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Salih Ates & J. Truman Stevens

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Teaching Line Graphs to Tenth Grade Students Having Different Cognitive Developmental Levels by Using Two Different Instructional Modules

SALIH ATES, *Department of Elementary Education, College of Education, Izzet Baysal University, 14280 Golkoy-Bolu, Turkey*

J. TRUMAN STEVENS, *College of Education, University of Kentucky, Lexington, Kentucky, USA*

ABSTRACT *This study was undertaken to explore two ways of teaching line graphs and to compare line-graphing skills of tenth-grade students having different cognitive developmental levels. Two chemistry classes participated in the study, which lasted approximately three weeks near the beginning of fall semester of 2000. Two intact classes were randomly assigned into one of the two treatment groups; one group completed a line-graphing unit with computer-supported activities called Treatment 1* ($n_1 = 22$)*, while the other group completed a line-graphing unit with non-computer-supported activities called Treatment 2* ($n_2 = 23$)*. The same teacher taught both treatments to the groups. It was determined that there were no statistically significant differences on line graphing mean scores, as measured by both Individualised Test of Graphing in Science (I-TOGS) and Performance Assessment Test (PAT), between the groups. The results of analysis of variance indicate that there were statistically significant differences among mean scores of the students having different reasoning levels. Analysis of pairwise comparisons among reasoning levels data indicate that formal reasoners significantly outperformed concrete reasoners in line-graphing post-test scores, while there was no significant difference in the line-graphing mean scores between concrete and transitional reasoners. Also Significant main effect was not found between mean scores of transitional and formal reasoners. Data collected indicate that there were no statistically significant interaction effects among treatments and scientific reasoning levels.*

Introduction

Graphs provide an invaluable aid in solving arithmetic and algebraic problems and representing relationships among variables. Graphs display mathematical relationships that often can not be easily recognized in numerical form (Arkin and Colton, 1940, p.4). Also graphs display trends as geometric patterns that our visual systems encode easily (Pinker, 1983). Graph construction and interpretation skills are obviously important for

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the development of scientifically literate individuals. A survey of 2500 pages from five scientific journals and six high school biology textbooks showed that there are about fifteen visual representations per ten pages (Roth *et al.*, 1999). Different types of graphs are appropriate for different purposes. It is suggested that one needs to select the right graph type for a given set of data and purposes (Kosslyn, 1985). The task of predicting a probable relationship between variables can be made easier using a line graph (Brasell & Row, 1993).

> In science, more than any other subject, students should be involved in predicting relationships between variables and attempting to quantify these relationships. Graph construction and interpretation are very important to science instruction because they are an integral part of experimentation, the heart of science. (McKenzie & Padilla, 1986).

Despite the number of graphs experienced by students, many researchers show that students of all ages have difficulty comprehending them (McDermott *et al.*, 1987; Leinhardt *et al.*, 1990). Previous studies indicate that lack of graphing skills is a handicap and a limiting factor in learning scientific concepts (Padilla *et al.*, 1986; McDermott *et al.*, 1987). Researchers also mention that literacy in graphing does not develop spontaneously and research is needed to determine effective methods of teaching and learning graphs.

Previous Studies about Line-graphing Comprehension

Previous studies of graphing have been concerned mainly with the ability to read different types of graphs and with the difficulty in constructing and interpreting the various kinds of graphs. For example, circle graphs are read most easily and accurately while line graphs provide more comprehension difficulties (Culberston and Power, 1959). Line graphs are more abstract presentations and consistent sequences of lengths are recognized less accurately and slowly than consistent sequences of angles (Weintraub, 1967). Kosslyn (1985) explains graph comprehension from the standpoint of human visual information processing. According to the author, graph comprehension involves two processes: (a) visual perception, the process of detecting the visual image of the graph, and (b) graphic cognition, the process of converting the visual image into meaningful information.

