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ABSTRACT

This study investigated the retention of meaningful understanding of the biological topics of meiosis, the Punnett square method and the relations between these two topics. This study also explored the predictive influence of students' general tendency to learn meaningfully or by rote (meaningful learning orientation), prior knowledge of meiosis, instructional treatment (students told relations between concepts, students asked to construct relations themselves) and all interactions of these variables on the retention of meaningful understanding of the topics. A 50-item Likert instrument taken by the students and teacher ratings of their students' approach to learning (meaningful, rote) were used in combination as a measure of students' meaningful learning orientation. The mental model technique was used to assess students' meaningful-level and rote-level understandings of the topics. Students were given a pre-test mental model on meiosis (prior knowledge variable) and were randomly assigned to the two instructional treatments. Results of correlations indicated that students' attainment of meaningful understanding as measured immediately after instruction was significantly and positively related with their retention of meaningful understanding. Stepwise multiple regressions revealed that students' retention of meaningful understanding of meiosis was predicted by student's meaningful learning orientation and prior knowledge of meiosis. The interactions of meiosis and meaningful learning orientation best predicted both student' retention of meiosis and the conceptual relation between the topics. None of the predictor variables (prior knowledge, meaningful learning orientation, and treatment) nor the interaction terms predicted students' retention of meaningful understanding of the Punnett square method. (Author/PR)

THE RETENTION OF MEANINGFUL UNDERSTANDING OF MEIOSIS AND GENETICS

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THE RETENTION OF MEANINGFUL UNDERSTANDING OF MEIOSIS AND GENETICS

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ABSTRACT

This study investigated the retention of meaningful understanding of the biological topics of meiosis, the Punnett square method and the relations between these two topics. This study also explored the predictive influence of students' general tendency to learn meaningfully or by rote (meaningful learning orientation), prior knowledge of meiosis, instructional treatment (students told relations between concepts, students asked to construct relations themselves) and all interactions of these variables on the retention of meaningful understanding of the topics. A 50-item Likert instrument taken by the students and teacher ratings of their students' approach to learning (meaningful, rote) were used in combination as a measure of students' meaningful learning orientation. The mental model technique (Cavallo, 1991; Mosenthal & Kirsch, 1991) was used to assess students' meaningful-level and rote-level understandings of the topics. Students were given a pre-test mental model on meiosis (prior knowledge variable) and were randomly assigned to the two instructional treatments. Immediately following the instructional treatments, students were given a mental model test on meiosis, the Punnett square method and on the procedural and conceptual relations between these two topics. After four weeks, the students were again given the mental model tests. Results of correlations indicated

that students' attainment of meaningful understanding as measured immediately after instruction was significantly and positively related with their retention of meaningful understanding. Stepwise multiple regressions revealed that students' retention of meaningful understanding of meiosis was predicted by students' meaningful learning orientation and prior knowledge of meiosis. Students' meaningful retention of the conceptual and procedural relations between the two topics was best predicted only by their prior knowledge of meiosis. The interaction of meiosis and meaningful learning orientation best predicted both students' retention of meiosis and the conceptual relation between the topics. None of the predictor variables (prior knowledge, meaningful learning orientation, treatment) nor the interaction terms predicted students' retention of meaningful understanding of the Punnett square method.

The Retention of Meaningful Understanding of Meiosis and Genetics

INTRODUCTION

A valued outcome of student learning in science is the formulation of sound conceptual knowledge about the world and the way it works. To accomplish this goal, learning science should involve the construction of knowledge and allow students to create new ideas from what is already known. Learning should not only be concerned with knowing information about science, but should involve the formulation of relations among the conceptual and theoretical knowledge of science (Driver & Erickson, 1983). Ausubel (1963, 1968) describes the formulation of relationships between theoretical concepts in making sense of the world as "meaningful learning."

