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The Effects of Inquiry-Based Instruction on the Development of Integrated Science Process Skills in Trainee Primary School Teachers with Different Piagetian Developmental Levels

Araştırma Yoluyla Öğretim Metodunun Farklı Zihinsel Gelişim Dönemlerindeki Sınıf Öğretmenliği Öğrencilerinin Bilimsel İşlem Becerilerinin Gelişimine Etkileri

Salih ATEŞ
Abant İzzet Baysal Üniversitesi Eğitim Fakültesi İlköğretim Bölümü Fen Bilgisi Öğretmenliği Anabilim Dalı, Bolu-TÜRKİYE

ÖZET

Bu çalışmada, araştırma yoluyla öğretim metodunun farklı zihinsel gelişim dönemlerindeki sınıf öğretmenliği öğrencilerinin bilimsel işlem becerilerinin gelişimine etkilerini belirlemek amaçlanmıştır. Çalışmanın örneklemini sınıf öğretmenliği 3. sınıfta okuyan üç gruptan toplam 103 öğrenci oluşturmaktadır (Erkek=30, Kız=73, Yaş: 19 ile 22 arası). Öğrencilere üç test uygulanmıştır. İlk olarak öğrencilerin ön bilimsel işlem becerilerini belirlemek için Bilimsel İşlem Becerileri Testi II (Test of İntegrated Process Skills II) uygulanmıştır. Daha sonra öğrencilerin zihinsel gelişim dönemlerini belirlemek için Mantıksal Düşünme Yetenek Testi uygulanmıştır. Ön-testlerin uygulanmasından sonra, üç gruptaki öğrenciler bilimsel işlem becerilerini geliştirmek amacıyla araştırma yoluyla öğretim metoduna göre tasarlanmış dört etkinliği tamamlamışlardır. Son olarak öğrencilerin bilimsel işlem becerilerini belirlemek için Bilimsel İşlem Becerileri Testi II son-test olarak tekrar uygulanmıştır. Ortak değişkenli varyans analizi (ANCOVA) sonuçları, araştırma yoluyla öğretim modelinin farklı zihinsel gelişim evrelerindeki öğrencilerin bilimsel işlem becerilerinin gelişimindeki etkisinin istatistiksel olarak anlamlı gösterdiğini ortaya koymuştur. Farklı zihinsel gelişim dönemlerindeki öğrencilerin son-test puan ortalamaları karşılaştırıldığında, Soyut işlem dönemindeki öğrencilerin son-test puan ortalamalarının hem somut işlem hem de geçiş dönemindeki öğrencilerin son-test puan ortalamalarından istatistiksel olarak anlamlı bir şekilde yüksek olduğu görülmüştür. Fakat somut işlem ve geçiş dönemindeki öğrencilerin son-test puan ortalamaları arasında istatistiksel olarak *anlamlı bir farklılık bulunmamıştır. Grupların testin alt boyutlarından aldıkları puan ortalamalarının analizleri sonucunda, soyut işlem dönemindeki öğrencilerin testin bütün alt boyutlarındaki puan ortalamalarının somut işlem dönemindeki öğrencilerin puan ortalamalarından yüksel olduğu görülmüştür. Soyut işlem dönemindeki öğrencilerin testin sadece iki alt boyutundaki puan ortalamalarının geçiş dönemindeki öğrencilerin puan ortalamalarından yüksel olduğu görülmüştür. Soyut işlem ve geçiş dönemi öğrencilerinin puan ortalamalarının karşılaştırılmasında testing altboyutlarının hiçbirinde farklılık gözlenmemiştir. Bu çalışmanın bulguları daha önce bu alanda yapılan çalışmaların sonuçlarıyla karşılaştırılmış ve öğrencilerin bilimsel işlem becerilerini geliştirmek için bazı öneriler sunulmuştur.*

Anahtar kelimeler: Araştırma yoluyla öğretim modeli, zihinsel gelişim dönemleri, bilimsel işlem becerileri.

