Layered models of research methodologies

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Abstract

The status of research methodology employed by studies on the application of AI techniques to solving problems in engineering design, analysis, and manufacturing is poor. There may be many reasons for this status including: unfortunate heritage from AI, poor educational system, and researchers' sloppiness. Understanding this status is a prerequisite for improvement. The study of research methodology can promote such understanding, but most importantly, it can assist in improving the situation. This paper introduces concepts from the philosophy of science and builds on them models of worldviews of science. These worldviews are combined with a research heuristics or research perspectives and criteria for evaluating research to create a layered model of research methodology. This layerd model can serve to organize and facilitate a better understanding of future studies of research methodologies. The paper discusses many of the issues involved in the study of AI and AIEDAM research methodology using this layered model.

> How can our intellectual life and institutions be arranged so as to expose our beliefs. conjectures, policies, positions, sources of ideas, traditions, and the like —whether or not they are justifiable—to maximum criticism, in order to counteract and eliminate as much intellectual error as possible? (Bartley, 1962, p. 140)

1 Introduction

The term *methodology* means different things for different researchers. Some researchers equate methodology with method. In doing so, research methodology becomes synonymous to the activities performed in research projects; for example, conducting observational studies of designers and using the results to guide the development of CAD tools. While such description important, it misses fundamental information that is part of the literal meaning of the term methodology: *the theory of methods.*

In this paper, we discuss the literal meaning of the term and some of its interpretations that are related to the study of artificial intelligence techniques in solving engineering design, analysis and manufacturing problems (AIEDAM). Clearly, the issues involved in studying theories of any kind are relevant. Therefore, central to this discussion are questions such as (Bunge, 1983, p. 1):

> (1) What can we know? (2) How do we know? (3) What, if anything, does a subject contribute to his knowledge? (4) What is truth (5) How can we recognize truth? [...] (6) Is there *a priori* knowledge, and if so of what? (7) How are knowledge and action related? (8) How are knowledge and language related?

These questions are studied in the philosophy of science, and more specifically in *epistemology* — the philosophical branch that deals with the theory of knowledge. Given the apparent insoluble status of these questions, why are we attempting to deal with them? What do we hope to achieve by studying research methodology? Why do we think that it is worthwhile for researchers and not just for philosophers do address these questions? Bartley's quote provides some motivation for such study; if we observe the number of papers discussing the myths, legends, and fallacies associated with some AI topics (e.g., AI (Fox, 1990), expert systems (Liebowitz, 1987; Mettrey, 1992), fuzzy logic (Cox, 1992), or machine learning (Buntine, 1990)) we may start to appreciate what such a study can offer.

This paper starts by introducing basic concepts from the philosophy of science that are related to research methodology (Section 2). The paper explains through various arguments why the study of AIEDAM research methodology is critical to research quality (Section 3). Subsequently, the paper focuses on the research methodology of AI and AIEDAM (Section 4). The issues involved in their study are discussed at various levels. The paper does not attempt to delineate all issues since many of them cannot be known *a priori.* Rather, the paper aims to provide the background, motivation, and a framework for organizing and understanding studies of AIEDAM research methodology.

2 Philosophical preliminaries

Methodology, immediately connotes with philosophy. We do not deal with the philosophy of science in this paper, but we will borrow from its sources as necessary to explain issues central to research methodology. In particular, we discuss three issues: the evolutionary nature of research methodology, a model of a worldview, and two example worldviews that we employ.

2.1 The evolution of the concept of research methodology

We have been referring to research methodology as the theory of methods. As any other concept, its meaning evolves continually. We can demonstrate this by tracing its meaning since Leonardo da Vinci's time. Leonardo (1452-1519) was an artist and an engineer who combined the two in his quest for knowledge of all kinds, but for practical purposes. While he used experiments, they were not systematic; his measurements were imprecise; and he lacked adequate language for expressing his ideas (Gille, 1966). Interestingly, at the beginning of his *Notebooks*, Leonardo discussed three propositions that capture three ideas central to science: the essence of empiricism, the importance of mechanistic inquiry, and the primacy of mathematical explanations.

Leonardo's propositions were adopted partially by Descartes (1561-1626) and Bacon (1596-1650). While Descartes elevated mathematical reasoning as the sole source of knowledge, Bacon advocated for a deductive induction of theories from a comprehensive set of observations of some empirical phenomena. Nobody seemed to have followed either in practice. For example, their contemporary Galileo (1546-1642) had mainly employed geometric formalization and thought experiments, a mix of the two that is very different from what we would expect of researchers today but nonetheless, one that associated him with the invention of the scientific method (Pitt, 1992). Similarly, Newton (1643-1727) employed mathematical reasoning but added unproved assumptions when they helped to explain natural phenomena. Over the years the term research methodology evolved through various stages in which the status of theories changed from entities that can be deduced, confirmed, refuted to being arguments justified by some statistical inference (Giere, 1984).

Clearly, research methodology — the *prescriptions* or the acceptable ways of doing science or as Bunge (1983) called it, *prescriptive epistemology* — has evolved through the years. It evolved whenever the working interpretation of the time would no longer be meaningful or appropriate such as after the development of quantum mechanics. Such evolution necessarily happens in any man-made artifact ranging from theories to mundane objects such as utensils (Petroski, 1992).