Meaningful learning is a constructive process in which the learner strives to build an understanding of the information and observations which make up the "body of knowledge" of science (Pines & West, 1986). In meaningful learning, new concepts are most often "subsumed" by existing concepts and organized in a hierarchical framework (Ausubel, 1963). The hierarchical relationships individuals make between concepts often result in the formulation of sound understandings and enable learners to apply meaningfully learned concepts to new situations or problems (Ausubel, Novak, & Hanesian, 1978). Furthermore, students that learn concepts meaningfully are thought to retain their network of understanding over a period of time (Bodolus, 1986; Cliburn, 1988; Pankratius, 1987).

In contrast with meaningful learning is rote learning, in which new knowledge may be attained by verbatim memorization and incorporated into a person's knowledge structure without connecting it to information or frameworks previously acquired (Ausubel, 1963; Baird, 1986; Novak, 1988). Concepts learned by rote are not "subsumed" and do not fit within one's conceptual structure in any sensible way. Thus, a conceptual framework of understanding is not developed and therefore does not serve as the basis for new understanding. Since rote learners are said to formulate weak cognitive frameworks or none at all, they are thought not to retain information learned over time (Novak, 1988).

The meaningful and/or rote learning of meiosis and the relationship of meiosis with genetics has warranted particular interest in science education (Browning, 1988; Cho, Kahle & Nordland, 1985; Kinnear, 1983; Stewart, 1982,1983; Stewart & Dale, 1989). Research in this area has shown that students are able to use Punnett square diagrams to solve genetics problems successfully, but with little or no understanding of how the use of this tool relates with meiosis and fertilization of gametes (Cho, Kahle, & Nordland, 1985; Kinnear, 1983; Stewart, 1982, 1983). One important indication of the prior research was that some students do tend to learn meiosis and the Punnett square method by forming relationships between concepts, but others tend to learn these concepts by rote (Stewart & Dale, 1989).

Previous reports of the current study explored factors which may help explain why some students attain meaningful understandings of these biological concepts whereas others attain only rote-level understandings (Cavallo, 1991; Cavallo & Schafer, in preparation). The earlier study used a technique called "mental modeling" (Mosenthal & Kirsch, 1991; Mosenthal & Kirsch, in press) to measure students' rote-level and meaningful-level understandings of meiosis, the Punnett square method and the relationship between these topics (see Cavallo, 1991). The major findings were that students generally tended to learn concepts meaningfully or by rote (meaningful learning orientation) (Donn, 1989; Entwistle & Ramsden, 1983), and this tendency was positively related with the level of meaningful understanding they attained (Cavallo, 1991). Prior knowledge of meiosis was also found to be related with students' attainment of meaningful understanding of meiosis and of genetics topics (Cavallo, 1991), which was similar to findings of a study by Stewart and Dale (1989). Two instructional treatments, one based on Ausubel's (1963) reception learning model (students told relationships between meiosis and genetics concepts) and one based on Osborne & Wittrock's (1985) generative learning model (students asked to construct relationships themselves), were found not to be significant factors in students' attainment of meaningful understanding (Cavallo, 1991).

The current research is an extension of the previous research by Cavallo (1991) and primarily focussed on exploring the extent to which students retained meaningful understandings of meiosis, the use of the Punnett square method in genetics, and the procedural and conceptual relations between these topics over time. This research also investigated factors (meaningful learning orientation, prior knowledge, instructional treatment) which may be related with the retention of meaningful understanding of these biological concepts. The purposes of this study were as follows:

1. To determine the relationship between the level of meaningful understanding acquired immediately after instruction and the level of meaningful understanding retained after four weeks on the biological topics of meiosis, the Punnett square method and the relations between these topics.

2. To explore the relationship of students' meaningful learning orientation, prior knowledge of meiosis, and instructional treatment (students told relationships, students asked to construct relationships themselves) with retention of meaningful understanding of meiosis, the Punnett square method and the relations between these topics.

3. To investigate the relative predictive influence of students' meaningful learning orientation, prior knowledge, instructional treatment and all interactions of these variables on students' retention of meaningful understanding of meiosis, the Punnett square method and the relationship between these topics.

