

INQUIRY-BASED INSTRUCTION IN SECONDARY AGRICULTURAL EDUCATION: PROBLEM-SOLVING – AN OLD FRIEND REVISITED

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Abstract

In the quest for more effective teaching and learning methods, one particular approach has surfaced as a “method of choice” for science educators: inquiry-based learning. A careful examination of this method suggests that it is very similar to the problem-based learning approach used by many agricultural educators. This study sought to synthesize research reported by earlier investigators—science educators and agricultural educators—who examined inquiry-based learning and who researched the problem-solving approach. It was also designed to examine similarities between the two approaches and to describe their level of “pedagogical congruence.” It was concluded that significant agreement exists between what some eminent scholars have said is the recommended pedagogy for improving student achievement and the teaching and learning exercised in many agricultural education classrooms. Future research should attempt to measure the science achievement of agricultural education students and teachers’ use of the problem-solving approach. If significant positive associations are established, then professional development and learning resources supporting use of the problem-solving approach should be developed and delivered. In addition, investigations should be carried out to better understand how agriculture teachers operationalize the problem-solving approach.

Introduction and Conceptual Framework

It is widely accepted that students’ learning contexts should be coupled with multiple opportunities in which they “construct” or make meaning of their learning as it begins, progresses, and escalates. This approach to learning, identified as one of several forms of constructivism, owes its philosophical and theoretical roots to philosophers and theorists such as Jean Piaget, John Dewey, and Lev Vygotsky (Doolittle & Camp, 1999). Further, recent discoveries by cognitive and developmental psychologists suggest strong support for much of the epistemological basis posited by constructivist theorists (Bruer, 1999; Caine & Caine, 1991; D’Arcangelo, 2000). To a great extent, inquiry-centered, inquiry-oriented, or inquiry-based learning, as it is practiced in secondary science education

(e.g., the “Learning Cycle”), is deeply rooted in a constructivist or hands-on/minds-on (Haury & Rillero, 1994; National Research Council, 1996; Von Secker & Lissitz, 1999) approach to learning (Haury, 1993/2002).

The National Science Education Standards state that, “Inquiry into authentic questions generated from student experiences is the central strategy for teaching science” (National Research Council, 1996, The Standards section, para. 8). And, that, “Developing understanding presupposes that students are actively engaged with ideas of science and have many experiences with the natural world” (National Research Council, 1996, Perspectives and Terms . . . section, para. 9). Rettig and Canady (1996) reported that in schools where active learning methods prevail, the students demonstrated “significantly higher achievement as

measured by the National Assessment of Educational Progress” (p. 2). Moreover, Darling-Hammond and Falk (1997) concluded,

Teachers in these [successful] schools offer students challenging, interesting activities and rich materials for learning that foster thinking, creativity, and production. They make available a variety of pathways to learning that accommodate different intelligences and learning styles, they allow students to make choices and contribute to some of their learning experiences, and they use methods that engage students in hands-on learning. Their instruction focuses on reasoning and problem solving (p. 193)

Instruction in secondary agricultural education inculcates much of what these (Darling-Hammond & Falk, 1997; National Research Council, 1996; Rettig & Canady, 1996) and other scholars (Bloom, 1974; Carroll, 1989; Glaser, 1963) identified as variables required for cognitive learning to occur effectively, including learning in science. These propositions are congruent with the prevailing philosophy of agricultural education: experiential learning that is rich in opportunities for problem-solving delivered through the many authentic contexts comprising the agricultural, food, and natural resources system.

