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ABSTRACT

There is a growing sense of frustration among members of the science education research community that results from the fact that the impact of research in science education on classroom practice has been disappointing. In this theoretical paper, the questions of relevance and accountability in science education research are first reviewed and then addressed via comparison of the two most prevalent research methodologies: causal empirical-analytic, and naturalistic-hermeneutic. Critical theory and action research are proposed as alternative paradigms. A study planned at Purdue University (Indiana) is discussed in terms of the three interpretations. (JRH)

A CRITICAL EXAMINATION OF RELEVANCE IN SCIENCE EDUCATION RESEARCH

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ABSTRACT

In this theoretical paper, the questions of relevance and accountability in science education research are first reviewed and then addressed via comparison of the two most prevalent research methodologies: causal empirical-analytic, and naturalistic-hermeneutic. Critical theory and action research are proposed as alternative paradigms. A study planned at Purdue is discussed in terms of the three interpretations.\

THE PROBLEM OF ACCOUNTABILITY IN SCIENCE EDUCATION RESEARCH

There is a growing sense of frustration among members of the science education research community that results from the fact that the impact of research in science education on classroom practice has been disappointing, to say the least (Shymansky & Kyle, 1990). Wright (1993) offered four reasons why science education research is often irrelevant to the classroom teacher.

> 1. Science education research isn't a well defined discipline supported by a systematic base of knowledge. The preponderance of such research is carried out by graduate students as part of their Ph.D. program, rather than by seasoned teams with adequate funding. The preponderance of the research is "...conducted in isolation, with little focus, no agenda related to practice and no agreement on which methodologies are appropriate"
>
> 2. Science education researchers have little or no interest in practical, applied classroom issues. There is a sense that researchers are mainly "...concerned with maintaining a status as the theoretical spokespersons for the enterprise. ... Researchers in science education want to be seen as having an elevated status rather than dirtying their hands with the day-to-day problems faced by teachers and students in the science classrooms..."
>
> 3. Science education research hasn't recognized that educational practice isn't a scientific culture but a craft involving extensive unspoken personal experience and intuition. "Beliefs and practices drive the teaching enterprise, not research-based findings." Wright suggests that "...as long as we persist in applying the simplistic agricultural models of research (that look for simple cause and effect) to the very

> complex and contextual educational settings, then there is little hope of influencing the science teaching enterprise".
>
> 4. Science education research is still in its infancy. We are still in the process of finding out what is out there in science classrooms.

All but the last of Wright's criticisms can be viewed as paradigmatic problems of science education research. Ph.D. research is principally done to demonstrate theoretical and methodological mastery within a paradigm, not to solve practical problems of instruction. The goal of this research isn't an incremental improvement of practical instruction, but a revolutionary change in current practice as a result of instructional innovation (measured by quantitative methods) or a reconstruction of the learning experience and perspectives of the participants in instruction (measured by qualitative means).

Practicing teachers therefore view science education research as something apart from, theoretically superior to, and not really interested in classroom practice from the teacher's perspective, but from that of an external "expert." They view science education research as something *done to* teachers and students by *outsiders* who aren't interested in contributing to the everyday craft of teaching. Because this research doesn't directly benefit the teacher, the teacher has little stake in trying to decipher and implement those pieces of research that are actually actionable.

This dilemma concerning the relevance and validity of educational research isn't new; more than a half-century ago, John Dewey (1929) remarked on the direction and worth of educational research, and clearly subjugated theoretical rigor to educational practice:

> The answer is that (1) educational practices provide the data, the subject-matter, which form the problems of inquiry... These educational practices are also (2) the final test of value of the conclusions of all researches... Actual activities in education test the worth of scientific results... They may be scientific in some other field, but not in education until they serve educational purposes, and whether they really serve or not can be found out only in practice. (p. 33)

We would like to suggest that the irrelevancy of science education research at present results from limitations in the two prevalent methodological paradigms used to conduct such research. These paradigms (quantitative, causal models of educational interventions

and qualitative, hermeneutic-natural approaches for the noninterventionary study of educational practice) are limited because neither fits actual instructional practice in the classroom. The methodologies and criteria used to judge worth in these kinds of research are driven by the search for theoretical perspectives sought by individuals who aren't (at the moment) teachers, and these methodologies and criteria are both inappropriate for and insufficient to the needs of class oom teachers.