METHODOLOGY

Assessment of Meaningful Understanding

The mental model technique (Kirsch & Mosenthal, in press; Mosenthal & Kirsch, 1991; Mosenthal & Kirsch, in press) was used to measure students' meaningful understandings of the three biology topics. The mental model assessment is an open-ended question assessment designed to reveal in detail, students' understandings of any given topic. The mental model assessment technique requires that students provide a comprehensive written description of their understanding of a particular topic. The knowledge that students express is parsed into individual, information-bearing propositions, which are then mapped on a template or grid designed to represent the nature of their understanding. The result of the mental model procedure is a qualitative description and quantitative measure of learners' meaningful or rote understandings of any given topic.

In this study, the understandings assessed were of meiosis, the Punnett square method, and of the procedural and conceptual relations between these two topics. The procedural relations are indicated by students' understanding of how meiosis and Punnett squares "work" together. For example, an understanding of the procedural relations would be evident in students' explanations of how meiosis works (i.e., there are two cell divisions, in the first phase chromosomes replicate, etc.) in relationship with how the Punnett square method is used (i.e., write the genes from the sperm cell on one side of the diagram, etc.). An understanding of the conceptual relations would be represented by students' explanations of connections between what is involved in meiosis (i.e., genes of chromosomes in gametes) and why meiosis occurs (i.e., number of chromosomes and associated genes reduced to haploid number in preparation for fertilization) and its relationship with what is represented by using Punnett squares (i.e., genes of gametes from meiosis are used in Punnett squares to show fertilization) and why Punnett square diagrams are used (i.e., to predict possible genes for certain traits in offspring). The criteria for measuring the conceptual relations between meiosis and the Punnett square method were based on research by Cho, Kahle and Nordland (1985).

Instrumentation and Procedures

This study was carried out in tenth grade biology classrooms (N=140) during regular instructional periods. Students were given the Learning Approach Questionnaire (LAQ), a 50-item Likert-scale instrument for measuring students' tendency to learn meaningfully or by rote (Donn,1989; Edmonson, 1989; Entwistle & Ramsden, 1983; Novak, Kerr, Donn, & Cobern, 1989). In addition, the four teachers of the students in the sample were asked to rate their students on a scale ranging from meaningful to rote according to specific criteria described during a series of training sessions by the researcher (Cavallo, 1991). Based on a composite (meaningful learning orientation score) of the self-reported LAQ scores and teacher ratings, the students were identified as either meaningful, mid-range, or rote with respect to the way they learn.

Students were given a mental model pre-test to assess their prior knowledge of meiosis. Meiosis was used since it was considered an important underlying topic for the meaningful understanding of genetics topics in research by Stewart and Dale (1989). Students had been given instruction on meiosis prior to the study by their respective teachers but they had not been instructed on genetics nor on the use of Punnett square diagrams. Students were also given mental model pre-tests on the Punnett square method and the relationship between meiosis and the Punnett square method. As expected, students had no prior knowledge of either of these topics.

Students were randomly assigned to one of two auto-tutorial printed instructional treatments. In both treatments, the presentation of meiosis, fertilization, the inheritance of traits and the Punnett square method were identical. One treatment (reception treatment) provided information, then highlighted, and answered and explained questions specifically relating meiosis and the use of the Punnett square method. In Treatment 2 (generative treatment), the same information and highlighted questions were provided but the students were to construct the answers and explanations relating the topics themselves. The instruction used in this study was patterned after computer-assisted instruction developed by Browning (1988).

After the administration of the instructional treatments, students were given the same three-question mental model test as was given in the pre-test (meiosis, the Punnett square method, the relations between the topics). Four weeks later, the students were again given the mental model test on these topics.

RESULTS

Students' pre-test, post-test and retention mental model tests were scored using the parsing method described by Mosenthal & Kirsch, (1990) and detailed in a previous study (Cavallo, 1991). Pre-test mental model scores were obtained for meiosis and these scores were used as the prior knowledge variable. Post-test and retention mental model scores were obtained from students' explanations of: 1) meiosis, 2) the use of the Punnett square method, 3) the procedural relations between meiosis and Punnett squares, 4) the conceptual relations between meiosis and Punnett squares.[1] Results of the data analyses are reported as follows.

[1] The third mental model test question asked students to describe the relationship between meiosis and the use of the Punnett square method. Students' explanations on this question were scored in two ways. One score represented their understanding of the procedural relations, the second score represented their understanding of the conceptual relations.