If these prescriptions evolve, than at best they are *working hypotheses* of what should be done to achieve some research goals. Thus, we can study the evolution of hypotheses that researchers employ and their utility in achieving research goals. This may turn research methodology into a *descriptive* enterprise with practical consequences to research.

2.2 A model of a worldview

Research methodology can be described as a collection of methods for doing research and their interpretations. If we ask what do different worldviews of science adopt as their research methodology and why, we will find that research methodology is intimately connected with, and constrained by, the worldview it serves. In this paper we model the concept *worldview* as a position about three issues (Guba, 1990b): *ontology*, *epistemology*, and *methodology*.

Ontology deals with the nature of the things we know about the world or the nature of the world. A central ontological question is "do we know things about the 'real' world or is our knowledge a reflection of our manipulation of the world?" To illustrate the conflict, consider that much of science is based on the use of scientific instruments that allow us access to those phenomena that can be detected or measured only by them. Consequently, our relation with the world is through these instruments (i.e., is hermeneutic). Further, we do not just develop scientific instruments but also create complete artificial settings which we study; for example, a CAD system with its user. Although we can be rather confident that the artificial setting exists since we have created it, we cannot be sure that a *phenomenon we wish to study* in relation to the setting really exists.

Epistemology deals with the relation between humans and their knowledge. We have already mentioned some of the central epistemological questions in the introduction. Answers to these questions may advocate that facts have a prime status while others may claim that theories are the reflection of nature. A third position may state that theoretical concepts are meaningful only if they involve some activity such as measuring, and a fourth position may claim that we arrive at knowledge by participating in social processes. These epistemological positions together with those about ontology, imply adopting different research methods and their interpretations as illustrated in Section 2.3.

Methodology deals with the methods for creating knowledge about the world and the interpretation of this knowledge in light of the ontological and epistemological positions. Methodology is concerned with questions such as: how is research planned and executed, how are theories created and tested, and how are the tests interpreted.

There are at least two concepts in science that resemble this model of a worldview: Kuhn's paradigm (Kuhn, 1962) and Lakatos' research programme (Lakatos, 1968). A paradigm is more fuzzy than the model of worldview described herein; it is a corpus of concepts and theories shared by a group of scientists. In periods of "normal science" scientists employ various imprecise criteria to guide their research. When certain anomalies are discovered, paradigms may clash, leading to revolutionary changes that cannot be explained on the ground of empirical evidence or rationalization. In contrast, a research programme has a hard core which is kept fixed and auxiliary hypotheses that protect the hard core from any contradicting evidence. The work of scientists is the development of these auxiliary hypotheses using some standards. A major difference between these models is the conceptualization of a change in science: according to Kuhn, change comes through "irrational" revolutions, whereas according to Lakatos, through the use of acceptable evaluation criteria and judgment.[1]

A worldview has a profound interaction with the research questions we choose to investigate. Some questions are interesting or even meaningful only within a particular worldview and some research questions limit our horizon to seek alternative worldviews. For example, the question "can machine think?" is important to mainstream AI but is inconsequential to the view of AI as an engineering discipline. A concept of worldview is also linked to a host of issues other than the three aforementioned including: training (in doing research and practice), ethics, and values. We will not deal with these issues here but see (Guba, 1990b) for such discussion.

2.3 Scientism and practicism

There may be several worldviews of science. There are, however, two worldviews that outline the range of possible worldviews: *scientism* and *practicism*.[2]

The first and most prominent in science, engineering, as well as in other academic disciplines (even though we have witnessed its demise in philosophy), is *scientism*. It represents the essence of worldviews like rationalism, positivism, post-positivism, and logical empiricism. Even if there are major differences among these positions, at a meta-theory level they are the same (Weimer, 1979). The position of scientism about the three issues is as follows (Guba, 1990a):

Ontology:	*Realist*—reality exists "out there." Reality operates according to cause-and-effect free-context laws. By discovering these laws science achieves its goal to predict and control phenomena (whether natural or otherwise).
Epistemology:	*Objectivist*—researchers can acquire objective knowledge about the real world through the employment of appropriate methodology.
Methodology:	*Experimental/manipulative*—hypotheses are stated in advance and are subjected to test under carefully controlled conditions. The researcher adopts a distant position, thus achieving value-free knowledge.

Figure 1 outlines a common model of the research methodology of scientism. The execution of each of the steps becomes candidate for a methodological study; although the structure is assumed to be given.

Figure 1: Research methodology of scientism (adapted from (Schumm, 1991))

Practicism is the rival worldview that captures the essence of perspectives such as action research,

[1]There are also other interpretations of Kuhn and Lakatos' views (Weimer, 1979).

[2]Rowan (1981) mentions a list of 19 perspectives which can be grouped into fewer worldviews. Also, there are many variations on scientism and practicism (including variations on their names), some that depend on the particular discipline and some on the personal interpretation of writers. See (Guba, 1990b; Reason and Rowan, 1981; Smith and Dainty, 1991) for three examples. The present interpretation is different than those in some aspects.

participatory action research, human-centered engineering, or critical constructivism (a hybrid of critical theory and constructivism). The position of practicism about the three issues is as follows (Guba, 1990a):

Ontology:	*Relativist*—reality exists in the mind of people and within a certain value-laden theoretical framework. By interacting with the world, people can reconstruct their perception of it in their mind. When the interaction involves technological or organizational changes, the goal of the inquiry may be achieving improved practice.
Epistemology:	*Critical subjectivism*—since theories about reality are value-laden, there can be nothing but a subjectivist interaction with the world. To avoid misuses of subjectivism a critical methodology must be adopted.
Methodology:	*Critical hermeneutic/dialectical*—Reality is constructed through the identification of multiple (including contradicting) constructions and their critical comparison, thus improving the grounds for making informed choices between constructions.

