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By-Ramsey, Gregor A.; Howe, Robert W.

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Reviewed is research on instructional procedures used to teach science in secondary schools. This part, the first of a two part review, discusses studies emphasizing outcomes obtained from generalized instruction in a classroom or classroom-laboratory setting. Outcomes discussed include knowledge of science content and concepts, understanding the scientific enterprise, critical thinking, and attitude development. The review is summarized by ten conclusions arising from the implications of the research studies reviewed. An extensive bibliography of the field is included. (GR)

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An Analysis of Research on Instructional Procedures in Secondary School Science

Part I—Outcomes of Instruction

GREGOR A. RAMSEY AND ROBERT W. HOWE

Information Analyst and Acting Director, Respectively
ERIC Information Analysis Center for Science Education
Columbus, Ohio

THIS REVIEW of research related to the teaching of science focuses on instructional procedures used in the secondary schools. The review is being presented in two parts. Part I, in this issue, includes studies emphasizing outcomes obtained from generalized instruction in a classroom or classroom-laboratory setting. Part II includes studies that identified a particular instructional procedure; it will appear in the April issue of *The Science Teacher*.

To bring a paper of this nature into something like a manageable form, the research reviewed has been restricted to that completed during the past decade. This has meant ignoring the many valuable early studies on which the more recent work has been built. While this removes some historical perspective, it allows in the space available sharper delineation of the present frontiers.

Two types of confusion in the field have complicated the reviewers' task. The first is the confusion between a course description (as outlined by a text or course of study) and the instructional procedures used to teach it. The difficulty arises because the science course improvement projects are considered by their proponents to be more than just course descriptions; they are expected also to define instructional procedures. This may well be possible; however, to what extent is likely to be highly variable, and this difficulty is compounded further by some researchers presuming that a traditional course description also implies some mythical "traditional procedure." This is unlikely to be so.

The second difficulty arises from the confusion of terms used by researchers to describe instructional procedures. What exactly a "traditional" method is, how an "open-ended" approach differs from a "nondirected" approach, or a "problem-solving" method from an "inductive" method, or team teaching from "large group–small group instruction" adds to the general air of disorder which prevails in the field and restricts the possibilities for the reviewers to make generalizations regarding instructional procedures by combining the findings of a number of studies.

For this two-part review, the authors decided to concentrate on those research studies that attempted some objective evaluation of instructional procedures in terms of clearly defined outcomes. The focus was either on the outcome attained or the instructional procedure used. In this first part the focus is on the outcomes of instruction; for example, knowledge attainment, understanding the scientific enterprise, development of attitudes, critical thinking, and psychomotor skills. Part II will focus on the means employed; for example, individual instruction, team teaching, and audio-visual instruction.

When the papers were analyzed according to instructional aims, 97 were directed toward knowledge of content as the prime outcome expected, while 30 attempted to develop outcomes other than content knowledge—outcomes from the cognitive, affective, and psychomotor domains. They did this, however, from the context of the conventional class-teacher instructional arrangement. Only 34 studies used an instructional method other than the conventional one to attempt to develop outcomes other than knowledge achievement. Thus, researchers were reluctant to manipulate two unfamiliar variables at once. If an instructional means was the focal point (e.g., team teaching), then the outcome evaluated was knowledge achievement. Likewise, if the researcher wished to focus on attitudes, then he usually went to a conventional class setting to do it. For example, with audio-visual aids as the instructional means, 15 studies looked for content outcomes, and only 2 for a change in attitude, yet audio-visual aids may well be an effective means for influencing an attitude change.

Another classification is according to subject areas. There were 42 papers in biology, 18 in physics, 28 in chemistry, and 5 in earth science. Fifty-eight were classified in the area of general science or had general applicability to all fields.[1] The biological sciences seem to have a commanding lead in the research on instructional procedures.

The Relationship of Science Courses to Student Outcomes

In this part of the review, we discuss those studies that investigated the outcomes obtained when various courses were taught in a classroom setting. This group included many studies comparing science course improvement projects with more traditional courses and some in which more novel procedures were tried in the classroom.