ABSTRACT

This study was carried out to explore the effects of inquiry-based instruction in developing integrated science process skills of trainee primary school teachers with different Piagetian developmental levels. One hundred-three junior college students (male=30, female=73, age 18-20) from three intact classes participated in the study. Students were given three tests. First, Test of Integrated Process Skills II (TIPS II) was administered to assess preintegrated science process skills of students. Second, the Classroom Test of Formal Reasoning was administered to determine students' Piagetian developmental levels (concrete, transitional, and formal). After pretesting, students in each intact class completed four activities developed on the basis of inquiry-based technique of teaching science to enhance science process skills. Finally, all students were given TIPS II as a posttest. Results of ANCOVA showed that the main effect of inquiry based instruction on integrated science process skills of students at the different developmental levels was significant. Analysis of pairwise comparison among developmental levels data revealed that the students at the formal level performed significantly better than the students at both concrete and transitional levels with respect to the acquisition of integrated science process skills. The results showed no significant difference between concrete and transitional students. The results of this study also indicate that formal students overscored concrete students in all subtests of post TIPS II. Formal students also overscored transitional students in the subtests 2 and 4 of TIPS II (Defining operationally and Interpreting & graphing data). The results of the present study also showed that there is no statistically significant difference between concrete and transitional students' mean scores in subtests of post TIPS II. Based on the findings of the study some recommendations will be presented.

Key words: Inquiry-based teaching, integrated science process skills, Piagetian developmental levels

1. Introduction

In many science curricula developed recent years, it has been emphasized that acquisition of the science process skills should be one of the major goals of science instruction. The National Science Education Standards states that "science as inquiry is basic to science education. Students at all grades should have the opportunity to use scientific inquiry, including asking questions, planning and conducting investigations" (National Research Council, 1996, p. 105). In England and Wales, Attainment Target 1 (Sc1) in the Science National Curriculum is devoted to scientific investigations (Department of Education and Science, 1991). An increasing emphasis on process skills is also characterized for Australian Schools in A Statement on Science (Australian Educational Council, 1994).

The understanding of methods and procedures of scientific investigations are called procedural skills (Lawson, 1995). They are related to proficiency in 'doing' aspects of science and are associated with cognitive and investigative skills. Brotherton and Preece (1995) stated that a hierarchy exists to the thinking skills and patterns essential to the scientific inquiry. Brotherton et al. (1995) reported a two-level hierarchy (basic and integrated) of process skills. Basic skills include observing, measuring, using numbers, classifying, seriating, predicting, and inferring. Integrated science process skills, relied upon more sophisticated cognitive abilities, include stating hypotheses, identifying and controlling variables, defining operationally, interpreting data, and experimenting. Padilla, Okey, and Dillashaw (1983) believe that basic skills provide a foundation for the acquisition of integrated process skills.

1.1. Previous Studies about Science Process Skills

Several studies have been sought to determine the relationship between formal reasoning skills (identifying and controlling variable, correlational, combinatorial, probabilistic, and proportional reasoning) as described by Inhelder and Piaget (1958) and integrated science process skills. Previous findings suggest a close link between these skills (Padilla et al., 1983; Brotherton et al., 1995). Padilla et al. (1983) state that the ability to identify and control variables involves the same steps as in conducting experiments. Also, experiments in science classes may involve proportional and correlational reasoning skills in data analysis tasks. Brotherton et al. (1995) reported a considerable overlap between science process skills and formal reasoning skills.

Results of several studies have shown that students' scientific process skills can be developed by using inquiry or investigative approach of teaching and learning science that gives them opportunities to practice these skills (Scharmann, 1989; Roth and Roychoudhury, 1993). Scharmann (1989) reported that science activities with large process components assist to develop science content knowledge and to foster an understanding of the nature of science. Many researchers have indicated that inquiry teaching results in greater student achievement and enhances positive attitudes toward science more than traditional strategies of teaching science do in science classrooms (Basaga, Geban, and Tekkaya, 1994; Ertepınar and Geban, 1996). On the other hand, German (1989) found that directed-inquiry teaching approach has no significant effect on the learning of science process skills. Arena (1996) indicated that the acquisition of process skills requires continued instruction and that students if used in a brief, limited fashion do not retain the skills. The researcher argued that process skills are more efficiently learned when the context is familiar and relevant to the students.