Practicism have an explicit stand on the value, ethics, and human nature issues, especially when they are interpreted in the context of social sciences. For example, in management science human nature would be deterministic under scientism and voluntary under practicism.[3]

Figure 2 outlines a model of the research according to practicism. It presents a holistic, contextualized, and interactive view of research. Each of these interactions or influences may be a subject to revisions or methodological studies which can revise the complete model including the addition or deletion of influencing factors or relations.

Figure 2: A contextualized model of practicism (adapted from (Smith, 1991))

Scientism and practicism are diametrically opposing worldview models. Yet each of them is a self-consistent model in that their ontology, epistemology, and methodology do not contradict one another. Such contradiction would occur in a model with a realist ontology, objectivist epistemology, and dialectic methodology. The consistency is also manifested in Table 1 which summarizes the two worldviews.

3 Why study AIEDAM research methodology?

The evolving and social nature of methodology does not empty the usefulness of some principles for evaluating scientific theories (Kuhn, 1987) nor does it mean that methodology is merely an art that is not amenable to systematic study. The next sections discuss this in more detail.

[3] AI foundations, being rooted partly in management science through Simon's views, assume that human nature is deterministic.

Table 1: A summary of two worldviews (adapted from (Smith and Dainty, 1991; Reason and Rowan, 1981))

	Worldview	
Dimension	*Scientism*	*Practicism*
Researcher's relationship to setting	Detachment, neutrality	Immersion
Validation basis	Measurement, logic, reliability, external validity	Experiential
Researcher's role	Onlooker	Actor
Source of categories	*A priori*	Interactive emergent
Aim of inquiry	Universality and generalizability	Situational relevance
Type of knowledge acquired	Universal, *theoria*, precise, causal, cumulative, reductionistic	Particular, *praxis*, imprecise, multiple causation, problematic, holistic
Nature of data and meaning	Factual, context free	Interpreted, contextually embedded
Status of science as a field of knowledge	Privileged, progressive, autonomous	Not separated from other fields of knowledge
Value content	Value free	Value laden
Aim of science	Prediction and control	Promotion of human development

3.1 General motivation

First, we observe that there are differing viewpoints about the role of AIEDAM research: some researchers think that AIEDAM research is about gaining an *understanding* of some phenomena (e.g., *what* is design?) while others stress the *practical relevance* of research (e.g., *how* can we aid design?). These differing objectives are originating from the two perspectives of research discussed in Section 2.3: *scientism* and *practicism*. Recalling the different methodologies that each of these worldviews entail, it is clear that each of these objectives has its own suitable effective method of inquiry. It thus becomes useful to study which technique is most suitable to achieve a specific research objective and in what circumstances is it effective.

The differences between understanding and practical relevance become apparent in two possible debates. In one debate, some researchers argue that research has led to the understanding of some phenomena while others comment that research tools are not used in practice (National Research Council, 1991) thus questioning the understanding achieved by research (Reich, 1992). This debate cannot be resolved. In the second debate, some researchers argue that research cannot lead to the understanding of some phenomena (e.g., Wilkes' claim that present AI research cannot lead to mimicking human intelligence (Wilkes, 1992)) while others question or dismiss such claims by defending AI technology, arguing that AI has impacted practice (e.g., the comments by Hayes, Novak, and Lehnert to Wilkes position in *CACM*, 35(12):13-14). Such debate is meaningless because the second claim does not address the criticism and the first claim does not argue with the second. For example, independent of whether Wilkes analysis is correct or not, technological or practical impact can provide no evidence that AI can mimic human intelligence (West and Travis, 1991), nor does Wilkes question such impact. Clearly, given different worldviews, there is no consensus on the status of research and the criteria for its evaluation, and there is a confusion between the positions of the different worldviews. Both problems could benefit from a study of research methodology.

Second, we learn that there is an increasing number of critiques on, and differing viewpoints about, research methodology of many disciplines relevant to the study of AIEDAM including: social sciences (Guba, 1990b; Palumbo and Calista, 1990; Reason, 1988; Whyte, 1991), management science (Argyris, 1980; Smith and Dainty, 1991), information systems (Bjerknes et al, 1987; Floyd et al, 1992), and various branches of engineering (Addis, 1990; Reich, 1992; Vincenti, 1990). These critiques are rooted in observations that scientism — the *model* of science that drives much of contemporary research methodology — is flawed, and that modeling science as a contextualized enterprise is more akin to the practice of science. These critiques display the tension between scientism and practicism and tell us that models of AIEDAM research must be reflected upon since some of these models might be deficient.

Third, no one can deny that research is a very complex and demanding design activity including: the selection of research questions; the solicitation of funding; the planning and executing of research activities; and participating in social activities such as attending academic meetings. As a practical activity, research can benefit from the kind of reflection-in-action so fundamental to the successful practice of different practitioners (Schön, 1983). Clearly researchers, as other practitioners, reflect while pursuing their activities, for example, in the face of an impasse in their research. The study of AIEDAM research methodology can provide much information for resolving such impasses. It is instructive to remind that reflection-in-action was construed as an explanation of practical competence that arose out of a critique of technical rationality which, according to scientism, is the source of practical competence. Unfortunately, reflection is foreign to scientism (Habermas, 1971) because scientism forces its followers to "objectivate" themselves out from studies. Again, these perspectives on the source of practical competence are manifestations of the tension between scientism and practicism.

