EFFECTS OF LEVEL OF OPENNESS IN AGRISCIENCE EXPERIMENTS ON STUDENT ACHIEVEMENT AND SCIENCE PROCESS SKILL DEVELOPMENT

Edward W. Osborne
University of Florida

Abstract

Level of openness in an experiment refers to the extent to which students are provided procedures for performing the lab. In traditional approaches students follow a very prescriptive format, often working to verify what is already known, as opposed to undertaking true experimentation. Many teachers and researchers today are calling for a more open and investigative approach to student experimentation. This study compared the effects of level of openness in agriscience experiments on student achievement and understanding of science process skills. Nine teachers who had previously taught the Biological and/or Physical Science Applications in Agriculture courses (BSAA and PSAA) participated in the study. Each teacher taught three BSAA and two PSAA labs over a 30-day period. Teachers were provided lesson plans corresponding to their randomly assigned teaching approach. Students completed pretests on the BSAA and PSAA labs and science process skills, with these scores used as covariates. The GEFT learning style assessment was used to determine preferred learning styles. The Test of Integrated Process Skills was used to assess students' science process skills. Students in the study were predominantly field dependent learners. MANCOVA and follow-up univariate analyses of covariance procedures were used. Students in the traditional (prescriptive) lab format scored significantly higher on all three dependent measures (BSAA achievement test, PSAA achievement test, and science process skills) than those in the more open, investigative group. Females scored higher than males in the control group but lower than males in the treatment group. Dependent measures were not influenced by learning style

Introduction

The release of *Understanding Agriculture, New Directions for Education*, by the National Research Council in 1988 set in motion a curricular emphasis in agriscience in the secondary schools that continues to gain momentum over 10 years later. The report recommended development of special applied science courses in agriculture that would be viewed as complementary to regular science course offerings and worthy of receiving science credit toward high school graduation and college entrance (National Research Council, 1988). The 1989 report of the American Association for the Advancement of Science further supported this approach when it recommended that applications of science be taught in relevant technological fields, such as agriculture (Project 2061, 1989). Many states responded to this call for curriculum reform by developing new and/or revised courses that emphasized agriscience. Illinois became an early leader in this effort with the release of the Biological and Physical Science Applications in Agriculture (BSAA and PSAA) courses, beginning in 1991. This four semester series of courses has targeted high school students who have completed basic course work in science (biology) and math. Course design has required that experiments be used as the predominant teaching method, and course content has focused on agricultural practices and the corresponding science concepts and principles that explain the basis for these practices. By 1997 over 80% of approximately 266 responding teachers reported that they incorporate the BSAA and PSAA labs into their existing courses, and many Illinois teachers offer BSAA and/or PSAA as separate courses (Illinois Agricultural Education Survey, 1997). Today, these course materials have been used by agriculture teachers in practically every state in the nation.

With the move toward lab-based, agriscience courses taught via experimentation, teachers have found themselves confronted with a number of significant new instructional questions and challenges. Traditionally, agriculture teachers have seldom used experiments as a teaching strategy. In fact, experimentation as a teaching technique has been infrequently used throughout the secondary school curriculum. Even the current "hands-on science" trend has not emphasized true experimentation as a method of learning. Thus, even with the hands-on science movement, many teachers may feel unprepared to effectively teach science using experiments as the predominant teaching method (Osborne, 1992).

A number of teachers and researchers have begun to question the traditional, or "cookbook," method of learning in the science laboratory. Gallet (1998) suggested that traditional cookbook labs are more concerned with the ends of the experiment than the means of reaching them. He described traditional science lab activities as superficial, characterized by a high degree of memorization and dependence on the instructor. He further claimed that students in these labs retain little of what they learn and have difficulty applying what they know. Gallet was very critical of the cookbook approach to science lab activities, stating that:

> "Recipe experiments tend to sterilize imagination and initiative, leave no room for hypotheses, trials, errors, … and above all, preclude students' involvement in the decision-making process. Many parameters that are fundamental to the scientific method are left out by the …cookbook-formula approach." (Gallet, 1998, p. 73)

Herman (1998) indicated that the investigative nature of labs can be enhanced by (1) providing instructions on performing the experiment while leaving data analysis or hypothesis formation open and/or (2) requiring students to design their own experiments. She encouraged science teachers to move toward investigative labs by converting at least one lab per semester to an investigative format. Further support for this view was contained in the 1990 report of the American Association for the Advancement of Science (AAAS), which recommended that science laboratories be open-ended and investigative rather than confirming what is already known (AAAS, 1990). McIntosh (1995) stated that science teachers seldom ask their students to design their own experiments or organize their own data. He stressed the importance of providing students practice in performing critical investigative skills.

