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ABSTRACT

Much of the focus in science education has been on the theoretical constructs and practical implications of conceptual change. History of science, cognitive theory, and alternative conceptions have been used as backdrops for the study of the child's conceptual movement away from naive beliefs about scientific phenomena. In this study, conceptual shifts were proposed as means of examining the process of conceptual change. The relationship of reasoning level, science process skills, gender, and instructional treatment to conceptual shifts in grade 10 biology students were compared. Student reasoning levels were evaluated using the Test of Logical Thinking (TOLT). The Test of Integrated Process Skills (TIPS) was used to measure the students' proficiency with science process skills. Five concept evaluation statements were used to determine the students' understandings of the concepts of diffusion, the cell, circulation, plant food production, and genetics. All instruments were used in a pretest/posttest format. Results indicated that instructional treatment was the only factor that significantly influenced positive shifts in student understanding of a concept. Gender was found to have a moderate influence in an honors class. Reasoning level and prior knowledge did not correlate positively with shifts in student understanding. (Author/CW)

An Analysis of the Relationships of Formal Reasoning, Science Process Skills, Gender, and Instructional Treatment to Conceptual Shifts in Tenth Grade Biology Students

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Abstract

Much of the recent focus in science education has been on the theoretical constructs and practical implications of conceptual change. History of science, cognitive theory, and alternative conceptions have been used as backdrops for the study of the child's conceptual movement away from naive beliefs about scientific phenomena. In the present study, conceptual shifts--any changes, positive or negative, in the way a child perceives a concept--are proposed as means of examining the process of conceptual change. Several factors were predicted to influence the quality and quantity of shifts in tenth grade biology students' understanding of the concept of diffusion. The effects of reasoning level, science process skills, gender, and instructional treatment on conceptual shifts in tenth grade biology students were evaluated.

The research utilized tenth grade biology students in a small midwestern city. Two teachers participated in the study. Each teacher employed a different instructional method; teacher LC used the learning cycle and teacher EX taught by exposition. Student reasoning levels were evaluated using the Test of Logical Thinking (TOLT). The Test of Integrated Process Skills (TIPS) was used to measure the students' proficiency with science process skills. A concept evaluation statement (CES) was administered in August, 1988 to determine the students' prior knowledge of the concept of diffusion. The CES was readministered in February, 1989 to assess changes in student understanding. A scoring scheme comprised of 11 ordinally arranged categories was used to quantify the shifts in student understanding.

Examination of the data using a General Linear Model for analysis of variance indicated that instructional treatment was the only factor that significantly influenced positive shifts in student understanding of the concept. A t test confirmed that the mean conceptual shift of the students in the learning cycle classes was significantly greater than that of the exposition students ($p=.002$). Multiple regression analysis revealed that TIPS, in combination with instructional treatment, explained a large portion of the variance. Gender was found to have a moderate influence in an honors class included in the learning cycle sample. Reasoning level and prior knowledge did not correlate positively with shifts in student understanding.

An Analysis of the Relationships of Formal Reasoning, Science Process Skills, Gender, and Instructional Treatment to Conceptual Shifts in Tenth Grade Biology Students

Introduction

Extensive efforts in science education research have recently been devoted to examination of the theoretical constructs and practical implications of conceptual change in children. Several authors have compared the evolution of children's ideas concerning scientific phenomena to the pattern of conceptual change in the history of science (Wandersee, 1986, and Wiser and Carey, 1983). Others have sought to understand these changes in light of cognitive theory (Carey, 1985; Hewson and Hewson, 1984; and Osborne and Wittrock, 1983). A third group has researched "errant", "alternative", "naive", or "mis-" conceptions to elucidate possible patterns in the formation of children's ideas about science concepts (Lawson and Thompson, 1988; Marek, 1986; Osborne, 1981; and Westbrook & Marek, in press).

Conceptual change implies that the child's perception of a scientific phenomenon has progressed in the direction of a scientifically accurate viewpoint. However, all movements in a child's understanding are not in a positive direction. Shifts away from the acceptable scientific explanation are also representative of a change in the way a child thinks about a scientific concept. In addition, small shifts in the quality of the student's understanding of a concept may appear unimportant when the students' understanding still falls far short of that of an expert. Examining conceptual <u>shifts</u>, i.e., any change in the way a child understands a concept, may provide information concerning patterns within a conceptual change framework.