The outcomes investigated are classified under the headings *Knowledge* (which includes concept and content achievement), *Understanding the Scientific Enterprise,* and *Critical Thinking Ability.* A further category, *The Development of Psychomotor Skills,* was found to be void; the only reference to these outcomes will be made in Part II under *Laboratory Procedures.*

Knowledge

Many of the studies in this area were comparative, seeking to discover whether students learn as much when one or another of the newer courses is taught as they do in a traditional course. This concern was understandable over the period when new courses were being introduced, and many researchers seemed preoccupied with this line of approach in the early 1960's. About twenty studies attempted to compare student outcomes on the basis of the kind of course outline used. Only in the very best, however, where sampling techniques and experimental design were carefully chosen, could one feel reasonably certain that any differences found were due to the manipulated variable (e.g., the course taught) and not uncontrolled factors like teacher characteristics.

The better studies also spread the evaluative net wide, testing for more outcomes than just knowledge of content. These designs took into account grade level, teacher background and experience, school size, and other factors that could influence instruction.

Biology

There were many opportunities for comparisons in this field. With three standard Biological Sciences Curriculum Study (BSCS) versions, innovations like the BSCS "Laboratory Blocks," and the so-called traditional courses, the number of comparisons possible is large.

Grobman, in an extensive study [20], and Lisonbee and Fullerton [33], Lance [30], and Lewis [32], in smaller studies, compared one or another of the BSCS versions with a traditional course. In general, BSCS students scored higher on BSCS comprehensive tests while there was little difference between BSCS and traditional course students on traditional tests (e.g., the Nelson Biology Test). Boys in general outscored girls. These conclusions were confirmed in a study by Moore [36] when he controlled the teacher variable by selecting a superior teacher to teach both the BSCS classes and the traditional classes.

The evidence seems clear that BSCS students learn as much traditional biology as do students in traditional classes, but outperform them when BSCS achievement tests are given. It is likely that other investigations of this type will only further substantiate these findings. Research should now be directed toward different ways of using the materials to see which produce specific outcomes in students. One such study was carried out by Gennaro. [17] His aim was to see whether a "Laboratory Block" approach, when supplemented by assigned readings, was as effective as a "traditional" approach to teaching the BSCS Yellow Version. Although no significant achievement differences were found, the study does give a lead to new avenues for research with these course improvement projects.

Several studies used the lecture-discussion method of teaching as the standard against which to measure various methods of classroom presentation. Oliver [39], Newman [37], Coulter [9], Baumel [5], and Taylor [49] designed studies along these lines. In general they obtained no definite results that would indicate one method superior to another. This is largely to be expected. Teacher variability and characteristics may influence class learning far more than does the external arrangement imposed. In none of the studies, however, was there a significant difference in favor of the deductive method, nor was lecture-demonstration superior to small group instruction.

These studies point to the conclusion that the external arrangement imposed in terms of the course taught or pedagogical method used generally has made little difference to the knowledge outcome of students as measured by current tests. Therefore, other outcome gains must be looked at before one can decide which course or which teaching arrangement is best for any given situation. Perhaps a far more important factor is the philosophical approach of the teacher and the way he works within the external restraints imposed. A profitable line of research could be to compare outcomes obtained by using teachers with different characteristics within any one given external arrangement.

Chemistry

Chemistry, like biology, has had considerable research time devoted to comparison studies between Chemical Education Material Study (CHEM Study), the Chemical Bond Approach (CBA), and one or another of the traditional courses, and little devoted to more basic research on chemistry instruction. Altendorf [2], Rainey [43], and Anderson [3] made comparisons of CHEM Study students and those in traditional courses. From their studies it seems that students taking the CHEM Study course learned as much traditional chemistry as did students in traditional courses.

Many of the difficulties experienced by these early researchers in terms of sample size, teacher background, etc., were overcome in a recent 1967-68 study by Troxel [52] in Iowa and Illinois. He stratified his sample care-

[1] The figures quoted refer to the total number of papers reviewed which discussed instructional procedures. Many of these were nonevaluative descriptions of procedures and for this reason were not included in the paper, but appear in the bibliography.

fully and considered only students in large schools being taught chemistry by teachers who had a certain minimum background of experience in teaching the subject. He compared students in CHEM Study, CBA, and a conventional course and found that students enrolled in CHEM Study and CBA performed significantly better than did students enrolled in the conventional course. The study indicated the superiority of both course improvement projects in the hands of experienced teachers.

