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Education research in the biological sciences: A nine decade review

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A. Introduction

1. Focus

In this review of biology education research (BER), I focus on how teaching and learning of the emerging sub-disciplines of biology have developed historically at the higher education level, primarily in the United States. I have included investigations on children and high school students where that work was especially informative and influential in BER. I have reviewed and cited work published in English between the late 1800s and 1990, and have referenced a few recent reviews so readers can extend my coverage into current research on each topic.

2. Guiding questions for this review

a. When did BER arise, at which institutions, and under what impetus?

b. When and where did the first doctoral and post-doctoral programs for BER begin?

c. How was BER viewed initially, and are there indicators showing that its status has changed over time?

d. What theoretical frameworks have guided the development of BER?

e. What are the key milestones that define the changing focus of BER over time?

3. Methodology and sources

To select articles and dissertations to review here, I queried ten online databases for journals with the index terms: *biology education* or *science education* in their titles:

1. Directory of Open Access Journals
2. EBSCOhost Academic Search
3. EBSCOhost Arts and Sciences
4. Google Scholar
5. Highwire Press
6. JSTOR Arts & Sciences
7. Proquest/Galileo
8. PubMed Central
9. Springer Standard Collection
10. Wiley Interscience

This search yielded a total of 61 journal titles. This list was narrowed to 25 (Table 1) by weeding out those dealing with unrelated subjects (e.g. library science education). I then scanned the table of contents of available issues of each journal, selecting articles whose titles appeared to be relevant to answering the above guiding questions regarding BER. Those journals that had short publication histories, such as *CBE-Life Sciences Education*, which has only nine volumes to date, allowed me to scan every issue. For journals with early publication dates, I sampled the contents of every fifth or tenth issue, again selecting articles with relevant titles. In addition, I scanned several available bibliographies of science education research, selecting studies relevant to the biological sciences with publication dates in the 1920s to 1980s as search terms. These included the series known as the "Curtis Digests" published between 1926 and 1957 by Francis Curtis (Curtis, 1932; Nisbet,1974; Blosser, 1976) at the University of Michigan and three other authors, the extensive bibliography of published investigations prepared by Charles J. Pieper of New York University (Pieper, 1931-32), as well as other well-known compilations (Anderson, 1973; Duit, 2009; Hake, 1999: Lee et al., 1967; Majerich et al., 2008; Yager, 1980). To find doctoral dissertations, I searched the Proquest *Interdisciplinary Dissertations & Theses* database using index terms to select for documents dealing with college biology education.

Table 1. Selected Journals with titles containing index terms: "science education" or "biology education"

Journal	Year of Vol. 1
Advances in health sciences education	1996
Anatomical sciences education	2008
Biochemistry and Molecular Biology Education	1972
Canadian journal of science, mathematics and technology education	2001
CBE life sciences education	2002
Education Sciences and Psychology	2002
The electronic journal of science education	1996
Eurasia journal of mathematics, science and technology education	2005
International journal of educational sciences	2009
International Journal of Environmental & Science Education	2006
International journal of science and mathematics education	2003
International journal of science education	1979
International Online Journal of Educational Sciences	2009
Journal of Biological Education	1967
Journal of Microbiology and Biology Education	2000
Journal of Natural Resources and Life Sciences Education	1972
Journal of Science Education	1992
Journal of Science Education and Technology	1992
Journal of science teacher education	1989
Psychological Science & Education	1996
Research in Science & Technological Education	1983
Research in science education	1971
Science & education	1992
Science education	1916
Studies in Science Education	1974

Finally, I have a personal database of over 350 education-related book and monograph chapters and journal articles from which I selected about 80 contributions that deal specifically with research in biology teaching and learning. In all, the above process yielded over 300 printed or online articles. From the list of references cited in each of these articles, I chose 104 with publication dates between 1900 and 1990 and 15 recent reviews that were germane to the guiding questions to read more carefully. These are discussed below and listed in the references at the end of this paper.