The above opinions relate to levels of openness in the science laboratory, particularly when using experiments as the teaching method. Openness refers to the extent to which the research problem, procedures, and results are made known to the students prior to performing the experiment. Tamir (1989) proposed use of a content analysis scheme for determining openness in science lab activities. In a purely traditional (cookbook) lab students would be given the problem, procedures, and results. Thus, the level of openness would be very low. The opposite extreme provides a completely open learning atmosphere in all three of these areas of the experimentation process. In this latter design, the students are given none of the key aspects of the lab. That is, the lab is "open," and the learner is given no "recipe" for lab success. Tamir's work demonstrated that experiment-based curriculum materials for high school students have typically had very low levels of openness. Theoretically, experiments with greater openness can be expected to improve student motivation, investigative skills, and achievement. Thus, the problem under investigation in this study was the lack of empirical evidence to support investigative versus traditional (cookbook) science labs. Does a more open, investigative approach to learning with experiments better promote student achievement and enhance science process skills?

Conceptual Framework

The conceptual framework for the study was an adaptation of the basic tenets of a model for the study of teaching and learning developed by Dunkin and Biddle (1974). These researchers developed a model for the study of teaching that included student presage variables (what students bring to the learning situation), teacher presage variables, context variables (characteristics of the community and classroom that are relevant to learning), teaching/learning process variables, and outcome or product variables (areas of student growth, improvement, and satisfaction). The model developed for this study used the same major headings as the Dunkin and Biddle model. These headings were revised and detailed for the context of teaching agriscience (see Figure 1). The elements of the model that were addressed in this study are shown in bold print. These include the student presage variables of learning style, gender, and science process skills and outcome variables of student achievement and science process skills. The specific learning process under investigation was the level of openness of agriscience experiments. This model suggested that students and teachers bring many abilities and characteristics to the learning environment that impact the nature of the teaching and learning process and the eventual outcomes achieved.

Purpose and Objectives

The purpose of this study was to determine the effects of level of openness of agriscience experiments on student achievement and science process skills. The following null hypotheses were tested at the .05 level of significance:

HO_1: There is no difference in achievement, as measured by score on the BSAA posttest, between secondary agriscience students given open lab experiments and those given prescriptive lab experiments.