Research Methodologies: The Quantitative Tradition

The paradigm for quantitative research in science education has roots in the natural sciences and psychology. Although there has been much debate regarding the evolution of the paradigmatic stances employed (positivism, neopositivism, behaviorism, and so forth), this research seeks causal relations between the kinds of instruction used and student learning. It frequently involves comparisons of an instructional innovation with "standard" instruction (interpreted as the absence of the innovation). The most striking examples of experimental design based on this paradigm are those of Campbell & Stanley (1963).

In the wrong hands, this paradigm can give rise to a "sports mentality" approach to curriculum evaluation (Bodner, 1992) – limited comparisons of treatments and controls unreasonably removed from regular and possible classroom practice are statistically compared and victory or defeat for or against the innovation is declared. Because the methodology removes the experimental situation from the realm of the working classroom, assumes unreasonable controls of implementation and usually compares immature innovations, the results of these researcher-driven "horse races" often aren't deemed worthwhile by working teachers. To them, the purpose of this research is to demonstrate researcher control over arcane experimental ritual, not to improve the lot of the teacher.

Research Methodologies: The Qualitative Tradition

Qualitative research provides a worthwhile paradigm to answer Wright's fourth criticism of research in science education – that we are still finding out what's out there in the classroom. Unfortunately, as working professionals, teachers are quite aware of what is happening in their classes – they don't believe that they need to be the subjects of anthropological research.[1]

[1]In a recent seminar at a major university, a graduate student interested in the problems of a

The appeal of naturalistic research to working teachers is similar to that of Piaget's theory of genetic epistemology. The information informs and provides material to reflect upon, but by nature isn't designed to guide active intervention. Naturalistic research methodologies have forsworn this role to the experimentalists. Unfortunately, teachers work in a world of continuous intervention into human learning. While the qualitative tradition in science education research can inform teachers, it is mainly done to inform researchers. Because, once again, research doesn't meet the needs of working teachers, it has little of any effect on classroom practice.

Unorthodox Methodologies: Formative Research

In what amounts to a rejection of the "methodolitry" endemic to the qualitative and quantitative research paradigms, formative research has been conducted that was designed to benefit educational practices. This research is described by Walker (1992) as follows:

> "Formative researchers use such methods as reviewing research, consulting experts, constructing conceptual models, measuring characteristics of the intended audience for the educational program, and trying out prototypes in laboratories and in realistic field settings. They seek to learn about such matters as the readiness and needs of the audience, the value of the content to society and to the audience, the appeal of the planned program to the audience, the receptivity of teachers to it, and its utility and appeal for both students and teachers. Formative research is usually eclectic in its choice of techniques for eliciting data, including self-reports (in the form of diaries, interviews or questionnaires), observations, tests, and records" (p. 111).

Walker describes the validity of this kind of activity as follows:

> "...formative research draws its greatest credibility from (1) the close similarity between the intended situation in which data are collected and the situation of ultimate interest (trying out prototype materials in a classroom can be very close to using final versions in typical classrooms) and (2) the compelling face validity of the data collected (observations of classroom interaction, test scores, and so on)" (p. 111).

minority group noted that he received opposition to his classroom visits from members of the minority community -- who were tired of being the subjects of another study of why they didn't succeed. They wanted someone to intervene, to help them become more successful.

He also cites examples of such unorthodox formative educational research.