B. Origins of BER

1. When and where did BER arise?

Much of the research on education in the biological sciences over the past century has been devoted to answering questions about the relative efficacy of three historic approaches to teaching and learning that have origins during the rise of higher education in the United States in colonial times: (a) *lectures*, in which the professor usually read from prepared notes, often to large classes; (b) *formal disputation*, in which students opposed one another in debate to sharpen their thinking and argumentation skills; and (c) *experiential learning*, usually in a laboratory or field setting (see Scott, 2006; DeHaan, 2008 for further historical perspective).

At the turn of the century, the anatomist/embryologist Franklin Paine Mall famously urged students to "learn by doing" in the laboratory (Mall, 1908) and laboratory exercises became commonplace in anatomy, botany and physiology courses. But the earliest studies in the twentieth century of how to improve science education were performed, not by scientists in the biological disciplines but by faculty and their graduate students in schools and colleges of education. Various aspects of teaching high school and introductory college science were explored, mainly in physics and chemistry, only rarely in biology. Throughout most of the 20th Century research specifically aimed at biology education has constituted only a small fraction of discipline-based education investigations. According to Fensham (2004), a field of research can be recognized as such when it has: academic recognition, research journals, professional associations, and research conferences. From a sampling of almost two thousand education research publications and dissertations listed in the published compilations noted above, covering the period 1920 to 1989, 93% (almost 1800) were studies of sciences other than biology or of more general aspects of teaching science unrelated to a specific discipline. Only 141 (~7 %) were concerned with biology subjects or students, only about half of those (75) were at the college level, and most were published after 1960 (Table 2).

Table 2. BER publications and dissertations in selected compilations

Years	Total Sci Ed	Total BER	BER HS	BER UG	Pubs	Diss	% BER	% BER HS	% BER UG	Reference
1920-1969	65	2	1	1	65	0	3%	2%	2%	Duit, 2009
1920-1989	74	10	2	8	68	6	14%	3%	11%	Majerich et al., 2008
1963-1964	45	8	0	8	8	37	18%	0%	18%	Lee et al., 1967
1960-1980	206	24	9	15	0	206	12%	4%	7%	Yager, 1980
1970-1979	225	9	5	4	225	0	4%	2%	2%	Duit, 2009
1971	337	45	28	17	114	223	13%	8%	5%	Anderson, 1973
1980-1989	984	43	21	22	984	0	4%	2%	2%	Duit, 2009
TOTAL/%	1936	141	66	75	1464	472	7%	3%	4%	

Two additional criteria for defining a research field are the existence of research centers and programs of training in the specialty (Fensham, 2004). In the first half of the twentieth century there were isolated investigators conducting education research on various aspects of biology instruction but they were few in number, often not well known to each other, and with limited avenues of publication. Centers with substantial numbers of education researchers, such as those at University of Chicago, Stanford, and Ohio State University were housed in the School or College of Education, faculty investigators were not biological scientists, and they only rarely focused their attention on biology instruction. Attention to teaching and learning in the biological disciplines increased slowly after WWII, with rapid growth in number of BER dissertations and publications appearing mainly in the 1980s and beyond (DeHaan, 2005; Wood, 2009; Dirks, 2011).

