Learning from the NRC report "Scientific Research in Education"

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Abstract

In 2002, the National Research Council released a report of the Committee on Scientific Principles for Education Research entitled "Scientific Research in Education." One goal of the committee was to examine and clarify the nature of scientific inquiry in education. They concluded that the following six principles underlie scientific inquiry: 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; and 6) disclose research to encourage professional scrutiny and critique. The report discusses each of these principles and how they may be applied to education research.

In this paper, I explore these principles as applied to education research in science, technology, engineering, and mathematics disciplines. I draw parallels and contrasts with engineering disciplinary research to illustrate the common and unique features of research within the education context. Finally, I offer a preliminary article review guide based on the principles.

Introduction

During the late 1990s, policy makers and politicians, as well as teachers and parents, demonstrated frustration with education research. Many persons claimed that the results of education research were not helpful for changing classroom practice and the research was not "scientific" enough (NRC, p. 28). Eventually, legislation was proposed that defined controlled experiments as the only rigorous method for conducting education research, with the implication that federal funds should only fund this type of research. In response, the National Research Council (NRC) conducted a study "to examine and clarify the nature of scientific inquiry in education and how the federal government can best foster and support it" (NRC, p. 1). In this paper I will focus on the first goal and leave the consideration of government support to future papers.

The NRC Committee was comprised of a diverse group of education researchers from academia, foundations, and government centers. They spent three years meeting, researching, and discussing the issues. The report, issued in 2002 through the National Academy Press, is intended to encourage discussion, present ideas and examples for consideration, and further understanding of the nature of research in the context of education.

In this paper, I first review the six principles of scientific research laid out in the report, using concrete examples from education research in science, technology, engineering, and mathematics (STEM). Next, I discuss the parallels between education research and engineering disciplinary research. I note the commonalities as well as the differences which make education research a different enterprise than engineering research. Then I use the principles to develop criteria for high quality research in STEM education by offering a preliminary article review guide. My goal in this paper is to encourage discussion of the NRC report and its ideas and potential applications in STEM education research.

Why does it matter if one's work is considered "scientific"?

What is the importance of having one' work judged to be scientific? The first and primary reason is funding, especially federal funding. In the past decade, frequent calls for "evidence-based education reform" have been made by politicians, policy makers, and budget writers. There is a general feeling of frustration with seemingly constant educational reform and no obvious progress. A bill was presented to Congress which stipulated the criteria for research to be funded through federal dollars. This bill essentially limited research to experimental designs, which are notoriously difficult and expensive to enact in educational settings. Clearly, there is a need for a national conversation regarding what kinds of research should be funded with federal and state tax dollars. The NRC report was an attempt to encourage that conversation through an initial discussion of scientific research which is seen to provide the most valuable evidence. Hence, having one's work seen as "scientific" opens doors to funding sources that are not available for "non-scientific" work.

Funding, of course, is critical to the tenure and promotion process. Faculty members in STEM disciplines who want to make education research their primary research program must be able to get funding for their projects. Furthermore, funding from federal sources, such as the National Science Foundation, may carry more prestige than funding from small, private foundations. During the tenure and promotion process, a faculty member builds their prestige and reputation, through presenting research at conferences and in journals. Scientific research will contribute more positively to that reputation in STEM education than will non-scientific research. These three things together, funding, tenure and promotion, and prestige and reputation, lead to more academic freedom. As I was advised time and time again upon completing my Ph.D., "Do what the system rewards. Then when you have achieved tenure, you can do what you want." The system definitely rewards scientific research more than non-scientific research.

Guiding Principles Underlying Scientific Research

The six scientific principles discussed below apply to all scientific research, including research in education. The principles are familiar to researchers in STEM disciplines, but still provide springboards for discussion as to the types of research projects which are included and excluded by differing interpretations of the words. *Perhaps the most important lesson which these principles can emphasize for STEM education researchers is the need for moving from implicitness to explicitness in articulating the research design and process.* As a community, we need to expect researchers to explain why they chose the research design they did and what designs they rejected and why. Before we can judge the trustworthiness of the research outcomes, we have to understand thoroughly the research design and process which was followed. Although we teach this level of explicitness to senior design teams, we have not practiced it as a community in engineering education research. Let's now consider each principle and the criteria and lessons it provides, keeping in mind that this paper is only one possible interpretation of the principles.