While the acquisition of science process skills and the correlation among formal reasoning and integrated science process skills have been widely investigated, little research has been conducted to investigate the effective ways of enhancing scientific procedural skills of pre-service elementary teaching students and possible differential effects of inquiry-based instruction on different groups at college level. Kahle and Meece (1994) suggested that research should be conducted to examine possible differential effects of instructional approach on different individuals. This study was conducted to investigate the effectiveness of inquiry-based instruction in developing integrated science process skills of pre-service elementary teaching students having different piagetian developmental levels.

Research Question

The following research question framed this study: How effective is inquiry-based instruction to develop integrated science process skills of college juniors having different Piagetian developmental levels?

2. Design

Sample

This study was conducted at the Abant İzzet Baysal University in Turkey. One hundred three junior college students taking a required 'Science Teaching I' course in the pre-service elementary teacher department participated in the study. The age of students was between 18 and 21 and there were 73 female and 30 male. All students, in three intact classes, took major science classes such as introductory physics, chemistry, life science, and science laboratory during freshman and sophomore years.

Procedures

The research design employed in this study was the one-group pretest-posttest design. All students in three intact classes were administered two tests. First, the Test of Integrated Process Skills II (TIPS II) was administered to assess the pre integrated science process skills of students. Second, the Classroom Test of Formal Reasoning was administered to determine students' Piagetian developmental levels (PDL). After pre testing, in each intact class four or five students formed a group. Then, all groups completed four activities developed based upon inquiry-based technique of teaching science to enhance science process skills. Finally, all students were administered the TIPS II as a posttest.

Development of the instructional Materials

Four instructional activities developed for the research project. The activities were developed based upon inquiry-based techniques of teaching science and each activity emphasized integrated science process skills. Activities used in the research were the following: 1) Bouncing ball, 2) Soil experiment, 3) The towel test, and 4) Pendulum. Since the project emphases were centered on the science process skills of students rather than content knowledge, activities and experiments were chosen from different science content areas. One and half-hour lesson plans were designed based on inquiry-based teaching for every activity. At the beginning of each activity, the teacher demonstrated an introductory activity, which is related to the content area in the primary activity to motivate and encourage students to the instruction. Also the teacher led each group in designing a controlled experiment to investigate the relationship between variables. In the closing section, each group shared the findings with the others and tried to make a logical conclusion about the investigation conducted.

Assessment instruments

a) Integrated Science Process Skills: Students' integrated process skills were assessed using the Test of Integrated Process Skills II (TIPS II). The test was developed by Burns, Okey, and Wise (1985) and has been used in many researches (Padilla et al., 1983; Brotherton et al., 1995; Ertepınar et al., 1996). This is a 36-item multiple-choice test designed to assess a range of integrated process skills. It takes about 40 minutes to complete. Five integrated process skills measured in the test and the number of test items in each skill are follows: Identifying variables (12), Operationally defining (6), Stating hypothesis (9), Data and graph interpretation (6), and Designing experiment (3). The test was translated and adopted into Turkish by the researcher (Ateş and Bahar, 2002). The reliability of the Turkish version was found to be 0.74.