Historically, learning in agricultural education has been both “hands-on” and “minds-on” in intent, design, and delivery. It is an appealing and robust curriculum in which students can learn scientific laws, concepts, and principles in a contextual fashion (Conroy, Trumbull, & Johnson, 1999). In fact, Shepardson (1929) proclaimed that, “Agriculture is a meeting-ground of the sciences. Physics and chemistry lie at its base. To these elements biology adds its conception of organism. Mathematics is their common instrument” (p. 69). Further, Hillison (1996) concluded that from passage of the Hatch Act in 1887 until implementation of the Smith-Hughes Act three decades later agricultural education was known

for at least three attributes: 1) its strong scientific basis, 2) its close ties to the USDA, including, in some cases, Congressional District Agricultural Schools that were integral components of agricultural experiment stations, and 3) its teachers who were well-grounded in, and prepared to teach, scientific laws and principles in the context of agriculture, food, and the natural world. Concomitantly, Conroy et al. (1999) posited that secondary agricultural education “provides a conduit for motivating students to learn science and mathematics, and provides hands-on practical experiences to complement theory” (The Context section, para. 5).

Dewey also described an inquiry or problem-based approach that he called “reflective thinking” (Lass & Moss, 1987, p. 279); it involved five specific steps or aspects: “felt difficulty, its location and definition, suggestion of possible solution, development by reasoning of the bearings of the suggestion, further observation and experiment leading to its acceptance or rejection” (as cited in Lass & Moss, 1987, p. 279). Dewey’s model is consistent with that recommended by The National Science Education Standards (National Research Council, 1996) and with the problem-solving approach advocated by numerous agricultural educators (Boone, 1990; Crunkilton & Krebs, 1982; Flowers & Osborne, 1988; Krebs, 1967; Lancelot, 1944; Newcomb, McCracken, & Warmbrod, 1993; Phipps & Osborne, 1988). The presumption of a “common pedagogical denominator” between the two disciplines—science education and agricultural education—served as the basis of inquiry for this study.

Purpose of the Study and Related Research Questions

The primary purpose of this study was to provide a synthesis of selected research describing the inquiry-based and problem-solving approaches to teaching and learning with emphasis on implications for improving student achievement in science. Research questions supporting this purpose follow:

1. What have science education researchers concluded about inquiry-based teaching and learning in science education and its role in improving student achievement?
2. What have agricultural education researchers concluded about the problem-solving approach to teaching and learning in secondary agricultural education and its role in improving student achievement?
3. Are the inquiry-based and problem-solving approaches to teaching and learning substantially similar?
4. What are implications for future practice and research in agricultural education regarding use of problem-solving as an inquiry-based teaching and learning approach and its potential for improving student achievement in science?

Procedures

Sources of data included findings, conclusions, implications, and recommendations made by theorists and practitioners in science and agricultural education, respectively, who have described and, in some cases, explored the inquiry-based and problem-solving approaches to teaching and learning, and their potentials for influencing student achievement. The literature reviewed included doctoral dissertations, national commission reports, articles from professional journals and magazines, books, papers from research conference presentations, on-line Internet publications, and related resources. Studies appearing in these references were found through library system searches at Oklahoma State University and through on-line search engines. Cited manuscripts were published from 1918 through 2003. All references were subjected to internal and external criticism. Selected guidelines for conducting a form of integrative inquiry were followed (Marsh, 1991, pp. 271-283).

Findings

What Science Educators Have Said About How Students Learn Best
The National Science Education

Standards posit five assumptions about science teaching, including the belief that, "What students learn is greatly influenced by how they are taught" (National Research Council, 1996, Science Teaching Standards section, para. 3). Moreover, in 1996, the Standards called "for a pedagogical shift from a teacher-centered to a student-centered instructional paradigm" (Von Secker & Lissitz, 1999, p. 1110). It was thought that teaching practices closely identified with teacher-centered instruction were incongruent with students acquiring higher-order thinking skills and problem-solving behaviors. Further, it was held that a more student-centered approach to learning "engages students in socially interactive scientific inquiry and facilitates lifelong learning" (p. 1110). Moreover, science educators assert that fundamental to a student-centered approach to learning science is the practice of inquiry. The National Science Education Standards describe inquiry as

a multifaceted activity that involves making observations; posing questions, examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (National Research Council, 1996, Principles and Definitions section, para. 24)

Inquiry-based learning has been praised for requiring the student to do more than just report on a topic. The student must go beyond the simple memorization of facts and regurgitation of information and into the realm of creating new and deeper understanding through identification and subsequent application of solutions to a specific topic (Owens, Hester, & Teale, 2002). To this end, Gerber, Marek, and Cavallo (1997) concluded that, "In [science] classes taught by inquiry, individuals are

actively engaged with others in attempting to understand and interpret phenomena for themselves; and social interaction in groups is seen to provide the stimulus of differing perspectives on which individuals can reflect” (p. 3).