2. BER investigations of instructional strategies

In the 1920s and 1930s, scattered studies began to appear of the relative values of various means of teaching science, those favoring information transfer and rote memorization as in the lecture/demonstration method, and those that encouraged more student-centered, disputation-like methods that included group discussion and independent laboratory work. From research in developmental psychology came reminders that students learn best through experience (Dewey, 1916; 1938). In a study of the effectiveness of botany and zoology instruction, Ralph Tyler (1934) at Ohio State University presciently defined learning objectives as improvement in a series of desired abilities (e.g. to recall facts and principles, formulate generalizations from data, plan an experiment to test a hypothesis, apply principles to new situations). In a year-long investigation, he periodically measured student improvement and retention of learning with specially designed examinations. But unlike Tyler's effort, when laboratory learning techniques were made available in college biology courses elsewhere, what were intended as occasions for students to have first-hand experiences with their subject materials and to test ideas for themselves, in practice often became times for slavish repetition of assigned exercises directed by step-by-step instruction manuals. Despite criticisms of such practices (e.g. Gerard, 1930; Nelson, 1931; Voss & Brown, 1968) early BER investigations performed within the education community began to shed doubt on the efficacy of inquiry-based instruction. The first comparison quasi-experiments (no randomization) I could find were designed to test whether in biology (Cooprider, 1922; Johnson, 1928) or other sciences (Downing. 1931) independent student work in a high school laboratory setting was any more effective in improving test scores than instruction with the traditional lecture-demonstration method. These early investigations showed little benefit. A study by J. Darrell Barnard at the Colorado State College of Education (Barnard, 1942), which appears to be the first controlled quasi-experiment to compare the effectiveness of the lecture-demonstration method and a problem-solving laboratory approach to teaching biology at the college level, again showed no appreciable differences on test scores. In a study twenty years later of 924 non-major students, Dearden (1962) compared demonstration and problem-based methods of teaching college biology, and again found no differences in measurements of learning. Later studies (e.g. Yager et al., 1969) and periodic comprehensive reviews of the literature continued to show few advantages of inquiry-based teaching in biology and other sciences (Downing, 1931; Cunningham, 1946; Kittell, 1957; Nachman and Opochinsky,1958; Kersh, 1962; Dubin and Taveggia,1968; Singer and Pease, 1978; Lott, 1983; Wise and Okey,1983; Leonard, 1988). Only toward the end of the 1980s and beyond has research begun to reveal fairly consistent, if small, advantages of inquiry-based instruction (see Anderson, 2002; Dirks, 2011). Centers where such research was performed in the period, 1920-1940 included Teachers College of Columbia University, School of Education of City College of New York, the Colleges of Education at Colorado State, Ohio State, Pennsylvania State and Stanford University, and the Universities of Chicago, Iowa, Michigan, Minnesota, Texas, and Wisconsin.

During the early decades, concerns among scientists over the stilted, unproductive laboratory experiences that had become common prompted the first radical "experiments" in instructional approaches by faculty outside schools of education using their college biology students as subjects. At Ohio State University, Homer Sampson (in collaboration with Ralph Tyler, see above) changed the instructional mode of the general botany course to a *problem-discussion* method (Sampson, 1931) that we might now recognize as *problem-based learning.* At about the same time, a new faculty member at the University of Chicago, Ralph Gerard, (1930) took over teaching the traditional pre-medical physiology course. In these two efforts, Sampson at Ohio State and Gerard in Chicago, introduced what appear to be the first university level *guided inquiry* courses in the biological sciences. To judge student learning and the value of the course, neither Gerard (1930) nor Sampson (1931) offered quantitative assessments of their results. Both men judged the success of their courses qualitatively through student questionnaires and interviews, and by what they noted as clear gains in the students' ability to discuss problems intelligently (see Tyler, 1934).

3. Research on Student Reasoning

The conceptual and pedagogical framework that we now refer to as critical or scientific thinking originated early in the century, and much of the effort of BER has been devoted to a search for strategies that foster these skills in the biological sciences. Downing (1928) published a list of the elements of scientific thinking based on his own analysis of the published works of great scientists. The concepts were put on a more scientific basis in developmental psychology with the work of Piaget and his colleagues (Inhelder & Piaget, 1958) and Bruner (1961). Inquiry-based instructional strategies that foster these abilities and are applicable to secondary and post-secondary teaching environments have been investigated during the 1960-1989 period (Raths et al., 1966; George, 1968; Moll & Allen, 1982). Notable among these approaches have been (a) techniques to help students conceptualize rather than just memorize; (b) group discussion, usually in a laboratory setting; (c) problem solving and problem-based learning; (d) prior knowledge and alternate conceptions; and (e) computer-assisted instruction.