Some researchers in disciplines overlapping AIEDAM have already reflected publicly upon their research activities. For example, researchers working on human computer interaction (HCI) have reflected on the lack of influence of cognitive psychology research on the development of HCI systems (Carroll, 1991); researchers working on the development of knowledge-based expert systems have commented that much user control is required for the successful development of systems (Marques et al, 1992; McDermott, 1994); and researchers working on information systems and, in particular, on computer-supported cooperative work (CSCW) have learned that a collaborative research of developers and users (e.g., participatory design (PD)) may be a prerequisite for projects success (Floyd et al, 1992; Muller et al, 1992). These examples at least suggest that similar approaches might be necessary, or at least useful, to meet AIEDAM research goals.

In spite of the need to study research methodology, it is lacking from AI (Cohen and Howe, 1988; McDermott, 1981; West and Travis, 1991) engineering design (National Research Council, 1991; Ullman, 1991; Reich, 1992), or AIEDAM. There are, of course, numerous studies on, and critiques of, AI research methodology, even by prominent researchers (Bundy, 1990; Hall and Kibler, 1985; McDermott, 1981; Partridge and Wilks, 1990). Nevertheless, the number of these studies or critiques is negligible. In many cases, these critiques are based on the study of AI research projects (Ritchie and Hanna, 1984) or AIEDAM research projects (Cohen and Howe, 1989; Fenves et al, 1994; Reich, 1993a). Note that while such reflections are consistent with some worldviews, notably practicism, they are outside the realm of scientism because case-study methods are neither controlled nor objective and, certainly, controlled experiments cannot be performed at the level of research projects if only for resource constraints. Scientism cannot accept a situation that contradicts its method of inquiry thus, attempts to ignore the study of research methodology.

So far, we have motivated the study of research methodology by giving a *biased* exposition of two perspectives of science. Personal preference aside, the reason for giving practicism some preference over scientism is its inferior status among researchers: The majority of researchers in all disciplines subscribe, in theory, to variants of scientism which they associate with a mature discipline (Bailey, 1992; Dixon, 1987; Nazareth and Kennedy, 1993), although in practice, they may employ different perspectives. Scientism is also predominant in the education of engineers and researchers in most disciplines (Kerr and Pipes, 1987; Schön, 1983; Reich, 1992).

3.2 A layered model of research methodology

The concept of research methodology transcends the level of worldview to include at least two additional levels. The second level includes *heuristics* for doing research: these are methods for modeling and solving problems in a particular manner. They are particularly useful for guiding the *creation* of theories. In each research worldview there can co-exist different heuristics for doing research and some heuristics can serve several worldviews. Therefore, researchers may choose one or many heuristics depending on the context of their research as displayed in Figure 2. They should be careful, however, to make sure that their heuristics are compatible with their worldview. Useful heuristics include:

- *Cognitive science perspective* is informed by insight from psychology. The work on case-based reasoning originated from this perspective.
- *Decision science perspective* attempts to augment the deficiencies of human decision-maker, such as psychological biases. A system consisting of a human and an AI tool is expected to perform better than human experts (Levi, 1989).
- *System science perspective* attempts to view a project within a larger system that is expected to function. This view can lead to the development of embedded systems.
- *Software engineering perspective* attempts to create software for doing specified tasks. Exploratory programming is a prime example of this heuristic.

The third level deals with *specific issues* such as the methods for evaluating hypotheses and the criteria for such evaluations (Adelman, 1991; Adelman et al, 1994; Cohen and Howe, 1989).

Given these layers, we cannot limit the study of research methodology to a particular level of abstraction and refer to the models of research methodologies as *layered models*. Table 2 depicts the three layers each with several examples. Not all the combinations of worldviews and research heuristics have been practiced or are meaningful. Similarly, not all triplets of worldview/heuristics/specific issues are meaningful. Some of the issues related to the first and second layers are outlined in (Hall and Kibler, 1985), and issues related to the third layer are discussed in (Adelman, 1991; Adelman et al, 1994; Cohen and Howe, 1988)

Table 2: A layered model of research methodology

Layer	*Examples*
Worldviews	• Practicism • Scientism
Research heuristics (sources of theories or hypotheses)	• Cognitive science • Decision science • Formal methods • Human centered • Software engineering • Systems science
Specific issues (evaluation or goodness criteria)	• Formal representation • Parsimony • Practical relevance

3.3 Hypotheses and their experimental testing

In order to demonstrate the importance of studying research methodology let us examine an issue that transcends the three layers of research methodology: *the relation between hypotheses and experimental testing*. We have already mentioned several perspectives on the relative status of hypotheses or theories and experimental evidence or facts. Amongst the perspectives is the one that views theories as primary and another that views facts as primary. But, the relation is more entangled.

To start with, some hypotheses are irrefutable or untestable. For example, Duhem (1982) discussed Poincaré's hypothesis that "the center of gravity of an isolated system can have only a uniform rectilinear motion." Unfortunately, the only true isolated system is the universe, but since we can observe only relative motions, we will never be able to test Poincaré's principle. Therefore, we will always be free to assume or believe it is true. In Duhem's words, such hypothesis "cannot be refuted by experiment because the *operation which would claim to compare them with the facts would have no meaning.*" (emphasis in the original, p. 166) This places Poincaré's principle outside the scope of interaction with evidence or facts.