> "Uri Treisman (Henkin and Treisman 1984; Treisman 1983), while a graduate student working with Professor Leon Henkin at the University of California at Berkeley, carried out a chain of studies that were by traditional standards methodologically primitive but nevertheless exceptionally productive". [...] *"By any reasonable standards for curriculum research, this [Treisman's study] was an outstanding study.* The researcher focused his attention on the crucial practical problem, observed practices closely, kept himself open to a wide variety of evidence at every stage of the inquiry, compared circumstances in which a practice seemed to succeed with circumstances in which it failed, searched for factors in the situation that could be changed, redesigned practices to reflect what he thought he had learned from his observations, and tested the new practices by using the standards of achievement actually employed in the real course. His results have been widely reported and have already begun to influence research and practice in mathematics education (Gillman, 1990). And all this work was accomplished in three years on a modest budget".

Dewey's concerns with methodologically-rigorous research are recapitulated by Elliott Eisner (1979) when discussing formative research. As Walker notes (1992, p.107) Eisner rejected the scientist's criterion of truth in favor of utility: "What we can productively ask of a set if ideas is not whether it is REALLY true but whether it is useful."

To achieve profound insights into the active teaching and learning processes, formative researchers have deliberately chosen to reject methodological rigor in favor of utility. By the prevailing methodological standards of the behavioral and social sciences, in contrast, these studies are merely intriguing observations that prove nothing (Walker, 1992, p. 114).

However effective and relevant these cases of unconventional science educational research have been to working teachers, they don't provide the guidance and methodological interpretation required to establish a systematic base of knowledge for science education research. To achieve this we need a paradigm. We suggest using Critical Theory (Schroyer, 1973; Young, 1990) as the basis of that paradigm.

CRITICAL THEORY

Critical theory was perhaps best set forth by the German sociologist-philosopher Jurgen Habermas (Gortzen & van Delder, 1970; McCarthy, 1979; Roderick, 1986; Sabia & Wallulis, 1983). Mezirow (1981, p. 3) describes Habermas as follows.

> "Jurgen Habermas is widely considered as the most influential thinker in Germany over the past decade [1970-80]. As a philosopher and sociologist he has mastered and creatively articulated an extraordinary range of specialized literature in the social sciences, social theory and the history of ideas in the provocative critical theory of knowledge and human interests. His roots are in the tradition of German thought from Kant to Marx, and he has been associated with the Frankfurt School of critical theorists which pioneered in the study of the relationship of the ideas of Marx and Freud. "

Habermas' Three Domains of Knowledge

Habermas argued that human interest generates knowledge in three generic cognitive areas or domains shown in Table 1: technical (work), practical (social), and emancipatory. These areas are "knowledge constitutive" because they determine appropriate actions for obtaining knowledge and judging whether knowledge claims can be warranted. These areas define cognitive interests or learning domains, and are grounded in different aspects of social existence: work, interaction, and power. For our purposes, Habermas redefines human knowledge so that the mandate for formal knowledge creation is extended beyond the realm of the professional researcher and into that of all of the participants in human endeavors (e.g. teachers and students).

Table 1

Habermas' Three Domains of Knowledge (after Tinning, 1992)

Type of Human Interest	Kind of Knowledge	Research Methods
Technical - WORK (prediction)	Instrumental (causal explanation)	Positivistic Sciences (empirical-analytic methods)
Practical - INTERACTION (interpretation and understanding)	Practical (understanding)	Interpretive Research (hermeneutic methods)
Emancipatory - POWER (criticism and liberation)	Emancipation (reflection)	Critical Social Sciences Critical Theory Methods (including action research)

Technical (Work) Knowledge

Work, in its broadest sense, refers to the way one controls and manipulates one's environment. Technical, or work, knowledge is commonly instrumental in nature – it is based on empirical observations and governed by technical rules. The criterion of effective control of reality directs what is (or isn't) appropriate action for acquiring knowledge in this domain. The research methodology characterized by this domain is therefore the empirical-analytic sciences using hypothetical-deductive theories. Habermas classifies much of what we consider physical science research domains – e.g. Physics, Chemistry and Engineering – as belonging to this domain.

