

Towards Identification and Classification of Core and Threshold Concepts in Methodology Education in Computing

Matti Tedre, Danny Brash, and
Sirkku Männikkö-Barbutiu
Department of Computer and Systems Sciences
Stockholm University
Sweden
matti|danny|sirkku@dsv.su.se

Johannes Cronjé
Faculty of Informatics and Design
Cape Peninsula University of Technology
South Africa
cronje@cput.ac.za

ABSTRACT

Research methodology is a quintessential component of science, but methods differ greatly between sciences. In computing, methods are borrowed from many fields, which causes difficulties to methodology education in computing. In our methodology courses in computing, we have observed a number of core and threshold concepts that affect students' success. This essay describes a work in progress towards understanding those core and threshold concepts in methodology education in computing, classified along two dimensions. We classify methodological concepts in terms of standard elements of research design in students' projects in computing, and in terms of their centrality and difficulty. We present examples of three types of troublesome knowledge concerning methodology: the strangeness and complexity of methodological concepts, misimpressions from everyday experience, and reasonable but mistaken expectations.

Categories and Subject Descriptors

K.3.2 [Computers and Education]: Computer and Information Science Education—*computer science education, curriculum*

General Terms

Human Factors

Keywords

Methodology, Computer science education, Computing curricula, Threshold concepts, Troublesome knowledge

1. INTRODUCTION

Methodology is a quintessential component of scientific research and dictionary definitions of 'scientific' refer to methodologically sound, rigorous activities. As different kinds of

research employ different methods, methodology education differs between academic disciplines. In natural sciences students learn things like empirical laboratory work and statistical methods while in social sciences various qualitative and quantitative methods are part of the curriculum.

However, in computing, methodology has historically been an overlooked activity. Reviews of methodology in computing have pointed out deficiencies in many fields of computing, including information systems [31], computer science [23], and software engineering [33]. Some critics have argued that methodological terminology is sloppily used in computing [34]. In computing experimentation terminology is used differently from many other fields [28]. Others have argued that precautions against bias are often not taken [7, 8]. Yet others have argued that computing researchers just act like scientists but do not really do science [17].

The science of computing is so broad that different fields emphasize different kinds of research methodology education. In the field of information systems, which has social science methodology at its core, calls for stringent adherence to recognized research methodology can be found [10, 11]. Theoretical computer science employs deductive reasoning and analytical methods, although those are rarely explicitly described in research papers [10]. Human-computer interaction uses a variety of methods from various traditions, including behavioural sciences and social sciences. In systems development, engineering methods and techniques are common. In the recent years, methodological debates concerning system development has lead to an increased use of design science [15] as a methodological framework.

No quick improvement can be expected in research practice as long as methodology is not properly addressed in computing education. It has been argued that instead of methodology education, students learn methodological skills through mentoring and model learning—such as examining previous research reports [9]. Curricula guidelines in computing are thin on methodology courses. The ACM/IEEE curriculum report CC2001 [6] does not include a single course on methodology. Some of computing's field-specific curriculum guidelines—such as CS2008 (for computer science) and GSwE2009 (for software engineering)—offer little in terms of methodology. Other curricula—such as IS2010 for information systems and CE2004 for computer engineering—are more concerned with methodology education in their fields.

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than the author(s) must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from permissions@acm.org.

ITiCSE'14, June 21–25, 2014, Uppsala, Sweden.

Copyright is held by the owner/author(s). Publication rights licensed to ACM.

ACM 978-1-4503-2833-3/14/06 ...\$15.00.

<http://dx.doi.org/10.1145/2591708.2591758>.

Education in computing fields is not just an academic issue. ICT has a great impact on the economy and functions of society, and when ICT systems fail, modern societies may grind to a halt. ICT's crucial role in industry and society creates various kinds of pressure towards university education in computing. Computing education has to balance between legislation regarding higher education, academic goals, and the needs of industry. In legislative terms, methodological knowledge and skills are, in many countries, decreed by the national agency for higher education. In our case, Sweden, methodological education is legislation-bound already on the B.Sc. degree level [26]. In terms of academic goals, computing education must prepare students for the possibility of following research careers, which puts more pressure on methodology education. In terms of industry, computing education must supply a skilled workforce—which is often research-intensive R&D (research and development) work.