While some hypotheses *cannot be tested*, others could. Nevertheless, it is uncertain that such testing would be beneficial to scientific progress. For example, in the case of the theory of thermodynamics, some experiments were distracting (Truesdell, 1982). There are therefore conditions under which experimental evidence might be ignored and contrasting hypotheses retained (Agassi, 1975). In fact, significant theorizing by Galileo (Feyerabend, 1975) and others progressed in the face of contradicting evidence.

In spite of this complex relation between theories and facts, the acceptable practice is the one employing statistical inference on data gathered from controlled experiments for selecting between rival hypotheses. But using statistical inference is not without its presuppositions or misuses (Hooke, 1983; Shvyrkov, 1987). Sometimes useless results are portrayed as successful, while in other situations results seemingly useless (e.g., from confounded statistical experiments) can be analyzed to reveal some useful insight (Brinberg et al, 1992).

So far this discussion was aimed at promoting the study of research methodology using ideas from the main stream worldview—scientism. We should note that researchers subscribing to other worldviews must be aware that completely different issues may be present in their research; for example, controlled experiments may not work if one adhere to participatory action research (PAR) (Blumberg and Pringle, 1983). Similarly, the ideas relevant to worldviews other than scientism may not work for projects that are in tune to scientism (Sloane, 1991).

From this discussion, it is clear that the principle of testing by experiments, interpreting the data, and using it in evaluating hypotheses is not trivial. Thus, we need not be hard pressed to justify or falsify theories. Indeed we cannot do it in principle because any empirical evidence could be incorporated to save any hypothesis. This does not mean that we need to adopt a conventionalist approach saying that theories are simply selected by convention; nor does it mean that experimental testing can be eradicated, thus inviting sloppiness. The complex relation between hypotheses and empirical evidence demonstrates that experimental testing must be used carefully, studied, and reflected and improved upon, by members that pledge allegiance with any worldview.

4 The study of AI and AIEDAM research methodology

From all research disciplines AI must be most reflective upon its methodology due to two reasons: it is young and it has "hutzpa." AI is a young discipline and as one that is supposedly in a pre-theoretic stage it permits much exploratory research with informal testing. AI allows *doing scruffy research in a scruffy manner* and even advocates that such style may be a source of power (Lenat and Brown, 1984; McDermott, 1981). AI is most vulnerable because it makes claims far beyond what other disciplines dream of making (Sharkey and Brown, 1986) — the prime one being that of mimicking human intelligence.

The need for reflection is not taken seriously in AI. First, AI has evolved really only one serious paradigm (Newell, 1983). Although other worldviews exist, most notably the one of applied AI, or AI as an engineering enterprise (Bundy, 1990), they are not separated from the dominant worldview by detailing the differences—simply recall Wilkes' position about hard-core AI and Hayes', Novak's, and Lehnert's responses discussed in Section 3. It had been said that AI methodology is a mess that needs to be sorted out (Bundy and Ohlsson, 1990); that AI researchers often make the mistakes of their preceding peers (McDermott, 1981); that AI researchers are hyper-sensitive to criticism, especially that dealing with the foundation of AI (West and Travis, 1991); or that AI researchers do not want to deal with philosophical issues originating from AI (Partridge and Wilks, 1990). A prime example is the reaction of the AI community to Winograd after the publication of *Understanding Computers and Cognition* (Winograd and Flores, 1986) that challenged the underlying assumptions of AI (West and Travis, 1991).[4]

This status and attitude makes AI looks similar in structure (although not in its way of evolution) to a research programme: it has an unchallenged hard core that states that "a physical symbol system has the necessary and sufficient means for general intelligent action" (Newell and Simon, 1976, p. 116) and various auxiliary hypotheses that are developed to protect it. Independent of whether the hard core can or cannot be tested seriously, for example, through some Turing test (and whether such test is truly a test of the hypothesis (Halpern, 1987)), it is accepted without much self criticism and maintained without supporting evidence (Dietrich, 1990). It also suffers from the misuses of terminology (McDermott, 1981) that perpetuate various legends, myths, and fallacies related to AI.[5] We believe that the study of AI research methodology will improve this situation.

AIEDAM research borrows much of its legitimacy, approaches, and theories from general AI research, as well as the need for methodological studies. But, the study of AIEDAM research methodology is more critical than that of AI because in engineering the phenomena under investigation or the inquiry context is always changing due to engineering advances. A positive example of understanding this issue is the statistical technique bootstrap that eliminates many assumptions required for classical statistical techniques and that was made possible by the availability of fast computing power (Efron and Tibshirani, 1991). A negative example is the desire to build HCI tools by doing cognitive science research—Pylyshyn (1991) acknowledges that this approach has proved fruitless.

Having established the need to study AI research methodology in general, we can elaborate on some of its ingredients, involving the three layers of the model of research methodology. First, researchers can question the hard core by trying to understand its source or what are the consequences that this hard core entail that are not articulated.[6] Researchers can evolve an alternative research paradigm. Such paradigm is already emerging in the form of AI as a practical engineering discipline.