Practical (Social) Knowledge

The domain of practical or social knowledge is the result of human social interaction or "communicative action." Social knowledge is governed by binding consensual norms, which define reciprocal expectations about behavior between individuals. Social norms can be related to empirical or analytical propositions, but their validity is grounded "only in the intersubjectivity of the mutual understanding of intentions." The criterion of clarification of conditions for communication and intersubjectivity (the understanding of meaning rather

than causality) is used to determine what is appropriate action for obtaining knowledge. Much of the historical-hermeneutic disciplines – descriptive social science, history, aesthetics, legal, ethnographic literary, and so forth are classified by Habermas as belonging to the domain of the practical.

Emancipatory Knowledge

The emancipatory domain includes "self-knowledge" or self-reflection. This involves interest in the way one's history and biography has expressed itself in the way one sees oneself, one's roles, and social expectations. Emancipation occurs when we are freed from libidinal, institutional, or environmental forces that limit our options and rational control over our lives that have been taken for granted as beyond human control. (A process also known as "reification.") Insights gained through critical self-awareness are emancipatory in the sense that at least one can recognize the correct reasons for his or her problems. Knowledge is obtained by self-emancipation through reflection leading to a transformed consciousness or "perspective transformation." According to Habermas (Mezirow, 1981), examples of critical sciences that operate within the emancipatory domain include psychoanalysis and the critique of ideologies (e.g., sexual, racial, religious, educational, occupational, political, economic and technological ideologies).

Habermas and Action Research

Although action research will be described in detail in the next section, if we are to presume that critical theory provides a paradigm for action research methodologies, it is important to establish the relationship between action research and critical theory. The educational action research movement predates Habermas. Action research can readily be traced back to the end of World War II when social psychologist Kurt Lewin (1946) developed most of the current methodological characteristics. Habermas has provided a theoretical background to the methodologies advocated by proponents of action research (Kemmis & McTaggart, 1990), not vice-versa.

Kemmis and McTaggart (1990) point out that there is considerable "...debate about the extent to which action research is *a research methodology or technique* on one hand or *a broad approach to social research and reform* on the other." Kemmis also raises the issue of where action research should be located, either as "...part of the *wider field of*

social theory or in the narrower focus of *education and the development of educational theory*." This is exemplified by a basic dichotomy between the different schools of action research, where some researcher are concerned with "*...the development of teacher's (or others') theories of education and society* while other researchers concern themselves with *questions of social and educational change* – improvement, reform and innovation."

ACTION RESEARCH

Action research (Kemmis, 1983; McTaggart, 1991; Tinning, 1992) has been described as a recursive, reflexive, dialectical technique that aims to help people investigate reality in order to change it, or to change reality in order to investigate it, by changing their practices in a collaborative, self-reflective spiral of cycles (Kemmis and McTaggart, 1988). It is an informal, qualitative, formative, subjective, interpretive, reflective, and experiential model of inquiry in which all individuals involved in the study are knowing and contributing participants (Hopkins, 1985). Action research is a deliberate social process designed to help members of a group learn more about their practices, their knowledge of their practices, the social structures that constrain their practices, and the social environment in which these practices are expressed and realized. A "... process of learning by doing – and learning with others by changing the ways they interact in a shared social world in which, for better or for worse, we live with the consequences of one another's actions" (Kemmis and McTaggart, 1988).

Action Research represents a growing field of educational research whose chief identifying characteristic is the recognition of the pragmatic requirements of educational practitioners for organized reflective inquiry into classroom instruction. It is a process designed to empower all participants in the educational process (students, instructors and other parties) with the means to improve the practices conducted within the educational experience. All participants are knowing, active members of the research process.