Factors which have been linked to student understanding of science concepts would logically be expected to have an effect on conceptual shifts. Lawson and Thompson (1988) found reasoning level to be the most consistent predictor of student understanding of certain concepts related to genetics

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and natural selection. The effects of gender on student achievement have also been evaluated (for review, see Becker, 1989). A positive correlation between the student's prior knowledge and level of understanding after instruction has been reported by several authors (Glasson, 1989; Lawson, 1983; Lawson & Thompson, 1988). Other studies have indicated that inquiry-oriented, laboratory-centered pedagogy enhanced student understanding of science concepts (Glasson, 1989; Purser & Renner, 1983; and Schneider & Renner, 1980).

Evaluation of student understanding of diffusion, a concept common to physical science and biology curricula across secondary school grade levels, was selected as the focus of the present study. Previous _ex post facto_ evaluations (Haldar & Abraham, 1990; Simpson & Marek, 1988; and Westbrook & Marek, in press) involving the diffusion concept indicated student understanding to be independent of grade level, school size, or developmental level. The purpose of this research was to identify and analyze factors that influence shifts in tenth grade biology students' understandings of the concept of diffusion. The effects of reasoning level, ability to utilize science process skills, gender, and instructional treatment on the qualitative and quantitative nature of the students' conceptual shifts were analyzed.

Materials and Methods

The students used in this study were taken from five introductory tenth grade biology classes in a small midwestern city. Two classroom teachers participated in the research project. Teacher LC, a white female with seven years of teaching experience, had participated in an institute funded by the National Science Foundation at the University of Oklahoma Science Education Center in the summer of 1988. During the workshop, Piaget's cognitive and developmental theories were discussed and the teachers actively participated in the related pedagogy, i.e. the learning cycle (Marek & Westbrook, 1990). Teacher LC agreed to use the learning cycle curriculum for biology during the 1988-1989 school year. The researcher observed the teacher at intervals throughout the nine month period to insure that the teacher was implementing the curriculum and the method. The format of the learning cycle consisted of a student exploration to gather data concerning a science concept, a class discussion over the data to invent the concept, and an expansion of the concept through additional laboratory work and readings. The diffusion concept was taught in late September, 1988 in an investigation titled, "Function of Cell Organelles". The idea of diffusion of material across a membrane was explored through microscopic observations of the differential uptake of Lugol's iodine and black India ink by algal cells. That idea was expanded as the students investigated the movement of glucose down a concentration gradient established in a dialysis set-up. The dialysis investigation also provided the students with an opportunity to observe the uniform distribution of materials in the diffusion process.

Teacher EX, a white male with 18 years of classroom teaching experience, was selected on the basis of his responses to a survey administered to the workshop participants and their peer teachers prior to the 1988 summer institute (Bryant, Westbrook, & Marek, 1989). Teacher EX appeared to be a conscientious teacher committed to a text-based, expository pedagogy. Classroom observations were made by the researcher at intervals during the school year. The instructional routine consisted of a brief chapter overview by the teacher, text-related (Smallwood & Alexander, 1981) reading and writing exercises by the students, class discussion over the reading assignments and worksheets, a test review, and a chapter exam. Laboratory exercises were limited to dissections conducted during the second academic semester. The diffusion concept was introduced in late September, 1988 in a chapter titled, "Cellular Traffic." The students first read about the nature of a concentration gradient; a description of the diffusion of a drop of blue dye in a beaker of water was included in the text. A diagram of the diffusion of sugar molecules in a container of water was also provided. The textbook definition of diffusion was, "The process by which molecular collisions cause a substance to move down a concentration gradient" (Smallwood & Alexander, 1981, p. 92). A discussion of the movement of perfume molecules through the air was provided in the text as an additional example. Descriptions of the processes of osmosis, active transport, facilitated diffusion, endocytosis, and exocytosis followed.

The students of both teachers were evaluated using three instruments. The Test of Logical Thinking (Tobin & Caple, 1981) and the Test of

Integrated Process Skills (Dillashaw & Okey, 1980) were administered in late August, 1988. The 10 item multiple choice Test of Logical Thinking (TOLT) was used to ascertain the student's use of particular formal operational schemata, i.e. proportional reasoning, separation of variables, propositional logic, correlations, and combinatorial logic. Each formal operational scheme was examined by use of two items. Each item required the student to select a response and a reason. The TOLT data were analyzed under the assumption that a student who possessed a particular reasoning ability would correctly answer all four of the questions for the pair of related items. The correlation data reported for the TOLT test indicated that performance on the related pairs should be equivalent. The 36 item Test of Integrated Process Skills (TIPS I) examined the students' abilities to identify variables (12 items), identify and state hypotheses (9 items), assess operational definitions (6 items), design investigations (3 items), and graph and interpret data (6 items).