This essay is based on the experiences of methodology educators from three universities: Cape Peninsula University of Technology, South Africa; Tumaini University, Tanzania; and Stockholm University, Sweden. The essay uses Stockholm University's computer science department, DSV, as an example. Typical of educational programs in computing, for 35 years after DSV was founded in 1966, methodology education did not exist as a curricular subject. The main focus of education and research at the department was artifact development. Over the years the department grew steadily in size and scope, encompassing an increasingly broad range of computing fields. That diversification encouraged the department to begin teaching research methodology in 2001, after which various initiatives have been introduced to improve the quality and quantity of methodology education.

Concerned with students' methodological understanding and skills, DSV initiated a department-wide initiative to improve methodology education. A number of courses were established on three levels—B.Sc., M.Sc., and Ph.D. level—and their coherence with the broader aims of education at the department was monitored. Emphasis of methodology in thesis grading was strengthened. A department-wide three-level quality control system for theses was introduced (supervisor, reviewer, and examiner). However, during the implementation of some changes we identified a number of troublesome concepts for students; concepts that were pivotal for understanding the topic but that were conceptually difficult, counter-intuitive, or alien to students [18]. Such threshold concepts need to be properly addressed because the learning of other concepts requires understanding of those threshold concepts [18, 20]. The issues with methodology education were, and are, complicated by the widely differing backgrounds of DSV's students: At the start of their studies some students have an extensive methodological training, while other students have very little.

This essay identifies troublesome concepts in methodology courses in computing, and proposes a distinction between core concepts [1] and threshold concepts [18, 20] in methodology courses in computing. This essay also presents examples of three sources of trouble concerning methodological concepts: misimpressions from everyday experience, the strangeness and complexity of methodological concepts, and reasonable but mistaken expectations [20]. The essay paves a way for further research and educational interventions concerning threshold concepts of methodology education in computing.

2. TROUBLESOME KNOWLEDGE

Threshold concepts and troublesome knowledge are topics of interest in educational research [19]. Perkins [20] discussed five kinds of “troublesome knowledge”: ritual, inert, alien, tacit, and conceptually difficult knowledge. In computing education, many threshold concepts in methodology courses are conceptually difficult knowledge. Perkins wrote that difficulties with conceptually difficult knowledge may arise from misimpressions from everyday experience, the strangeness and complexity of scientific concepts, and reasonable but mistaken expectations. All those can be readily identified in methodology education in computing fields.

Some concepts in computing methodology education are muddled by misimpressions from everyday experience. Take, for instance, “hypothesis”: The everyday use of the word “hypothesis” refers to a supposition or assumption, and the casual meaning of the word may carry to terms like “null hypothesis,” which in methodology language should be testable and neutral. Similar, the casual meanings of terms like “factor”, “random”, and “significant” sometimes carry to research reports. Other concepts may appear strange and complex: Take ontological categories, for instance: The fact that 8 bits make a byte is a mind-dependent fact [29] may sound strange (how can a fact be mind-dependent?). Yet other concepts are confusing due to reasonable but mistaken expectations. Take, for instance, statistics in research: After a certain point in sample size, population has negligible effect on confidence—for example, statistically speaking, a random sample of 500 respondents is equally useful for the 150 thousand users of a specialized software product as it is for the 150 million users of a social networking website.

Equally difficult with some central methodological concepts might be what Meyer and Land [19] called each field's “ways of thinking and practicing” and what Perkins [20, p.42] called “epistemes”—“manners of justifying, explaining, solving problems, conducting enquiries, and designing and validating various kinds of products or outcomes”. Epistemes are perhaps the main expected learning outcome of methodology courses, but much of the epistemes lie hidden beneath the surface of publications. Research reports provide the student only limited windows to epistemes of the field. Perkins [20, p.42] warned that without epistemes, students in science and mathematics may display ritualized routines instead of genuine disciplinary enquiry and problem solving. Insofar as knowledge is ritualized and tacit, learning how to conduct scientific work can be seen as a lonely rite de passage where little guidance aside from mentor-apprentice relationships is provided. However, as both the student body as well as computing as a discipline are becoming increasingly heterogeneous, there is an increasing need to introduce methodology, an essential element of disciplinary ways of thinking and practicing, into curricula, as well.

