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EFFECTS OF INVESTIGATIVE LABORATORY INSTRUCTION ON CONTENT KNOWLEDGE AND SCIENCE PROCESS SKILL ACHIEVEMENT ACROSS LEARNING STYLES

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Abstract

The purpose of this study was to determine the effect of investigative laboratory integration on student content knowledge and science process skill achievement across learning styles. Treatment groups utilized one of three levels of treatment: subject matter approach without laboratory experimentation, subject matter approach with prescriptive laboratory experimentation, and subject matter approach with investigative laboratory experimentation. A nonequivalent control group quasi-experimental design was used. A purposively selected sample based upon the ability of the teacher to effectively deliver the treatments was selected from the population of students enrolled in an introductory agriscience course. Using regression analyses it was determined that learning style, teaching method, ethnicity, content knowledge pretest scores, and science process skill pretest scores accounted for 33% of the variance in content knowledge gain score. Learning style, gender, teaching method, science process skill pretest scores, and content knowledge pretest scores accounted for 36% of the variance in science process skill gain score. Students taught using the subject matter approach or the investigative laboratory approach were reported as having higher content knowledge and science process skill gain scores than students taught using the prescriptive laboratory approach.

Introduction

The idea that teaching is both an art and a science has become increasingly accepted by those in the education profession (Berliner, 1987). The practitioner of this somewhat paradoxical approach requires both preparation and practice to become a master at this craft. Within the field of agricultural education, an additional and somewhat contradictory dialogue is occurring. This discussion attempts to answer the question, "Is agricultural education vocational or academic?"

The answer to this question may be that agricultural education is both – vocational and academic. In its 1988 report, the National Research Council (NRC) called for curricular expansion in agricultural education, with greater inclusion of scientific subject matter into the traditional production agriculture curriculum. Whereas this expansion was not a call to completely abandon its vocational past, it was a call for the "teaching of science through agriculture" (p. 5).

The scientific literacy needs of individuals entering careers in agriculture are becoming increasingly important. Employees in today's job market need to know how to learn, reason, think creatively, make decisions, and solve problems. Both science and agriscience education can contribute in an essential way to the development of these skills (National Academy of Science (NAS), 1996). Likewise, with the need for inclusion of science-based concepts into the agricultural education curriculum, new methods for teaching these materials need to be investigated. Science education literature tells us that shifting to an emphasis on active science learning requires a shift away from traditional teaching methods (NAS).

Theoretical/Conceptual Framework

The model proposed by Mitzel (Dunkin & Biddle, 1974) laid the foundation for evaluating teaching effectiveness and provided the theoretical framework for this study. Building upon the teaching effectiveness criteria suggested by Mitzel, the model identifies variables that affect the teaching-learning process and categorizes them into four groups: context variables, presage variables, process variables, and product variables. Context variables are those conditions to which the teacher must adjust. Context variables in this study are formative experiences (age, gender, socioeconomic status), student characteristics (ability, knowledge, attitudes), school and community characteristics (ethnic makeup, school size, climate, busing), and classroom variables (class size, textbooks, technology).

Presage variables are those characteristics of teachers that may affect the teaching and learning process, such as personal formative experiences, teacher training experiences. Process variables are those activities that influence classroom teaching. They may consist of the classroom actions by both the teacher and the pupil. The final category, product variables, represents the outcomes of teaching and can be grouped into two categories: immediate pupil growth and long-term pupil effects. Examples of product variables include a change in learning, attitudes, skill development, or adult personality development (Dyer, 1995).

According to Bransford, Brown, and Cocking (2000), a major goal of teaching is to prepare students to be able to adapt knowledge to various problems and settings – and using multiple contexts. One of the most effective techniques employed by teachers is the use of laboratory activities (American Association for the Advancement of Science (AAAS), 1993). However, laboratory activities, as they are currently used, often fail to engage students in a "mental struggle," as suggested by Clough (2002). According to Clough, laboratory experiences need to be more than just an activity with a pre-determined outcome. They need to be true experiments, and not cookbook activities that stifle student thinking.

One means to engage students in the manner suggested by Clough (2002) is through the used of investigative activity integration. This is defined as the use of laboratory exercises in which the students develop the questions to investigate, procedures to follow, and means to report findings of their investigation. The classroom teacher provides guidance and advice, but does not inform students of expected outcomes prior to student completion of the exercise (Myers, 2004).