The students were also asked to respond to the following Concept Evaluation Statement (CES) concerning the concept of diffusion. The CES had been validated and used in previous research (Westbrook & Marek, in press):

> A ten gallon glass container setting on a table is full of clear water. Several drops of dark blue dye are dropped on the surface of the water. In a paragraph, explain what will happen to the dye. Be sure to write down any specific details about the process you describe. Name the process.

The CES was administered in a pretest-posttest format. The pretests were given in late August, 1988; posttesting occurred in early February, 1989. The posttests were given approximately 16 weeks after instruction of the concept was completed. A retention test was considered to be a more reliable indicator of student understanding than a test administered immediately after instruction. Student understanding of the concept was determined by using a revision of a Concept Evaluation Scheme (CESCH) suggested by Westbrook & Marek (in press). In this scheme the students responses were evaluated and categorized as indicating one of the following levels of understanding: complete understanding (CU), sound understanding

(SU), partial understanding (PU), partial understanding with misconception (PS), specific misconception (SM), and no understanding (NU).

In the present study the PU and PS categories were hierarchically arranged to ascertain minor shifts (positive or negative) in student understanding. A no response (NR) category was added to distinguish between NU and NR (Table 1). The final hierarchy of understanding was composed of 11 categories. This format provided a structure in which shifts in the understanding of the concept could be viewed. The ordinal arrangement of the categories allowed for the application of tests for statistical significance.

Results

Five classes of students, two from teacher EX and three from teacher LC, were tested. The sample for the study was limited to 28 males and 36 females who had completed the TOLT, TIPS, and CES pretest and posttest instruments. The average age of the 64 students in the sample in August, 1988 was 15 years 2 months. One of the classes of teacher LC was considered to be an honors class. Participation in this class was based on student volition rather than standardized test scores or grade point averages. Had this study been a comparison study between the EX and LC groups, the honors class would have been deleted from the sample. However, since the object of this study was to examine factors that effect shifts in student understanding of the diffusion concept, the honors group was included in the sample. Inclusion of the LCH group also enhanced the upper range of TOLT and TIPS scores available for analysis. Results are reported indicating the inclusion or exclusion of the honors class (LCH) data.

The summary of the pretest and posttest scores of all the students examined (Table 2) gave little insight into the changes in student understanding of the diffusion concept. A schematic portrayal of the data (see Figure 1), however, indicated that only seven (11 %) of the students maintained their initial level of understanding of the concept. Thirty-nine (61%) of the students increased their understanding. Eighteen students (28%) exhibited a negative shift in understanding.

The results of a General Linear Model for analysis of variance for the effect of TOLT pairs correct, TIPS total score, gender, and instructional treatment on the shifts in student understanding appear in Table 3. Instructional treatment was the only factor evaluated that significantly influenced the conceptual shifts in the students' understanding. A summary of the students' scores for the TOLT (Table 4) however, indicates that the student scores were not of a suitable range for an extensive analysis of the effect of concrete and formal reasoning on conceptual shifts.

The shifts in understanding for the LC, EX, and LCH groups are diagrammed in Figure 2. A Ryan-Einot-Gabriel-Welsch Multiple Range Test revealed that the mean shifts for LCH (x=2.56) and LC (x=1.10) were significantly different (p=.05) from the mean shift for EX (x=-1.31). A _t_ test for the maximum shifts of the LC and EX groups (LCH excluded) indicated that the variances were significant (p=.002).

The students in the learning cycle classes were also more likely to use terminology associated with the diffusion concept. Twenty-five (66%) of the students in the LC and LCH classes correctly labeled the process as diffusion on the CES posttest. Only three (12%) of the students in the EX class could identified the process. Errant terms (i.e. fusion, chemical breakdown, transfusion) used by the EX students were not related to the process of diffusion or to related concepts. The LC and LCH students who incorrectly labeled the process used terms from the related concepts they had studied (i.e. active transport and osmosis). Only one student (4%) from the EX classes discussed the movement of the dye down a concentration gradient. Twenty three (61%) of the 38 students in learning cycle classes referred to the movement of the dye from a higher concentration to a lower concentration. Few students in any class (LCH, n = 5 ; LC, n = 2; EX, n = 1) used the term "molecule" in their response to the diffusion CES.

A summary of TOLT pairs correct, TIPS total score, and mean shift in understanding from the pretest to the posttest with respect to group and gender occurs in Table 5. The greatest mean shifts in understanding occurred among the males in the LC classes (x=2.4) and the females in the LCH class (x=3.2).

Student performance on the posttest did not correlate with the pretest scores. The Pearson correlation coefficient for the combined sample was

.19. The correlations between the pretest and posttest scores for the LCH, LC, and EX groups were r=.49, r=.25, and r=.19, respectively.