a. <u>Conceptualizing versus memorizing</u> The differences between memorizing information and learning for understanding were made explicit when cognitive psychologist, Benjamin Bloom and his colleagues at the University of Chicago published Bloom's Taxonomy of cognitive skill levels (Bloom et al., 1956), a publication that was soon cited in biology textbooks of the time (Voss & Brown, 1968). To help students struggling with biological concepts, J. D. Novak (1970) at Cornell University introduced concept mapping (Novak, 1977; Arnaudin et al., 1984). After George (1968) found that instruction in critical thinking offered advantages to high school biology students, R. D. Allen and his colleagues at West Virginia University began to use lecture time to teach critical thinking skills to introductory college biology students, employing video and discussion during class to enable students to apply concepts as they learned them. With these quasi-experiments, they were among the first to show significant improvements in pre/post tests of students' critical thinking skills (Moll & Allen, 1982).

b. Group discussion and cooperative learning. An important pedagogical shift from whole-class lecture or individual instruction to various forms of group discussion and cooperative learning began in the early 1970s. Over the years, this has come to encompass various types of guided activities, often with groups of 2-10 students, termed small group learning (SGL). The movement toward SGL was driven largely by earlier research among social psychologists showing the beneficial effects of cooperative learning and student discussion as contrasted with competitive or individual instruction (e.g. Deutsch, 1949; Hammond and Goldman, 1961; McClintock and Sonquist, 1976). SGL was first presented as an explicit instructional strategy when Frank Lyman introduced think-pair-share (Lyman, 1981).

Evidence for the benefits of cooperative learning was presented in 1981, when David Johnson and his colleagues in the Department of Psychology at the University of Minnesota published a meta-analysis of 122 experimental studies (Johnson et al., 1981), only one of which was carried out in a college biology classroom (Starr & Schuerman, 1974). The strong conclusion from this analysis was that student cooperation is superior to competition or to individualistic instruction in promoting achievement in learning.

c. Problem solving and problem-based learning (PBL). In the 1960s, Joseph J. Schwab, himself trained in genetics, contrasted problem solving and hypothesis testing in biology versus physics (Schwab, 1962). Serious investigations of problem solving in the biological sciences, however, did not begin until twenty years later with Lawson's studies of students' formal reasoning patterns in a general biology course (Lawson & Snitgen, 1982; Lawson, 1985), and observations on problem solving by genetics students by Smith & Good (1984).

Although it is often claimed that PBL originated in medical education in the 1970s as an alternative to information-dense lectures given to large classes (Barrows, 1980), the "problem approach" to teaching high school biology was tested much earlier (Burnett, 1938), and quasi-experiments with college students in a laboratory setting were initiated in a biology classroom at Colorado State University (Barnard, 1942) and Michigan State College (Mason, 1952) and in zoology (Frings and Hichar, 1958) at Pennsylvania State University. None of these papers reports meaningful improvements in student learning. Wider BER investigations of the many variations of instruction through problem solving (Smith & Good, 1984) and of PBL (Barrows, 1986) began mainly in the late 1980s and grew in the following decades (Woods, 1994; Allen & Tanner, 2003).

d. Prior knowledge and alternative conceptions. It was established from early psychological experiments that misconceptions and prior knowledge can influence what individuals observe and learn. In the 1930s, H. W. Rickett, at Ohio State University, railed against misconceptions purveyed in current textbooks of zoology, genetics and botany (Rickett, 1933). Cyril Hancock, a high school biology teacher in Montana, was the first to document a long list of common misconceptions held by his students (Hancock, 1940), years before Rosalind Driver concluded that such alternate conceptions interfere with learning (Driver & Easley, 1978). This "expectancy effect" was first clearly demonstrated in a biology laboratory setting in studies of high school students' observations of the crustacean *Daphnia* (Hainsworth, 1956). Well-known naïve conceptions such as that plants obtain nutrients from the soil to increase biomass (Wandersee, 1983), and many prior concepts related to genetic transfer and evolution by natural selection have proven to be difficult for students of all ages to overcome (Brumby, 1979; 1981; Krajcik et al., 1988). At the University of Wisconsin, Madison, studies beginning in the 1980s (Collins, 1989; Collins & Stewart, 1987; see Stewart, 1990) contributed to investigations of alternate conceptions of meiosis (Stewart, 1988). These findings were used in the development of a computer-based model of instruction, the MENDEL tutoring system (Streibel et al, 1987), and the development of the Genetics Construction Kit (Jungck & Calley, 1985; Collins & Stewart, 1987; Peterson & Jungck, 1988) that were explicitly designed to help students convert their alternate conceptions into canonical knowledge. Genetics education researchers from this decade also explored related issues (Fisher,1985; Bishop & Anderson, 1986; Stewart, 1990). Research on alternate conceptions has been captured in a series of comprehensive bibliographies compiled by Helga Pfundt and Reinders Duit. As of the end of the time period covered by this report, they listed over 1500 studies (Pfundt & Duit, 1988). The most recent bibliography included 8400 entries (Duit, 2009).