Scientific Principle 1: Pose significant questions that can be investigated empirically

Two important criteria are embedded within this principle. First, the questions must be significant. At first glance, this seems obvious; after all, who would spend their time researching a question they did not think was significant? So the real criteria is *to whom is this question significant and why*. Many granting agencies insist that significance be shown by connecting the research to direct changes in the classroom or students' experiences, which corresponds to Boyer's[2] "scholarship of application." However, I think it is important to remember the need for "scholarship of discovery" in STEM education as well. In these research projects, deeper understanding of a situation or phenomenon is the goal, not direct change in the classroom. Deeper understanding of students' perspectives and experiences is needed in order to design potentially effective education reforms. Reforms must then be evaluated using rigorous research methods. If these discovery projects are not funded and pursued, we will continue to design programs and interventions with out-dated understandings developed primarily though our own experiences and perspectives as faculty members. The timeline to connect discovery research to reform may be several years.

The second important criterion is that the questions must be investigated empirically. Webster's dictionary defines empirical as "relying on or gained from observation or experiment rather than theory." For the scientific and engineering community, hard data which is measured objectively is seen as natural, normal, and, frequently, the only valid source of data. Therefore, it is not obvious how this criterion excludes any valuable research. One example from physics is "string theory," which at this point in history may not be investigated empirically. Hence, by this criterion, string theory research is not scientific. Theoretical research is usually a necessary precursor to empirical research, but according to this criteria, it is not scientific.

How does this criterion exclude important education research? It excludes what Boyer called the "scholarship of integration." This research process brings together theories from different areas to derive new theories, which then can be the foundation of new research projects. For example, Waller[3] conducted a research project which brought together communication theories and the results from studies of engineering project design teams. Specifically, she considered how communication across genders as cross-cultural communication could explain the study outcomes of women and men not liking mixed-gender design teams. These "thought experiments" lead to recommendations for changing the way project design teams are structured and supported during their work. However, this work is not scientific according to this criterion. The high expectations in STEM disciplines for one's research work being funded externally combined with funding being limited to "scientific research" mutually restrict the types of education research being done by STEM faculty.

Scientific Principle 2: Link research to relevant theory

This criterion calls for explicit links between the research question and relevant theory *as well as* between the research design/methodology and relevant theory. In 14 years of reviewing papers, hearing presentations, and reading articles on engineering education in the U.S., I have noticed that this principle is given only brief attention. My observation is that we need to look more broadly at relevant theory across a variety of disciplines, instead of just citing STEM education literature. For example, if one is researching the impact of urban/rural/suburban backgrounds on students' success in engineering, the expansive literature on urban K-12 education should be included as well as the important literature on cultural capital. We need to become familiar with databases to search in education, psychology, sociology, etc. In addition, we need to clarify which perspectives are influencing our research. For example, is one considering leadership to be a personal quality and taking a psychological approach or is one considering it to be a group dynamic and taking a sociological approach or is one taking some other approach entirely? A few databases that I find helpful for broad literature reviews are Academic Search Premier, ERIC, and J-Stor. In addition, I recommend searching the Dissertation Abstracts Database in the beginning of any new research project. Often, students in education, sociology, psychology, etc. use a STEM discipline as their context, but never publish in the STEM education journals.

The second impact of this principle is to point out the need to move from implicitness to explicitness in terms of research design and methodology. In our disciplinary research, STEM faculty members are well-trained to describe all of the important conditions and processes under which experiments are conducted and data are collected. Furthermore, lab notebooks are meticulously kept to document every decision to change protocols. This same explicitness is necessary in education research. For example, if individual interviews are conducted, why was the choice made over focus groups? Who conducted the interviews and what was their relationship to the participants? At what time during the semester were they conducted and what was going on locally that may influence the data? Were the interviews transcribed? By whom? What analysis method was used to reduce the data? What interpretation method was used? Why? If a survey is conducted, details should be given regarding checks for validity and reliability. How are we convinced that the respondents interpreted the questions in the manner that the researchers intended? If we compare groups, are we sure that cultural influences are accounted for? Why were those particular statistical tests chosen and are they theoretically and practically appropriate? How much are the assumptions of the tests violated, e.g. normality and independence? Who dropped out of the study and how are they different from those who persisted? How trustworthy is the generalizability of our results if response rates are below 75%? In qualitative, quantitative, and mixed-method research, there are dozens of design and methodology questions that should be answered in order for the community to review and critique the work (See Principle 6 below). Providing this explicitness requires space in our articles and time in our presentations, but is a crucial part of conducting high quality research.