Combined Effects.

Multiple regression analyses (see Table 7) were used to determine the combinations of effects that best explained the conceptual shifts among the students sampled. Several methods were used in the analyses in order to ascertain the importance of the total TIPS and TOLT scores as well as the individual process skills and schemata. In the first method, the total TIPS score and instructional treatment accounted for 24% of the variance when LCH was excluded and 37% of the variance when LCH was included. The TIPS total score was also included in the best model in the third method. Identifying and stating hypotheses was the individual process skill that most influenced shifts in student understanding. The TOLT total score did not combine with any other factors to effect the shifts in understanding, but the individual schemata of proportional reasoning, combinatorial logic, and correlations did influence shifts in understanding. Gender appeared only in the regression profiles that included the LCH group.

Discussion

Regardless of the analysis used, instructional treatment proved to be the best predictor of positive shifts in student understanding of the concept of diffusion. These data confirm the findings of a similar study by Cowan (1989) which reported that students involved in a learning cycle class exhibited greater understanding of the diffusion concept than those in a traditional, exposition classroom. High TIPS scores, in combination with instructional treatment, correlated with greater shifts in student understanding. Identifying and stating hypotheses appeared to be the process skill most associated with greater shifts in understanding. Gender appeared in the best regression models when the LCH group was included in the data pool. That influence may have resulted from the fact that some of the greatest positive shifts in understanding (eg. from NU to SU) were made by the LCH females. Previous gender-related studies have indicated that females are generally motivated to be high achievers in science classes, but that their male counterparts actually do better in the classroom. In this case, the highly motivated females were in an environment that encouraged the use of social and communication skills. The combination of motivation and environment may have had a positive influence on the achievement of the females in the LCH class. These results may warrant future gender-related studies with students in learning cycle classrooms.

Other studies have shown prior knowledge (Glasson, 1989) and developmental level (Lawson & Thompson, 1988) to be important factors in student attainment of an understanding of scientific concepts. Prior knowledge did not correlate with positive shifts in student understanding in this study. Certain aspects of formal reasoning, i.e. proportional reasoning, combinational logic, and correlations, were found to be influential when in concert with other factors. Analysis of the relationship between reasoning ability and student understanding was limited by the few students who correctly answered four or five pairs of items on the TOLT. A previous cross-age study by Westbrook and Marek (in press) indicated that neither repeated exposure to the diffusion concept across grades nor developmental (reasoning) level influenced student understanding of the concept.

The impact of instructional treatment on student understanding of the diffusion concept should not be perplexing. The students in the exposition-oriented classes read three paragraphs about diffusion, answered questions in the text about the concept, and then read about related concepts (mass flow, osmosis, and active transport). The examples given in the Smallwood and Alexander textbook were very similar to the scenario in the CES. The students read about dye dropped into a beaker and about sugar diffusing in a container of water. The students in the learning cycle classes conducted investigations in which they observed the differential passage of materials into a cell, the movement of glucose down a concentration gradient, and the uniform distribution of diffusing substances. The time spent investigating and discussing diffusion and the related concepts was much greater in the learning cycle classes than in the exposition classes. The products of the two forms of instruction are clearly illustrated in Figure 2. Although the exposition group began with the greatest percentage (61.5%) of students exhibiting some understanding of the concept, Table 6 shows that 65.4% (n=17) of the EX student responses on the posttest reflected some misconception (PS or SM). Eleven of those 17 students received scores of SM, NU, or NR, which indicated no correct information concerning diffusion was given in response to the posttest CES. The intervention of instruction and time apparently undermined the understanding the EX students exhibited on the pretest. Conversely, 50% (n=19) of the learning cycle students exhibited misconceptions prior to instruction while only 36% (n=14) of the student responses indicated misconceptions on the posttest. Only one of those students gave a response that was scored as SM; none of the LC students received scores of NU or NR on the posttest.

Although the description of diffusion in the Smallwood and Alexander text immediately preceded a discussion of osmosis and active transport, none of the students in the EX class identified the process in the CES as being osmosis or active transport. Four students in the learning cycle classes identified the process as osmosis, two called it active transport, and one described the scenario as a concentration gradient. This confusion could be considered detrimental, but the students who errantly labeled the process had related the diffusion CES scenario to the content of the classroom investigations. The students were not able to distinguish the movement of water across a membrane from the movement of the dye in water. This confusion between the diffusion of dye in water and osmosis was also reported by Westbrook and Marek (in press) in an unrelated study. Restructuring the curriculum to separate instruction about the concepts of diffusion and osmosis could serve to alleviate the confusion.

