the problem space, specific research question, available technologies and instrumentation, and cost or ethical considerations. If such interpretations of this policy exclusively privilege [randomized controlled trials] and quantitative evidence, it would disregard high-quality, qualitative research approaches and other contemporary approaches and, thus, the evidence flowing from such inquiries. [6, p. 5, our italics]

We perceive from the above quote that high quality in research requires that the approach, and type of evidence collected, be aligned to the “the problem space, specific research question, available technologies and instrumentation, and cost or ethical considerations”. On this note, Case and Light [7] argue that “methodological decisions need to be more explicitly represented in reports … in engineering education research”. However, in an earlier review and meta-analysis of qualitative research in EER conducted by Koro-Ljungberg and Douglas [8] it was found that the issue of methodology has received limited explicit discussion in the EER literature and that many studies lacked epistemological consistency. Therefore, methodological and epistemological awareness and consistency are clearly examples of important factors contributing to the quality of an EER research paper but appear to be rarely discerned.

1.2 Method versus problem led research

Streveler and Smith [9] define “rigorous research in engineering education by using the guidelines provided by the [US] National Research Council (NRC) in Scientific Research in Education” [4]. According to the NRC, scientific research in education should:

1. Pose significant questions that can be investigated empirically
2. Link research to relevant theory
3. Use methods that permit direct investigation of the question
4. Provide a coherent and explicit chain of reasoning
5. Replicate and generalize across studies
6. Disclose research to encourage professional scrutiny and critique
Nevertheless, Borrego and Bernhard note that the NRC’s report [4] is situated in the “curriculum studies” tradition and it should also be noted that these criteria are not quality criteria, but criteria for what would count as \textit{scientific} research in education. They have also explored differences in US-based “curriculum studies” and EU “didaktik” traditions [10, 11]. In the “didaktik”-tradition \textit{what} should be learned and \textit{why} it should be learned is an important question where quality of instruction is judged in terms of the professional appropriateness of knowledge and skills learning. “Bildung”, i.e. the formation of the individual as a whole beyond knowledge and skills is also deemed an important concept [12]. In the “curriculum studies” tradition \textit{how} a given topic is best taught is an important question where quality of instruction is judged in terms of student achievement on (objective) tests and student perception of classroom activity. Borrego and Bernhard relate these differences to Bishop’s [13] analysis of mathematics education research where he explains that differences in conceptions of quality in research can be traced back to “problem-led” and “method-led” educational research traditions. According to Bishop, problem-led researchers “would judge research quality by what light is shed by the research on the problem under consideration,” in other words, “the quality of the ideas and insights generated” (p. 716). In contrast, a “method-researcher would argue that, without methodological criteria, such research is worthless” (p. 716). Method-led researchers would judge research quality in terms of the proper use of methodology and quality of the evidence.

1.3 \textbf{Qualitative versus quantitative research}

One of the dangers in conducting qualitative research is that it may appear easy and less rigorous than quantitative research. While quantitative research requires use of statistical methods which can provide an aura of trustworthiness, qualitative research can appear at first glance as if it simply involves interviewing a few people and then writing up a summary. … In fact, qualitative research can be just as difficult to conceptualize, and be as methodologically and theoretical challenging, if not more challenging, than quantitative research. [8, p. 172]

We think that what we convey in this paper will be relevant to quantitative research, but we focus on qualitative research, as it is the area that brings up the most controversial discussions about quality in EER today. Qualitative research is often more difficult for engineers to become accustomed to than technical studies [cf. 14]. Quantitative research usually relies heavily on positivist traditions that assume it is possible to measure an objective reality and conduct statistics on the data in order to reveal the ‘truth’ about a particular context, or in post-positivist traditions, falsify hypothesis generated by theory. This implies that we can state that one teaching method is ‘better than another’. Qualitative researchers would rarely make such a claim but might question what ‘better’ actually means.

The above argument is further complicated by the fact that rarely do scientists and engineers discuss their underlying epistemology, nor necessarily know what it constitutes. The implication of this is that many researchers who move from technical to educational research, intent on ensuring ‘rigour’ and proving to their engineering peers that their work is valid, often adopt a positivistic stance that in their own technical research may not have been so immediately apparent. This concern for their work to be accepted as being rigorous often leads to an over-dependency on quantitative studies.