In computing, the context of knowledge creation is separated from the knowledge of justification. It is excessively difficult to learn the disciplinary ways of thinking and practicing from research reports, as they only present the context of justification. For example, similar to mathematics, in various theoretical branches of computing the research report presents a proof, but offers little insight on the actual process that led to the proof: Which heuristics were applied, what dead-ends were traversed, and in general, how exactly was the problem approached (see, e.g., [21]). In experiment-based branches of computing, few traces of the context of

	Knowledge and Understanding	Competence and Skills	Judgment and Approach
B.Sc. Degree	Students should ... • be aware of similar research problems that have been studied in recent years in the same domain. • understand what types of situations qualify for ‘research problems,’ on the basis of previous research.	Students should be able to ... • formulate a research problem in such a way that it deals with applied or theoretical problems that actually need solving and fill a gap of knowledge within the domain. • ground a research problem in scientific literature or justify a design problem.	Students should be able to ... • evaluate the degree of relevance of particular research problems for filling gaps in knowledge in a particular domain. • assess the ethical and societal dimensions of a chosen research problem.
M.Sc. Degree	Students should ... • understand similar research problems within a domain.	Students should be able to ... • distinguish and identify different types of problems, such as a lack of knowledge, artifacts, or processes that require improvement, a need for evaluation, or the need for development of new artifacts or processes.	Students should be able to ... • assess and discuss the implications of dealing with particular and varying research problems in varying circumstances and under changing conditions.

Table 1: Examples of Learning Objectives at DSV: Problem Description

discovery can be found from research reports: What really drove the researcher, what bad theories and bad hypotheses were filtered out, what guesses, intuitions, and approximations went into the model-building, and so forth. In engineering types of computing research, things like product specifications offer little information about exactly how and why did those specifications emerge. Methodology education should be able to open the black box of research reports and let students understand how knowledge is created.

3. CORE CONCEPTS

A major difficulty in methodology education in computing comes from the vast amount of new, conceptually difficult knowledge. Terminology is often dense, unrelated to other computing courses, and core concepts and threshold concepts can be hard to identify. In order to clarify the conceptual complexity, we present the core concepts and learning objectives for each state of a typical student research project. Different concepts are needed at different levels. This section outlines the vast amount of conceptually difficult knowledge, which methodology education in computing has to deliver, and which is often new to students. The section also uses those concepts to construct examples of learning objectives for a methodology course (Table 1 and Table 2).

Research Problem

Each research study in computing is a response to a problem, ranging from scholarly problems to evaluation problems to design and development problems [24]. Computing deals with a range of different kinds of problems, and different types of problems are rooted in different intellectual traditions [30]. Understanding what different kinds of problems entail is difficult as it stands, different kinds of problems each introduce their own sets of concepts, and they all point to different research trajectories. The problem statement plays a fundamental role by describing the rationale for research, grounding the study within a specific domain, and driving the research project. Table 1 presents example learning outcomes concerning research problem statements.

Core Concepts: Gap of knowledge, Research problem, Topic, Problem types, Literature review, Background

Aims, Objectives, and Questions

Proceeding from a research problem to research questions might not be conceptually challenging, but it introduces terminological complexity, and terminology should be in agreement throughout the project. A research aim, or purpose, when it exists, corresponds to the research problem, and

is often expressed in verbs that define the type of research and resonate well with the problem type; verbs such as ‘explore’, ‘describe’, ‘develop’, and ‘evaluate’ [5]. Other common conceptualizations of research aims include exploratory, explanatory, descriptive, and emancipatory research [16, 32], or observation, description, prediction, and experimentation (e.g., [14, 22]). In some studies, particularly in evaluation and development, objectives present specific statements about how the research aim is going to be met, expressed in strong active verbs, such as ‘classify’, ‘define’, ‘implement’, and ‘test’ [27]. If aims, objectives, research questions, and subquestions are all present, they should form a tight fit. In some studies, such as some design research projects, there are no explicit questions but aims and objectives instead (cf. [15]), and sometimes research is defined through research acts [24, pp.32–34]. Table 2 presents example learning outcomes concerning research aims, objectives, and questions.