Why was student understanding of the concept of diffusion so effected by instructional treatment and yet resistant to factors such as prior knowledge and reasoning ability which have been identified as predictors of student understanding of other concepts (Lawson, 1983; Lawson and Thompson, 1988; Glasson, 1989; Westbrook, 1987)? The issue becomes more paradoxical when one considers the ubiquitous nature of a student's real world contacts with the concept. Haldar and Abraham (1990) have proposed that the student's inability to conceptualize the particulate nature of matter prevents development of a complete understanding of concepts like diffusion. The student observes and offers explanations for diffusion-related events at a macroscopic level, but cannot identify or explain the microscopic, particulate nature of the phenomena. The data reported from this study would support that perspective. Only eight of the 64 students examined referred to the molecular nature of the process in response to the diffusion CES. The fact that one LC student referred to "cells" in the water and others alluded to the presence of "semi-permeable water molecules" and "membranes of water" indicated that some students could recall the language of the concept but were limited by misconceptions about the particulate, or microscopic, nature of the materials. Most of the students who displayed a minimal understanding of the concept responded to the CES by predicting that the dye would spread out and turn all the water blue. That explanation parallels the observable, macroscopic aspects of the diffusion process. The students in the LCH and LC classes took the explanation one step further and identified the presence of a concentration gradient. The students in the learning cycle classes had collected data and had observed the movement of glucose down a concentration gradient. Hence, that aspect of the process was part of their own experience. None of the students mentioned the movement of the dye due to random collisions with other dye and water molecules. Obviously no student had observed those collisions. The student's understanding of the concept was limited to the extent of direct experience with the concept. That raises a question concerning the depth and degree of understanding a teacher can reasonably expect from students at this grade level.

Review of the study indicated certain limitations that serve as suggestions for future research. First, the small sample sizes precluded strong inferential statements about the effect of any of the variables on conceptual shifts. The small sample could also be considered a strength. Analysis of the responses of a few students allows the researcher to project and then investigate relationships at a more descriptive level. The results of analyzing individual shifts in student understanding and identifying the changes that occurred produced a markedly different result than had the scores simply been averaged and the significance of the variances assessed. Little difference in the number of student responses relegated to the general categories of understanding (CU, SU, PU, PS, SM, NU) existed between the pretests and posttests. However, an analysis of the minor shifts in understanding provided a rich portrait of the differences in understanding that existed between students in the exposition classes and those in the learning cycle classes. A summary analysis would have also washed out the numerous negative shifts that occurred after instruction. These shifts are of importance because they indicate misconceptions that the students developed during the course of instruction.

Second, if the TOLT and TIPS instruments had been readministered in February, 1989, a relationship between conceptual shifts and changes in reasoning ability and use of process skills could have been more thoroughly investigated. The TOLT and TIPS were posttested in late May, 1989. Those scores were not reported in this presentation as they were not considered to be valid indicators of the students' abilities in February. In any school-related research the investigator must serve the goals of the study project while considering the integrity of the classroom environment. In this case, the researcher decided against an additional two day disruption to the participating teachers' classrooms.

Third, the CES did not require the students to apply the diffusion concept to related material. A knowledge of the concept of diffusion is of limited value to a high school student, but is prerequisite to an understanding of the transport of materials into and out of the cell. Piaget's model of knowledge construction suggests the existence of a significant relationship between reasoning ability and the degree to which the student can conceptualize connections among related concepts (Piaget, 1979). An expansion of the present study to include analysis of student understanding of, and application to, related concepts appears warranted.

The ultimate products of concept research in science education should be improved science curriculum and effective classroom pedagogy. An understanding of the way students think about science concepts and the factors that effect their thinking will aid in attaining those goals. Science educators have been tentative about prescribing one pedagogy over another. If the goal of instruction is to enhance understanding as well as encourage rational and scientific process skills, it would appear reasonable to utilize a method consistent with those goals. Only two of the students in this study successfully completed either four or five of the pairs of questions on the TOLT test. Most of the students exhibited little capacity for utilizing formal reasoning strategies. These data echo the results of other studies which have shown that tenth grade students generally do not possess formal operational reasoning abilities (Purser and Renner,1983; Renner, et al., 1978). Few tenth grade students are capable of assimilating observable, concrete concepts by exposition; their ability to accommodate to formal (abstract) concepts through reading and lecture is highly unlikely (Purser and Renner, 1983). In addition, a study by Renner, et al. (1978) reported small increases in intellectual development among tenth grade students. These students are struggling with the physiological, social, and emotional burdens of adolescence. A classroom environment in which the developmental and social needs of the students are met is crucial. Current textbook-oriented curricula in biology require students to assimilate a great deal of information through the abstract modes of reading and lecture. The learning cycle provides a pedagogical structure in which concrete concepts can be taught in a developmentally appropriate manner. The students are encouraged to participate in physical interactions with concept-related materials as well as in social interactions with their peers. The current problem in the science education community does not appear to be a matter of lack of information concerning the development of student understanding of scientific concepts. Rather, the issue could be that probable solutions that do not coincide with the traditional instructional paradigms are not embraced by the classroom teachers.