What results from the above is an unhealthy dichotomy between qualitative and quantitative studies, which is often confused with the underlying epistemology. Quantitative studies are, as stated above, \textit{usually}, but not necessarily, related to positivist or post-positivist traditions. It is equally possible to undertake qualitative work that resides firmly within these traditions. This is why stating the underlying epistemology is so critical. It is not possible to comprehend or judge the quality of work and the claims it makes unless its epistemology is understood.
2 QUALITY CRITERIA IN EDUCATIONAL RESEARCH

As a backdrop to a discussion concerning quality in EER we have summarized some proposed quality criteria for chemistry, mathematics and qualitative education research in Table 1. In mathematics education research, quality criteria have been discussed extensively; the reason for this is probably due to this field of research being under pressure to get accepted as a legitimate branch of mathematics research [13]. In the same manner, tension between quantitative and qualitative research approaches, NRC’s Scientific Research in Education [4] as well as the wish for “Gold Standards” anchored in political decisions by the US government has fostered an extensive and sometimes heated debate surrounding quality criteria for education research in general. It is beyond the scope of this paper to review this debate.

Table 1. Some proposed quality criteria for education research.

<table>
<thead>
<tr>
<th>Quality criteria in Chemistry Education Research</th>
<th>Quality criteria in Engineering Education Research</th>
<th>Quality criteria in Qualitative Education Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theory-relatedness</td>
<td>Quality scholarship in engineering education is:</td>
<td>Worthy topic: The topic of the research is:</td>
</tr>
<tr>
<td>• The theory base</td>
<td>• Inspired by real educational problems.</td>
<td>• Relevant</td>
</tr>
<tr>
<td>• Reference to previous studies</td>
<td>• Informed by theory and other literature</td>
<td>• Timely</td>
</tr>
<tr>
<td>The quality of the research question</td>
<td>describing prior work within and beyond the</td>
<td>• Significant</td>
</tr>
<tr>
<td>• Connection to existing literature</td>
<td>field/home country.</td>
<td>• Interesting</td>
</tr>
<tr>
<td>• Relevance for practice</td>
<td>• Systematic and intentional, with</td>
<td></td>
</tr>
<tr>
<td>• Ethical issues</td>
<td>documented decisions ideally based on well-</td>
<td></td>
</tr>
<tr>
<td>• falsification of hypotheses</td>
<td>planned collection and analysis of empirical</td>
<td></td>
</tr>
<tr>
<td>Methods: Appropriateness of the method</td>
<td>data.</td>
<td></td>
</tr>
<tr>
<td>a) Quantitative methods</td>
<td>• Consistent with the perspectives and</td>
<td></td>
</tr>
<tr>
<td>• Reliability</td>
<td>chosen methodologies (quantitative,</td>
<td></td>
</tr>
<tr>
<td>• Validity</td>
<td>qualitative or mixed).</td>
<td></td>
</tr>
<tr>
<td>• Level of significance</td>
<td>• Presented (at least in part) in a form that</td>
<td></td>
</tr>
<tr>
<td>b) Qualitative methods</td>
<td>engineering academic staff can understand</td>
<td></td>
</tr>
<tr>
<td>• Documentation of procedures</td>
<td>and use, including by discussing implications</td>
<td></td>
</tr>
<tr>
<td>• Interpretation by logical inference</td>
<td>of the research.</td>
<td></td>
</tr>
<tr>
<td>• Systematic</td>
<td>• Situated in international and inter-</td>
<td></td>
</tr>
<tr>
<td>• Closeness to subjects</td>
<td>disciplinary contexts, by demonstrating</td>
<td></td>
</tr>
<tr>
<td>• Communicative validity</td>
<td>awareness of how common the problem is,</td>
<td></td>
</tr>
<tr>
<td>• Triangulation</td>
<td>what is being pursued elsewhere, and the</td>
<td></td>
</tr>
<tr>
<td>Presentation and interpretation of results</td>
<td>likelihood that results are or are not generali-</td>
<td></td>
</tr>
<tr>
<td>Implications for practice</td>
<td>zable/transferable to other contexts</td>
<td></td>
</tr>
<tr>
<td>Competence in chemistry</td>
<td>(disciplines and/or countries). We note that</td>
<td></td>
</tr>
<tr>
<td></td>
<td>in order for an EER topic to be worthy of</td>
<td></td>
</tr>
<tr>
<td></td>
<td>inquiry, it need not be broadly generalizable.</td>
<td></td>
</tr>
<tr>
<td>Quality criteria in Mathematics Education Research</td>
<td>Quality criteria in Qualitative Education Research</td>
<td>Quality scholarship in engineering education:</td>
</tr>
<tr>
<td>Mogens Niss [17]</td>
<td>Quality of a study in general</td>
<td>• Inspired by real educational problems.</td>
</tr>
<tr>
<td>Quality of the underlying research</td>
<td>• Perspective awareness</td>
<td>• Informed by theory and other literature</td>
</tr>
<tr>
<td>• Quality of the research question(s)</td>
<td>• Internal consistency in a study</td>
<td>describing prior work within and beyond the</td>
</tr>
<tr>
<td>• Quality of the research design</td>
<td>• Ethical values</td>
<td>field/home country.</td>
</tr>
<tr>
<td>• Quality of the research findings</td>
<td>Quality of the results:</td>
<td>• Systematic and intentional, with</td>
</tr>
<tr>
<td>Quality of the dissertation as a report of the</td>
<td>• Richness in meaning</td>
<td>documented decisions ideally based on well-</td>
</tr>
<tr>
<td>work done</td>
<td>• Structure</td>
<td>planned collection and analysis of empirical</td>
</tr>
<tr>
<td>• Scientific/scholarly quality of the exposition</td>
<td>• Contribution to theory development and new</td>
<td>data.</td>
</tr>
<tr>
<td>• Communicative quality.</td>
<td>knowledge</td>
<td>Quality criteria in qualitative education:</td>
</tr>
<tr>
<td>Quality of the results:</td>
<td>Validity of the results:</td>
<td>Worthy topic:</td>
</tr>
<tr>
<td>• Discourse criterion</td>
<td>• Discourse criterion</td>
<td>• Relevant</td>
</tr>
<tr>
<td>• Heuristic value</td>
<td>• Heuristic value</td>
<td>• Timely</td>
</tr>
<tr>
<td>• Empirical anchorage</td>
<td>• Empirical anchorage</td>
<td>• Significant</td>
</tr>
<tr>
<td>• Consistency</td>
<td>• Consistency</td>
<td>• Interesting</td>
</tr>
<tr>
<td>• Pragmatic criterion.</td>
<td>• Pragmatic criterion.</td>
<td></td>
</tr>
</tbody>
</table>