e. <u>Computer-assisted instruction</u>. With increasing access to classroom computers, user-friendly software, and growing data-bases, BER investigations that began in the early 1980s were initially aimed at determining if computer-based instruction could assist certain groups of disadvantaged students (Bangert-Downs et al., 1985; Roblyer et al, 1988; Robertson, et al., 1987). John R.

Jungck at Beloit college was a pioneer in this area, with BIOQUEST (Jungck & Calley, 1985; Peterson & Jungck, 1988), a one-year introductory biology course centered around 12 strategic simulation programs.

4. *Under what impetus did BER arise?*

Three social forces drove the rise of research in science education and specifically of BER. These were (a) changing views of education that accompanied the growth and evolution of the American university system; (b) the creation and increasing influence of scientific journals, usually linked to professional societies; and (c) economic and intellectual forces unleashed by World War Two and the U.S.-Soviet post-war competition..

a. <u>Changing views of education</u>. In the early 1900s, most college faculty devoted themselves primarily to teaching, which was widely considered to be an art (Royce, 1891) rather than a science amenable to systematic investigation (Lagemann, 2000, p.232). Education research grew slowly with the development of the first centers of science research activity at institutions such as Johns Hopkins University (founded in 1876) where faculty members first began to take on the roles of both teachers and scientific investigators. By the 1920s, the systematic study of the emerging social and psychological fields that impact teaching and pedagogy was well established. Educational psychology, educational testing, the history of education, education policy and pedagogical strategies all became foci of research (Lagemann, 2000, p. 19-20). But, as noted above, research explicitly on biology education was rare.

b. <u>Professional societies and publications</u> Scientific societies constituted a second major force in the growth of BER, both by promoting research and by creating outlets for publications. *Science Education,* one of the first American discipline-based education journals, appeared in 1916, serving for two decades as the only U. S. outlet for BER publications (see Table 1). Most of the authors of articles in the early volumes were affiliated with elementary and secondary schools. After volume 30 (1946) the number of college and university authors rises markedly; for volumes 51-60 the mean percentage of higher education authors is 89% (Champagne & Klopfer, 1977). The National Association of Biology Teachers began publishing the *American Biology Teacher* in 1938. In 1946, the American Institute of Biological Sciences (AIBS, 1951) set in motion the processes required for publication of the *AIBS Bulletin* (later to be re-named *Bioscience*). The National Association for Research in Science Teaching began publishing the *Journal of Research in Science Teaching* in 1963.

c. World War II and the post-war U.S.-Soviet competition. The 1940s and 1950s saw a growing recognition by leaders in science of the need to nurture and enhance the country's scientific talent. This concern reached extreme heights in reaction to the Soviet Union's perceived superiority in science education as evidenced by their successful launch of the Sputnik rocket in 1958. One result was a call for the injection of federal funds into education research. In *Science – The Endless Frontier*, Vannevar Bush called for the formation of a National Research Foundation (established in 1950 as the National Science Foundation), and advocated support for both research in the scientific disciplines and that in education for science (Bush, 1945). NSF grants to support college physics and high school mathematics education were soon awarded, and in 1957, shortly after the Soviet Union's launch of Sputnik 1, Congress doubled the NSF appropriation and more than tripled that for science education.