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Table 1

Criteria for Scoring Student Responses to the Diffusion CES

Score	Criteria
CU	The student response parallels a theoretical, scientific view of the concept. The response must include all of the following: The random movement of the molecules of the blue dye from areas of high concentration to areas of low concentration. This random movement results in the blue dye molecules being evenly distributed throughout the water. The process is known as diffusion.
SU	The student response is complete, but not molecular in nature. The response is concrete rather than theoretical. For example, "The dye will randomly move from the place where there is more dye to a place where there is less dye until all the water is blue. This is called diffusion." No attempt is made to identify the molecular interactions and none of the information contained in the response is inaccurate.
PU1	The student response conveys a partial understanding of the concept at either a theoretical or concrete level. No incorrect information occurs in the response. The response must include three of the following used correctly: diffusion, movement from high concentration of dye to low concentration of dye, solution turns blue, dye spreads out evenly over the solution, random movement as cause of dye dispersal.
PU2	The student response conveys a partial understanding of the concept at either a theoretical or concrete level. No incorrect information occurs in the response. The response must include two of the items listed for PU1.
PU3	The student response conveys a partial understanding of the concept at either a theoretical or concrete level. No incorrect information occurs in the response. The response must include one of the items listed for PU1.
P1S	The student response conveys a partial understanding of the concept, but contains incorrect information as well. The response must include three of the items listed in PU1 above.
P2S	The student response conveys a partial understanding of the concept, but contains incorrect information as well. The response must include two of the items listed in PU1 above.
P3S	The student response conveys a partial understanding of the concept, but contains incorrect information as well. The response must include one of the items listed in PU1 above.
SM	The student response conveys a misconception or errant understanding of the concept. No correct information occurs in the response. Examples include incorrect use of terms such as osmosis, concentration gradient, and semi-permeable membrane; dye disappears; atoms attaching, breaking, clinging, combining, or disappearing; dye or molecules or particles of dye floating, becoming lighter, disappearing; dye or molecules or particles of dye clinging to side of the container.
NU	The student response indicates that the student had no understanding of the concept. Responses include "I don't know", nonsensical answers, a repeat of the question, and no answer.
NR	No response, page blank.

Table 2

Summary of Pretest and Posttest Scores on the Diffusion CES for All Students

	CU	SU	PU1	PU2	PU3	P1S	P2S	P3S	SM	NU	NR
Pretest	0	0	0	15	20	0	2	17	4	5	1
Posttest	1	4	10	15	3	0	8	11	8	1	3

Table 3

General Linear Model (GLM) Results of Effect of TIP, TOLT, Treatment, and Gender on the Conceptual Shifts of All Students

Source	DF	Type III SS	F value	PR > F
TIP total	1	6.49	0.98	.330
TOLT pairs	1	7.07	1.07	.310
Instructional Treatment	2	94.11	7.12	.002
Gender	1	4.45	0.67	.420
Gender with Instructional Treatment	2	27.55	2.08	.130