A review of research produced few studies that addressed the effect of investigative activity integration on student content knowledge achievement or science process skill development. Some studies were found that examined the training received by agriscience teachers to prepare them to integrate scientific concepts (Johnson, 1996; Thompson, 1998). However, the majority of studies in this area have examined only teacher attitudes and perceptions toward science integration (Balschweid & Thompson, 1999; Connors & Elliot, 1994; Layfield, Minor, & Waldvogel, 2001; Newman & Johnson, 1993; Thompson & Balschweid, 1999; Welton, Harbstreit, & Borchers, 1994).

A review of research on the use of teaching science principles in an agricultural context, and/or in teaching methods that involve active learning strategies, produced mixed results. Roegge and Russell (1990) reported significantly higher scores in applied biology and overall achievement by students who incorporated biological principles into agricultural instruction. Chiasson and Burnett (2001) found that agriscience students tended to earn higher scores than non-agriscience students. Mabie and Baker (1996) reported that participation in agriculturally-oriented experiential activities positively impacts the development of science process skills. Downing, Filer, and Chamberlain (1997) found a moderately positive correlation between the preservice teachers' competency levels of science process skill and attitudes toward science. Osborne (2000) reported very low science process skill scores, but higher science process skills

and achievement scores for students who participated in prescriptive laboratories. Not all studies, however, reported positive results when using science related instruction. Germann (1989) reported that the use of a directed-inquiry approach had no significant effect on the learning of science process skills or on cognitive development. Osborne recommended that a study similar to his be completed and that the effects of learning style be investigated.

Little is known about the influence of learning styles on how students respond to laboratory activities. However, much of the reported learning styles research confirms that students enrolled in agriculture courses and/or colleges tend to be field-independent learners (Cano 1999; Cano & Garton, 1994; Marrison & Frick, 1994; Torres & Cano, 1995; Whittington & Raven, 1995).

One of the simplest and most extensively examined learning style instruments is the Group Embedded Figures Test (GEFT) (Witkin, Oltman, Raskin, & Karp, 1971). This instrument divides students into one of two categories: field-independent or field-dependent. Field-independent learners are more analytical in the way they perceive the world. These learners are able to provide structure and organize information on their own. This ability often leads to field-independent students requiring less teacher guidance in developing strategies to solve problems (Ronning, McCurdy, & Ballinger, 1984).

Individuals classified as field-dependent by the GEFT are normally more social in their nature. They have a global perception of the world which often leads to these individuals finding it more difficult to solve problems (Ronning et al., 1984). This is often a cause of field-dependent learners needing to have structure and organization provided for them by an external source. This could lead to students of this learning style requiring a more student-centered teaching approach and more direction on how to structure and solve agriscience problems.

Dyer and Osborne (1996) determined the learning styles of 258 students in 16 agricultural education classes in Illinois. In addition to the categories of field-dependent and field-independent identified by Witkin et al. (1971), Dyer (1995) identified a third category, field-neutral. This study found that students classified as field-neutral in their learning style had higher achievement scores when taught using the problem solving approach instead of the subject matter approach to teaching.

Research attempting to identify the most effective teaching methods to be used by teachers for science-based agriculture lessons has been, at best, inconclusive. Moreover, most research dealing with student content knowledge achievement in agricultural education has relied on descriptive and causal-comparative methods (Edwards, 2003). Slavin (2003) stated that more studies utilizing experimental designs are needed in this area.

This study sought to determine if integrating investigative laboratories in a manner that would encourage students to engage at a higher cognitive level, would significantly affect content knowledge achievement and science process skill proficiency level. If so, findings from this study could be utilized by agriculture teachers in middle and high school settings, as well as by teacher educators at colleges and universities.

Purpose and Objectives

The purpose of this study was to determine the effect of investigative laboratory integration on student content knowledge achievement and science process skill development across different learning styles. The following objectives guided this study.

1. Describe the learning styles and other demographic characteristics of participants.
2. Describe the variance in content knowledge gain score attributed to learning styles and other demographic characteristics.
3. Describe the variance in science process skill gain score attributed to learning styles and other demographic characteristics.