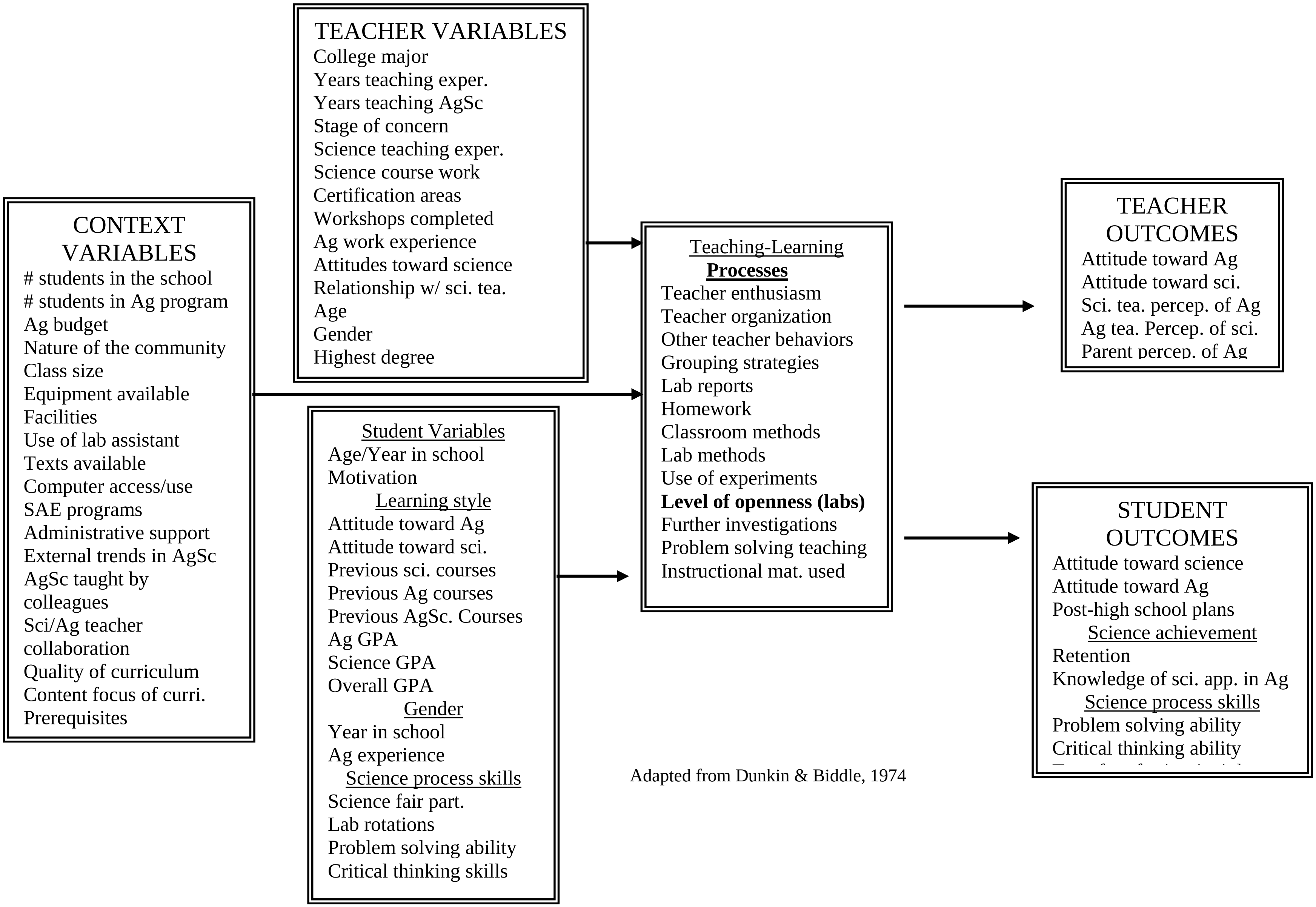
HO_2: There is no difference in achievement, as measured by score on the PSAA posttest, between secondary agriscience students given open lab experiments and those given prescriptive lab experiments.

HO_3: There is no difference in science process skills, as measured by score on the Test of Integrated Process Skills Test (TIPS II), between secondary agriscience students given open lab experiments and those given prescriptive lab experiments.

Research Procedures Used

This study was conducted using a quasi-experimental design. Random assignment of subjects to treatment groups was not possible, so intact groups (classrooms) were used. The research design used was the nonequivalent control group design as described by Campbell and Stanley (1963). The first observation consisted of the BSAA pretest and the pretest for science process skills (TIPS I). The experimental treatment was an open, investigative approach to experimentation in five agriscience labs, while the control was the more traditional, "cookbook" approach to the experiments. Students completed the GEFT learning styles assessment about midway through the study schedule. The PSAA pretest was completed just prior to beginning the first PSAA lab. Posttests were administered after the three BSAA labs were completed and after the two PSAA labs were completed. A delayed retention test and an attitude assessment were dropped, due to the length of the study and the heavy amount of testing already involved. Threats to internal validity in this design included regression and interaction. However, since the groups were not selected as a result of extreme scores, regression effects posed a minimal threat to internal validity. The interaction threat was reduced by using the subject matter and science process skills pretests as covariates in the statistical analysis

Figure 1. Conceptual Model for Research on Agriscience Curriculum and Instruction



The population for the study included all Illinois high school students enrolled in laboratory-based agriscience courses. The accessible population was students enrolled in the 42 agriculture programs in the state that offered either the BSAA or the PSAA course during the 1995-96 school year. Agriculture teachers at twenty schools were purposively selected from the set of 42 schools, invited to participate in the study, and asked to indicate their preferences for labs to teach from among a list of 11 possible labs. Fourteen teachers indicated their willingness to participate. Since a purposive sample was taken, results of this study cannot be generalized to a larger population. The 14 schools were randomly assigned to the treatment and control groups (seven schools in each group). Of the 14 teachers, nine completed all or major portions of the study and provided usable data for analysis. This included five assigned to the control group and four schools assigned to the treatment group (76 and 74 students, respectively). Nearly all students were 15 or 16 years old.