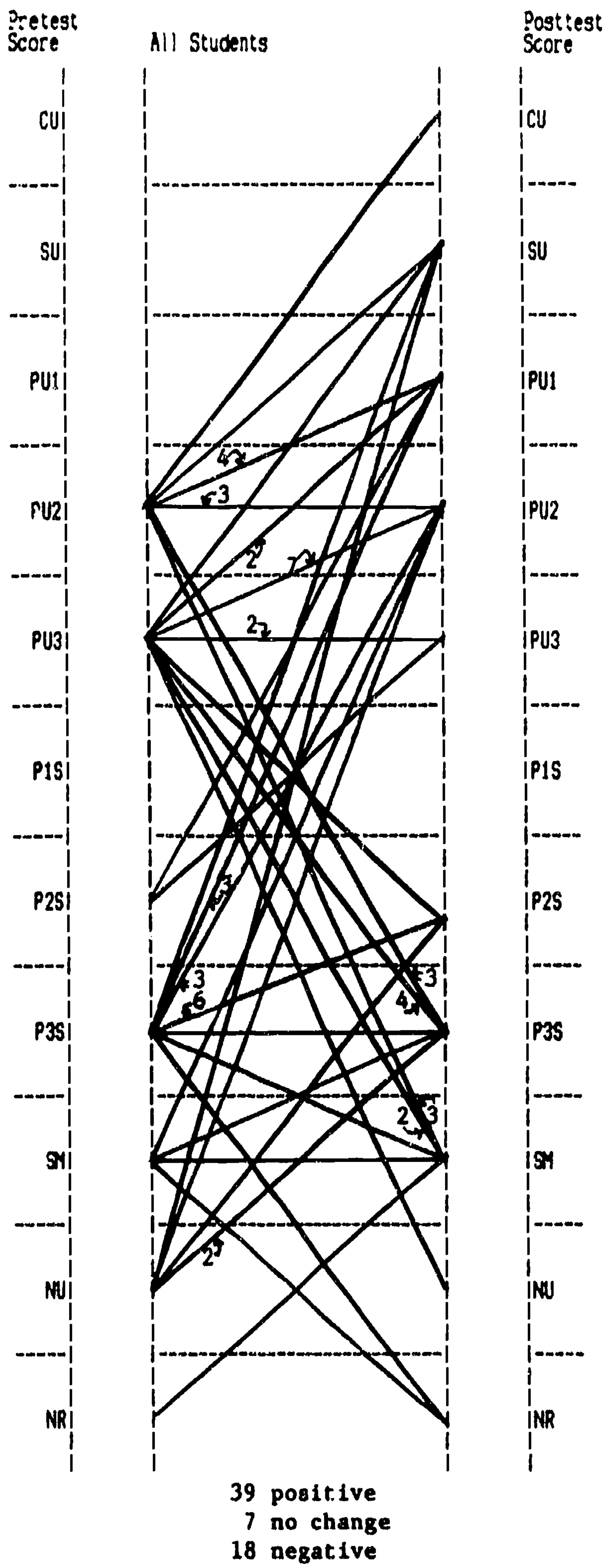

Figure 1. Shifts in understanding of the diffusion concept from pretest to posttest of all students in the study.

Table 4

Frequency of TOLT Pairs Correct and TIPS Total Scores for the Learning Cycle Honors (LCH), Learning Cycle (LC), and Exposition (EX) Classes.

Number correct	LCH	LC	EX	TOTAL
TOLT Pairs				
0 of 5	5	8	17	30
1 of 5	6	6	2	14
2 of 5	4	5	3	12
3 of 5	2	1	3	6
4 of 5	0	0	1	1
5 of 5	1	0	0	1
total	18	20	26	64
TIPS				
0 to 8	0	0	1	1
9 to 17	1	13	14	28
18 to 23	11	7	9	27
24 to 29	4	0	2	6
30 to 36	2	0	0	2
total	18	20	26	64