Other studies of interest include one by Sister Ernestine Marie [35] who showed the superiority of inductive methods of teaching over deductive in a ten-year study, and one by Ledbetter [31] who showed that students free to choose where they would begin their study of chemistry, how they would proceed, and how they would evaluate themselves achieved as well as did students taught chemistry in the normal way. Both these studies have implications for classroom instruction.

Berger [7] investigated a basic problem in teaching chemistry, the teaching of chemical formulas. He showed that a method based on the periodic table for obtaining valences rather than one based on rote memorization produced greater retention of the skill of writing chemical formulas even though little difference was noted immediately after the teaching sequence. It seems that if teaching is directed toward understanding the science principle rather than toward simply learning some rules, greater retention is achieved.

Research on chemistry instruction relied heavily on the course description providing the instructional procedure. There were no reports identified of research that evaluated different methods of using the CHEM Study materials. Hopefully, this is the approach that future research will take, since the evidence seems clear that in terms of knowledge outcomes, little difference can be detected between a traditional course and one of the newer courses. Desired outcomes other than knowledge, qualifications and experience of the teachers, and available facilities must all be considered when predicting the successful introduction of a new course into a school situation.

Physics

Most of the research in this area has also consisted of comparison studies, usually between Physical Science Study Committee (PSSC) physics and traditional courses. It is interesting that no research of a comparative nature has been reported in the literature on Harvard Project Physics (HPP). Research relating to HPP has been primarily directed toward developing instruments or determining more basic characteristics of physics teachers and students.[2]

Heath [22] and Berry [8] in smaller comparative studies investigated the influence of PSSC physics and traditional physics on student achievement. No significant differences were detected on the Cooperative Physics Test which may be considered to favor the traditional groups. On PSSC tests, PSSC students achieved at a significantly higher level.

Two other studies in this area, one by Crumb [11] and one by Trent [51], were concerned more with understanding science and will be dealt with under that heading. Crumb did make some allowance for teacher background in terms of whether the teachers had received education related to PSSC. He was able to detect differences in the methods used by teachers whose classes showed the highest mean gains on the tests and those which showed the lowest, but this did not necessarily reflect educational background.

From these comparative studies it appears that PSSC students seemed to learn as much traditional physics as did students in traditional classes, but learned significantly more PSSC-type material. Little other research was reported, and none was directed toward finding the most effective ways of using the PSSC materials. No evaluation was discovered of instructional procedures used with the Introductory Physical Science (IPS) course.

General Science

Much of the research in this area was concerned with comparing problem-solving or laboratory methods with traditional methods. Such studies seemed to be directed to students of differing abilities, anticipating that one or another method would be more suitable, but often these "either-or" comparisons appear to oversimplify the problems involved.

Mahan [34] and Johns [24] investigated the problem-solving method. They found this effective for developing problem-solving skills and knowledge in students irrespective of ability, and it tended to increase student retention of information for a greater period of time.

Klausmeier and Wiersma [29] were concerned with compressing content into shorter time periods for students of high ability. In their study, experimental students who had three years of science and mathematics reduced to two years achieved as well as did matched control students who took the courses in the normal way. The advantages of this condensation can be passed on to students by allowing them options like graduating early, taking advanced placement work, or obtaining part-time employment. Much more work would need to be done before this method of condensation could become universal for high-ability students, but it points clearly to the need for individualized programs which meet the requirements of each student.

The evidence seems clear that a problem-solving method is an effective way of transmitting science knowledge. When this is used in a laboratory setting, as in a study by Toohey [50] in which he compared laboratory methods of teaching with lecture methods, there are definite advantages in learning and retention.

The demands on the teacher occasioned by a full laboratory-centered course are slowly becoming less with increasing use of small-scale methods, quick-to-assemble kits, and simple prepackaged experiments. Hopefully, an increasing number of general science teachers will be encouraged to try a laboratory-centered problem-solving approach.

Earth Science

The only comparative study identified as relating to the Earth Science Curriculum Project (ESCP) and traditional courses in earth science was one carried out in Iowa by Schirner. [45] His study was a much wider one than simply the effect of a particular course description on out-

[2] Welch, Wayne W. "Harvard Project Physics, Research and Evaluation Bibliography, November 1968." Harvard Project Physics, Cambridge, Massachusetts.

comes. It also included teacher action and teacher philosophical orientation. He used ninth-grade students studying earth science in ESCP and non-ESCP courses and found that each group of students scored significantly higher on their own final examination than did their counterparts in the other course.