[4] Not that this book is free of criticism. My major criticism is the utilization of Heidegger's ideas without thinking of their relation to him being a Nazi and ignoring the ramification that this might have on the new understanding the book proclaims. A small sample of sources on this issue includes (Bernstein, 1992; Farías, 1989; Wolin, 1990).

[5] Some of the papers discussing those myths were written by prominent AI researchers but they did not ponder about AI hard-core. For example, Fox (1990) considered the following facts: "search is a core AI concept;" "AI reduces search combinatorics by applying situational knowledge;" "AI enhances search through the use of opportunism;" "knowledge representation is a core AI concept;" and "AI knowledge representation extends quantitative models by abstraction and differentiation." The way the facts were stated, they only dealt with AI technology, not underlying assumptions.

[6] Some answers to these questions can be found in (Waring, 1991; Weizenbaum, 1976; Winograd, 1990).

Second, researchers can study the practice of AI researchers and the outcomes of their research projects to better associate research perspectives or heuristics with their successes or failures. Third, researchers can study specific detailed issues in pursuing different research methods such as various methods of evaluation. The following subsections briefly discuss these issues.

4.1 Questioning the hard core: Programs as hypotheses and their experimental testing

It is common to perceive AI programs as research hypotheses or theories. However, AI programs do not fit well the model of theories in science. They are hard to evaluate, for example, consider the testing of theories through their behavior — a form of Turing test. Suppose that a system arrives at a solution to a problem where experts contend that there is not enough evidence to reach a conclusion. "Is the system brilliant? or precocious (Pople, 1985)?" Did the theory receive positive support? The answers depend on the *way* the system arrived at the conclusion. But in order to uncover this way, one has to look inside the program, not merely at its trace, and AI programs are too big to be comprehensible. Thus, even if a claim is made that a program implements a theory, it is almost impossible to verify such statement. Consequently, the perceived explanatory power of programs is not realized (Sharkey and Brown, 1986).

If AI programs are too complex to be parsimonious and too hard to understand; if their behavior is hard to justify; and if they rarely generalize to be applicable to many situations; can their behavior at least be replicated? The AI solution to this challenge is the reconstruction of AI programs. Unfortunately, there are hardly any examples of rational reconstruction of large AI programs (Campbell, 1990). To illustrate, even the successful reconstruction of Protos (Bareiss, 1989) into CL-Protos (Dvorak, 1988) does not count as a reconstruction because it was carried out within the same research group that developed it; therefore, beside the written material that documents the theory that Protos embeds, the original developers assisted in the reconstruction task. A true reconstruction is supposed to rely only on written documents; otherwise, how can anybody claim that its source of power if the written theory.

To exacerbate these difficulties, the description of AI programs is deficient: language is misused (McDermott, 1981), and omissions and errors are made in reporting (Grabiner, 1986; Ritchie and Hanna, 1984). If programs are hardly reconstructed, at least they need to be made available so that their behavior could be experimented with by other researchers (Reich, 1991). In this case, CL-Protos is one good example.

The preceding discussion suggests that AI programs are not really theories. There is a different paradigm for AI that may relieve some of these problems even if not eliminate them: AI as an engineering discipline whose aim is to build practical tools. For such a worldview, theories need not be easily transferable, they can be context dependent. However, the need for their proper evaluation is still central.

4.2 An alternative paradigm: AI as an engineering discipline

To better understand the alternative paradigm consider the role that is assigned to computers in scientism and practicism and how these roles guide AI research. Scientism contends that computers can mimic human thinking. The theoretical arguments for this capability tend to be philosophical while the empirical work can only deal with simplified behavior or even fail to demonstrate its claims. For example, see the critique of: the Logic Theorist and GPS (Dietrich, 1990), AM and Eurisco (Dietrich, 1990; Ritchie and Hanna, 1984), and BACON (Chalmers et al, 1992; Dietrich, 1990; Grabiner, 1986).

In contrast, the engineering approach had successes such as: MACSYMA, DENDRAL, R1/XCON, and others (Dietrich, 1990; Dym and Levitt, 1994; Tomiyama, 1994). The engineering viewpoint simply argues that computers can become effective engineering tools. There are no grand theories to this viewpoint; the empirical work deals with building systems and demonstrating their practical effectiveness. It becomes critical to determine what constitutes such acceptable demonstration.

Adopting a practical objective does not guarantee research success. Primarily, since a practical objective is only one part of practicism. To illustrate, consider the development of various general AI tools (or shells), such as KEE, ART, or Nexpert. According to Fikes, these tools have hardly been used for building real applications (Hayes-Roth and Fikes, 1991). The common practice, according to Hayes-Roth, is the building of many *ad hoc* systems that have little sharing between them (Hayes-Roth and Fikes, 1991). Looking at Table 1 we can see that the research products of practicism are contextually embedded and particular, rather than context free or general. Therefore, the actual practice of building applications is not surprising.

Practical success implies a significant understanding of the target application domain. A good understanding can lead to major success (e.g., the finite-element program STRESS), while exercising less involvement in practice may lead to practically irrelevant research (Fenves et al, 1994; Reich, 1994). Practicism demands researchers immersion in practice. This immersion may be approximated or take different forms such as: revising the educational system so that researchers have significantly more practical training (Dym and Levitt, 1994); engaging in participatory (Reich, 1994) or collaborative (Steinberg, 1994) projects; or letting those experts in the application domain (i.e., target users of the tools) to control the product (Marques et al, 1992; McDermott, 1994). Another view argues that the building of practical tools requires professional system builders (Hayes-Roth and Fikes, 1991). It is unclear what is the role that this view assigns to other potential contributors to the development of tools.