The subject matter tests were developed by the researcher, with questions directly based upon the BSAA and PSAA labs taught by the teachers. Twelve multiple choice questions were developed for each of the five labs. The BSAA pretest and posttest each contained 36 items, while the PSAA pretest and posttest contained 24 items. Final

K-R 20 reliability coefficients were .51 for the BSAA pretest, .55 for the PSAA pretest, .47 for the BSAA posttest, and .68 for the PSAA posttest. The posttests represented parallel forms of the pretests and were developed by shifting the order of response choices, using different distracters, and changing the numbers in given situations.

Students' learning styles were determined using the Witkin et al. (1971) Group Embedded Figures Test (GEFT). This instrument has been commonly used in agricultural education research, as well as in many other disciplines. The GEFT is a standardized instrument having an established validity and a reliability coefficient of .82. The Test of Integrated Science Skills (TIPS) consists of 36 multiple choice questions that are designed to test students' ability to state hypotheses, operationally define variables, design investigations, and interpret data. This test was developed for secondary students without preference to a particular area of science. The TIPS instrument has an established validity and a Cronbach's alpha reliability of .89. TIPS II is a parallel version of TIPS I (Dillashaw and Okey, 1980).

Table 1.
Differences in the Control and Treatment Procedures

Step in the Experimentation Process	**Control Group (Traditional Approach)**	**Treatment Group (Investigative Approach)**
Identify the research problem	Teacher presents	Students identify
Determine the design and procedures for the experiment	Teacher presents	Students determine
Identify the materials needed	Teacher gives the list of materials to the students	Students determine the materials needed, based upon their design and procedures
Identify anticipated findings	Teacher leads discussion of expected results	Students identify hypotheses in writing
Determine data summary procedures	Teacher presents a sample data summary chart and explains	Students develop their own data summary strategy/format
Identify conclusions	Teacher leads a discussion of conclusions	Students identify their conclusions in writing, followed by teacher discussion and modification
Identify follow-up investigations	Teacher leads a discussion of possible follow-up experiments	Students identify their own follow-up experiments. Teacher discusses general design possibilities. Students select one of the ideas for further investigation and plan a detailed design.

The total estimated time for teaching the five labs and administering the pretests and posttests was 30 school days. Teachers were provided copies of all tests and lesson plans in advance, along with specific instructions about the order of teaching and testing. All teachers taught the same five labs: Environmental Factors Affecting Germination, Salinity and Seed Germination, Transpiration in Plants, Cutting and Conveying: Use of Simple Machines, and Chemistry of Popcorn. These labs were drawn from the BSAA and PSAA Teacher's Guides. In addition, student texts have been developed for the BSAA and PSAA courses, and the five labs assigned were included in the texts. Teachers received an outline of the experimentation process and lesson plans adjusted for their treatment or control group. Lesson plans for the two groups were identical for the suggested Interest Approach, discussion of

Agricultural Applications (practices), and the Purpose and Objectives of the experiment. Teachers in both groups also used the same guide questions to focus student reflection and discussion after the experiment was completed. Table 1 explains the differences between the treatment and control teaching strategies. All participating teachers were asked to provide audio tapes of two class periods taught during study. Although only four of the nine teachers (two in the control group and two in the experimental group) provided tape-recorded sessions, examination of the dialogue that occurred during these classes confirmed that these teachers were correctly using their assigned approach to lab openness.

Data were analyzed using the SPSS for Windows statistical software. Hypotheses were examined using multivariate analysis of covariance (MANCOVA), followed by univariate analysis of covariance (ANCOVA) to determine the source of variance. Independent variables included gender, learning style, and group (treatment versus control). Dependent variables included BSAA achievement score, PSAA achievement score, and score on the Test of Integrated Science Skills (TIPS II). Covariates included the PSAA and BSAA pretests, plus TIPS I. Pearson correlation coefficients were calculated to determine the relationships between the covariates of the dependent variables. TIPS I correlations with the three dependent variables ranged from .18 to .52. The BSAA pretest correlations with the dependent variables ranged from .13 to .41, while the PSAA pretest correlations ranged from .33 to .47. Thus, all three covariate measures remained in the statistical analysis.