For the purpose of statistical analysis, objectives two and three were posed as null

hypotheses. All hypotheses were tested at the .05 level of significance. The following null hypotheses were tested:

- HO_1: There is no difference in the content knowledge gain scores of agricultural education students taught using the subject matter, prescriptive laboratory, or investigative laboratory approaches.
- HO_2: There is no difference in the science process skill gain scores of agricultural education students taught using the subject matter, prescriptive laboratory, or investigative laboratory approach.
- HO_3: There is no difference in the content knowledge gain scores of agricultural education students of various learning styles.
- HO_4: There is no difference in the science process skill gain scores of agricultural education students of various learning styles.
- HO_5: There is no difference in the content knowledge gain scores of agricultural education students of varying learning styles taught using the subject matter, prescriptive laboratory, or investigative laboratory approach.
- HO_6: There is no difference in the science process skill gain scores of agricultural education students of varying learning styles taught using the subject matter, prescriptive laboratory, or investigative laboratory approach.

Procedures

This study utilized a quasi-experimental design, since random assignment of subjects to treatment groups was not possible. Intact groups were used and treatments were randomly assigned to groups. The three treatments used were: (1) subject matter instruction only with no laboratory activities, (2) instruction with prescribed laboratory activities in which activities are conceived and orchestrated by the instructor, and (3) instruction accompanied by investigative laboratories in which the student designs and conducts the laboratory experience. The study followed a variation of the nonequivalent control group design (Campbell & Stanley, 1963). Gall, Borg, and Gall (1996) state that the only essential features of this design are nonrandom assignment of subjects to groups and administration of a pretest and posttest to all groups.

The population for this study was students enrolled in an introductory agriscience course. A purposively selected sample based upon the ability of the teacher to effectively deliver the three teaching approach treatments was selected from the population. Each teacher was randomly assigned one of the three treatments. Ten teachers at ten different schools within Florida were selected to participate in this study. The factor of individual teaching ability of the teachers involved in the study was addressed by the use of a number of different teachers within each treatment. Furthermore, professional development in the form of personal and videotaped instructions and demonstrations was provided for each teacher as outlined by Boone (1988). All materials needed by the teacher to deliver the treatment (lesson plans [plant germination and plant functions], handouts, assessment instruments) were provided by the researcher. The subject matter to be taught remained the same among all three sets of instructional plans. The instructional plans were evaluated for content validity by a panel of experts from the University of Florida and were deemed appropriate for delivery via all three treatments. Furthermore, teachers audio recorded each lesson in which the treatment was delivered. Audio tapes were analyzed to determine if the appropriate treatment was delivered. The treatment was delivered during the fall 2003 semester lasting 4 – 6 weeks in length.

Campbell and Stanley (1963) identify several threats to internal validity. The nonequivalent control group research design controls all of the threats except regression and interaction. Since none of the groups were selected via extreme scores of any kind, regression effects should not be a serious threat (Campbell & Stanley). The use of multiple classroom settings was used

to reduce the risk of interaction. Also, using the covariates of content knowledge achievement pretest and science process skill pretest scores to statistically adjust the means on the posttest addressed this concern (Gall et al., 1996).

A total of 501 students were enrolled in classes in the selected schools. Within this total, 168 students were enrolled in the subject matter only treatment, 151 in the prescriptive laboratory treatment, and 182 in the investigative laboratory treatment. No data were received from one participating school, and one teacher was determined, through a review of the audio tapes, to not have fully delivered the treatment. Students in these classes were removed from the study. Therefore, it was determined that 352 students received treatment that could be documented. Within this total, 75 students were enrolled in the subject matter only treatment, 137 in the prescriptive laboratory treatment, and 114 in the investigative laboratory treatment.

Parallel instruments were developed to collect pretest and posttest content knowledge achievement data. Response rates of 70.7% and 62.5%, respectively, were secured. Validity was established through review by an expert panel of college of agriculture faculty. Instruments were field tested using students not included in the study. Reliability was calculated using the Kuder-Richardson 20 formula, with a reported reliability coefficient of .92.