The action research framework is most appropriate for participants who recognize the existence of shortcomings in their educational activities and who would like to adopt some initial stance in regard to the problem, formulate a plan, carry out an intervention, evaluate the outcomes and develop further strategies in an iterative fashion, given the initial stance that pedagogical shortcomings exist. The action research tradition allows the use of many techniques of data collection, and action research studies typically make use of both

qualitative and quantitative measures and analyses. These data are used to suggest and refine these interventions in the curricular activities and to guide further research during succeeding terms.

Some of the most widely accepted definitions of action research include the following:

> [Action research] ...aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework. (Rapoport, 1970)
>
> Action Research is a form of self-reflective inquiry undertaken by participants in social (including educational) situations in order to improve the rationality and justice of (a) their own social or educational practices, (b) their understanding of these practices, and (c) the situations in which the practices are carried out. It is most rationally empowering when undertaken by participants collaboratively...sometimes in cooperation with *outsiders*. (Kemmis, 1983)
>
> [Action research] ...is the systematic study of attempts to improve educational practice by groups of participants by means of their own practical actions and by means of their own reflection upon the effects of those actions. (Ebbut, 1983)

In short, action research is characterized by the constraints and strengths that provide a research methodology intended to be a workable technique for working classroom teachers.

Action Research Designs

The essentials of action research design are described by Elliott (1978) in terms of the following characteristic cycle:

- initially an exploratory stance is adopted, where an understanding of a problem is developed and plans are made for some form of interventionary strategy. *(The Reconnaissance & General Plan)*
- then the intervention is carried out. *(The Action in Action Research)*
- during and around the time of the intervention, pertinent observations are collected in various forms. *(Monitoring the Implementation)*
- the data are examined for trends and characteristics, and a new strategy developed for implementation. *(The Revised Plan or Maintaining the Action)*
- the new interventional strategies are carried out, and the cyclic process repeats, continuing until a sufficient understanding of (or implementable solution for) the problem is achieved.

Action research is iterative or cyclical in nature and is intended to foster deeper understanding of a given situation, starting with conceptualizing and particularizing the problem and moving through several interventions and evaluations. One representation of an action research protocol by Kemmis (1983) is provided in Figure 1, which displays the iterative nature of action research along with the major steps of planning, action, observation and reflection before revising the plan. In some ways, action research is similar in nature to the numerical technique known as successive approximation – the goal is to achieve a desirable outcome by a process of repeated iterations.