Findings

Approximately 72% of the students in the study were male, and another 28% were female. These same percentages held true (within a few percentage points) for the makeup of the control and treatment groups. The average GEFT score was 9.64 and 9.08 for all males and females in the study, respectively. Scores below the national norm of 11.3 are considered to represent a field-dependent learning style. Scores ranged from 0 to 18, with 51% of the students scoring nine or lower. Overall, nearly two-thirds of the students were classified as field-dependent learners. Table 2 below provides the percentage of students by gender and group.

Table 2.
Frequency and Percentages of Students by Group, Gender, and Learning Style

Learning Style	**Group**		**Gender**	
	Control	Treatment	Male	Female
Field dependent	49 (68%)	40 (58%)	64 (63%)	24 (63%)
Field independent	23 (32%)	29 (42%)	38 (37%)	14 (37%)

The MANCOVA procedure was used to simultaneously test for the effects of the treatment on multiple dependent variables while statistically adjusting group means to account for pre-existing differences between the groups on the variables of interest. The Box's M statistic was used to assess the homogeneity of the within-cells variance-covariance matrices. The statistic of 48.32 with an F value of .643 (36,187) was not significant (p = .941). Therefore, the assumption of homogeneity of dispersion matrices was met. Levene's Test (p > .05) indicated that the error variance of the dependent variables was equal across all groups. Descriptive statistics for each of the covariate measures are listed in Table 3. Students in the traditional approach group (control) had slightly lower scores on the TIPS I and the BSAA pretest, while their scores were slightly higher on the PSAA pretest. Covariate adjustments were made to these group means to control for pre-treatment differences.

Table 3.
Mean Covariate Scores by Level of Openness Group

	Traditional Approach		**Investigative Approach**	
	M	SD	M	SD
TIPS I	18.00	6.16	19.83	6.14
BSAA Pretest	13.55	4.70	14.46	5.35
PSAA Pretest	10.46	3.23	9.09	3.03

Hotelling's T^2 statistic for the effects of level of openness on the dependent variables was .46, F (3,68) = 10.50, $p < .001$. Follow-up univariate analysis of covariance indicated significant differences in all three dependent measures in favor of students in the control group (see Table 4).

Table 4.
Univariate Analysis of Treatment Effects

Variable	**MS**	**F**	**p**
Science Process Posttest	534.13	15.50	< .001
BSAA Posttest	332.18	17.57	< .001
PSAA Posttest	209.95	19.43	< .001

Hotelling's T^2 statistics for the effects of gender and learning style were not significant. However, the interaction of group and gender was significant, with a statistic of .16, F (3,68) = 3.60, p = .018. Univariate follow-up up analyses indicated significant differences in student achievement on the PSAA posttest ($F = 10.77$, $p = .002$). Female students in the control group scored higher on the PSAA posttest than male students in the control group, while female students in the treatment group scored lower than males.

Results of the MANCOVA and subsequent ANCOVA were used to evaluate the three null hypotheses formulated for the study. Means were statistically adjusted, using the three covariate measures. The three null hypotheses stated that there is no difference in achievement, as measured by scores on the BSAA posttest, the PSAA posttest, and TIPS II, between secondary agriscience students given open (investigative) lab experiments and those given prescriptive (traditional) lab experiments. Student achievement was measured by the number of correct responses on each of the three instruments. Table 5 contains the summary statistics for the univariate tests. Results indicated that students in the control group scored significantly higher on all three achievement measures (see Table 4 for F statistics and levels of significance).

Table 5.
Mean Achievement Scores by Treatment

	Control Group		Treatment Group	
	Observed Mean	Adjusted Mean	Observed Mean	Adjusted Mean
TIPS II	18.39	21.03	14.57	14.37
BSAA posttest	19.36	23.97	19.36	17.74
PSAA posttest	16.54	17.74	15.49	13.56

* Adjusted means evaluated at 20.77 for the TIPS II, 14.81 for the BSAA pretest, and 9.85 for the PSAA pretest.