Core Concepts: Empirical research, Analytical / theoretical research, Desk study, Research acts, Question, Subquestion, Aim, Objective, Explanation, Demonstration, Evaluation, Description, Prediction, Exploration

Research design

The next sets of concepts arise from research designs, which vary between fields of science and between qualitative, quantitative, and mixed-methods types of research [4]. In exploratory types of research, designs are often descriptive, while in confirmatory types of research, experimental designs and correlational designs are common. Strategies of inquiry [4, pp.11–15] are common tools for a high-level overview and organization of research projects—and for improving alignment and congruence, which refers to how the parts of research study logically follow from each other and fit together. The different types of research design introduce a large number of complex but central concepts, which should be introduced from B.Sc. level upwards.

Core Concepts: Research design, Strategies of inquiry, Resource planning, Focus, Scope, Delimiters, Qualifiers, Hypothesis, Experiment, Independent and dependent variables, Construct, Category, Intervention, Control group, Experimental group, Survey, Phenomenology, Case study, Alignment, Congruence

Theoretical and conceptual frameworks

Theory can play various roles in research, but understanding those roles poses conceptual difficulties for students. In quantitative research, theories may provide, for instance, testable variables, models, or frameworks [4, Ch.3]. In qualitative research, theories may provide, for instance, a “vocab-

	Knowledge and Understanding	Competence and Skills	Judgment and Approach
B.Sc. Degree	Students should ... • understand what constitutes a research question and how it is derived from, and related to, a research problem. • be familiar with different types of research questions.	Students should ... • be able to search for and pinpoint relevant scientific literature to enable the formulation of research questions.	Students should ... • be able to evaluate the potential implications of answering particular research questions for the researcher, for potential beneficiaries of research, and society in general.
M.Sc. Degree	Students should ... • understand the feasibility of answering particular research questions. • understand the potential and expected scientific, technical, and social impacts of answering the research questions. • be familiar with the different types of answers that different types of research questions require, such as descriptions, explanations, artifacts, correlations, causal relations, comparisons, identification, and definition.	Students should be able to ... • define aims of research, and derive measurable objectives that respond to the research aims. • refine and divide research questions into concrete, coherent, and researchable components that become subquestions. • formulate research questions in a variety of ways that allow the focus to be shifted towards different perspectives, depending on context and timing of the research as well as on different stakeholders.	Students should be able to ... • evaluate the need for particular questions to be answered. • determine the limitations and utility of answering particular research questions.

Table 2: Examples of Learning Objectives: Research Aims, Objectives, and Questions

ulary” for phenomena and processes or a “lens” for interpreting results. Instead of a theoretical framework, many studies employ conceptual frameworks, both of which require properly done literature reviews [25]—although small-scale practice projects can rarely be literature driven. Theoretical frameworks are tightly interwoven with aims of research, as well as different philosophical assumptions, yet students can be very selective with some of those concepts [12, 29].

Core Concepts: Theoretical and conceptual framework, Ontology (e.g., mind-dependence, mind-independence), Epistemology (e.g., subjectivity, intersubjectivity), Model, Theory, Realism, Relativism, Postpositivism, Critical theory, Constructivism

Information needs and data collection instruments

Answering an empirical research question requires a properly executed collection of data that is of the right type and comes from the right source. Consequently, getting the data collection instruments right is crucial for a successful research project. Students often have preconceptions of terms ‘research data’ and ‘methodology’ due to widespread use of those terms. A number of concepts are related to data collection, and confusion is common between, for instance, primary and secondary data and qualitative and quantitative data. In empirical testing of computer systems, inputs, outputs, measuring instruments, parameters and databases are not always obvious and require specific attention. Simulation, emulation, and benchmarking are often used in experimental strategies for design research in computing [13].

Core Concepts: Data types, Data formats, Qualitative data, Quantitative data, Data collection method, Discrete, Continuous, Primary data, Secondary data, Demographic data, Computer-generated data, Questionnaire, Interview, Observation, Input, Output, Parameter, Simulation, Emulation, Benchmarking

Selection of information sources

Towards the end of the research project, retaining conceptual and terminological coherence becomes increasingly difficult. Depending on the type of research, a number of concepts are associated with sampling, selection of informants, or choice of data sources. In quantitative research ‘randomness’ is one of the more difficult concepts, as the term is often confused with its everyday meaning. In qualitative research, purposeful sampling strategies are often not described to the

extent they should be described—such as maximum variation, theory-based, or deviant case selection [3]. Data collection through social networks is notoriously problematic for traditional sampling terms. Laboratory and field testing of computer systems often lack proper description and justification of the setup, parameter choices, measured outputs and variables, and choice of competing systems [2, 7, 8].