<u>The relationship between students' meaningful understandings of meiosis, the Punnett square method and the relations between these topics after instruction and their retention of meaningful understanding four weeks after instruction</u>

Students' mental model post-test scores obtained immediately after the instruction were correlated with retention mental model test scores taken four weeks later. The results of the correlations are presented in Table 1.

TABLE 1. CORRELATION MATRIX OF STUDENTS' POST-INSTRUCTION TEST SCORES AND RETENTION TEST SCORES.

	RETENTION TEST SCORES			
	MEIOSIS	PUNNETT SQUARES	PROCEDURAL RELATION	CONCEPTUAL RELATION
POST-TEST SCORES				
MEIOSIS	.50**	.27**	.19	.33**
PUNNETT SQUARES	.44**	.42**	.33**	.37**
PROCEDURAL RELATION	.32**	.29**	.43**	.50**
CONCEPTUAL RELATION	.30**	.28**	.38**	.47**

* $p < .05$, ** $p <$ 01.

As observed from the correlation matrix shown in Table 1, the attainment of meaningful understanding of each of the topics is significantly and positively correlated with students' retention of meaningful understanding of the same topic. Thus if students attained a meaningful understanding as measured immediately after instruction they likely retained a meaningful understanding of that same topic four weeks later. Additionally, with the exception of meiosis and the procedural relation between meiosis and Punnett squares, students' meaningful understanding each topic is correlated with retention of any of the other topics. In other words, if students tended to attain a meaningful understanding of a topic (i.e., meiosis) they also tended to retain meaningful understanding of any of the other topics (i.e., Punnett squares). The meaningful attainment-meaningful retention relationship is consistent across the different topics.

The relative importance of meaningful learning orientation, prior knowledge and treatment on students' attainment of meaningful understanding

Correlations and stepwise multiple regression analyses were conducted to determine the best predictor (prior knowledge of meiosis, meaningful learning orientation and treatment) of students' retention of meaningful understanding of meiosis, the Punnett square method and the relations between these topics. The results of the correlations are reported in Table 2. Results of the stepwise regression analyses are summarized in Table 3.

TABLE 2. CORRELATIONS OF STUDENTS' MEANINGFUL LEARNING ORIENTATION, PRIOR KNOWLEDGE AND TREATMENT WITH RETENTION TEST SCORES.

	RETENTION TEST SCORES			
	MEIOSIS	PUNNETT SQUARES	PROCEDURAL RELATION	CONCEPTUAL RELATION
MEANINGFUL LEARNING ORIENTATION	.25*	.03	.01	.06
PRIOR KNOWLEDGE (MEIOSIS)	.30**	.09	.25*	.21*
TREATMENT	.04	.11	-.10	-.06

* $p < .05$, ** $p < .01$.

TABLE 3. STEPWISE MULTIPLE REGRESSIONS ON STUDENTS' MEANINGFUL RETENTION OF MEIOSIS, THE PUNNETT SQUARE METHOD AND THE PROCEDURAL AND CONCEPTUAL RELATIONS, WITH STUDENTS' MEANINGFUL LEARNING ORIENTATION, PRIOR KNOWLEDGE AND TREATMENT AS PREDICTOR VARIABLES.

RETENTION TEST	PREDICTOR VARIABLES (SIGNIFICANT $p<.05$)	VARIANCE	F	p
MEIOSIS	PRIOR KNOWLEDGE	.09	8.38	.005
	MEANINGFUL LEARNING ORIENTATION	.04	4.50	.037
PUNNETT SQUARES	NONE OF THESE VARIABLES WERE SIGNIFICANT PREDICTORS			
PROCEDURAL RELATION	PRIOR KNOWLEDGE	.06	5.80	.0181
CONCEPTUAL RELATION	PRIOR KNOWLEDGE	.04	4.03	.0478

The correlation and regression analyses indicate that meaningful learning orientation was an important factor only for students' meaningful retention of meiosis. Prior knowledge of meiosis was a significant factor in predicting students' retention of meiosis and the procedural and conceptual relations between the topics. None of the predictor variables seemed to influence students' retention of meaningful understanding of Punnett square diagrams.