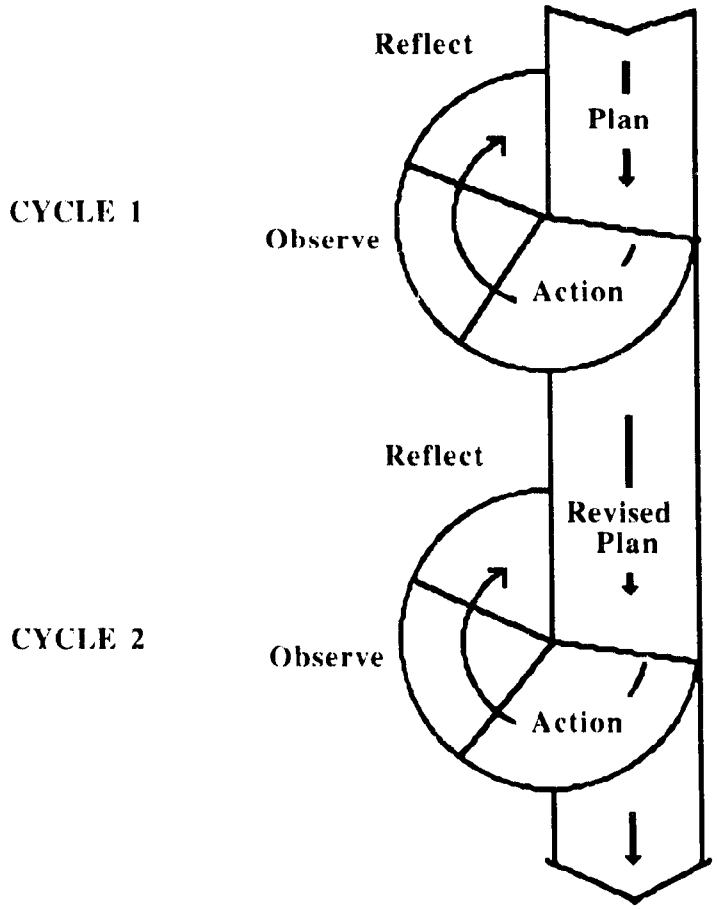

Figure 1. Action research protocol (after Kemmis, in Hopkins, 1993)

Later cycles through the action research spiral reflect changes made as a result of reflection on the experiences of earlier iterations. Figure 2, for example, reflects the evolution of the general idea or main topic of interest throughout the process.