5. When and where did the first doctoral and post-doctoral programs for BER begin?

I was able to obtain information on biology education doctoral programs from published sources (Yager, 1980; Heffron, 1995) and from an email survey of 26 current science educators

(Appendix). From a search of Proquest *Dissertation Abstracts*, the index string "education OR learning AND college OR undergraduate OR university" retrieved a total of 31,396 dissertations between 1930 and 1989. Adding the root "biol*" to the string, reduced the number to a total of 401 related to college level biology education or learning. The numbers sorted by decade show a 40-fold growth of total doctoral training over that sixty year period. But consistent with the slow growth of BER described above, the fraction of dissertations related to biology remained under 1.5% (Table 3).

Table 3. Education research dissertations, total and biology-related (1930-1989)

Decade	Total	Biology	% Biology
1930-1939	435	2	0.46
1940-1949	581	4	0.69
1950-1959	2212	21	0.95
1960-1969	2780	27	0.97
1970-1979	7396	97	1.31
1980-1989	*17992*	250	1.39
Total (1930-1989)	**31396**	**401**	**1.27**

Source: ProQuest Dissertation Abstracts

From the thirty-five institutions with the largest science education programs, sampled at five-year intervals between 1960-1980, Yager (1980) found a total of 206 doctoral dissertations. Of these, 15 (7.3%) were related to undergraduate biology instruction, and fewer than 20% of the faculty in these institutions expressed an interest in research in science education (Yager, 1980). Nonetheless, a few centers where training of doctoral students in BER emerged in this period, though none of these was housed in a life science department. Some of the leaders and their institutions are listed in table 4, which also lists the field and year of their doctorate. All but one of those listed were trained as educators; none was active in research in a biological discipline.

Table 4. Leaders in doctoral training of biology education researchers

PhD	Name	Institution*	School/Dept.	PhD Field
1927	Tyler, Ralph W.	U Chicago	Col of Educ.	Educ. Assess.
1947	Hurd, Paul D.	Stanford U	Schl of Education	Science Educ.
1949	Lee, Addison E.	U Tex-Austin	Sci. Educ. Cntr	Science Educ.
1951	Fowler, H. Seymour	Penn State U	Col of Educ.	Nat'l History
1956	Yager, Robert E.	U Iowa	Sci. Ed. Cntr.	Plant Physiol
1958	Novak, J. D.	Cornell U	Biol/Educ	Sci Ed/Biol
1963	Shrum, John W.	U Georgia	Col Educ	Earth Sci
1963	Voss, Burton E.	U Michigan	Schl. of Educ.	Science Educ.
1964	Anderson, Ronald D.	U Colorado	Col of Educ.	Education
1968	Anderson, O. Roger	Columbia U	Teachers College	Botany
1970	Layman, John W.	U Maryland	Sci. Tchng Cntr	Science Educ.
1979	Stewart, James H.	U Wisconsin	Schl. of Educ.	Curric.& Instr.

*Longest career time

6. How was BER viewed initially, and are there indicators showing that its status has changed over time?

Expressions of dissatisfaction with post-secondary education in the life sciences emerged early in the 20th Century: with fact-stuffed textbooks, tedious lectures, and little opportunity for students to "learn by doing" (Mall, 1908). Much of the criticism came from medical educators and from leaders within the science education community itself, and research efforts to improve teaching and learning biology were weak. (Flexner, 1908; Nelson, 1931). John Nisbet (1974) reviewed fifty years of research in the first six Curtis Digests and pointed out numerous weaknesses (Curtis, 1932), while Yager (1980) noted that science educators were "largely illiterate with respect to science" (p. 83). Other reviewers of the time made similar criticisms (Anderson, 1973; Blosser, 1976). Only in the 1980s are there indications of an improved view of BER within the scientific community. The increasing number of BER dissertations (Table 3); the incorporation in 1983 of the National Center for Science Education in Washington, DC, with its emphasis on evolutionary biology; the establishment in 1988 of the Center for Biology Education at the University of Wisconsin with support from the Howard Hughes Medical

Institute were some of the early signs of growing respect for BER that then blossomed in the late 1980s and beyond.