4.3 Research perspectives/heuristics: Sources of hypotheses

In Section 3.2 we discussed the layered model of research methodology. A combination of a world-view and a research heuristic or perspective provides much of the guidance for research. Hall and

Kibler (1985) discussed five AI perspectives: performance AI, constructive AI, formal AI, speculative AI, and empirical AI. These perspectives are some combinations of worldviews and research heuristics and are not just worldviews.[7]

Examples of these combinations that follow Table 2 are (note that some examples could be placed in multiple combinations):

- Scientism—Formal methods: logic as presented in (Genesereth and Nilsson, 1987). Note that by removing the introductory chapter of this book, the techniques described in it can serve well a practicist—formal method perspective. This combination is similar to Hall and Kibler's formal AI.
- Scientism—Cognitive science: hard core AI, e.g., Soar (Laird et al, 1987). This combination is similar to Hall and Kibler's empirical AI.
- Scientism—Human centered: this combination is *incompatible*.
- Scientism—Systems science: vision (Marr, 1982). This combination have some overlap with Hall and Kibler's formal AI.
- Scientism—Software engineering: e.g., CYC (Lenat et al, 1986). This combination contains Hall and Kibler's speculative AI, and part of constructive AI.
- Practicism—Formal methods: proof planning (Lowe, 1994) or qualitative physics (Tomiyama, 1994).
- Practicism—Cognitive science: case-based reasoning (Pearce et al, 1992).
- Practicism—System science: integration of AI with other software tools and hardware (Pardee et al, 1990), or robotics (Brooks, 1991).
- Practicism—Software engineering: building performance tools, e.g., MACSYMA (Moses, 1971), situated software tools (Marques et al, 1992; McDermott, 1994), or computational design aids (Steinberg, 1994). This combination includes Hall and Kibler's performance AI.

Few of the combinations involving practicism have actually been tested in practice, yet the examples depicted are of those projects whose stated objective is demonstrating practical relevance. This goal is bound to drive researchers to conduct methodological reflection because its attainment requires a continuous improvement of research practice.

[7]To illustrate, when they mention that Feigenbaum shifted from empirical to constructive AI, they really meant that he changed his research heuristic from cognitive science to software engineering, while maintained his adherence with scientism.

4.4 Specific issues: Goodness or evaluation criteria

There can be many ways to assess the quality of AI projects. Some criteria for assessing the quality of AI projects seem straight forward (Bundy, 1990):

- Parsimony: but we have already claimed that most AI programs do not satisfy it;
- Clarity is a prerequisite: but AI programs are not clear, sometimes not to their developers;
- Power—wide range of applicability (e.g., counter to a PhD program): but this contrasts with Hayes-Roth (Hayes-Roth and Fikes, 1991) and with our previous analysis;
- Completeness (be finished and work): but this can hardly be done unless the target practical domain is fully understood;
- Correctness (behave as intended): but can this be assessed?, just consider the vast amount of literature on the validation of expert systems which cannot guarantee correctness; and
- Commercial success: we can hardly quarrel with this.

Interestingly, even though this list seems impossible to satisfy by any research project, it may still be consistent with practicism and lead to practical success due to the last item. From a pracisist perspective this list may be seen as an ideal that can hardly be attained.[8]

There are many specific issues and details that play different roles in the evaluation of research projects,; details on such issues can be found elsewhere (Adelman, 1991; Adelman et al, 1994; Cohen and Howe, 1988; Reich, 1993b). Independent of all the details, the rule that must be followed is that the way a hypothesis is tested depends on the answer sought from the test. If the purpose is improving practice, then a study that illustrates such improvement should be furnished. If the purpose is to understand how does the hypotheses function given different parameters, then controlled experiments must be performed. If the purpose or research is the creation of an implementable theory, one should create computer models of the hypothesis and show that the computer model indeed implements the theory. There is no need to test the practicality of the theory (but there cannot be such claim without such demonstration).

The analyses of tests also depend on the objective of research: statistical inference is suitable for controlled experiments and more complex analysis may be needed for assessing practical improvements (e.g., quality of practice, time to perform practical activities, revenue of practitioners).

[8] Bundy and co-workers attempt to adhere to these principles by the development of proof planning (Bundy, 1988; Lowe, 1994).

5 Summary

This paper has covered many grounds, and in a partial manner only. We have discussed the philosophical background of sciencific research methodology and presented several motivations for conducting methodological studies of AIEDAM research. We have illustrated the complexity of the issues involved in such studies by discussing AI research methodology and its problems and by describing a framework that can help organize and understand such studies. We hope that this is not a summary but the preview of a continuous reflection that will AIEDAM improve research practice.