Inquiry-based (-oriented or -centered) instruction is frequently implemented as the “Learning Cycle Approach” in science education (Abraham, 1997; Gerber et al., 1997; Sunal, n.d.; Trowbridge & Bybee, 1996). Gerber et al. (1997) posited that, “Teachers can facilitate the development of scientific reasoning abilities of their students through the incorporation of inquiry-oriented teaching strategies, such as the learning cycle” (p. 11). In support, Musheno and Lawson (1999) concluded that,

“Research has supported the effectiveness of the learning cycle in encouraging students to think creatively and critically, as well as in facilitating a better understanding of scientific concepts, developing positive attitudes, . . . improving science process skills, and cultivating advanced reasoning skills” (p. 24).

The learning cycle is steeped in the Piagetian model about how humans acquire, interpret, and, eventually, transfer learning, especially, as it relates to concept formation or cognitive construction and then to future application (i.e., “transfer”) toward problem resolution (Doolittle & Camp, 2003; Fosnot, 1996; Lind, 1999). Moreover, Sunal (n.d.) maintained that,

the learning cycle is designed to adapt instruction to help students become aware of their prior knowledge, foster cooperative learning and a safe positive learning environment, compare new alternatives to their prior knowledge, connect it to what they already know, construct their own ‘new’ knowledge, and apply the new knowledge in ways that are different from the situation in which it was learned.

Accordingly, some researchers (Abraham, 1997; Hofstein & Lunetta, 1982;

Johnson & Lawson, 1998; Lind, 1999; Musheno & Lawson, 1999; Sunal, n.d.) describe the learning cycle model as having three distinctive phases or parts: exploration (experience), invention (interpretation) and expansion (elaboration). Trowbridge and Bybee (1996) further operationalized the model as comprising five stages: engagement, exploration, explanation, elaboration, and evaluation. (See Sunal for a comparative explanation of the learning cycle and its application in science teaching.)

What Science Education Researchers have reported about Student Achievement in Science

Gerber et al. (1997) compared the effects of science classroom teaching procedures—non-inquiry versus inquiry—on students’ scientific reasoning abilities. The investigators found that the scientific reasoning ability of seventh-grade students who received science instruction in inquiry-based classrooms was significantly higher than their counterparts who had not. Von Secker and Lissitz (1999) evaluated the effects of teachers implementing “instructional emphases [, i.e., learner-centered methods such as laboratory inquiry,] recommended in the National Science Education Standards” (p. 1111) on the achievement of tenth-grade science students. The study’s achievement test included questions about biology, earth science, physics, and chemistry, and stressed “higher-order thinking as well as understanding of fundamental concepts and mastery of basic skills” (p. 1114). The researchers found that, “Teacher-centered instruction is negatively associated with student achievement in science” (p. 1119). Specifically, students’ mean science achievement was nearly one-half standard deviation lower in schools where teacher-centered instruction was one standard deviation above average. In contrast, students’ mean science achievement increased by nearly four-tenths of a standard deviation “for every 1 SD increase in the amount of emphasis placed on laboratory inquiry” (p. 1120). Von Secker and Lissitz concluded that, “The strongest empirical support for instructional recommendations

set forth in the [National Science Education] Standards was observed for instruction that emphasized laboratory inquiry” (p. 1121). They also asserted that the learner-centered practice of laboratory inquiry was “invariably associated with higher achievement overall and with more equitable achievement among students with different demographic profiles” (p. 1121).