b) Piagetian Development Levels: The students were administered the Classroom Test of Formal Reasoning to determine their PDL. The first version of the test was developed in 1978 (Lawson, 1978) and was slightly modified in 1992 (Lawson, 1992a). This test measures a student's ability to apply scientific and mathematical reasoning involves in testing hypotheses. Validity of the test has been established by several studies (e.g., Lawson, 1978, 1992a, 1995). The same version used for the 1992a Lawson study was used in the study. It is a 12-item paper and pencil test and takes about 40 minute to complete. The type of reasoning needed on the test include conservation (items 1and 2), proportions (items 3 and 4), controlling variables (items 5 and 6), hypothesis testing (items 7 and 8), probability (items 9 and 10), and combinations (items 11 and 12). For each item, students were expected to provide an answer as well as an explanation of the answer. One point was awarded when both the answer and the explanation were correct; otherwise no points were awarded. Response scores of students for items in this instrument can range 0 to 12. Students were classified as being concrete, transitional or formal reasoner based upon performance on the test. In the many administrations of this test, there have been slight variations in the cut-off points of scores used to designate students as concrete, transitional, or formal reasoner. Mostly, scores of 0-4 represent concrete reasoning, 5-8 represent transitional reasoning, and 9-12 represent the formal reasoning (Lawson, 1992b). For the sake of consistency the cut-off points used in the 1992b Lawson study were also used for this study. The test was translated and adopted into Turkish by the researcher (Ateş, 2002). The reliability of the Turkish version of the test was found to be 0.79.

3. Results

Classroom Test of Formal Reasoning scores were analyzed to determine PDL of students based upon performance on the test. According to this analysis, 31 students (30%) scored between 0-4, 59 students (57%) scored between 5-8, and 13 students (13%) scored between 9-12 and they were classified as being Concrete, Transitional, and Formal reasoners respectively. The percentages for the corresponding classification of the college students in the 1992a Lawson study were, 14%, 47%, and 41%.

Pre TIPS II scores were analyzed to compare the groups' (Concrete, Transitional, and Formal reasoners) pre-integrated science process skills. ANOVA techniques were used to determine if pre TIPS II mean scores of the groups differed statistically. Pre TIPS II mean scores were found to be statistically different among Concrete, Transitional, and Formal reasoners ($\underline{F}= 3.2$, $\underline{p}=0.04$). A post hoc comparison test was performed using the Bonferroni method to see which set of PDL group means showed statistical difference. The results indicate that there was a mean difference between formal and concrete reasoners while there was no significant mean difference between formal and transitional and between transitional and concrete reasoners. Pre TIPS II scores were further analyzed to determine if this variable is a significant predictor of the post TIPS II score and an appropriate covariate. A pre TIPS II score was incorporated into a regression equation for a post TIPS II score. The equation yields an R^2 value of 12% and the pretest score is a statistically significant predictor of the posttest score at the 0.001 alpha level ($\underline{t}=12.7$, $\underline{p}=0.001$). The correlation coefficient between Pre and post TIPS II scores was 0.34 and correlation was significant at the 0.001 alpha level. Thus, when post TIPS II scores were analyzed, a pre TIPS II score was used as a covariate.

The objective of this study was to determine whether inquiry-based instruction is equally effective to develop integrated science process skills of college juniors classified as being concrete, transitional, and formal reasoners? Post TIPS II scores were analyzed to compare the groups' post-integrated science process skills. Table 1 represents statistics of pre and post TIPS II mean scores of the groups.

Table 1: Pre and Post TIPS II Mean Scores by PDL (n=103)

		Pretest		*Posttest*	
PDL	*Subtests of TIPS II*	*M*	*SD*	*M*	*SD*
Identifying & controlling variables		*4.5*	*2.3*	*8.2*	*2.2*
Defining operationally		*1.7*	*2.0*	*3.8*	*1.4*
Concrete	*Stating hypothesis*	*6.8*	*1.8*	*6.5*	*1.7*
(n=31)	*Interpreting & graphing data*	*4.9*	*1.2*	*4.7*	*1.2*
Experimenting		*2.5*	*0.5*	*2.3*	*0.6*
	Total	*20.4*	*3.5*	*25.5*	*4.9*
Identifying & controlling variables		*5.2*	*2.3*	*8.9*	*2.3*
Defining operationally		*2.7*	*2.2*	*4.0*	*1.1*
Transitional	*Stating hypothesis*	*6.9*	*1.8*	*7.3*	*1.4*
(n=59)	*Interpreting & graphing data*	*5.0*	*1.6*	*5.1*	*0.9*
Experimenting		*2.8*	*0.6*	*2.6*	*0.6*
	Total	*22.7*	*4.5*	*27.8*	*3.8*
Identifying & controlling variables		*5.9*	*2.1*	*10.1*	*1.6*
Defining operationally		*3.5*	*2.4*	*5.0*	*1.0*
Formal	*Stating hypothesis*	*7.9*	*1.7*	*8.0*	*1.0*
(n=13)	*Interpreting & graphing data*	*5.4*	*0.6*	*6.0*	*0.0*
Experimenting		*2.9*	*0.5*	*3.0*	*0.0*
	Total	*25.5*	*4.6*	*32.1*	*2.7*
	Total	*22.9*	*4.5*	*28.5*	*4.4*