In STEM disciplines, we use a very precise lexicon, often using mathematics to express the relationships between concepts. In the social sciences, including education, the meaning of words is debated, contextual, historical, and often personal. To say for example, that one is taking a feminist perspective only conveys that gender is somehow important. Instead, education articles usually specify what feminist perspective is being used (e.g. liberal, cultural, social constructivist, poststructrual) and how that perspective influences the research from conception through dissemination. In engineering education, we often fail to specify with enough detail what we mean by words such as interactive web site, design project, life-long learning, diversity, etc.

Scientific Principle 3: Use methods that permit direct investigation of the question

This principle also supports the discussion above regarding explicit discussion of research design and methodology choices. Many different methods of inquiry are available in education; however, not every method is appropriate for every question and different methods presuppose different conditions. For example, let us consider options for investigating why students leave engineering with the goal of making recommendations to improve retention. One option is to analyze data already in the system, e.g. course taking patterns, grades, and on or off-campus housing, comparing those who switch with those who stay. Another option is to survey students when they switch majors and have them rank order a list of reasons according to their influence on the student's decision. This method presupposes that the researchers know, before the research is done, which reasons are most likely to influence persistence decisions. Another option is to interview students when they switch and let them give the reasons. Interviewing allows a more direct investigation of the question, but requires more resources in data collection and analysis. The tradeoffs among options should be explicitly discussed and the final decision justified. When data is collected with more than one method and the findings reinforce each other, then the research study has a stronger trustworthiness.

Scientific Principle 4: Provide a coherent and explicit chain of reasoning

Principle 4 is an example of opening up discussion and possibilities for expanding research methods in STEM education. Note that, according to these principles, the research does not have to "prove" anything or provide a sufficiently small p-value. Instead, the criterion is a coherent and explicit chain of reasoning. The NRC report observes that "The extent to which the inferences that are made in the course of scientific work are warranted depends on rigorous reasoning that systematically and logically links empirical observations with the underlying theory and the degree to which both the theory and the observations are linked to the question or problem that lies at the root of the investigation" (p. 66). Observations are linked to theory and the question and the theory is linked to the question. I would add that the design and methodology must also be linked to the theory, the question, and the observation.

In addition, this principle requires that assumptions underlying the inferences made should be clearly articulated. Estimates of error should also be included to the greatest extent possible. Perhaps most importantly, and most new to STEM education researchers, is the idea that alternative explanations must also be included and dealt with in a rational, systematic, and compelling way. In quantitative research, the design of the study often helps to rule out alternative explanations, for example, random assignment to control or experimental groups helps to rule out hidden variables. In all scientific research studies, investigators must consider alternative explanations and provide a coherent and explicit chain of reasoning regarding the extent to which they can be ruled out.

Scientific Principle 5: Replicate and generalize across studies

Replication and generalization help to clarify the limits of theories and inferences and are an important component of scientific research. Replication refers to the ability to repeat an investigation in more than one setting and achieve the same results. This is common practice in STEM disciplinary research in order to confirm findings. When similar results can not be generated, then the entire research project is in doubt. Consider, for example, the cold fusion results announced by one laboratory, but in the end, discredited because they could not be replicated in any other laboratory. Replicating social science research is more difficult than replicating research in engineering. The contextual factors and lack of control that characterize work in the social science realm make direct replication in another setting impossible in a strict sense. Hence, social science researchers have developed other means of ensuring trustworthiness, such as triangulation, comparative analysis, and rich description.