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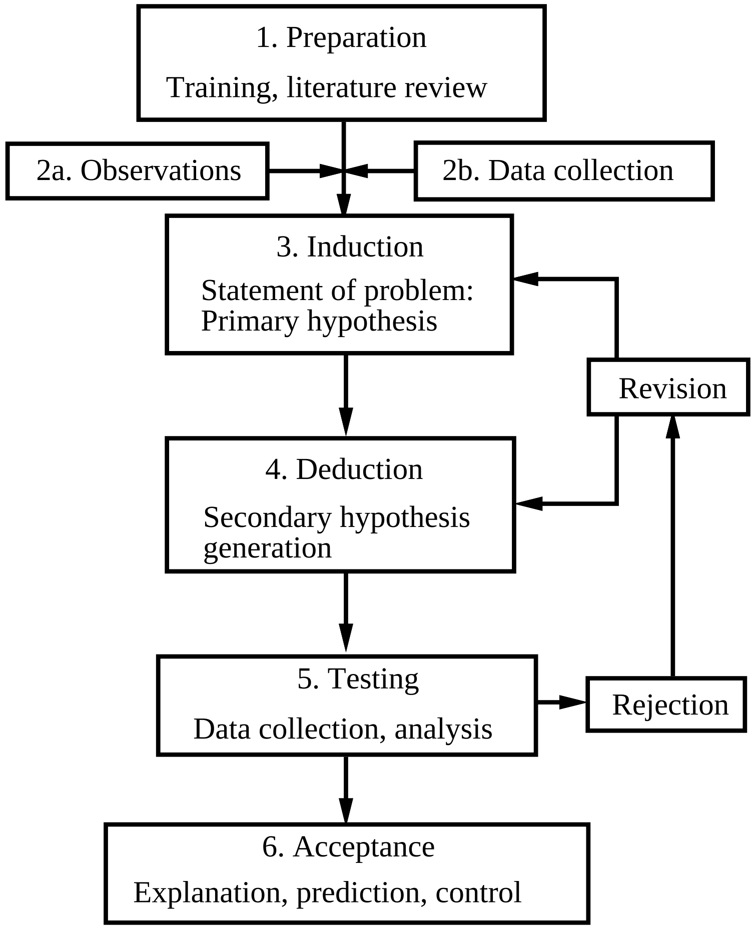
Figure Captions

- Research methodology of scientism (adapted from (Schumm, 1991))
- A contextualized model of practicism (adapted from (Smith, 1991))


1. Preparation
Training, literature review
2a. Observations
2b. Data collection
3. Induction
Statement of problem:
Primary hypothesis
Revision
4. Deduction
Secondary hypothesis
generation
5. Testing
Data collection, analysis
Rejection
6. Acceptance
Explanation, prediction, control

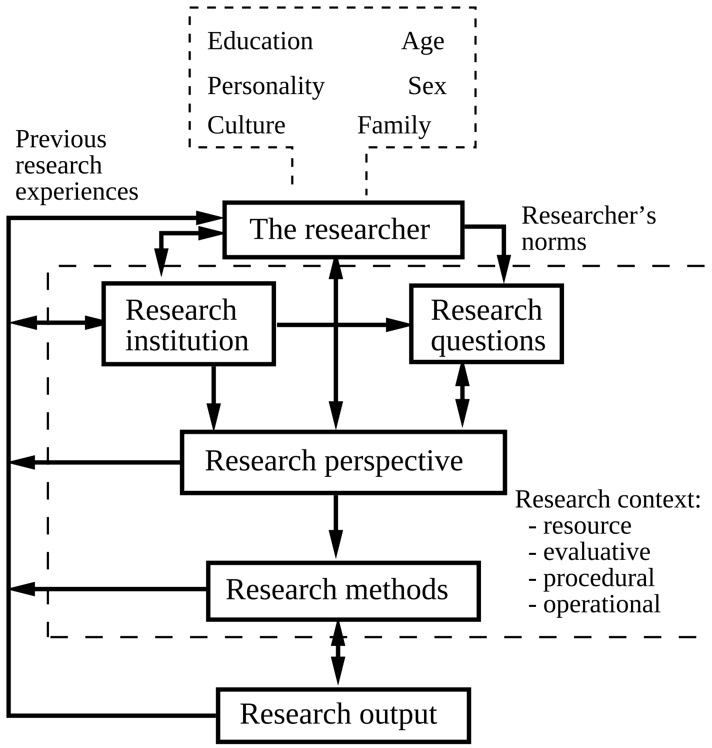

Education
Age
Personality
Sex
Culture
Family
Previous research experiences
The researcher
Researcher's norms
Research institution
Research questions
Research perspective
Research context:
- resource
- evaluative
- procedural
- operational
Research methods
Research output

Table Captions

- A summary of two worldviews (adapted from (Smith and Dainty, 1991; Reason and Rowan, 1981))
- A layered model of research methodology

	Worldview	
Dimension	*Scientism*	*Practicism*
Researcher's relationship to setting	Detachment, neutrality	Immersion
Validation basis	Measurement, logic, reliability, external validity	Experiential
Researcher's role	Onlooker	Actor
Source of categories	*A priori*	Interactive emergent
Aim of inquiry	Universality and generalizability	Situational relevance
Type of knowledge acquired	Universal, *theoria*, precise, causal, cumulative, reductionistic	Particular, *praxis*, imprecise, multiple causation, problematic, holistic
Nature of data and meaning	Factual, context free	Interpreted, contextually embedded
Status of science as a field of knowledge	Privileged, progressive, autonomous	Not separated from other fields of knowledge
Value content	Value free	Value laden
Aim of science	Prediction and control	Promotion of human development

Layer	*Examples*
Worldviews	• Practicism • Scientism
Research heuristics (sources of theories or hypotheses)	• Cognitive science • Decision science • Formal methods • Human centered • Software engineering • Systems science
Specific issues (evaluation or goodness criteria)	• Formal representation • Parsimony • Practical relevance