Johnson and Lawson (1998) compared gain in scientific reasoning ability of community college students enrolled in a biology course. Approximately one-half of the students received instruction through a teacher-directed approach while one-half learned via an inquiry-based approach. The investigators found that students who received biology instruction through the inquiry approach “showed greater improvement in [scientific] reasoning ability . . . than the expository students” (p. 100). The inquiry students also showed higher overall performance in biology achievement. Johnson and Lawson concluded that, “nothing of importance seems to be lost by switching to inquiry instruction, and much seems to be gained” (p. 100).

Problem-Solving as an Inquiry-Based Teaching and Learning Approach

Science educators (Abraham, 1997; Gerber et al., 1997; Hofstein & Lunetta, 1982; Johnson & Lawson, 1998; Musheno & Lawson, 1999; Sunal, n.d.; Trowbridge & Bybee, 1996) assert that the preferred pedagogical method for teaching science effectively is an inquiry-based instructional approach. Moreover, science education researchers (Gerber et al., 1997; Johnson & Lawson, 1998; Musheno & Lawson, 1999; Von Secker & Lissitz, 1999) have demonstrated empirical evidence supporting that position. Frequently, an implicit component to systematic inquiry, especially, at the initial or “exploration” phase of learning, is the presentation of a “problem” and the subsequent pursuit of a solution. Glasgow (1997) operationalized the “problem-based approach” (p. 49) to learning as one that

teaches self-directed learning techniques . . . as well as traditional lectures and discussions supporting problem solving. Students are expected to analyze problems, locate relevant materials and resources, use computer-based technology, and develop habits of lifelong learning and independent study. Students practice identifying problems and outcomes (p. 49)

Agricultural educators (Boone, 1990; Cano & Martinez, 1989; Conroy et al., 1999; Crunkilton & Krebs, 1982; Dyer & Osborne, 1996; Flowers & Osborne, 1988; Hammonds, 1950; Krebs, 1967; Newcomb et al., 1993; Phipps & Osborne, 1988; Torres & Cano, 1995a; Torres & Cano, 1995b) have supported Glasgow’s contentions about problem-based learning (PBL), i.e., inquiry-based instruction and problem-based learning are substantially similar in intent, process, and anticipated learning outcomes. Moreover, “In the broad context of general education[,] inquiry or problem-based learning (PBL) are more generally used terminologies than problem solving, but the fundamental aspects of problem solving and inquiry or PBL are analogous” (Doolittle & Camp, 2003, p. 1). See Figure 1 for a comparison of steps comprising the learning cycle approach (Trowbridge & Bybee, 1996) in science education and the steps in implementing the problem-solving method, as described by agricultural education researchers.

The problem-solving method has long been considered a significant part of the pedagogical foundation on which the educational philosophy of agricultural education rests. However, the reason(s) this method was adopted in such a wholehearted manner is somewhat unclear. Moore and Moore (1984) concluded that its acceptance was simply a “historical accident” (p. 5), one that occurred due to a convergence of events. These researchers claimed that problem-solving was adopted as a “method of choice” simply because of its popularity

with the likes of Dewey, Kilpatrick, and others who supported that approach to learning. Moore and Moore went so far as to assert that secondary agricultural education might have evolved very differently in its approach to teaching and learning had it begun under a different

era of educational philosophy. Lass and Moss (1987) supported their assertion: “Since Dewey was at the peak of his career when agricultural education emerged as a secondary school subject, many of the early teachers were influenced by Dewey’s teachings and readings” (p. 280).

<i>Learning Cycle</i>	<i>Newcomb et al.</i>	<i>Crunkilton & Krebs</i>	<i>Phipps & Osborne</i>
Engagement	Interest approach	Interest approach	Experience provocative situation
Exploration	Group objectives /questions	Group objectives	Explore references/sources
Explanation	Problem solution	Solving the problem	Arrive at a group solution
Elaboration	Testing solutions	Special events/activities	Attempt a trial solution
Evaluation	Evaluating results	Evaluation and application	Evaluate the effects

Figure 1. A Comparison of the Learning-Cycle Approach in Science Education and Selected Problem-Solving Approaches to Teaching and Learning in Agricultural Education.