Core Concepts: Selection of informants, Sampling strategies, Probability and nonprobability sampling, Sample, Population, Representative and purposeful sampling, Stratified and comprehensive sampling, Exploratory sample, Random / systematic / convenience sampling, Data saturation, Social networks, Automatic data collection, Log files

Research ethics

The relevant concepts of research ethics in methodology education range from those that should be introduced to students on their first year, like plagiarism, to those that are relevant much later in students’ work, such as authorship in journal articles and conflicts of interest. Most importantly, those computing research studies that use human participants require proper permits and procedures.

Core Concepts: Research ethics, Informed consent, Data protection, Security, Anonymity, Research permits, Plagiarism, Authorship, Intellectual property, Conflicts of interest, Disclosure / non-disclosure

Data analysis and discussion

Analysis of data presents a set of concepts tightly interrelated with the previous sets, as well as a number of specific concepts. Qualitative and quantitative data and methods of analysis form a fourfold table, in which each quadrant introduces a specific set of concepts, principles, and processes [24]. Some of the harder concepts include, for instance, the distinction between correlation and causality, the differences between types of measurement (nominal, ordinal, interval, ratio), and the differences between reporting, analyzing, and discussing. The term “analysis” is sometimes used by students in its everyday use—meaning the provision of a detailed or complex opinion and reflection. That is, students may provide opinions instead of a rigorous, methodologically sound analysis.

Core Concepts: Data analysis method, Qualitative and quantitative analysis, Inference, Descriptive statistics, Inferential statistics, Transcript of data, Types of measurement,

	Basic concepts	Intermediate concepts	Advanced concepts
Research problem	Background, Research problem* , Topic	Problem types, Systematic literature review	Gap of knowledge*
Aims, Objectives, Questions	Empirical research* , Research aim, Research question, Description, Exploration	Subquestion, Objective, Demonstration, Evaluation	Analytical / theoretical research, Desk study, Prediction, Explanation, Research acts
Research design	Case study, Research design, Delimiters, Focus	Strategies of inquiry, Resource planning, Qualifiers, Scope, Context, Congruence, Survey, Phenomenology, Category	Intervention, Hypothesis, Experiment* , Independent and dependent variables, Control group, Experimental group, Alignment, Construct
Theoretical frameworks	Theory* , Concept	Model, Theoretical framework	Conceptual framework
Research philosophy		Epistemology* , Subjectivity, Inter-subjectivity	Ontology, Mind-dependence, Mind-independence, Realism, Relativism, Postpositivism, Critical theory, Constructivism
Data collection	Data types, Data formats, Qualitative data* , Quantitative data* , Data collection method, Interview, Observation, Primary data*	Discrete, Continuous, Secondary data, Computer-generated data, Social networks, Questionnaire, Input, Output, Parameter	Demographic data, Simulation, Emulation, Benchmarking
Sources of information	Selection of informants, Exploratory sample, Convenience sampling, Purposeful sampling strategies	Nonprobability sampling, Sample, Population, Systematic sampling, Data saturation, Stratified sampling, Comprehensive sampling, Automatic data collection, Log files	Probability sampling* , Representative sampling
Research ethics	Research ethics, Plagiarism, Informed consent* , Anonymity	Data protection, Security	Research permits, Disclosure, Non-disclosure, Authorship, IPR, Conflicts of interest
Data analysis	Data analysis method, Qualitative analysis, Coding, Memoing, Classifying, Transcript of data	Quantitative analysis, Descriptive statistics, Types of measurement, Midpoints, Spread of data, Statistical significance, Data visualization	Inference, Inferential statistics* , Hypothesis testing
Quality measures	Rigor, Confirmability, Trustworthiness, Credibility, Transferability, Dependability, Peer checks, Member checks, Bracketing	Reproducibility, Measurability, Bias* , Generalizability, Reliability, Validity	Triangulation, Testability
Reporting	Abstract, Citation, Bibliography, Paraphrasing, Verbatim quote, Tenses, Rich description* , Practical contribution	Congruence, Facts, Interpretations, Layers of data	Theoretical contribution, IMRAD, Style manual