The influence of all interactions of prior knowledge, meaningful learning orientation and instructional treatment as predictors of students' retention of meaningful understanding of meiosis, the Punnett square method in genetics and the relations between these topics

Interaction terms were created by multiplying the predictor variables (prior knowledge, meaningful learning orientation, treatment) in every way possible. The interaction terms included the following: 1) prior knowledge x meaningful learning orientation, 2) prior knowledge x treatment, 3) meaningful learning orientation x treatment, and 4) prior knowledge x meaningful learning orientation x treatment. These four interaction terms were correlated with retention test scores, and entered as predictor variables of retention scores in stepwise multiple regression analyses. Table 4 shows correlations between the interaction terms and retention scores for meiosis, Punnett squares and the procedural and conceptual relations between the topics. Table 5 summarizes the results of stepwise multiple regressions analyses with the interaction terms used as predictor variables of retention test scores.

TABLE 4. CORRELATIONS OF STUDENTS' PRIOR KNOWLEDGE, MEANINGFUL LEARNING ORIENTATION AND TREATMENT INTERACTION TERMS WITH RETENTION TEST SCORES.

	RETENTION TEST SCORES			
	MEIOSIS	PUNNETT SQUARES	PROCEDURAL RELATION	CONCEPTUAL RELATION
PRIOR KNOWLEDGE X MEANINGFUL LEARNING ORIENTATION	.38**	.09	.20	.21*
PRIOR KNOWLEDGE X TREATMENT	.21	.08	.07	-.04
MEANINGFUL LEARNING ORIENTATION X TREATMENT	.13	.14	-.07	-.04
PRIOR KNOWLEDGE X MEANINGFUL LEARNING ORIENTATION X TREATMENT	.26*	.11	.08	-.02

* $p < .05$, ** $p < .01$.

TABLE 5. STEPWISE MULTIPLE REGRESSIONS ON STUDENTS' MEANINGFUL RETENTION TEST SCORES OF MEIOSIS, THE PUNNETT SQUARE METHOD AND THE PROCEDURAL AND CONCEPTUAL RELATIONS, WITH ALL POSSIBLE INTERACTIONS BETWEEN STUDENTS' MEANINGFUL LEARNING ORIENTATION, PRIOR KNOWLEDGE AND TREATMENT AS PREDICTOR VARIABLES.

RETENTION TEST	PREDICTOR VARIABLES (SIGNIFICANT $p < .05$)	VARIANCE	F	p
MEIOSIS	MEANINGFUL LEARNING ORIENTATION X PRIOR KNOWLEDGE	.14	14.25	.0003
PUNNETT SQUARES	NONE OF THESE VARIABLES WERE SIGNIFICANT PREDICTORS			
PROCEDURAL RELATION	NONE OF THESE VARIABLES WERE SIGNIFICANT PREDICTORS			
CONCEPTUAL RELATION	MEANINGFUL LEARNING ORIENTATION X PRIOR KNOWLEDGE	.04	4.09	.0462

The stepwise multiple regression analyses using the interaction terms as predictor variables revealed that the interaction between prior knowledge of meiosis and meaningful learning orientation explained the variance in retention test scores for meiosis and the conceptual relation between the two topics. The regression lines for meiosis and conceptual relation test scores were calculated and plotted in Figures 1 and 2.

Figure 1. Regression lines for retention test scores of meiosis by prior knowledge for meaningful learners, mid-range learners, and rote learners. This graph represents the interaction of students' meaningful learning orientation and prior knowledge in predicting means of retention mental model scores of meiosis.