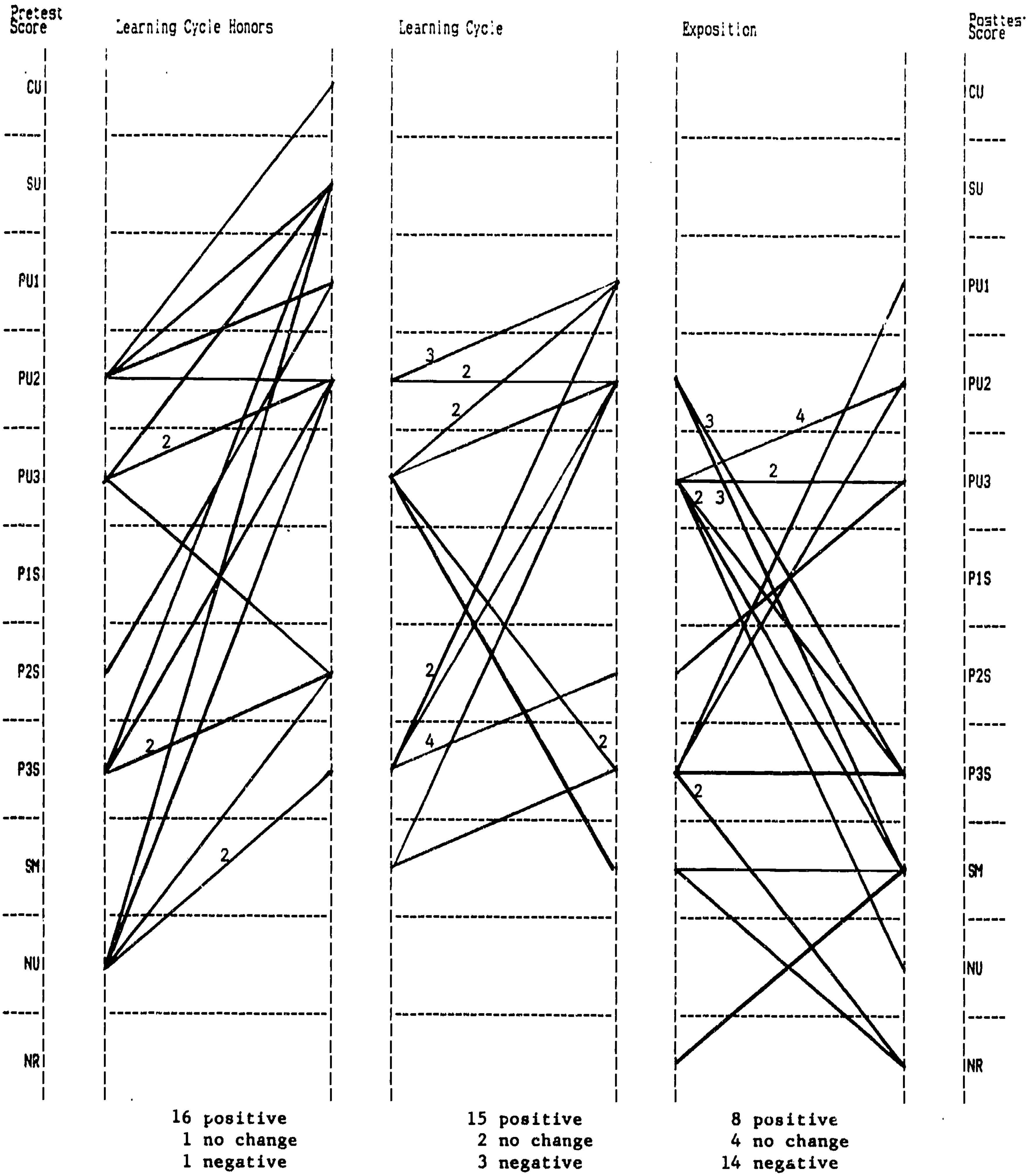

Figure 2. Shifts in student understanding for learning cycle honors (LCH), learning cycle (LC), and exposition (EX) classes.

Table 5

Summary of Means for Conceptual Shifts, TIPS (I) Scores, and TOLT Pairs Correct by Gender and Groups

Gender	n	Shift	TIPS (I)	TOLT
		($\bar{x}$)	($\bar{x}$)	($\bar{x}$)
Male				
LCH	9	1.89	25.11	1.44
LC	5	2.40	18.00	0.80
EX	14	-1.86	16.86	1.29
Combined Total	28	0.11	19.71	1.25
Female				
LCH	9	3.22	22.33	1.33
LC	15	0.67	15.47	1.00
EX	12	-0.67	15.83	0.25
Combined Total	36	0.86	17.31	0.83

Table 6

Frequencies of Student Scores on Diffusion CES Pretest and Posttest for the Learning Cycle Honors (LCH), Learning Cycle (LC), and Exposition (EX) Groups

	Pretest				Posttest			
	LCH	LC	EX	Combined Total	LCH	LC	EX	Combined Total
CU	0	0	0	0	1	0	0	1
SU	0	0	0	0	4	0	0	4
PU1	0	0	0	0	2	7	1	10
PU2	4	5	6	15	5	5	5	15
PU3	4	6	10	20	0	0	3	3
P1S	0	0	0	0	0	0	0	0
P2S	1	0	1	2	4	4	0	8
P3S	4	7	6	17	2	3	6	11
SM	0	2	2	4	0	1	7	8
NU	5	0	0	5	0	0	1	1
NR	0	0	1	1	0	0	3	3
Total	18	20	26	64	18	20	26	64

Table 7

Summary of Regression Analyses Showing the Percent of Variance (R**2) Explained by the Best Models

	EX, LC		EX, LC, LCH	
Method	Model	% Variance	Model	% Variance
TOLT Correct, Gender, TIPS Total, Instructional Treatment	TIPS, Instr. Treatment	24	TIPS, Gender, Instr. Treatment	40
	Instr. Treatment	17	TIPS Instr. Treatment	37
			Instr. Treatment	27
TOLT Schemata, TIPS Skills, Instructional Treatment	Instr. Treatment, Proportional Reas., Correlation, Indentifying and Stating Hypotheses	30	Instr. Treatment, Indentifying Stating Hypotheses, Proportional Reas.	40
TOLT Schemata, TIPS Total, Instructional Treatment	TIPS, Proportional Reas. Correlation Instr. Treatment	32	TIPS, Combinations, Gender, Instr. Treatment	44