* A candidate for threshold concept

Table 3: A Survey of Concepts from Basic to Advanced

Midpoints, Spread of data, Statistical significance, Coding, Memoing, Classifying, Rich description, Data visualization

Quality measures

Some of the most difficult new concepts to students is concerned with the self-evaluative aspects of a research study. Validity and reliability—the “twin pillars of science”—can be broken into a complex variety of concepts, and the four criteria of qualitative research—credibility, confirmability, transferability, and dependability [12]—each have their own nuances. The number of possible sources of bias, such as design, sampling, and nonresponse bias, is equally large and often those concepts are difficult to apply to research studies.

Core Concepts: Rigor, Reproducibility, Testability, Triangulation, Measurability, Bias, Generalizability, Reliability, Validity, Confirmability, Trustworthiness, Credibility, Transferability, Dependability, Member checks, Peer checks, Bracketing

Reporting

Compiling the pieces of research together into a coherent, well aligned report requires yet another set of conceptual and technical elements: those related to technical and academic writing. Congruence (compatibility and consistency of research elements) is a measure of conceptual and terminological rigor in a research report. Proper quoting, paraphrasing, and citing requires understanding of why literature

references are necessary. Academic writing, as well, has a great impact on the readability and credibility of a report.

Core Concepts: Abstract, Citation, Bibliography, Paraphrasing, Verbatim quote, Congruence, Tenses, Facts, Interpretations, Rich description, Theoretical and practical contribution, Layers of data, IMRAD, Style manual

4. DISCUSSION

The amount of new, conceptually difficult knowledge makes methodology courses hard for computing students, and it makes course design a challenge for educators. A conceptual analysis of the course contents, explication of learning objectives, and identification of threshold concepts plays a key role in developing methodology courses. This essay presents a set of core concepts in methodology education in computing and proposes candidates for threshold concepts (Table 3). The essay also gives examples of learning objectives for methodology education in computing (Tables 1 and 2). Our proposals, however, are only applicable to DSV’s social and human-oriented computing research, and are analytical instead of empirically grounded. The next steps in our project are to empirically evaluate the perceived difficulty of each of those concepts, to analytically establish the connections between the concepts, to survey the extent to which the same difficulties are found in other computing institutions, and to propose educational interventions for resolving the difficulties with those concepts.