As early as 1918, Nolan recognized the value of the problem solving method and the importance of providing authentic situations in which problems arise and then are solved by students. Later, Lancelot (1944) also wrote of the effectiveness of this method. He stated, “In general, those teachers who keep their students thinking teach their subjects by means of problems” (p. 144). Lancelot contended that all subjects can be taught effectively through the use of problems and that much effort should be put forth to recognize and develop useful problems. His work may have impacted other educators, e.g., Stewart’s 1950 publication of the text *Methods of Good Teaching* described an approach to teaching and learning very similar to Lancelot’s.

According to a historical analysis of problem-solving conducted by Moore (1994), the approach became more prominent in agricultural education textbooks in 1952 when Phipps and Cook

presented definitive steps that should be followed when implementing this type of instruction. Further, Krebs (1967) described his point of view concerning the practicality and usefulness of the problem-solving method when he stated, “One of the values inherent in a problem-solving approach in teaching is that it is not a process which is strange or unused by people in general” (p. 52). And, Phipps and Osborne (1988) posited, “Problem-solving teaching is recognized as an effective means of developing and securing desirable learning. It stimulates interest; develops thinking ability; and helps students to evaluate, draw inferences from, and make decisions essential to the solution of a problem” (p. 150).

The problem-solving approach has been widely accepted among agricultural educators but not unanimously: Moore and Moore (1984) expressed their discontent with the use of this method. The focus of

their objection(s) stressed difficulties associated with implementing the approach effectively rather than with any inherent “theoretical” inadequacy. While the researchers left no doubt concerning their position on using the method exclusively, they did concede that, if used properly, the problem-solving method could be a useful pedagogical tool.

Arguably, a strong case can be made that the pedagogical analogue or “form” of inquiry-based teaching and learning operationalized in secondary agricultural education is the problem-solving approach: a method that is used by many teachers to facilitate and extend student learning (Figure 1). To this end, Boone (1990) stated that, “The problem solving approach to teaching has been widely accepted as the way to teach vocational agriculture” (p. 18), and “When students solve real problems, use the scientific method to reason through a problem solution, test potential problem solutions, and evaluate the results of the solution, retention of knowledge learned through this activity has to be increased” (p. 25). Boone (1990) also opined that, “The problem solving approach to teaching increases the level of student retention of agricultural knowledge learned during an instructional unit” (p. 25). Further, Flowers and Osborne (1988) found “that for high level cognitive items [secondary agricultural education] students taught by the problem solving approach had less achievement loss than students taught by the subject matter approach” (p. 25). And, Dyer and Osborne (1996) concluded that “the problem solving approach is more effective than the subject matter approach in increasing the problem solving ability of [agriculture] students,” and, moreover, that the “increase transcends [students’] learning styles” (p. 41). Their findings also indicated that the problem-solving ability of students who are field-dependent learners could be enhanced “to a level of effectiveness nearly equal to that possessed by field-independent learners” (p. 41) with proper instruction.

Warmbrod (1969) described the problem-solving approach as “instruction [that] is student-centered rather than subject-centered; [where] instruction aims at the

development of and change in behavior of individuals” (p. 231). He also portrayed the approach as “teaching and learning [that] is a cooperative venture between the students and teacher rather than a completely teacher-dominated process” (p. 231). Further, Torres and Cano (1995a) posited that, “The use of thinking skills in problem situations is universally recognized as a prominent objective for all educational academies” (p. 46). In addition, Torres and Cano (1995b) argued that, “a more constant use of the problem-solving approach to teaching” could be a valuable method “by which we can excel in teaching higher-order thinking skills” (p. 9) in agriculture. (For a summary of learning benefits associated with using the problem-solving approach in agricultural education, readers are encouraged to see Crunkilton, 1984.)