Generalization is similarly difficult in education research. Outside factors change the historical and social context in which participants live. For example, one researcher was investigating students' viewpoints of the United States as an imperialistic nation during the Fall Semester of 2001. The terrorist attacks of September 11 dramatically impacted the students and their social world. Hence, her research became unreplicable and ungeneralizable because of societal change. Note, however, that at the same time, it became more valuable in a new way because it was gathering data during a unique moment in history.

On the other hand, contextual factors may influence the research in ways that are not recognized until the study is replicated. Many different research studies have been done on engineering schools as they adopt integrated curricula, design throughout the curriculum, and the ABET 2000 criteria. Programs and innovations that work very well at one institution have failed at other institutions, occasionally from factors such as "lame duck" Provosts, changing budget structures, or the lack of individual faculty "champions" supporting the particular program.

For STEM education researchers, perhaps the most important word in this principle is "across." Doing primarily statistically based studies, we understand that findings from the sample only generalize to the population from which the sample was drawn. Limits of generalization are inherent in the single study. In education research however, many studies are aimed at deeper, contextual understanding of a particular situation or phenomenon. Therefore, these researchers do not even claim that the results from one study are replicable or generalizable. Instead, they offer up their results with rich descriptions of the context so that others can decide if the results might apply to their own context. Until the study is replicated under new settings or with new participants, it can not be known if the findings apply elsewhere. An implicit value which I have seen enacted through engineering education conference attendees' questions is that knowing the generalizability of a study is necessary to value the study. I suggest that the community reconsider this idea, critiquing instead the rigor of the research design and methodology to evaluate education studies, while also taking on the challenge of replicating studies which are presented. These actions would increase the complexity of citation chains and raise the quality of accumulated understanding in STEM education.

Scientific Principle 6: Disclose research to encourage professional scrutiny and critique

In the NRC report, the authors state “Regardless of the medium, the goals of research reporting are to communicate the findings from the investigation; to open the study to examination, criticism, review, and replication (see Principle 5) by peer investigators; and ultimately to incorporate the new knowledge into the prevailing canon of the field” (p. 72). This second goal points out again the need for more explicit reporting of STEM education research processes. If the work is to be examined, reviewed, and replicated, then enough detail must be made available by the authors to allow others to respond. The NRC report authors emphasize “The extent to which new work can be reviewed and challenged by professional peers depends critically on accurate, comprehensive, and accessible records of data, method, and inferential reasoning” (p. 73).

How well does engineering education encourage professional scrutiny and critique? At a recent conference a few colleagues informally collected data by recording the types of questions asked after each presentation at several sessions during a national conference. The vast majority of questions centered around clarifying data, as in “How many students were in the pilot study?” and “What was the percentage of increase in test scores?” Only two questions regarding methodology were asked, and again they were clarifying what the speakers had said, not questioning why they had made the choices they had made. Perhaps this informal investigation should be replicated formally or perhaps, as a community, we should just commit to encouraging more professional critique at our conferences and in our conference review processes.

Together, these six principles describe criteria for all scientific research. Summarizing in one sentence, the executive summary of the report says: “To be scientific, the design must allow direct, empirical investigation of an important question, account for the context in which the study is carried out, align with a conceptual framework, reflect careful and thorough reasoning, and disclose results to encourage debate in the scientific community” (p. 6). Applying these ideas to education research is perhaps a bit more fuzzy and unclear than applying them to disciplinary research in STEM fields. In order to make these applications more clear, let’s discuss some of the similarities and differences between engineering disciplinary research and STEM education research.

Engineering Research and STEM Education Research

> “Education is multilayered, constantly shifting, and occurs within an interaction among institutions (e.g., schools and universities), communities, and families. It is highly value laden and involves a diverse array of people and political forces that significantly shapes its character. These features require attention to the physical, social, cultural, economic, and historical environment in the research process because these contextual factors often influence results in significant ways.” (p. 5)

This wonderful quote from the report illuminates many of the reasons why research in education is so difficult to conduct using experimental designs with random assignment. In the table below, I present a comparison between disciplinary research in engineering and education research in STEM. Although there are some similarities, the goal is to examine features that make education research different from the kinds of research most engineering faculty do for their dissertation and to establish their careers.