Rich rigour: The study uses sufficient, abundant, appropriate, and complex:
- Theoretical constructs
- Data and time in the field
- Sample(s)
- Context(s)
- Data collection and analysis processes

Sincerity: The study is characterized by:
- Self-reflexivity about subjective values, biases, and inclinations of the researcher(s)
- Transparency about the methods and challenge

Credibility: The research is marked by:
- Thick description
- Triangulation or crystallization
- Multivocality
- Member reflection

Resonance: The research influences, affects, or moves particular readers or a variety of audiences through:
- Aesthetic, evocative representation
- Naturalistic generalizations
- Transferable findings

Significant contribution: The research provides a significant contribution:
- Conceptually/theoretically
- Practically
- Morally
- Methodologically
- Heuristically

Ethical: The research considers:
- Procedural and situational and culturally specific, relational, and exiting ethics

Meaningful coherence: The study
- Achieves what it purports to be about
- Uses methods and procedures that fit its stated goals
- Meaningfully interconnects literature, research questions/ foci, findings, and interpretations with each other.
3 A PROLEGOMENON TO QUALITY CRITERIA FOR EER

In this chapter we propose tentative criteria for quality in (qualitative) engineering education research that draw mainly on Larsson’s criteria [18] as summarized in table 2. We maintain that there are sometimes contradictions or tensions between criteria and the adequate balance has to be found, and depending on the type of study, certain criteria are more important than others.

Table 2. Tentative quality criteria for (qualitative) engineering education research.