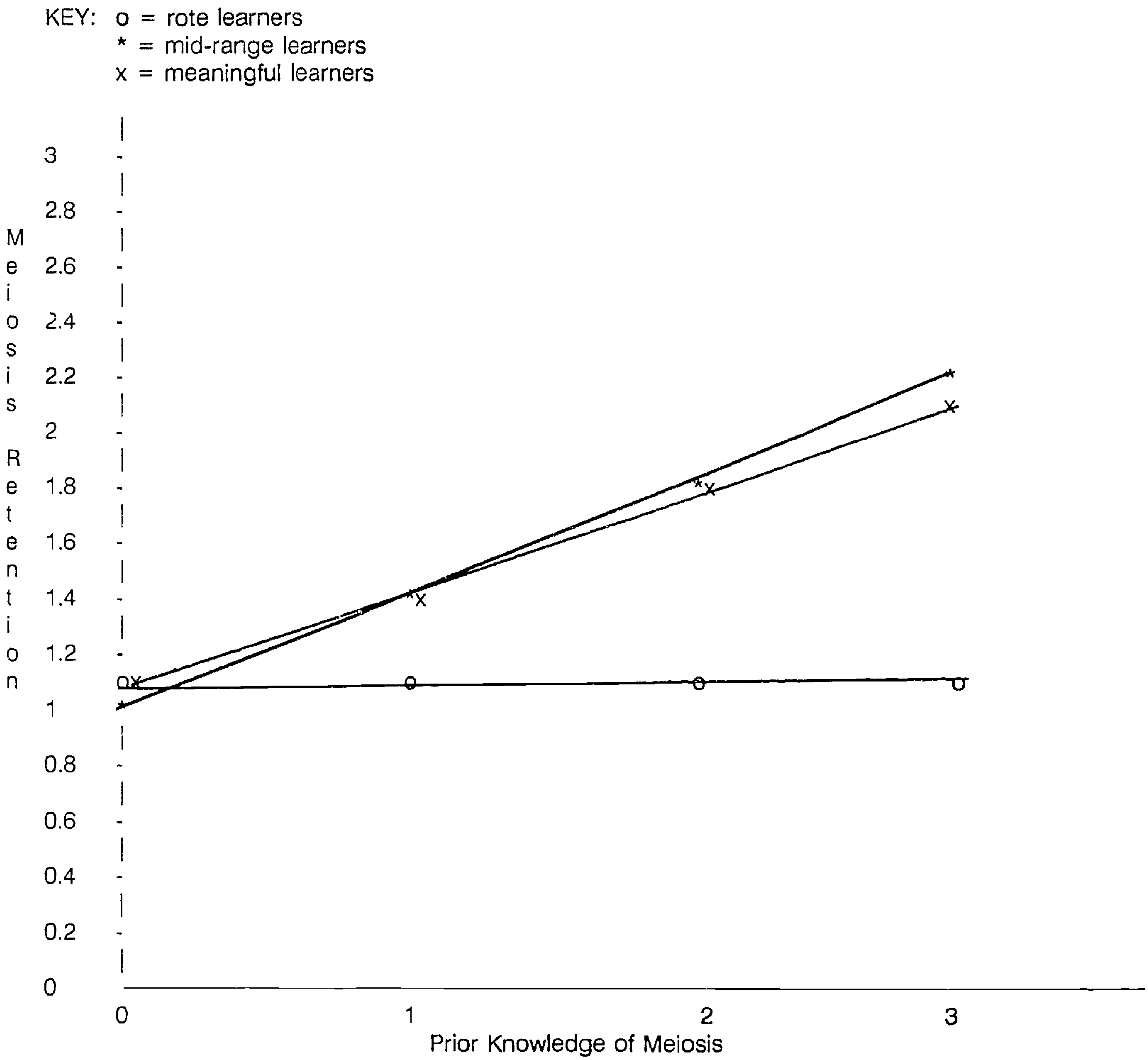