The findings of this study are in accord with most of the other comparative studies between a traditional course and a new course improvement project. Outcomes other than acquiring knowledge also seemed to favor the newer course project, and these will be drawn out in more detail in the next sections.

Understanding the Scientific Enterprise

In several studies a definite attempt was made to measure understanding of the scientific enterprise as one of the outcomes of a particular course sequence. The most common instrument used was the *Test on Understanding Science;* hence, findings in this area stand or fall on how well changes in scores on this particular instrument measure growth in understanding the enterprise of science.

In three studies BSCS materials were utilized in different ways to see whether any change in the range and extent of outcomes occurred. Yager and Wick [56] used the BSCS Blue Version and altered teacher emphasis. Gennaro used the BSCS Yellow Version as the basis for a multireference approach, while Sorenson used two "Laboratory Blocks" as the basis to compare laboratory-centered and lecture demonstration-centered instruction.

A multireference approach was found, by both Yager and Wick [56] and Gennaro [17], to produce greater gains in understanding the scientific enterprise and in critical thinking. Sorenson found that his laboratory-centered approach also produced significant changes in both these areas. Thus, it would seem that a multireference, laboratory-centered approach to biology will produce greater student growth in understanding the scientific enterprise and in critical thinking ability.

Crumb [11] and Trent [51] investigated understanding the scientific enterprise outcomes with students in PSSC and traditional courses. No allowance was made in the Trent study for teacher background, and Trent found no significant differences between the groups. Crumb, however, divided his students into four groups on the basis of the teachers' training; he found that students in PSSC classes showed a greater gain in understanding science over the school year than did students in traditional classes.

When teacher background is held constant in terms of training in the discipline, experience in teaching the course, and general philosophy, and student background held relatively constant by size of school, as in the Troxel study [52], there were significant gains in understanding science for students in CHEM Study and CBA courses over those in a traditional course. In general, analysis showed that students enrolled in CHEM Study developed a significantly better understanding of chemistry regardless of ability level, while students in the CBA program in the top third of their class develop into significantly better critical thinkers.

Another study on understanding the scientific enterprise identified besides those associated with the course improvement projects was one by Oliver. [39] He determined the effectiveness of the "History of Science Cases" instruction method for improving the students' understanding of science and scientific activity. Students in experimental classes made significant gains on the *Test on Understanding Science* compared to control groups; no significant differences were obtained in achievement of content.

The nature of the course taught and the background and experience of the teacher both seem to affect the gain in a student's understanding of the scientific enterprise. What relationship exists between these needs further research. Probably factors more fundamental than just teacher preparation are in operation, and these factors will form the basic personalities and teaching styles of each individual teacher. The whole area of understanding science is enigmatic. It is easy to define when measured by gains in a particular test, but what this really means in terms of a generalized understanding of science, and what the implications are to a teacher do not seem to be fully clear. It is an area in need of increasing attention from researchers.

Critical Thinking

This outcome has had little attention from researchers. It was usually evaluated using the *Watson-Glaser Critical Thinking Appraisal* as part of the general evaluative battery of tests. The items on this instrument do not refer specifically to science, so changes in scores may as readily be attributed to the social studies or English courses as to a particular science course. For this reason gains on the test can only validly be attributed to a particular instructional procedure in science if both the experimental and control groups have identical teachers and courses in all other subjects, and this is a difficult requirement to attain in practice.

George [18] used the Watson-Glaser instrument in a study to evaluate the claim that the new course improvement projects develop critical thinking. He used biology students enrolled in each of the three BSCS versions and in a conventional program in four high schools. He found that only those students who had been taught the BSCS Blue Version showed any significant gains over the conventional classes. Unfortunately, in this study only one teacher was teaching the Blue Version, while two to four teachers taught the other programs, so teacher background and ability were uncontrolled factors. However, the study shows that the mere fact that a BSCS program is taught does not necessarily mean that there will be gains in critical thinking over those obtained with a conventional course.

There are many factors operating in the development of critical thinking other than the course outline taught. This was supported in a study by Yager where the BSCS Blue Version was used as the content vehicle. It showed that the individual teacher does affect student achievement including critical thinking and that different teachers certainly differ in their ability to help students understand the nature of science.