<table>
<thead>
<tr>
<th>Quality of a study in general</th>
<th>Quality of the results</th>
<th>Validity of the results</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Perspective awareness</td>
<td>• Richness in meaning</td>
<td>• Discourse criterion</td>
</tr>
<tr>
<td>All studies has a perspective</td>
<td>Capture the essentials and at the same time maintain the nuances. Highlight what is unique to the specific phenomenon at hand.</td>
<td>In this criterion validity is viewed as a conversation about the world (or reality). The quality of argumentation and interplay of meanings.</td>
</tr>
<tr>
<td>• Acknowledging different knowledge traditions and cultures</td>
<td>• Structure</td>
<td>• Heuristic value</td>
</tr>
<tr>
<td>Respect and awareness of the perspective of other researchers</td>
<td>Interpretations should have a good structure. It should be possible to follow the reasoning.</td>
<td>To what extent will a reader be convinced by the presentation of the study to in seeing a particular aspect of reality in a new way?</td>
</tr>
<tr>
<td>• Upholding ethical values</td>
<td>• Contribution to theory development and new knowledge</td>
<td>• Empirical anchorage</td>
</tr>
<tr>
<td>How can the study contribute to enhancing the human condition?</td>
<td>How well do one relate to earlier theory. What is the original contribution of the study; something decisive or just a note in the margin?</td>
<td>The relation between reality and interpretation</td>
</tr>
<tr>
<td>• Informed by theory and other literature describing prior work</td>
<td>• Presentation of results</td>
<td>• Consistency</td>
</tr>
<tr>
<td>A researcher cannot perform significant research without first understanding the literature in the field.</td>
<td>Presentation relevant to proposed audience, clear and precise language, and a good balance between different parts of the presentation.</td>
<td>(including epistemological and theoretical underpinnings) The interplay between part and whole</td>
</tr>
<tr>
<td>• Research question</td>
<td>• Heuristic value</td>
<td>• Pragmatic criterion</td>
</tr>
<tr>
<td>Worthy topic: Relevant, timely, significant, interesting</td>
<td>Consequences of what the results brought about (for example in relation to teaching).</td>
<td>This is an aspect of what also is called ecological validity.</td>
</tr>
<tr>
<td>• Internal consistency in a study (including epistemology, ontology with methodology)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the following sections, we have chosen to provide a more explicit discussion about the criteria for quality of a study in general. In our view, these criteria are important, although given slightly different interpretations in different traditions, for qualitative as well as quantitative research in education. On the other hand, the discussion of the criteria for quality of the results and validity of the results will be rather brief to avoid exceeding the permitted space.

3.1 Quality of a study in general

Perspective awareness

*Without theory there is nothing to research* … In this way, theories provides both a framework for critically understanding phenomena [and] a basis for considering how what is unknown might be organized. … However, as used here, models, concepts and theories are self-confirming in the sense that they instruct us to look at phenomena in particular ways. This means that they *can never be disproved but can only be found to be more or less useful* … A methodology refers to the choices we make about cases to study, methods of data gathering, forms of data analysis etc. in planning and executing a research study. So our methodology defines how we will go about studying any phenomenon. … Like theories, methodologies cannot be true or false, only more or less useful. [19, pp. 3-4, our italics]

Based on the above quote, the bias of the authors and their perspective and positioning theoretically and methodologically needs to be made explicit, as interpretation of data will be based on this as is discussed in sections 1.1-1.3 above. In order to appreciate the communicated results and their validity, the reader needs to “see through the lens” of the authors.

Acknowledging different knowledge traditions and cultures

No research paradigm has a monopoly on quality. None can deliver promising outcomes with certainty. None have the ground for saying ‘this is it’ about their designs, procedures, and anticipated outcomes. [20, p. 36]

High quality in this criterion is to display an awareness of, and respect for, other researchers’ perspectives, and to understand a piece of work within its own theoretical framework.
Upholding ethical values

Research quality … in a broad sense is a holistic judgement, from which no individual requirement could be removed. When the total research quality is judged, no qualities could be disregarded. Quality is judged by the compounded qualities originality, external and internal validity, precision and ethics. This means that the requirement of good research ethics is also included. [21, p. 24, our translation and italics]

While ethical considerations are very briefly discussed in the NRC report and in parts even described as something that “may weaken the strength of [a] research [design]” [4, p. 93], the Swedish Research Council on the other hand maintains good research ethics as an essential requirement for high quality as demonstrated in the quote above. Furthermore, the Swedish Research Council proposes the following eight ‘commandments’ [21, p. 24, our translation]:

1. You should speak the truth about your research
2. You should consciously scrutinize and describe the basis for your studies
3. You should openly describe methods and results
4. You should openly account for commercial connections and other liaisons
5. You should not steal results of research from others
6. You should keep good order in your research, for example through documentation and keeping archives
7. You should aim to conduct your research without harming humans, animals or the environment
8. You should be fair in your judgement of other persons’ research

The above are important because they maintain that ethics is much more than only conducting research “without harming humans or animals”. Fraud, withholding contradictory data, abuse of intellectual property, plagiarism, or lack of precision, in for example superficial studies about intelligence, criminality, ethnicity and so forth are all seen as examples of poor research ethics.