Many studies try to explain student difficulties in constructing and interpreting line graphs by correlating the development of formal thinking structure and line graphing skill. Results of these studies suggest a strong relationship between graphing skills and logical thinking (McKenzie & Padilla, 1984; Wavering, 1989; Adams & Shrum, 1990; Brasell & Rowe 1993; Berg & Phillips, 1994). Berg and Phillips (1994) found significant relationships among logical thinking structures, Euclidean spatial structures, and the ability to construct and interpret line graphs. The findings of the study also indicate that subjects who showed evidence of proportional reasoning did better on many graphing situations. This perspective demonstrates that proportional and correlational reasoning components of the formal operation are necessary for reasoning in graphing. Wavering (1989) indicates that seriation becomes the proportional reasoning needed for scaling data on axes, and one-to-one correspondence leads into pattern recognition. Pattern recognition becomes the early correlational reasoning needed to recognise the relationship between variables. Recently, groups of scientists have challenged the relationship between the development of reasoning and graphing. They criticise traditional views that graphing is a composite of individual cognitive abilities and skills. Roth and McGinn

(1996) claim that traditional views lead to an assessment problem in determining variation in performance across contexts and tasks and an attribution problem in locating difficulties of insufficient cognitive mechanisms by students. They provide an alternative perspective that views graphing as practice. The lack of graphing competence is explained in terms of experience and degree of participation, rather than in terms of cognitive ability. Roth and McGinn (1996) argue that a practice perspective successfully addresses the following issues. First, failure and success of some graphing curricula are understandable in terms of the presence or absence of social dimensions of the practice. Second, the practice perspective calls for new assessment practices. Third, the practice perspective requires alternative learning environments and new techniques for conducting research based upon open, inquiry contexts.

Previous Studies about Teaching and Learning of Line Graphs

There is a consensus that the power of graphing as an instructional tool is overlooked and that many schools fail to include graphing instructional units in the curriculum (Chambers *et al.*, 1983, p.1; McKenzie & Padilla, 1984; Cleveland, 1985, p.1; Leinhardt *et al.*, 1990; Mokros & Tinker, 1987; Wavering, 1989). Several studies show limitations in teacher subject-matter knowledge of graphing (Clement, 1989; Cited in Leinhardt *et al.*, 1990; Stein *et al.*, 1990). Ponte stresses that many pre-service teachers have difficulty making connections between graphical and numerical data (Cited in Clement, 1989). Stein *et al.* (1990) indicate that some teachers miss the most important aspect of graphing; the visual representation of mathematical functions.

Graph teaching and learning has undergone a transformation with computers revolutionising the capacity to collect, manipulate, and display information in a graphical format. Microcomputer-based laboratories (MBLs) are very effective in teaching graphing. Many recent studies have shown improvement in graphing abilities after experiencing MBLs (Linn *et al.*, 1987; Mokros & Tinker, 1987; Rowland, 1989; Adams & Shrum, 1990; Brasell & Rowe, 1993; Svec, 1995). The most apparent benefit of microcomputers is the removal of tedium and drudgery of low-level manual graph construction. This allows students to spend more time on higher-order graphing skills (Brasell & Rowe, 1993). However, Berg and Smith (1994) cite a major assessment problem related to determining effects of MBL on graphing. Student responses differ significantly when different instruments are used to assess both graphing abilities and the impact of MBLs. The authors suggest that studies be conducted to re-examine and determine the impact of MBL from a perspective of student-constructed graphs.

Design

Two intact classes were randomly assigned into one of the two treatment groups; one group completed a line-graphing unit with computer-supported activities called Treatment 1 (T1), while the other completed a line-graphing unit with non-computer-supported activities called Treatment 2 (T2). After the groups were formed, students in both groups were given two tests. First, The Individualized Test of Graphing in Science (I-TOGS) (Adams & Shrum, 1990) was administered to measure pre line-graphing scores of students. Second, the Test of Scientific Reasoning (TSR) (Lawson, 1978) was administered to determine students' cognitive developmental levels. Students in both treatments completed instruction specifically designed for the groups. Then, all students were given I-TOGS and an open-ended performance assessment test (PAT) as post-tests.

Participants

This project was conducted in a public high school in central Kentucky. Forty-five students from two advanced chemistry classes participated in the study. Most students were sophomores taking a required chemistry course and were not enrolled in any other advanced science courses. Students live in a rural area, but all of them live adjacent to a large population center in central Kentucky. Intact classes were randomly assigned into one of two treatment groups; one group completed a line-graphing unit with computer-supported activities called Treatment 1 ($n_1 = 22$), while the other completed a line-graphing unit with non-computer-supported activities called Treatment 2 ($n_2 = 23$). Treatments lasted about three weeks during the fall semester of 2000. An experienced chemistry teacher who holds a master's degree in science education taught instructional materials to the groups. The teacher was selected on a volunteer basis, and the same teacher administered both treatments to the two groups.