The Test of Integrated Process Skill (TIPS), developed by Dillashaw and Okey (1980), was used to assess the science process skill ability of students pre- and post-treatment. Parallel forms of this instrument were used to collect the data. A reliability of .72 was calculated KR-20. Response rates for pre- and post-treatment TIPS administration were 79.8% and 50.9%, respectively.

The Group Embedded Figures Test (Witkin et al., 1971) was used to assess the student learning style. Usable data were collected with a response rate of 81.0%. Data concerning the variables of student ethnicity, gender, and other demographic information were reported to the researcher by the school's student services department from student records.

Findings

The first objective sought to describe the purposively selected sample. A majority (62.7%) of students involved in this study were in the ninth grade, followed by the tenth grade (19.9%), eleventh grade (12.1%), and twelfth grade (5.3%). The majority of students in the study were male (66.5%) and "White, non-Hispanic" (56.0%), followed by "Hispanic" (34.5%), "Black" (7.9%) and "Other" (1.6%). The mean Group Embedded Figures Test (GEFT) score for respondents of this study was 7.6. Using GEFT scores, student learning style was classified using the following scale suggested by Dyer (1995): Field-dependent: 0-8; Field-neutral: 9-11; & Field-independent: 12-18. A majority of students (60.7%) were categorized as field-dependent in their learning style. Field-independent learners constituted the second largest group (23.2%) followed by field-neutral learners (16.1%).

Student content knowledge achievement was determined using the researcher developed content knowledge achievement pretest and posttest instruments. The maximum possible score on these parallel instruments was 50. The pretest mean was 16.88 (*SD* = 5.03), followed by a posttest mean of 20.62 (*SD* = 6.75). (Table 1.) The mean content knowledge gain score was 3.74 (*SD* = 6.13).

Students' science process skill levels were determined using the TIPS instrument. The maximum score of this instrument is 36. The pretest mean was 15.84 (*SD* = 5.25) across all students. A posttest mean of 15.56 (*SD* = 6.50) was reported across all respondents. The mean science process gain score was -0.27 (*SD* = 6.39).

Table 1
Individual Mean Test Scores by Treatment Group (n = 326)

	Treatment Group						Total	
	SM		PL		IL			
Instrument	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Content Knowledge Pretest	18.26	5.04	16.36	4.92	15.86	4.96	16.88	5.03
Content Knowledge Posttest	25.08	5.36	18.00	6.08	20.00	6.89	20.62	6.75
Science Process Skills Pretest	16.60	5.32	16.55	5.16	12.38	3.96	15.84	5.25
Science Process Skills Posttest	18.62	6.17	13.60	6.14	15.59	6.07	15.56	6.50
Content Knowledge Gain Score[a]	6.81	4.80	1.64	6.48	4.14	4.77	3.74	6.12
Science Process Skill Gain Score[a]	2.02	5.19	-2.95	6.19	3.21	5.80	-0.27	6.39

Note. SM = Subject Matter; PL = Prescriptive Laboratory; IL = Investigative Laboratory
[a] Gain score = Individual posttest scores minus individual pretest scores

The second objective sought to describe the variance in content knowledge gain score attributed to leaning styles, ethnicity, and other demographic characteristics. A backward regression procedure produced a model consisting of field-dependent learning style (t = -2.35, p = .02), subject matter treatment group (t = 2.40, p = .02), prescriptive laboratory treatment group (t = -3.86, p <.001), ethnicity (t = 2.27, p = .02), science process skill pretest score (t = 5.07, p <.001), and content knowledge pretest score (t = -7.77, p <.001). This model accounted for 33% of the variance in content knowledge gain score (Table 2).

Table 2
Backward Regression Analysis to Predict Content Knowledge Gain Scores (n = 352)

Variable	*B*	*SE*	*β*	*t*	*p*
Constant	9.42	2.04		4.62	<.001
Learning Style[a]	-2.25	.96	-.15	-2.35	.02
Treatment Group					
Subject Matter[b]	2.45	1.02	.18	2.34	.02
Prescriptive Laboratory[b]	-3.63	.94	-.29	-3.86	<.001
Ethnicity[c]	2.14	.94	.14	2.27	.02
Science Process Skill Pretest	.41	.08	.35	5.07	<.001
Content Knowledge Pretest	-.67	.09	-.54	-7.77	<.001