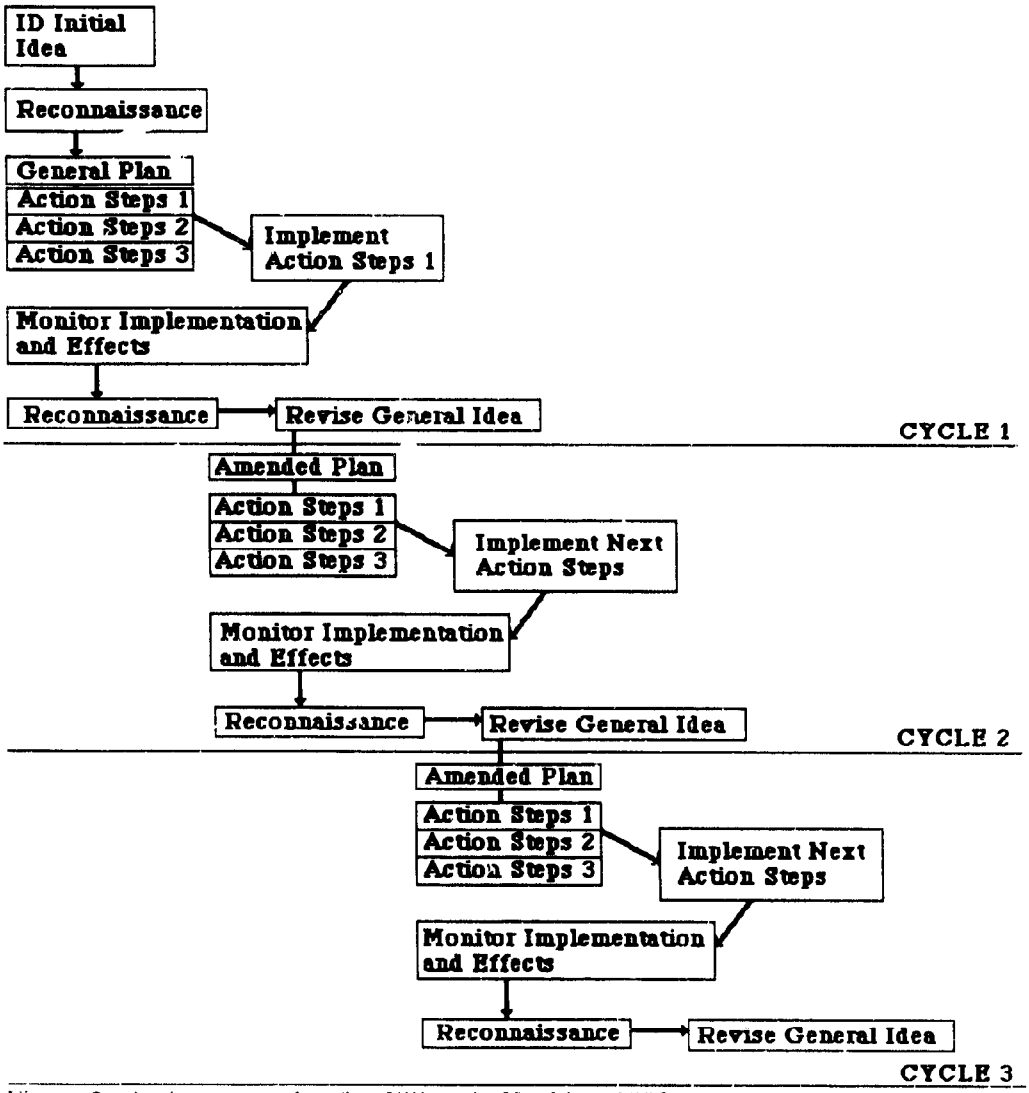

Figure 2. Action research (after Elliott, in Hopkins, 1993)

Elliott's model emphasizes constant evolution and redefinition of the original goal through a series of reconnaissances recurring every cycle. The reconnaissance necessarily includes some degree of analysis. This design permits much greater flexibility, and seeks to "...recapture some of the 'messiness' which the Kemmis version tends to gloss" [over] (Hopkins, 1985). Ebbutt (1983) illustrates the evolution of the *overall plan* through the spiral analogy in Figure 3.

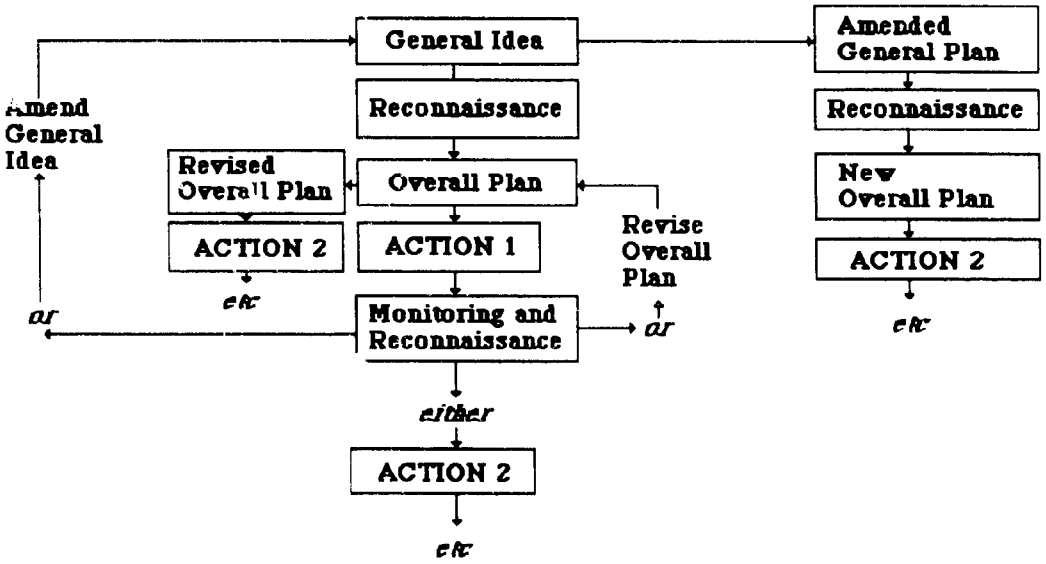

Figure 3. Action research protocol (after Ebbutt, in Hopkins, 1993)

The Role of Communication

One of the primary characteristics of action research is the degree of empowerment given to all participants. Involvement is of a knowing nature, with no hidden controls or preemption of direction by the researcher. All participants negotiate meaning from the data and contribute to the selection of interventionary strategies, including the researchers, the teachers, and the students.