The effects of inquiry-based instruction on post TIPS II adjusted mean scores of students having different PDL were examined by using ANCOVA with pre TIPS II scores used as a covariate. Results analyzed are presented in Table 2. As seen from Table 2, there was a significant difference in post TIPS II adjusted mean scores based upon PDL.

Table 2: ANCOVA Table for Post TIPS II Mean Scores by PDL

Source	*DF*	*SS*	*MS*	*F*	*P*
Corrected Model	*3*	*507.1*	*169.0*	*10.8*	*0.00***
Intercept	*1*	*1732.3*	*1732.3*	*110.4*	*0.00***
Pre TIPS II	*1*	*100.3*	*100.3*	*6.4*	*0.01**
PDL	*2*	*292.4*	*146.2*	*9.3*	*0.00***
Error	*99*	*1553.9*	*15.7*		
Total	*103*	*80865.0*			

**p<0.05, **p<0.01*

A post hoc comparison test was performed using the Bonferroni method to determine which set of PDL group means showed significant differences for post TIPS II scores. All Pairwise Comparisons among the groups were determined. The results of the analysis indicated that there was a statistically significant difference between formal and transitional reasoners' means. Significant main effects were also found between formal and concrete reasoners' means. Analysis of covariance indicated that there was not a statistically significant difference between transitional and concrete reasoners' mean scores. These results are shown in Table 3.

Table 3: Pairwise Comparison of Post TIPS II Adjusted Mean Scores by PDL

PDL		*D of M*	*SE of D*	*P*
Formal	*Transitional*	*3.72*	*1.23*	*0.00**
	Concrete	*5.79*	*1.34*	*0.00**
Transitional	*Concrete*	*2.07*	*0.88*	*0.06*

**p<0.01*

It was also determined which set of PDL group means showed significant difference in subtests of post TIPS II. scores, a post hoc comparison test performed using the Bonferroni method. All Pairwise Comparison among PDLs were determined. The results of the analysis indicated that there was statistically significant difference between formal and concrete reasoners' post mean scores in all subtests of TIPS II. In subtests 2 and 4 of TIPS II (Defining operationally and Interpreting & graphing data skills), significant main effects were found between formal and transitional reasoners' mean scores. Analysis of covariance also indicated that there were not statistically significant difference between transitional and concrete reasoners' mean scores in subtests of post TIPS II. These results are shown in Table 4.

Table 4: Pairwise Comparison of Post TIPS II Subtests' Mean Scores by PDL

Subtests of TIPS II	PDL		P
Identifying & controlling variables	Formal	Transitional	0.22
		Concrete	0.03*
	Transitional	Concrete	0.50
Defining operationally	Formal	Transitional	0.03*
		Concrete	0.05*
	Transitional	Concrete	0.99
Stating hypothesis	Formal	Transitional	0.30
		Concrete	0.00**
	Transitional	Concrete	0.06
Interpreting & graphing data	Formal	Transitional	0.01*
		Concrete	0.00**
	Transitional	Concrete	0.10
Experimenting	Formal	Transitional	0.07
		Concrete	0.00**
	Transitional	Concrete	0.08