Note. $F_{(190)} = 16.71$, p <.001; R^2 = .35; Adjusted R^2 = .33
[a] Coded as 1 = field-dependent; 0 = field-independent; [b] Coded as 1 = member of group; 0 = not a member of group; [c] Coded as 1 = white, non-Hispanic; 0 = minority

Objective three sought to describe the variance in science process skill gain score attributed to leaning styles, ethnicity, and other demographic characteristics. A backward regression model consisting of field-dependent learning style (t = -3.01, p = .003), prescriptive laboratory group membership (t = -5.30, p <.001), gender (t = -2.52, p = .01), science process skill pretest score (t = -6.51, p <.001), and content knowledge pretest score (t = 2.38, p =.02) was identified and accounted for 36% of the variance in science process skill gain score (Table 3).

The first two null hypotheses of no difference in content knowledge gain scores and no difference in science process skill gain scores among the subject matter, prescriptive laboratory, or investigative laboratory treatment groups were tested using a MANCOVA procedure. Hotelling's Trace statistic for group effects on the dependent variables was .12, $F_{(4, 154)}$ = 2.34, p = .05, with an effect size of .06 and power level of .67. Follow up univariate analyses of covariance revealed significant differences between the prescriptive laboratory group and the other groups in both content knowledge gain scores and science process skill gain scores. Therefore, both null hypotheses were rejected.

Table 3
Backward Regression Analysis to Predict Science Process Skill Gain Scores (n = 352)

Variable	*B*	*SE*	*β*	*t*	*p*
Constant	11.20	2.34		5.00	<.001
Learning Style[a]	-3.11	1.03	-.21	-3.01	.003
Treatment Group					
Prescriptive Laboratory[b]	-4.42	.83	-.35	-5.30	<.001
Science Process Skill Pretest	-.58	.09	-.49	-6.51	<.001
Content Knowledge Pretest	.22	.09	.18	2.38	.02
Gender[c]	-2.18	.87	-.16	-2.52	.01

Note: $F_{(157)}$ = 18.39, p <.001; R^2 = .38; Adjusted R^2 = .36
[a] Coded as 1 = field-dependent; 0 = field-independent; [b] Coded as 1 = member of group; 0 = not a member of group; [c] Coded as 1 = male; 0 = female

Null hypotheses three and four stating that no differences existed in either the content knowledge gain scores or the science process skill gain scores across learning styles was also tested using the MANCOVA procedure. Hotelling's Trace statistic for learning style effects on the dependent variables was .18, $F_{(4, 154)}$ = 3.37, p = .01. The effect size was .08 and the power was .84. Follow up univariate analyses of covariance failed to reveal significant differences across learning styles for either content knowledge gain scores or science process skill gain scores. The two null hypotheses failed to be rejected.

Null hypotheses five and six respectively stated that no differences existed in either the content knowledge gain scores or the science process skill gain scores across the learning styles of students taught using either the subject matter, prescriptive laboratory, or investigative laboratory

approach. Both hypotheses were tested using the MANCOVA procedure which produced a Hotelling's Trace statistic of .07, $F_{(8, 154)} = .65$, $p = .73$. The power was calculated at .29, with an effect size of .03. Since the multivariate analyses of covariance failed to reveal significant differences, the null hypotheses failed to be rejected.

Conclusions/Implications/ Recommendations

Participants in this study were predominantly white, male, and enrolled in the ninth grade. The majority of students were field-dependent in their learning style. The finding that approximately 17% of the students in the study were upperclassmen (11^{th} and 12^{th} graders) was somewhat surprising due to the introductory nature of the course. However, since this course counts as a science credit toward graduation, these older students may be enrolling in this course merely to earn a science credit, rather than because of an interest in agriculture. Other possible explanations may be that, due to more strict graduation requirements or possibly school overcrowding, these students were not able to enroll in this introductory course at an earlier date, or that these students perceive the agriscience course to be a less difficult science alternative. Further research is needed to understand the motivation of students enrolling in this type of agricultural education course.

Overall, posttest scores for students involved in the study were very low. Further investigation is needed to address why students achieved so poorly. It is of concern when a great deal of time is spent in teaching a unit of instruction and the result is a small amount of knowledge gain. The finding that students with less prior knowledge in the content area had higher content knowledge gain scores at the conclusion of instruction is contradictory to the findings of Roberts (2003) who reported the opposite in his study. However, students with greater science process skill achievement prior to instruction showed higher content knowledge gain.