	Engineering Research	**STEM Education Research**
Purpose	○ Solve problems for individuals, corporations, communities, and societies. ○ Improve quality of life	○ Design efficient and effective education systems ○ Solve problems in the educational process ○ Improve quality of educational experiences
Accumulation of understanding	○ Based on centuries of work ○ Long citation chains, with multiple groups working on the same problem with different perspectives and methods ○ Debates within professional community	○ Based on a few decades of research, at best ○ Short or no citation chains, with a single research group approaching a problem ○ Little direct debate in literature or conferences
Values	○ Usually claims to be objective and value-free	○ Values are obvious part of defining the problem and designing the solution
Perspectives	○ Scientific method is the dominant perspective	○ Multiple disciplinary perspectives: scientific, sociological, psychological, educational, multicultural, etc.
Evaluation of research process	○ Peer review based on common understanding of scientific process ○ Grant process	○ Peer review based on individual perspectives ○ Grant process
Evaluation of research outcomes	○ Industry/community review and adoption ○ Peer review based on common understanding of quality	○ Peer review ○ ABET review ○ Employers hiring graduates
Resources brought to research process	○ Faculty, usually as their primary research program ○ Graduate students ○ Post-doctoral assistants ○ Laboratories, computers, analysis software ○ Undergraduates	○ Faculty, often as their secondary research program ○ Occasionally, team members from outside engineering ○ Occasionally, graduate students or undergraduates
Subject of inquiry	○ Inanimate objects	○ Students, faculty, & administrators ○ Curricula ○ Pedagogies ○ Teaching/learning processes ○ Programs, departments, & colleges
Interaction between subjects	○ No interaction – independent samples	○ Highly interactive since teaching/learning is a social process

Variability in subjects	○ Research on inanimate objects allows researchers to minimize variance within subjects prior to research, e.g. alloys of equivalent mixtures	○ Students and faculty have a variety of experiences with previous formal and informal learning experiences which directly affect their experience of the research.
Human volition	○ Not applicable in many studies, with obvious exceptions of human-system interaction research	○ Subjects sign consent forms and may choose to leave the study at any time ○ Long-term follow-up is difficult
Ethical considerations	○ Play a minor role when researching inanimate objects	○ Play a major role with humans, e.g. How ethical is it to use a lecture only control group when over 100 years of research demonstrates that cooperative learning is more effective?
Relationships	○ Inanimate objects do not experience relationships with researchers.	○ In human research, relationships must be established before data collection can begin. After data is collected, the relationship must be resolved. Issues of power between participants and researchers are critical.
Context	○ Often in labs, therefore largely controllable	○ In classrooms, dorm rooms, libraries, etc., therefore not controllable

This table highlights why STEM faculty who are eminently trained to do disciplinary research may find it difficult to do education research. It indicates the need for workshops, short courses, case studies, and mentoring to be developed specifically for STEM faculty who want to engage in education research.

A preliminary research review guide

In this section I offer a preliminary research review guide. It is constructed not as a rubric or scoring device to quantify the quality of the research, but as a qualitative evaluation which aims to provide explicit feedback to the authors. Intentionally, each question is not a binary question or a Likert scale rating, so it is very different from the paper review forms being used in engineering education conferences. In addition, when using this review the reviewers and the authors must keep in mind that every research project always has room for increased rigor (usually through increased funding) and more explicit discussion (usually through increased page limits). Therefore a balance must be struck between the unattainable ideal and the constrained reality.

Finally, this research review guide is based on the six scientific principles and is organized around my own paradigm for understanding the research process. In my Introduction to Education Research workshops, I present a complete graph on five nodes (five nodes where each is connected to every other node). The nodes represent five aspects of research design:

research question, theory and perspectives, methodology (data collection and data analysis), interpretation (assigning meaning to the results of the analysis), and presentation. The graph depicts the research question as a visually central node to accentuate how it drives the decisions in the other nodes. In the following research review guide, each aspect is explored and its connection to the research question is emphasized.

Waller's Research Review Guide

Research Questions

- What is the overall issue being investigated?
- What are the specific research questions being addressed in this project?
- To whom are these questions significant and why?