Informed by theory and other literature describing prior work within and beyond the field/home country.

A substantive, thorough, sophisticated literature review is a pre-condition for doing substantive, thorough, sophisticated research. ‘Good’ research is good because it advances our collective understanding. To advance our collective understanding, a researcher or scholar needs to understand what has been done before, the strength and weaknesses of existing studies, and what they might mean. A researcher cannot perform significant research without first understanding the literature in the field. [22, p. 3, our italics]

A thorough review of previous literature serves as a foundation for any research project by placing it in the broad historical context of previous studies both nationally and internationally. Furthermore, “a good literature review is the basis of both theoretical and methodological sophistication, thereby improving the quality and usefulness of subsequent research”. [22, p. 4, our italics]

Research question

A crucial but typically undervalued aspect of successful scientific investigation is the quality of the question posed. [4, p. 55]

For example, Niss [17] maintains that “the issue of quality of the research undertaken takes its point of departure in research question(s) posed”. The question(s) clarity, precision, if they are genuine and non-rhetorical, their scientific and scholarly interest, if they are significant, relevant, original and researchable were seen as important aspects of quality. It is often argued “that research questions should drive data collection techniques and analysis rather than vice-versa” [23, p. 16]. However, a Larsson [18] argues that the norm this is too simplistic since the choice of methods and approaches also includes choice of perspectives that will influence the kind of results obtained. In a similar vein, it is reiterated that research “is always conducted within some broader understanding of what constitutes legitimate inquiry and warrantable knowledge” [24, p. 98, our italics]. This is expressed by Case and Light [7, p. 189] as “one’s choice of methodology will constrain what questions one can ask”. The explicit formulations of research questions do not play a prominent role in some disciplines and research traditions while in others they are formulated post hoc. Nevertheless,
we claim that all research attempts to answer research questions even if they are implicit. Good research is about asking good questions. Even if the explicit formulation of the research question is post hoc it serves the function of being a “clear signpost [without] the readers will be lost … not know[ing] the central ideas addressed in [the] study” [25, p. 112].

Internal consistency in a study (including epistemology, ontology with methodology)

Harmony should exist between the research question, assumptions about the research and the nature of the phenomenon to be studied, data collection, and methods of analysis. [18, p. 21]

This is perhaps [18] the most commonly used criterion but as was mentioned previously, one that is often missing [7, 8]. Beneath the surface of this criterion is the idea of construction of a whole where single parts are integrated and contribute to the building of a whole. The degree of harmony between the parts and the whole is seen as a criterion of quality.

3.2 Quality and validity of results

Qualitative and quantitative research procedures are but different forms of the analytic practice of re-representation in science, in that both seek to arrange and rearrange the complexities of ‘raw’ data. [They] differ ... in their approach to re-representing complexity. [The] very strength of quantification and numbers – that of simplification – is also its Achilles’ heel! [24, p. 42, our italics]

The quotation above presents the tension between richness in meaning and structure to the fore. In qualitative research, it is essential to not lose sight of the complexities, and hence, richness in meaning is important. However, even in qualitative studies there is a tension between richness in meaning and structure since an overview may be sacrificed if descriptions are “too rich”. Furthermore, in some qualitative approaches the distinction between quality of results and validity of results may not be clear and free from complication.

4 CONCLUSION

Disciplined inquiry does not necessarily follow well established, formal procedures: Some of the most excellent inquiry is free ranging and speculative in its initial stages, trying what might seem to be bizarre combinations of ideas and procedures, or restlessly casting for ideas. [26, p. 16]

The above closing quotation reinforces the notion that we should use criteria wisely and that they are certainly not “cast in stone”. Via this short paper we hope that we have given the reader some thoughts to stimulate critical reflection and debate. We are also in the process of compiling a longer text that will elaborate the topic more extensively and would welcome comments on our criteria. We will be happy to share drafts of that paper in the hope that this contributes to raising the quality of research in engineering education.

REFERENCES