C. What theoretical frameworks have guided BER?

1. *Constructivism.*

Much of the effort in BER over the past century has been devoted to testing the tenets of constructivism (reviewed in Cakir, 2008). Dewey set the tone and provided the term just before the turn of the century (Dewey, 1897/1998). Piaget's *Theory of Cognitive Development*, (Piaget, 1972; 1978), Ausubel's *Theory of Meaningful Verbal Learning* (Ausubel, 1963; Slavin 1988), and Vygotsky's *Social Development Theory* (Vygotsky, 1978) each modified Dewey's framework in ways that changed the focus of the biology education community from how instructors teach to how students learn (Raths et al., 1966; Bodner, 1986; Glasersfeld, 1989). Joseph Schwab (1962) extended constructivist ideas to develop a "didactic theory' of knowledge (Fox, 1985, p. 84) that emphasized creation of learning experiences through active participation of the student, discussion, and multiple conceptions of subject matter. Schwab's theoretical framework served as the basis, during the 30-year period that began in the 1960s, for many instructional strategies for teaching science as inquiry (Rutherford, 1964; Welch et al, 1983).

2. Conceptual change theory

From Piaget's work (1929) on children and Thomas Kuhn's ideas about paradigm change (1970) grew conceptual change theory (Carey, 1985; 2000) as well as an expanding body of research on alternate conceptions (see above). It is mainly in the 1980s, however, that the theory has been applied to how students learn college biology (Schaefer, 1979; Posner et al., 1982; Fisher, 1985; Tanner & Allen, 2005).

3. Other Theoretical approaches

a. Theory of social interdependence. Experiments on the benefits of group interaction in the 1940s led social psychologist Morton Deutsch (1949) to theorize that when people with common goals work with each other in cooperative fashion, results are better than if they compete or work alone. This theory was fundamental to the rise of the various forms of cooperative learning and SGL, such as peer instruction, think-pair-share, etc. Among the early investigators to test these strategies were Robert Slavin of Johns Hopkins University (Slavin et al., 1985) and David and Roger Johnson (e.g. 1989) of the University of Minnesota.

b. Theories of intelligence. Two theories of intelligence impacted education research in the life sciences during the final decades of the 20th Century: Feuerstein's (1979) theory of instrumental enrichment, and Gardner's (1983) theory of multiple intelligences.

D. What are the key milestones that define the changing focus of BER over time?

The markers that punctuate and define the development of BER have all been discussed in other contexts above:

- Dissatisfaction voiced early by members of the medical and education communities caused investigations designed to compare alternatives to the traditional lecture-demonstration methods of instruction commonly used in high school sciences. These produced uniformly negative results, with the initial exception of two "radical" experiments at the college level by Sampson (1931) and Gerard (1930).

- Constructivist theory, developed during the first half of the century, turned the focus of BER investigators from the instructor to cognitive activities of the learner, supported by recognition of the importance of alternate conceptions, the introduction of Bloom's Taxonomy (Bloom et al., 1956) and the development of a host of inquiry-based instructional strategies.

- Growing social acceptance of scientific investigation as a means of seeking useful knowledge.
- Appearance and expansion of a system of research universities and the formation of a host of scientific societies each with their professional journals.
- Growing federal funding from the newly established National Science Foundation after WW II for education research and specifically for BER
- The tradition of frequent extensive reviews of education research established early aqnd perpetuated (Pieper, 1931-32; Curtis, 1932; Nisbet, 1974; Yager, 1980; Duit, 2009).
- Establishment in the 1980s of the National Center for Science Education and university-based BER centers with support from federal and private foundation funds.

E. **Future historical research**

This review of publications and dissertations produced over a ninety year period has revealed that BER, as distinct from DBER, began early in the century with sporadic investigations. These were performed largely by science educators in colleges of education, and focused primarily on efforts to improve teaching in high school and introductory college biology courses. Only near the end of the period do we begin to see studies of learning and instruction by biological scientists. One important research area to emphasize for the future will involve qualitative investigations with surveys, interviews and case studies to determine when and how biological scientist began to change attitudes toward BER and learned how to become education researchers.

F. <u>Appendix</u>

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