**p<0.01, *p<0.05

4. Discussion

In the present study, it was intended to determine whether inquiry-based instruction is equally effective to develop integrated science process skills of college juniors having different Piagetian developmental levels or not? Analysis of covariance showed that results for the main effect of inquiry based instruction on integrated science process skills posttest mean scores of students at the different PDLs were significant. The results of this study revealed that the students at the formal level performed significantly better than the students at the both concrete and transitional levels on the post TIPS II. The results showed no significant difference between concrete and transitional students. The results of this study also indicate that formal students over scored concrete students in all subtests of post TIPS II. Students at the formal level performed better than students at the transitional level in the subtests 2 and 4 of TIPS II (Defining operationally and Interpreting & graphing data). The results of the present study also showed that there is no statistically significant difference between concrete and transitional students' mean scores in subtests of post TIPS II.

Results of this study support the notion that inquiry teaching method is better for the higher reasoning ability groups for the acquisition of critical thinking and problem solving skills (Johnson & Lawson, 1998; Cavallo, 1996). Many studies have also shown that reasoning patterns do develop across adolescence, at least in some students, play an important role in the ability to do science and to construct science concepts (Lawson, 1985; Shayer and Adey, 1993; Cavallo, 1996; Lawson et al., 2000). During inquiry teaching, students are mostly involved in gathering information, defining and controlling variables, collecting and analyzing data, stating hypothesis, and drawing logical conclusion. Arena (1996) pointed out that most of these skills rely upon more sophisticated cognitive abilities and require formal reasoning patterns to conduct a scientific experiment and solve a scientific problems. It was expected that formal students, capable of hypothetical-deductive reasoning, would perform better than concrete and transitional reasoners on achieving scientific process skills and determining possible relationships among variables. Formal students represent a general mode of intellectual functioning in turn of identifiable reasoning patterns (e.g., the isolation and control variables, proportional, correlational) to understand and assimilate both concrete and abstract instructional materials, while concrete reasoners are able to understand and assimilate only concrete instructional materials. Findings suggesting a close link between formal reasoning patterns and integrated science process skills may also explain the effectiveness of inquiry based instruction in developing formal students' science process skills. As Padilla et al. (1983) stated that the ability of identify and control variables, of proportional and correlational reasoning carried by formal students are required to conduct an experiments and analyze data collected during inquiry session. Result of the present study indicating that formal reasoner students scored significantly higher than transitional reasoners on interpreting and graphing data skills is consistent with previous studies (Wavering, 1989; Adams and Shrum, 1990; Berg and Phillips, 1994). Berg and Phillips (1994) found a significant relationship between formal reasoning and data analysis and graphing. The researchers reported that students who did not possess formal reasoning patterns were more likely to be dependent upon, and influenced by, perceptual cues and less able to interpret or construct graphs correctly.

5. Conclusions and Educational Implications

It may be claimed that to successfully implement inquiry-based instruction in science classes to enhance science process skills, students need to have higher level reasoning skills (e.g., identifying and controlling variables, proportional, probabilistic, correlational, and combinatorial reasoning). Results of this study indicate that students' reasoning levels should be considered in planning inquiry-based instruction to enhance integrated science process skills. Teachers who wish to use inquiry-based modules should be aware of reasoning levels of students. Formal students show more positive responses to the instruction than concrete and transitional reasoners. Consistent with findings in other studies, most of the college students were at concrete and transitional levels. These findings suggest that teachers who wish to use inquiry-based instruction to teach integrated science process skills should begin implementing an additional instruction to improve their students' reasoning skills. Although difficult to obtain, Researches have documented that improvements in reasoning skills, as a consequences of instruction are possible and of general use (Shayer and Adey, 1993; Lawson et al., 2000). Results of the present and previous studies also indicated that the acquisition of integrated process skills requires continued instruction and that students, if taught in a brief limited fashion, do not retain the skills. Clearly, much additional research is needed to determine how to design an instruction to enhance college students' science process skills.

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