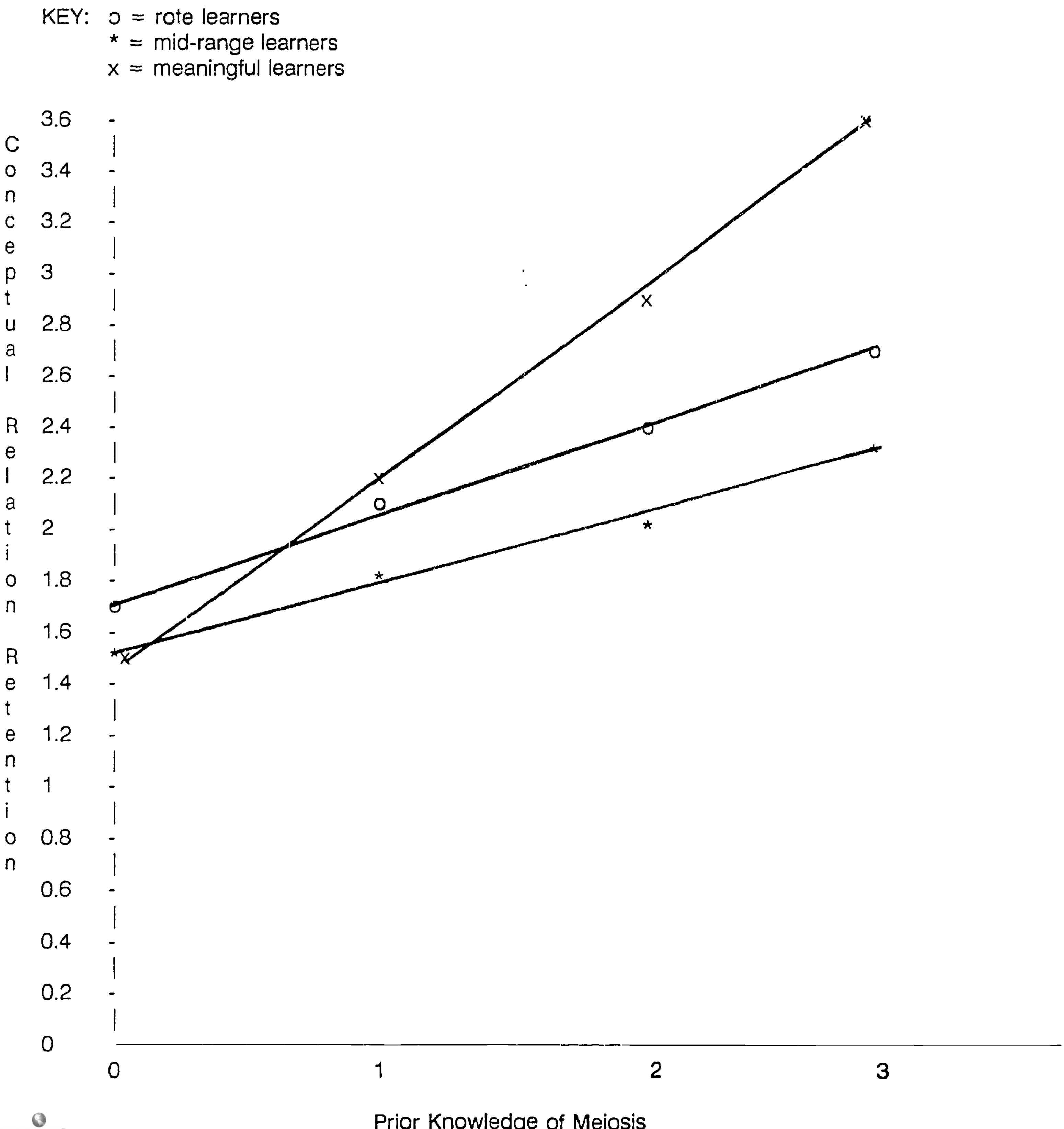