5. REFERENCES

- [1] J. Biggs and C. Tang. *Teaching for Quality Learning at University: What the Student Does*. Open University Press, New York, NY, USA, 4th edition, 2011.
- [2] J. Carreira and J. G. Silva. Computer science and the Pygmalion effect. *Computer*, 31(2):116–117, 1998.
- [3] J. W. Creswell. *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*. Sage Publications, Thousand Oaks, CA, USA, 3rd edition, 2007.
- [4] J. W. Creswell. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. Sage Publications, Thousand Oaks, CA, USA, 3rd edition, 2009.
- [5] J. C. Cronjé. The ABC (aim, belief, concern) instant research question generator. Unpublished Manuscript, 2012.
- [6] P. J. Denning, C. Chang, and CC2001 Joint Task Force. Computing curricula 2001: Computer science volume. pdf, March 2001.
- [7] D. G. Feitelson. Experimental computer science: The need for a cultural change. Unpublished Manuscript, December 3, 2006, 2006.
- [8] P. Fletcher. The role of experiments in computer science. *Journal of Systems and Software*, 30(1–2):161–163, 1995.
- [9] R. L. Glass. A structure-based critique of contemporary computing research. *Journal of Systems and Software*, 28(1):3–7, 1995.
- [10] R. L. Glass, V. Ramesh, and I. Vessey. An analysis of research in computing disciplines. *Communications of the ACM*, 47(6):89–94, 2004.
- [11] M. Goldweber, J. Impagliazzo, I. A. Bogoiavlenski, A. G. Clear, G. Davies, H. Flack, J. P. Myers, and R. Rasala. Historical perspectives on the computing curriculum. *SIGCUE Outlook*, 25(4):94–111, 1997.
- [12] E. G. Guba and Y. S. Lincoln. Competing paradigms in qualitative research. In N. K. Denzin and Y. S. Lincoln, editors, *Handbook of Qualitative Research*, pages 105–117. SAGE, London, UK, 1994.
- [13] J. Gustedt, E. Jeannot, and M. Quinson. Experimental methodologies for large-scale systems: A survey. *Parallel Processing Letters*, 19(3):399–418, 2009.
- [14] C. G. Hempel. *Aspects of Scientific Explanation And Other Essays in the Philosophy of Science*. The Free Press, New York, NY, USA, 1965.
- [15] P. Johannesson and E. Perjons. A design science primer. Unpublished Manuscript, February 25 2012.
- [16] C. Marshall and G. B. Rossman. *Designing Qualitative Research*. Sage Publications, Thousand Oaks, CA, USA, 4th edition, 2006.
- [17] G. McKee. Computer science or simply ‘computics’?, the open channel. *Computer*, 28(12):136, 1995.
- [18] J. H. F. Meyer and R. Land. *Threshold Concepts and Troublesome Knowledge: Linkages to Ways of Thinking and Practicing within the Disciplines*. Number 4 in Occasional Reports. ETL Project, Universities of Edinburgh, Coventry and Durham, 2003.
- [19] J. H. F. Meyer and R. Land. Threshold concepts and troublesome knowledge: An introduction. In J. H. F. Meyer and R. Land, editors, *Overcoming Barriers to Student Understanding: Threshold Concepts and Troublesome Knowledge*, pages 3–18. Routledge, London, UK, 2006.
- [20] D. Perkins. Constructivism and troublesome knowledge. In J. H. F. Meyer and R. Land, editors, *Overcoming Barriers to Student Understanding: Threshold Concepts and Troublesome Knowledge*, pages 33–47. Routledge, London, UK, 2006.
- [21] G. Pólya. *How to Solve It*. Penguin Books Ltd., London, UK, 2nd edition, 1957.
- [22] K. Popper. *The Logic of Scientific Discovery*. Routledge, London, UK, 1959.
- [23] V. Ramesh, R. L. Glass, and I. Vessey. Research in computer science: An empirical study. *The Journal of Systems and Software*, 70(1–2):165–176, 2004.
- [24] J. J. Randolph. *Multidisciplinary Methods in Educational Technology Research and Development*. HAMK University of Applied Sciences, Hämeenlinna, Finland, 2008.
- [25] J. J. Randolph. A guide to writing the dissertation literature review. *Practical Assessment, Research & Evaluation*, 14(13):1–13, 2009.
- [26] Swedish National Agency for Higher Education. National qualifications framework. Technical Report 12-5202-10, Högskoleverket, May 2011.
- [27] M. Tedre. Methodology education in computing: Towards a congruent design approach. In *Proceedings of ACM Computer Science Education (SIGCSE) 2013 Conference*, pages 159–164, Denver, CO, USA, March 6–9 2013. ACM.
- [28] M. Tedre and N. Moisseinen. Experiments in computing: A survey. *The Scientific World Journal*, 2014(# 549398):1–11, 2014.
- [29] M. Tedre and J. Pajunen. An easy approach to epistemology and ontology in computing theses. In *Proceedings of the 13th Koli Calling International Conference on Computing Education Research*, Koli Calling ’13, pages 97–104, New York, NY, USA, 2013. ACM.
- [30] M. Tedre and E. Sutinen. Three traditions of computing: What educators should know. *Computer Science Education*, 18(3):153–170, 2008.
- [31] I. Vessey, V. Ramesh, and R. L. Glass. Research in information systems: An empirical study of diversity in the discipline and its journals. *Journal of Management Information Systems*, 19(2):129–174, 2002.
- [32] G. H. von Wright. *Explanation and Understanding*. Routledge & Kegan Paul, London, UK, 1971.
- [33] M. V. Zelkowitz and D. R. Wallace. Experimental validation in software engineering. *Information and Software Technology*, 39(11):735–743, 1997.
- [34] M. V. Zelkowitz and D. R. Wallace. Experimental models for validating technology. *Computer*, 31(5):23–31, 1998.