Research Questions

It was intended that the following three questions be investigated: first, 'Do computer applications affect the line-graph construction and interpretation skills of students?', second, 'Is there a relationship between student cognitive developmental levels and line-graphing construction and interpretation skills?' and third, 'Are there interaction effects between methods of teaching graphing and the cognitive developmental levels of students?'

Treatments

Two parallel instructional units were developed for teaching data gathering, data analysis and line graphing to ninth through twelve graders. Both modules involve hands-on laboratory work and include eight activities based upon an investigative approach of teaching and learning science. One group used various computer applications (i.e., Universal Lab Interface, Graphical Analysis Software, Logger Pro Software, and a variety of laboratory sensors) to gather, analyse, and graph data. The second group conducted almost identical laboratory experiences, but they used traditional laboratory equipment (i.e., graph paper, ruler, stopwatch, and thermometer) in gathering, analysing, and constructing graphs. Each module has an instructional package including teacher and student materials. Names of the activities, graphing skills emphasised, and types of relationships studied in instructional units are summarised in Table 1. Since project emphases were centred on data collection and analysing skills of students rather than content knowledge, activities and experiments were chosen from different science content areas. Activities were independent from each other and one and half-hour lesson plans were designed for every activity. Each activity starts with a demonstration related to concepts and variables investigated in the activity. After the demonstration, students state a research question, conduct the experiment, collect data, graph data, and answer questions based upon analyses of the data. Some of the activities and experiments used in the modules were adapted and adopted from various sources (i.e., *Invitations to Science Inquiry* written by Tik L. Liem and *Physics with Computer and Physical Science with Computer produced* by Vernier Software).

TABLE I. List of the activities used in the study

Name of Activity	Skills Emphasised	Type of Relationship
1-Density	Constructing data table and axes Scaling, ordering the variables to the axes Selecting title for a graph	Directly Proportion
2-Fahrenheit and Celsius	Meaning of intercept Constructing algebraic equation Interpolating and extrapolating	Direct
3-Ohm's Law	Meaning of slope Introducing experimental error Introducing Best-Fit/Regression line	Directly Proportional
4-Freezing and Melting curves	Reading and interpreting a graph	Multiple
5-Boyle's Law	Introducing a non-linear curve Constructing an additional graph Transforming or manipulating data	Inverse
6-Period of a Pendulum	Transforming or manipulating data Constructing an algebraic equation for a non-linear curve	Square-root
7-Free Falling Object	Transforming or manipulating data Introducing a parabolic graph	Square
8-Light Intensity	Transforming or manipulating data	Inverse Square

Data Source

Recognising the importance of graphing skills in mathematics and science leads to the need for knowing student graph construction and interpretation ability levels. As a result, scientists have attempted to construct a valid and reliable instrument for assessing the line-graphing skills of students (Kerslake, 1977; McKenzie & Padilla, 1986; Wavering, 1989; Adams & Shrum, 1990; Beichner, 1994; Berg & Smith, 1994). Many of these tests are in multiple-choice format (Kerslake, 1977; McKenzie & Padilla, 1986; Beichner, 1994). One group uses interview techniques (McDermott *et al.*, 1987; Berg & Smith, 1994) and the other group uses the open-ended format (Adams & Shrum, 1990; Wavering, 1989).

Based upon recommendations from previous research, the Individualised Test of Graphs in Science (I-TOGS) and a Performance Assessment Test (PAT) were used to assess line-graphing skills of students. I-TOGS is an open-ended version of the Test of Graphing in Science (TOGS) developed by McKenzie and Padilla (1986). The TOGS instrument has a published reliability (KR-20) of 0.83. Adams and Shrum (1990) modified the TOGS to meet open-ended assessment standards and assess line-graphing skills of middle and high school students. The test comprises 26 items, and student scores for items in this instrument range from 0 to 26. The items test concepts of line graphing including construction and interpretation tasks. Content of the test includes a mixture of items from the physical and life sciences, but the test does not require that any particular science background be applied.