The teaching emphasis can be related to a desired outcome. The Yager and Wick study discussed in a previous section indicated this. Also, Kastrinos [26, 27] used a critical thinking method of teaching in an attempt to develop this skill in high school biology students. He evolved his own critical thinking test. He compared students trained in this way with students taught in a conventional text-recitation group and found that the critical thinking approach did produce, over a period of one semester, significant changes in students' ability to think critically.

Laboratory-centered instruction seems to enhance the development of critical thinking skills. The studies by Sorenson [48] and Johns [24] both support this position. A second finding of the Sorenson biology study was that there seemed to be little relationship between a student's mental ability and his changes in critical thinking or *Test on Understanding Science* score. While such a finding needs replication, it would contradict the notion that only high-ability students can be taught thinking skills and increase the evidence supporting the provision of laboratory problem-solving experiences for low-ability students as well as students of high ability.

The ESCP study by Schirner [45] gave evidence that the students studying the ESCP course developed into significantly better critical thinkers than did students taking a non-ESCP course, and also tended to show greater gains in understanding of science. He found, however, that the preparation, background, and philosophy of the teacher was extremely important. A student having a direct teacher with traditional beliefs had an advantage in a non-ESCP course but was at a disadvantage if in an ESCP course; a student with an indirect teacher having nontraditional beliefs had an advantage if in an ESCP course. Perhaps even more important, if a modern course is taught in a traditional manner, this results in lower student achievement than could be expected with the same teacher in a traditional course.

The extent to which PSSC, CHEM Study and CBA courses have been used to develop cognitive skills has had some attention from Herron [23], Heath [22], Crumb [11], and Troxel [52]. The evidence points strongly to the conclusion that these course experiences enhanced the cognitive abilities of the students taking the courses more than do traditional courses. For example, Herron used a factor analysis technique to compare CHEM Study and conventional course students on the development of cognitive abilities and found that conventional course students relied more on lower level cognitive abilities than did CHEM Study students. Heath found that a relationship existed between a student's score on a PSSC test and his cognitive style, while no similar relationship existed between achievement of a control group on a traditional test and cognitive style. Troxel [52] found that experiences in both CBA and CHEM Study were superior to a traditional course experience in developing critical thinking skills; and for able students, CBA was superior to CHEM Study.

The research tends to indicate that if an increased ability to think critically is a desired outcome, then an instructional procedure which is laboratory centered can be developed to increase this ability. Further research should be directed toward developing more efficient procedures for enhancing critical thinking skills and more effective science-oriented tests for measuring them. The development of critical thinking skills in students seems a profitable area for the classroom teacher to investigate.

The Schirner study suggests the importance of matching the course with the nature of the teacher teaching it if the students are to achieve their optimum with a particular teacher. A lowering of student achievement may be expected if a teacher with traditional beliefs is forced to teach a modern course.

Development of Attitudes

It is difficult to pinpoint exactly what is meant by the development of attitudes. If the development of a scientific attitude is meant, then characteristics to be evaluated include habits of accuracy, intellectual honesty, openmindedness, seeking cause-and-effect relationships, and the ability to suspend judgment. If the development of positive attitudes toward science or scientists is meant, then the feelings, opinions, emotions, and appreciations of our students must be evaluated. If the areas of student interest in science are the concern, then methods must be found for effectively identifying these areas so that instruction may be based more firmly on this interest and so that students may be directed into science careers which parallel their areas of interest.

A study which attempted to teach for a change in attitude was one by Davis. [13] He gave special instruction supplemented by magazine articles on race and fallout to see whether he could bring about attitude change. Using an instrument that he developed himself, he found that such instruction could change student attitudes, and this change did not depend on intelligence level.

Kahn [25] used current events as a basis for teaching attitudes to eighth-grade students. He developed charts which symbolically represented different attitudes and then applied these through discussion to pupil reports of the news. He found that significant changes in attitude did occur, irrespective of reading level.

Williams [54] identified a number of philosophical and psychological considerations which illustrated the way scientists accumulate knowledge. These were used to develop a model for producing teaching materials on the historical development of physiological concepts relating to blood circulation and kidney function. The premise was that information alone on how these concepts evolved would be sufficient to change student attitudes. Although this novel idea did not produce significant gains, subjective feedback seemed particularly good, and it might provide a lead for further worthwhile research.