Figure 2. Regression lines for the conceptual relation between meiosis and Punnett squares retention test by prior knowledge for meaningful learners, mid-range learners, and rote learners. This graph represents the interaction of students' meaningful learning orientation and prior knowledge in predicting means of retention mental model scores of the conceptual relation.



The slopes of the regression lines for meiosis retention indicate that meaningful, mid-range and rote learners appeared to have approximately equivalent retention of meiosis with low prior knowledge. With high prior knowledge however, meaningful and mid-range learners seem to have retained more meaningful understandings than rote learners.

The slopes of the regression lines for the conceptual relation indicate that, as with meiosis, all three learner groups retained about the same level of understanding of the conceptual relation with low prior knowledge. With high prior knowledge, meaningful learners retained more meaningful understandings than mid-range or rote learners.

DISCUSSION

The results of this study generally revealed that if students meaningfully understood meiosis, the Punnett square method and the relations between these topics after initial instruction, meaningful understanding was likely to be retained after a period of time. Conversely, if students attained rote knowledge of these topics after initial instruction, they were likely to have retained only rote-level knowledge of these topics after the four weeks. In other words, students with rote knowledge were not likely to have developed meaningful understandings of these topics over time. Furthermore, with the exception of meiosis and the procedural relation between the two topics, students' attainment of meaningful understanding of one topic was positively related with their retention of the other topics. This finding seems to indicate a pattern of attainment and subsequent retention of rote, mid-range and meaningful understandings of different topics among students. More research would be needed to clarify this relationship and the possible existence of learning patterns among students.

The results of this study also indicate that prior meaningful understanding of meiosis was important for the meaningful retention of meiosis, and of the relationships between meiosis and the use of Punnett square diagrams in genetics. In addition to prior knowledge, a meaningful learning orientation was also important for the retention of meaningful understanding of meiosis. This finding implies that retaining meaningful understanding of a topic such as meiosis, which is not directly experienced or observable, may require more than prior knowledge. Meaningful retention of meiosis, and possibly similarly abstract or intangible topics, may also require a tendency to actively create meaning from those prior understandings.

It was interesting to find that none of the predictor variables predicted the retention of understanding of Punnett square diagrams. This may be a reflection of the nature of the topic as a tool, or perhaps algorithm, to solve problems. It may not be conceptually related with other topics by students, thus meaningful learning orientation and prior knowledge would have little to do with retention of the topic. Alternatively, this finding may indicate that there may be other variables, such as logical thinking ability, which have a role in the retention of the Punnett square method. Other variables such as logical thinking ability should be researched to determine a possible influence on the retention of problem solving-oriented topics such as the Punnett square method.

The interaction between meaningful learning orientation and prior knowledge significantly predicted students' retention of meaningful understanding of meiosis and the conceptual relations between meiosis and the Punnett square method. From the correlations and regression lines it appeared that both meaningful and mid-range learners retained more meaningful understandings of meiosis with high prior knowledge than did rote learners. Meaningful prior understanding of meiosis may have helped meaningful and mid-range learners retain meaningful understandings of meiosis. However, meaningful prior understanding of meiosis did not seem to be a factor in the meaningful retention of meiosis among rote learners. It is also apparent from the regressions lines that with low prior knowledge, retention of meiosis is about equal for all three learner groups.

High prior knowledge seemed to be important for the meaningful retention of the conceptual relations between meiosis and the Punnett square method for all three learner groups. However, meaningful learners with high prior knowledge of meiosis seem to have retained greater, more meaningful understandings of the conceptual relations between meiosis and Punnett squares than rote or mid-range learners. For all three learner groups, retention of the conceptual relations appears to have been approximately equal with low prior knowledge. These findings indicate that prior meaningful understanding of meiosis may serve as an "anchor" for formulating conceptual relationships with new information on the Punnett square method (i.e., that the letters used represent genes on chromosomes, that "filling in" the boxes represents fertilization, that the genes used on the outside of the boxes represent genes of the sperm and egg cell, and that the chromosomes with genes within the sperm and egg cell are there as a result of meiosis). If meaningful learners, who tend to actively make connections and formulate relationships between ideas, have high prior knowledge of an underlying topic, conceptual relations between the topics may be particularly meaningfully retained. Thus, the tendency to actively formulate relationships between ideas, along with a sound foundation of relevant prior knowledge appears to be important for retaining inter-related, meaningful understandings of the conceptual relations between these topics in biology.

IMPLICATIONS AND SIGNIFICANCE

This study advances current understanding of students' attainment and retention of sound, inter-related understandings of science topics. Importantly, this research provides information on students' retention of meaningful understanding, and on variables which may relate with retention, particularly, relevant prior knowledge and students' meaningful learning orientation. With information obtained from this research, educators may be better prepared to help students achieve and retain meaningful understandings of science. Finally, the results of this study provide a foundation for future inquiry and research on student learning and retention.

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