In order to measure student post line graphing skills and compare outcomes from the two treatments, a performance assessment instrument (PAT) was developed. On the research instrument students were told that a group of scientists gathered the data listed in the chart to examine a possible relationship between two variables. The data set was for an increasing exponential curve (x^2). Students were asked to help the researchers analyse the data collected by graphing and identifying a possible relationship, if a pattern exists, between the two variables. At the end of students' work, they were also asked to do the following: (1) in your own words, describe the relationship between the two variables; (2) determine the slope of most appropriate regression line, and (3) write a correct algebraic equation for the relationship between two variables. Wavering (1989) used a similar format of this performance instrument to assess graphing skills of students in grades six through twelve. Wavering reports a high published content validity and inter-rather reliability of the instrument. The responses of students were evaluated using an eighteen-category rubric developed by doing a task analysis of appropriate line graphing (i.e., no attempt to make a graph, ordering the data in columns, constructing the axes, and identifying units for both variables). Similar but less detailed rubrics have been used in other studies (McKenzie & Padilla, 1986; Wavering, 1989). Scores of students for this instrument range from 0 to 18 (Ates, 2001).

Formal reasoning skills (cognitive developmental level) of students were assessed using the Lawson Classroom Test of Scientific Reasoning (CTSR) (Lawson, 1978). The test has a published reliability (KR-20) of 0.78. The test includes 12 items requiring subjects to isolate and control variables and use proportional, probabilistic, and conservation reasoning. Subjects are instructed to respond by checking the answer they think is correct and explaining why that answer was chosen. Lawson (1992) argues that correct responses and explanations are awarded one point for a possible total of 12 points. Response scores of students for items in this instrument range from 0 to 12. Ranges used to classify the developmental levels of students are as follow: scores of 0–4 represent concrete, 5–8 represent transitional, and 9–12 represent formal reasoning.

Data Analysis and Results

Since intact classes participated in the study, there was a possibility that differences in student capabilities, pre-graphing skills, and characteristics could affect the variables under study. Pretest data were analysed to compare the equivalence of the two groups. Table 2 represents summary statistics of pretest mean scores. ANOVA techniques were used to determine if line-graphing and reasoning pretest scores, differed statistically between groups. Table 3 shows ANOVA results of line-graphing pretest and reasoning scores by treatment. Line-graphing pretest and reasoning scores were found to be statistically the same for the two treatment groups.

Treatment, scientific reasoning levels and treatment-scientific reasoning levels interaction effects were analysed using analysis of variance (ANOVA) techniques for both measures of graphing skills. Summary statistics for these analyses are found in Table 4, while analysis of variance results are shown in Table 5.

Difference due to the treatment were not statistically significant at the 0.05 alpha level.

TABLE II. Summary statistics of groups' pretest mean scores

Pretests	Treatments	N	M	SD
Line Graphing (I-TOGS)	T1	22	12.2	3.2
	T2	21	12.0	2.7
Formal Reasoning (TSR)	T1	22	5.0	1.7
	T2	21	5.1	2.7

Note. Two students from T2 missed pretests.

TABLE III. ANOVA Table of reasoning and pre-line-graphing scores by treatment

Source	F	P
Pre-line-graphing scores	0.1	0.76
Formal reasoning Scores	0.0	0.95

TABLE IV. Summary statistics for I-TOGS post-test and PAT mean scores by treatment

Source	Treatment	Reasoning Level	N	M	St Dev
I-TOGS post	T1	Concrete	9	15.2	4.2
		Transitional	11	16.6	2.7
		Formal	2	21.5	0.7
		Total	**22**	**16.46**	**3.64**
	T2	Concrete	9	14.8	4.2
		Transitional	9	16.2	3.1
		Formal	3	19.0	2.0
		Total	**21**	**16.00**	**3.65**
PAT	T1	Concrete	9	10.44	3.32
		Transitional	11	11.36	2.84
		Formal	2	14.50	2.12
		Total	**22**	**11.27**	**3.10**
	T2	Concrete	9	10.00	3.67
		Transitional	9	11.22	3.11
		Formal	3	15.00	1.00
		Total	**21**	**11.24**	**3.49**

TABLE V. ANOVA Table for I-TOGS Post-test and PAT Mean Scores

Test	Source	DF	F	P
I-TOGS post	Treatment	1	0.17	0.68
	Reasoning Level	2	4.43	0.02*
	Treatment*Reasoning Level	2	0.20	0.82
PAT	Treatment	1	0.00	0.97
	Reasoning Level	2	4.53	0.02*
	Treatment*Reasoning Level	2	0.04	0.96

Note. *$p < 0.05$

The effects of scientific reasoning levels on line-graphing skills of students were examined. It was determined that there was a significant difference in line-graphing post-test mean scores based upon scientific reasoning levels. In order to determine which set of reasoning level group means showed a significant difference for line-graphing post-test scores; a post hoc comparison test was performed using the Tukey method. The results are shown in Table 6.