There are several studies in which an attitude change was found, although it was not specifically sought. Coulter [9] found that inductive methods of teaching produced significantly greater attainment of scientific attitudes and more positive attitudes to instruction than did deductive methods. Sorenson [48] found that laboratory-centered teaching produced significant desirable changes in dogmatism, while no such change was found in lecture-demonstration groups. Mahan [34] found that his problem-solving approach produced greater growth in personal adjustment and attitudes toward school than did the traditional approach. Thus it seems that an inductive, problem-solving, laboratory-centered approach can be expected to produce significant positive changes in student attitudes.

The extent to which student interests relate to student attitudes is very much a moot point. Yet it cannot be denied that the development of student interest in science is particularly difficult if students have negative attitudes toward science. These negative attitudes, and the development of student interests, are particularly important at the junior high school level. Craig and Holsbach [10] used existing student interests in general science students to develop others. Any student revealing low initial interest in a given content area was given supplementary learning experience in this area, using activities he enjoyed. This method was effective for raising the interest level of students with few interests but made little difference to those who already had a wide range of interest. To maintain the interest level of students where it is already high seems to present special problems. It would be interesting to investigate whether students with different interest profiles require fundamentally different instructional procedures.

The research on attitude development still leaves unanswered many fundamental questions. The evidence is mounting that attitudes can be measured and that teaching procedures can be devised to bring about attitude change. However, much more work is needed to bring about a refinement of instruments and procedures. There is still a large question mark over the relation between actual behavior and scores on pencil-and-paper tests, and fundamental work must be done to find what relation, if any, exists between them. A student's attitudes toward science may well be more important than his understanding of science since his attitudes determine how he will use his knowledge. For this reason the development of attitudes as a part of science instruction is an area requiring increasing research.

Conclusions

The following 10 points are stated without elaboration as tentative conclusions arising from this section of the paper where the focus of interest has been the outcomes obtained from instruction in a classroom setting.

1. There is considerable confusion in the terminology used to describe any given instructional procedure. Some standard set of terms needs to be devised so that the same descriptors are used for similar instructional means. Once these terms have been defined and become accepted by researchers, then maybe a truly viable instructional theory can arise to form a theoretical base for future research.
2. Students in newer course improvement projects achieve at least as much traditional content as do students in conventional courses and achieve more in the content area defined by the new course.
3. The background and philosophy of the teacher is important if a new course is being taught. Any given student will achieve more in a traditional course with a traditionally oriented teacher than he would have if the traditional teacher had taught a new course. Thus, new courses can only be successful if the teacher is adequately prepared and philosophically oriented to teach the course.
4. Teacher characteristics seem more significant in deciding outcomes than any imposed external arrangement; however, if some minimum criteria of teacher performance are defined, then the external arrangement, e.g., course description or pedagogical method, may have an effect on student outcomes.
5. Inductive, problem-solving, and laboratory-centered methods seem preferable to deductive-demonstration methods if outcomes other than knowledge are sought and if retention of knowledge over time is felt to be important.
6. Instructional procedures can be designed to teach students to think critically and to deepen their understanding of the scientific enterprise.
7. A desirable attitude change can be taught by carefully designed instructional procedures; this applies to all ability groups.
8. Much more useful information is likely to be gained by investigating different instructional procedures for teaching a given course or instructional module than by attempting to compare one course with another.
9. There is a deep need for more sensitive and more imaginative instruments for measuring various outcomes. The instruments available measure performance on pencil-and-paper tests but say nothing about many changes in behavior produced in students by the instructional procedure.
10. The development of psychomotor skills has been almost completely ignored by researchers in science education. How do laboratory-centered courses develop manipulative skills? What manipulations can a student at any level be expected to perform? Is there a hierarchy of skills to be developed in the laboratory? These are a few of the fundamental questions requiring answers from research studies.

These conclusions summarize the research findings as broad generalizations, and outline some of the deficiencies in the field. That generalizations like these can be misleading is a risk that the reviewers are prepared to take in the interests of delimiting the field into a form which can readily be assimilated. If research proves them to be wrong, then they will have fulfilled a purpose. If they convince a classroom teacher to try a different procedure to see whether it really does work better, then again they have performed a service.

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