Elliott considers the need for communication between all participants to be of paramount importance:

> Since action research looks at a problem from the point of view of those involved it can only be validated in unconstrained dialogue with them.
>
> Since action research involves unconstrained dialogue between "researcher" (whether he be an outsider or teacher/researcher) and the participants, there must be free information flow between them. (Elliott, 1978)

Reflection

Perhaps the key component involved in action research is the notion of *praxis*. Action research is intended to be the "...reflective counterpart of practical diagnosis ..." (Elliott, 1978). Schön describes the use of reflection to generate models from a body of previous knowledge. These models are used to frame a problem; then experiments are performed to bring about outcomes which are subjected to further analysis. This model (called reflection-in-action) frames means and ends interdependently and recognizes that there is little or no separation of research from practice, little or no separation of knowing and doing (Schön, 1983). Schön's model of reflection-in-action compliments the iterative and investigative natures of action research.

AN EXAMPLE OF THE THREE METHODOLOGIES

The design of an investigation performed at Purdue University might provide an ideal example of the difference between the approaches taken by someone guided by the three research methodologies (quantitative-experimental, qualitative-naturalistic, and action research).

Students enrolled in the organic chemistry course taught within the Pharmacy Department at Purdue were divided into two groups, more or less randomly. One group experienced a classic lecture approach to organic chemistry by two instructors with many years of experience at teaching organic chemistry via well-crafted lectures. The other group experienced a class in which the instructor asked them to work in groups of three on problems he brought to class. After the students worked together in class, they shared their results with the instructor, who then tried to examine the logical consequences of their answers. The students were encouraged to work together outside the classroom. The groups will also provided with time to discuss each hour exam before they split up to write

individual responses to the hour-exam questions.

This "experiment" was done at the request of the instructor of the experimental section, who believed that having students work together in groups would increase their retention of the material learned in the first half of this two-semester organic course. As the reader might expect, we collected quantitative data on student performance. The goal of this phase of the research, which was guided by the quantitative paradigm, was to probe questions such as the following.

> Is there any difference on the hour exams between the two sections?
> Is there an increase in the retention of material between semesters of the organic sequence?

Data designed to guide articulation of this approach to teaching organic chemistry in the future was collected by qualitative, ethnographic techniques taken from the naturalistic research tradition. On the basis of field notes, which report what happened on a day-to-day basis in the classroom, observations of both the students and their instructor during the course of the semester, and interviews with both students and the instructor, the research team hoped to find answers to the following kinds of questions:

> How do students interact when they work together?
> What do the students choose to talk about?
> What do the students discuss when they preview exams?
> What are the students perceptions of their instructor and each other?
> What are the instructor's and the students' beliefs about how learning occurs?
> What do the students believe is the role of the instructor in organic chemistry?
> What do students understand about organic chemistry?

The collection of the most important (and what we believe to be the most informative) data for the instructor was guided by critical theory and action research methodology. The goal of this phase of the research project was to collect information regarding our intervention, and try to judge its' worth with the active, knowing participation of the students involved, in order to guide further interventions in instruction. The kinds of critical questions asked included:

> What is the nature of the dissatisfaction that led the instructor to change the instructional situation?
> What factors make it difficult to change the instructional situation?
> What factors interfere with the ease with which this technique can be used by other instructors, or transported to different institutions?
> What effect does this mode of instruction have on the instructor's attitude toward teaching?
> Is this approach to organic chemistry more fun to teach?
> What effect does this have on students perception of the difficulty of organic chemistry?
> What do students understand about organic chemistry?
> Does this change when we alter the approach taken to instruction?
> Does the new instructional mode produce students who think more like an organic chemist?
> Does it produce students who understand what organic chemists do?

The goal of this research differs significantly from the goals of many experiments designed to probe the effect of alternative approaches to instruction. Our goal wasn't to decide whether this technique is "better" than the traditional approach to teaching organic chemistry. It was to obtain information that would allow us to maximize whatever beneficial effect this approach to instruction provides, and to minimize any negative effects that arise. By changing the nature of the questions being asked during this research, we expected to obtain information that is more useful not only to those doing the research, but also to the instructor who teaches the course. Ultimately, the relevance of our research is to be judged by the participants – the instructor and the students, rather than the profession science education research community.

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