Gender did not contribute significantly to explaining the variance in content knowledge achievement. However, learning style was found to play a role in knowledge gain. Students with a field-independent learning style were predicted to have more than double the content knowledge gain as compared to field-dependent learners when all other variables are controlled.

The regression equation predicted that white, non-Hispanic students would have content knowledge gain scores 2.14 times greater than that of minority students when all other variables are held constant. Further research is needed to better understand the cause of this gain discrepancy. Of particular interest is the effect of socioeconomic status of students on achievement. Are ethnicity and socioeconomic status coterminous as Abbot and Joireman (2001) suggest? If that is the case, what can educators do to mitigate the effect?

The regression equation predicts that female students are likely to attain 2.18 times the science process gain scores as compared to males, when all other variables are held constant. This contradicts the commonly held belief that females under-perform their male counterparts in science. However, it should be noted that agriculture often attracts females who tend to be field-independent in their learning style and therefore may not represent a normal distribution. Further research should be conducted to explain this large difference in gain between the genders.

The findings of this study suggest that students taught using either the subject matter approach or investigative laboratory approach to teaching had higher content knowledge gain scores than students taught using the prescriptive laboratory treatment level. This finding did not support the research conducted by Osborne (2000) involving similar secondary students.

Whereas it was reported by the teachers involved in this study that the investigative approach took a substantially longer period of time to implement than did the subject matter approach (1900 minutes, as compared to 1410 minutes, respectively), it would follow that most teachers would select the shorter time frame. However, upon investigation as to the level of cognitive ability at which content knowledge was assessed, the vast majority of questions on

the assessment instruments addressed only the lower levels of Bloom's Taxonomy (Anderson & Krathwohl, 2001). The question remains as to how these teaching approaches affect student understanding at the higher levels of Bloom's Taxonomy. Further research is needed to assess this question. Whereas it is understood that knowledge at the lower levels is needed to form a strong foundation upon which to build, it is equally important to address knowledge and understanding at the higher levels.

The findings of this study suggest that students taught using the investigative laboratory approach or the subject matter approach to teaching had higher science process skill gain scores than students taught using the prescriptive laboratory treatment level. This finding did not support the research conducted by Osborne (2000) or Germann (1989) involving similar secondary students. In light of these conflicting findings, further research into the effect of teaching method on student science process skill development is warranted.

Student learning style was not found to have significant influence on science process skill gain score either alone or in interaction with level of treatment (teaching method). The mean GEFT score was 7.6, indicating that, in general, this group was strongly field-dependent. Dyer (1995) stated that field-dependent learners tend to work better in situations where structure is provided for them, such as in the subject matter and prescriptive laboratory methods. Field-independent learners on the other hand tend to prefer a hypothesis-testing approach to learning and are better able to provide their own structure in learning activities such as in the investigative laboratory approach. Therefore, it stands to reason that field-independent learners would enjoy and perhaps experience more success in classrooms in which the investigative approach was utilized. Further investigation into this phenomenon is suggested.

Whereas the variables addressed in this study were able to describe 33% and 36% of the variance in content knowledge and science process skill gain scores, respectively, further research is needed to attempt to understand the unaccounted for variance. Research on the relationship between teaching methods, content knowledge, and science process skill achievement of high school students in agricultural education programs should continue. Other variables of interest are the effect of these teaching methods on student attitude as well as long and short term content knowledge retention.

As a clinical study, this study should be replicated using procedures that allow a higher degree of randomization and ultimately more generalizability. As noted by Edwards (2003), the research base in agricultural education is dominated by descriptive type research. More research using experimental methods are needed to assist the profession in advancing in the area of agriscience achievement. Additionally, investigative activity integration focuses on student inquiry as a learning method. The *Standards* (NAS, 1996) state that inquiry is key to student understanding of science. However, the *Standards* do offer a caution, indicating that conducting hands-on activities does not guarantee inquiry nor are hands-on activities the only way in which students can engage in inquiry. What is key is that inquiry activities are conducted to answer authentic questions generated from student experience.

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