Results indicate that there was a statistically significant difference between mean scores of concrete and formal reasoners. Significant main effect was not found between mean scores of transitional and formal reasoners. Also there was not a statistically significant

TABLE VI. Pairwise Comparison of I-TOGS Post-test Mean Scores by Reasoning Levels

Reasoning Levels	T	P
Concrete-Transitional	1.29	0.40
Concrete-Formal	2.96	0.01*
Transitional-Formal	2.15	0.09

Note. $^{*}p < 0.05$

difference between the mean scores of concrete and transitional reasoners. Interaction effects between treatment and reasoning levels of students for line-graphing post-test means scores were examined. No statistically significant interaction effects between treatment and cognitive development levels of students were found.

Discussion

Student line-graphing skills were measured by using both I-TOGS post-test and PAT scores. Overall, a review of results indicated that the main effects due to treatment were not significant. At the beginning of this study, it was intended to compare the effectiveness of two graphing modules and determine the effects of computer applications on teaching and learning of line graphs. One expectation was that students who received line-graphing instruction with computer-supported activities would outscore students who received instruction with non-computer-supported activities. Previous studies report that graph construction is tedious and involves drudgery and that students have serious difficulty with some graph construction processes. With the advent of new technology, computers can perform part of the construction actions, and students can examine many more graphs in a shorter period of time. This expectation was not confirmed.

One possible reason for the lack of significant differences in mean graphing scores is that even though a small difference in means scores can be attributed to treatments, both groups had significant gains on mean scores and both treatments were very effective ($\sim$35% gain in both groups). McKenzie and Padilla (1984) indicate that an instructional strategy consisting of activities resulted in higher levels of student engagement than an instructional strategy consisting only of written simulations in teaching and learning line graphs. Scientists also suggest that graph instruction should start with collecting real data and that all students should be led to construct graphs over extended periods of time and interpret the graphs using students' words (Arons, 1983; McKenzie & Padilla, 1984; Padilla *et al.*, 1986; Wavering, 1989). In this study both treatments included hands-on activities and were designed based upon an investigative approach to teaching and learning science. Students in both groups collected data in a real context, organized data in some fashion, and built a graph from data.

Another possible explanation as to why students who received line-graphing instruction with computer-supported activities could not outscore students who received instruction with non-computer-supported activities was the methodology and instrumentation used to assess the impact of computer applications on students' graphing skills. In this study the graphing skill of students was measured using two different instruments, I-TOGS and the Performance Assessment Test, both of which are open-ended items. Berg and Smith (1994) investigated effects of assessment instrumentation used to measure the effect of microcomputer-based laboratories (MBL) on graphing skills. The researcher found that there is as much as 19% difference in correct responses of students responding to multiple-choice and open-ended items. The authors suggest re-examination and determination of the impact of MBL on graphing skills by using open-ended test instruments.

Even though most recent studies have consistently shown improvements on graphing skills after experiencing MBL (Brasell, 1987; Linn *et al.*, 1987; Mokros & Tinker, 1987; Brasell & Rowe, 1993; Svec, 1995), few studies have attempted to determine the most effective way of teaching and learning graphs. Adams and Shrum (1990) investigated the effects of microcomputer-based laboratory exercises on the acquisition of line-graph construction and interpretation skills of high school students as measured by the I-TOGS. The authors found that a conventional group outperformed the microcomputer-based laboratory group on graph construction skills, while results for the main effect of the treatment were not significant for graph interpretation skills. McKenzie and Padilla (1984) studied the effects of three instructional strategies on the acquisition of skills necessary for line graphing. Three strategies examined were an activity-based approach, a written simulation-based approach, and a combination of activity and written simulation-based instruction. The researchers found no single instructional strategy to be superior to the others in regard to graphing achievement.