Perspective and Theoretical Framework

- What has previously been done on this issue? How does it relate to the current project?
- What peripheral areas of literature are important and how do they relate to the project?
- What perspective or theoretical framework is adopted for this study? What is being taken as given? What assumptions are being made? Why? How to they relate to the research questions?

Methodology

- What methodology (data collection and data analysis) is being used? Why? Are methodology choices related to other methodology choices for similar projects in the literature?
- How explicit are the authors in describing the methodology? How well could this study be replicated on the basis of what is written?
- How does the methodology allow direct investigation of the research questions?
- What are the limitations of the methodology?
- What assumptions and theory underlie the data collection? How appropriate are they, given the research questions?
- What assumptions and theory underlie the data analysis? How appropriate are they, given the research questions?
- How are trustworthiness, reliability, and validity for the data collection and analysis established?
- What claims of replicability and generalizability are the authors making for this particular study? How reasonable are those claims?
- How well did the authors explain their data analysis process and the findings of that process? How coherent and explicit was the chain of reasoning?

Interpretation

- What interpretations and meanings did the authors give to their findings? How well did these meanings address the research questions? How coherent and explicit was the chain of reasoning in the interpretation process?
- How is the interpretation linked to the perspective or theoretical framework of the authors?

- What other interpretations are reasonable? How did the authors discuss and/or rule out alternative interpretations?

Presentation
- Who is the expected audience for this paper? How well did the authors address the background knowledge, interests, and expectations of the audience?
- How well organized and logical is the presentation?
- If one idea/paragraph/section could be added to make the paper more explicit, what should it be? (Repeat until nothing needs to be added.)
- If one idea/paragraph/section could be left out without losing the necessary explicitness and chain of reasoning, what would it be? (Repeat until nothing could be left out.)
- How correct are the grammar and punctuation?
- Is every citation in the paper included in the references list? Is every reference cited in the paper?

Given the reality of the overextended faculty member's time, I doubt that such a comprehensive review will become the standard for engineering education conferences. However, perhaps it can be used as a helpful guide by authors as they are writing papers and articles.

This guide also brings out another issue that the engineering education community will need to discuss. The explicitness and rigor called for in the NRC report is difficult to achieve in a six page paper (the approximate length of a typical article). In education journals, fewer articles are published and each one is approximately 15 pages. Qualitative studies, in particular, need more space to present their evidence in the form of direct quotes and field notes. These data cannot be summarized into a handful of numbers and presented concisely in a table. Increasing the length of articles implies higher costs for journals or fewer articles, as well as more time for reviewers and readers to read and comprehend the papers. This trade-off between resources and explicitness will need to be addressed by the engineering education community.

Closing this paper and opening discussion

In this paper, I have tried to give an introduction to the NRC report, *Scientific Research in Education,* by discussing the report's six principles which underlie all scientific research. I have connected these principles to the current state of STEM education as I see it and offered my perspectives on the similarities and differences between engineering disciplinary research and STEM education research. Finally, I have offered a preliminary research review guide to open discussion about peer reviews of education research. My goal in this paper was to begin a dialogue which will enable STEM education research, and engineering education research in particular, to further coalesce and mature as a discipline in its own right. I hope this paper will spark further discussion in formal and informal spaces, within ourselves and in face-to-face meetings, and in print and electronic media. There are so many interesting and important questions to consider individually and as a community. A beginning list includes:
- In what ways does the STEM education research currently enact the principles of the NRC report?
- In what ways could it be done better?

- Are these the principles we, as a professional community, want to adopt for all of our research? If not, what would we change? Do we even need principles that apply to all STEM education research? Should we have different sets of principles for different types of research?
- How should we change (if at all) our journals, conferences, presentations, reviewing, etc. in light of the ideas in this report?
- How do we want to mentor new researchers into the field in light of this report?
- How should we lobby for changes in tenure and promotion processes for faculty who want to do education research within an engineering college?

I encourage all STEM education researchers to read the executive summary (if not the whole report) and then submit papers, presentations, panel sessions, workshops, special sessions, etc. to get a vigorous dialogue going. Let's talk!

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