Conclusions

Based upon the findings of the study, the following conclusions were drawn. (Note: The findings and conclusions of the study cannot be generalized beyond the data sample.)

1. Students in the data sample were predominantly field dependent learners.
2. Students who participate in a prescriptive (traditional) learning format when conducting experiments, as opposed to an open, investigative format, develop higher levels of science process skills.
3. Students who participate in a prescriptive (traditional) learning format when conducting experiments, as opposed to an open, investigative format, develop higher levels of achievement in biological and physical science applications in agriculture.
4. Based upon students' scores on the TIPS II instrument, the science process skills of students in the study are very weak.

Discussion and Implications

The results of this investigation are surprising, given current philosophical views that prevail in the literature. In particular, one would think that students who successfully designed their own laboratory investigations would develop more advanced science process skills. As stated earlier, the results of this study cannot be generalized to other groups. Many questions come to mind in reflecting upon the findings. Why did the students in the traditional (control) group outperform those in the open, investigative group, especially on the science process skills assessment? Did students follow the directions of the teacher and remain on task as they conducted their investigations? What were their thoughts about the open approach to experimentation? Unfortunately, the heavy testing activity associated with the study resulted in a decision to drop plans to gather data on student attitudes.

Bases upon analysis of the audio tapes provided by the four teachers, one of the teachers in the treatment group conducted detailed discussions with the students before they proceeded with their labs. Students made their own decisions about lab design and procedures, but they probably found the pre-lab discussion very helpful in making these decisions. The validating comments provided by the teacher may have caused some degree of openness to be lost from this particular class.

Overall student performance on the science process skills and achievement posttests was poor. Before scores were adjusted through the MANCOVA procedure, students in both groups correctly answered only about 50% of the items on the science skills pretest and posttest. Perhaps science process skills can be increased if the intervention occurs over a complete semester or even longer period of time. On the achievement pretests students answered about one-third of the items correctly and answered about one-half of the items correctly on the achievement posttests. Although the achievement scores increased, overall performance on all tests was poor. Only about 10% of the students scored 80% or better on the science process skills posttest and the BSAA posttest. About 20% of the students scored 80% or better on the PSAA posttest. Although these poor scores are not unusual in studies of this type in agricultural education, they are disturbing and warrant further consideration and analysis. Some caution is suggested in interpreting the results of this study due to the relatively low internal reliability estimates of the achievement tests (.47 to .68).

A large majority of the students in this study were field dependent learners. Given that students with this preferred learning style need to have structure provided for them in the learning environment, this suggests that students in the experimental group may not have responded well to the unstructured, open learning environment in which they were working. Field dependent learners would be expected to benefit from external structure provided by the teacher, which might explain to some degree the greater success realized by students in the traditional, prescriptive group. In addition, one might argue that students should study and learn under a prescriptive approach for some time before they are gradually moved toward an open, investigative approach to learning via experiments. This study was conducted near the beginning of the fall semester, and students in the treatment group had little experience at that point in learning through either a prescriptive or investigative approach. An intriguing outcome of the study was that females performed better in the control group and worse than males in the treatment group. A possible explanation is that, given the predominantly field dependent nature of all students in the study, the structure provided in the control group enabled female students to excel, whereas the lack of structure present in the investigative group made the female students more reluctant to outperform their male counterparts. Much research has demonstrated a pattern of lower achievement in science by female students, and those dynamics may have been influential in the outcomes of this study.

Recommendations

On the surface, the results of this study suggest that agriculture teachers with primarily field dependent learners should use a prescriptive, cookbook approach to their experiment-based agriscience labs. However, further study is clearly needed before this recommendation can be confidently forwarded. Areas of inquiry suggested include:

1. What are the effects of level of openness with students grouped by learning style?
2. What are the comparable attitudes of teachers and students who are teaching and learning under the prescriptive versus investigative laboratory approach?
3. How can student achievement scores be boosted across the board, regardless of the approach used in teaching with experiments?
4. What teacher behaviors and traits are conducive in teaching with an open format?
5. How can student performance in an investigative lab format be fairly and accurately evaluated?
6. Are certain types of labs best taught and learned under prescriptive versus investigative formats, and vice versa?
7. What student variables enhance performance and achievement under each of the learning formats?
8. Does class size have an impact on the success of the investigative approach?

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