As predicted, formal reasoning students scored significantly higher than concrete reasoners. This result is consistent with previous studies (McKenzie & Padilla 1984; Padilla *et al.*, 1986; Wavering, 1989; Brasell & Rowe, 1993; Berg & Phillips, 1994; Adams & Shrum, 1990). As mentioned by Wavering, seriation becomes the proportional reasoning needed for scaling data on axes and that one-to-one correspondence leads into pattern recognition. Pattern recognition becomes the early correlational reasoning needed to recognise the relationship between variables. Wavering argues that a significant number of students, even at the twelfth grade, have not fully developed the concrete level mental structure needed for seriation, although line graphing requires seriation along two axes as well as the establishment of ratio scale on these axes.

Since previous studies show a strong relationship between graphing skills and logical thinking, it was intended to determine interactions between graphing modules and reasoning levels because such interactions could provide valuable information and instructional hints in teaching and learning line graphs for students having different development levels. This expectation was not confirmed. Findings in this study are consistent with other studies of graphing (McKenzie & Padilla, 1984; Adams & Shrum, 1990). In this study, results indicate significant gains for all group post-test mean scores.

Limitations

The limitations that affect the results of this study include the following: (1) One teacher and 45 students participated in the study. One teacher taught the instructional treatments to the groups. It would have been desirable to have 45 classes as compared to 45 students in the study. A sample size of 45 was small and limits generalizing of results. The number of students was a logistical maximum based upon availability of schools and students volunteering to participate in the study. (2) The number of formal reasoners in treatment groups was very small. The reader should exercise care in interpreting the results related to formal reasoners. (3) The computer technology used in this study is just one of many computer applications. The reader needs to be aware of this fact and avoid over-generalising from the study. Statements regarding the general effectiveness (or ineffectiveness) of computers to improve instruction should be guarded.

Recommendations

Implications for Future Research

This study contributes to the determination of effective ways of teaching and learning line graphs and the effects of computer applications on line-graphing skills of high school students having different reasoning levels. A limited number of teachers (one teacher) and students ($n = 45$) participated in this study. It would be beneficial to conduct additional studies using a larger number of teachers and students. Both treatments appeared very effective in this study. In future studies, researchers may want to use a control group rather than compare two effective treatments. In this study, one group used computers to gather and analyse data. The second group conducted almost identical laboratory experiences but used more traditional laboratory equipment. Since data gathering equipment (i.e., probes, sensors, and computer software technology) are changing very fast, it is financially very difficult for teachers to upgrade equipment. It will be beneficial to compare and test the effectiveness of another module that contains a combination of the first and second treatments. The third treatment can use traditional laboratory equipment to gather data and computer-graphing software to graph and analyse data.

Implications for Practice

Both instructional modules used in this are equally effective for teaching graphing skills to tenth grade students. Implementation of the modules is very easy and applicable for normal science laboratory situations. The teacher and student materials are based upon an investigative approach of teaching and learning. Both modules are very easy to modify to fit any science class. During the activities, students work in groups to complete line-graphing activities to collect, analyse, and graph scientific data, and answer questions about line-graphing skills. Teachers who wish to use these materials should begin implementing these activities at the beginning of a semester or course. Students master many required laboratory and scientific reasoning skills while studying line graphs, including observation, raising a research question, and designing and conducting an experiment.

In order to reduce hand-graphing drudgery and examine more graphs in the same period of time, the instructional module that includes line-graphing activities along with computer-supported activities would be the preferred choice. The module, line-graphing activities with computer-supported activities, allows and assists students to practise a greater number graph construction and interpretation skills. For teachers who do not have an opportunity to use computer technology in the classroom, line-graphing activities with non-computer-supported activities can be used effectively to teach line-graphing skills. A critical feature of effective instruction in line graphing appears to be the active involvement of students in gathering and analysing real data. The results of this study indicate that Cognitive developmental levels of students should be considered in planning, teaching and learning line-graphing skills. Teachers may expect students having formal reasoning skills to perform at a higher level than concrete reasoner students do.

Correspondence: Salih Ates, Department of Elementary Education, College of Education, Izzet Baysal University, 307 Golkoy-Bolu, Turket. E-mail: states0@yahoo.com

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