Conclusions

Science education researchers posit that students achieve best in science when their learning experiences are constructivist (hands-on/minds-on) in design, i.e., active, relevant, applied, and contextual. Learning environments supporting sustained inquiry, e.g., a learning cycle approach to instruction, that are rich in concrete experiences show the greatest promise for improving student achievement (Abraham, 1997; Gerber et al., 1997; Haury, 1993/ 2002; Haury & Rillero, 1994; Hofstein & Lunetta, 1982; Johnson & Lawson, 1998; Lind, 1999; Musheno & Lawson, 1999; National Research Council, 1996; Trowbridge & Bybee, 1996; Von Secker & Lissitz, 1999). Agricultural educators propound that the problem-solving approach is a very effective means of teaching and learning that has been, and continues to be, a vital part of teaching and learning in agricultural education (Boone, 1990; Cano & Martinez, 1989; Conroy et al., 1999; Crunkilton & Krebs, 1982; Dyer & Osborne, 1996; Flowers & Osborne, 1988; Newcomb et al., 1993; Krebs, 1967; Phipps & Osborne, 1988; Torres & Cano, 1995a; Torres & Cano, 1995b). The literature reviewed in this study revealed substantial pedagogical agreement between the concepts of inquiry-based learning, as

described by science education researchers, and the problem-solving method proffered by agricultural educators (Figure 1).

Significant agreement exists between what some eminent scholars (Bloom, 1974; Carroll, 1989; Darling-Hammond & Falk, 1997; Glaser, 1963) have said is the recommended pedagogy for improving student achievement and the teaching and learning exercised in many agricultural education classrooms. The problem-solving method, as employed by many agricultural educators, appears to be an effective means of implementing an inquiry-based learning approach, one similar to what science educators describe. A comparison of steps for implementing the learning cycle and the steps described by agricultural education researchers for carrying out the problem-solving approach aligns very closely (Figure 1).

Recommendations

Findings of this research suggest that the problem-solving method, in particular, is secondary agricultural education's "pedagogical analogue" to the inquiry-based teaching and learning practices heralded by science education researchers. Accordingly, future practice and research should include the following:

1. More empirically-based research should be conducted to explore teachers' use of the problem-solving approach in the context of secondary agricultural education and subsequent student achievement in science.
2. Implicit is a need to also determine whether specific scientific concepts and principles, e.g., life sciences as opposed to physical sciences, are learned better by students through problem-solving than via other methods. Additional inquiry should be conducted toward that end.
3. Investigations should be carried out to better understand how agriculture teachers operationalize and use, or do not use, the problem-solving approach (Osborne, 1999). Special attention should be given

to identifying misconceptions or barriers that may prevent teachers from using the approach properly (Boone, 1990; Martinez, 1998; Warmbrod, 1969). Concomitantly, more should be learned about the "fitness" of existing curriculum materials as well as the need for new learning resources that may be better suited for the problem-solving approach to teaching and learning.

4. If a significant causal relationship is established between use of problem-solving in agricultural education and improving student achievement in science (Roegge & Russell, 1990), then the profession should redouble its effort toward preparing pre-service and in-service teachers to use the method effectively (Boone, 1990; Osborne, 1999).

Discussion and Implications

The pedagogical success of problem-solving rests upon agriculture teachers who are prepared to effectively use the method as they teach students and facilitate their learning: planning and designing a problem-based learning experience (Glasgow, 1997), properly executing such an experience, and then assessing and evaluating its outcomes. However, researchers (Boone, 1990; Moore & Moore, 1984; Osborne, 1999; Warmbrod, 1969) have also voiced doubts about the ability of some teachers to do so properly. To this end, Cano and Martinez (1989) recommended that, "Further research needs to be conducted to determine the extent to which problem-solving instruction, which has been the cornerstone of vocational agriculture, contributes to the cognitive ability and critical thinking ability development of the students" (p. 364). Boone (1990) also suggested further study about the effects of using problem-solving as measured by student achievement as well as training for teachers that would provide a clearer understanding of how to implement this practice.

More recently, the National Agricultural Education Research Work Group has called on the profession to "identify current research in agricultural education that

corroborates effective school-based educational practice, . . . and . . . to communicate and coordinate a research agenda that will aggressively examine research problems related to high school student achievement, particularly mathematics, science, and reading” (G. Shinn, personal communication, August 19, 2002). Findings of this study support that position.

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