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ABSTRACT

An investigation was designed to reveal, describe, and assess the rote-level and meaningful-level understandings students attained as they progressed through the learning of new concepts. This study used an assessment technique used in previous research called "mental modeling" to ascertain the nature (meaningful, rote) of the understandings 163 10th grade students acquired. This research also explored factors that may be related to students' acquisition of conceptually inter-related, meaningful understandings, specifically: (1) aptitude, (2) need for achievement, (3) meaningful learning orientation, and (4) gender. The goal of this research was to attain a better understanding of how students may formulate inter-related, meaningful understandings of science concepts. Analysis of the data from the Differential Aptitude Test and need for achievement questionnaire indicated significant gender differences between males and females. Male students scored higher than female students. Meaningful learning orientation was not significantly different between males and females. (PR)

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STUDENTS' MEANINGFUL UNDERSTANDING OF SCIENCE CONCEPTS: GENDER DIFFERENCES

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ABSTRACT

The purpose of this investigation was to reveal, describe, and assess the rote-level and meaningful-level understandings students attained as they progressed through the learning of new concepts. This study used an assessment technique used in previous research (Cavallo, 1991; Mosenthal & Kirsch, 1991) called "mental modeling" to ascertain the nature (meaningful, rote) of the understandings students acquired. This research also explored factors which may be related with students' acquisition of conceptually inter-related, meaningful understandings, specifically: 1) aptitude, 2) need for achievement, 3) meaningful learning orientation, and 4) gender. The goal of this research was to attain a better understanding of how students may formulate inter-related, meaningful understandings of science concepts.

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INTRODUCTION

A major concern in science education is students' acquisition of inter-related, meaningful understandings of science (Ausubel, 1963, 1968; Novak, 1988; Novak & Gowin, 1984). The meaningful understandings students acquire must be adequately measured however, in order to better discern the inter-relationships they have formulated of science. One recurring problem in education is that students' understandings may not be fully detected using traditional testing procedures since many students are able to obtain correct answers on tests with only rote knowledge of the subject matter (Ridley & Novak, 1983). It is important therefore to assess students in ways that fully reveal and measure their meaningful understandings. Novak & Gowin (1984) state that "educators need to find appropriate strategies for both teaching and assessment which identify the relevant concepts a learner has" (p. 8). One such assessment technique described in current reports and used in recent research is called "mental modeling" (Cavallo, 1991; Kirsch & Mosenthal, in press; Mosenthal & Kirsch, 1991; Mosenthal & Kirsch, in press).

The mental model technique reveals students' understandings and provides both a qualitative description and quantitative measure of those understandings (Cavallo, 1991). Furthermore, the mental model technique may be used to discern rote-level to meaningful-level understandings students possess of both conceptually-based and procedurally-based topics in science (Cavallo, 1991; Mosenthal & Kirsch, 1991; Mosenthal & Kirsch, in press).

In a previous study (Cavallo, 1991) students' meaningful understandings of meiosis, the use of the Punnett square method in genetics, and the relationship between these topics was assessed using the mental model technique. This research found that students' rote-level or meaningful-level understandings of the different biological topics were consistent across the different topics (Cavallo, 1991). In essence, if a student understood meiosis by rote, they also tended to understand the Punnett square method by rote and the relationship between topics by rote. Similar consistencies were found across the topics for students who had attained a meaningful understanding of meiosis (Cavallo, 1991). This same study (Cavallo, 1991) also explored factors which were thought to be related with students acquisition of meaningful understanding, particularly aptitude, meaningful learning orientation, and need for achievement. An important finding of this earlier study (Cavallo, 1991) was that students' meaningful learning orientation was important to their attainment of meaningful understanding.

Similar to the previous study, this research will seek to determine possible relationships of students' meaningful learning orientation with their attainment of meaningful understandings. Unique to this study will be an investigation of how these factors may be differentially related to males and females acquisition of meaningful understanding.

The purpose of this study is:

1. To determine if there are differences between males and females on variables which may be associated with science achievement: aptitude, need for achievement (achievement motivation), and meaningful learning orientation.
2. To investigate possible differences between males and females in science achievement as measured by a state biology examination with a a traditional (i.e. multiple choice questions) format.
3. To explore possible differences in achievement between males and females on open-ended (mental model) tests designed to assess meaningful understanding of biology topics: meiosis, the Punnett square method, and the procedural and conceptual relations between meiosis and the Punnett square method.
4. To find if variables which may be related with achievement (aptitude, need fo achievement, meaningful learning orientation) are differentially related to meaningful understanding of the biology topics (meiosis, the Punnett square method, and the relations) and to achievement on the state biology examination for males and females.

METHODOLOGY

SAMPLE

The sample consisted of 163 tenth grade students (average age 15.5 years) attending a suburban high school in central New York state. The students were enrolled in Regents Biology (a college preparatory course) in seven classes taught by four different teachers. Due to absenteeism, 140 students (70 males, 70 females) were used in the analyses for this study. The ethnic background of the sample was 139 Caucasian and 1 Asian-American.

PROCEDURES

The study involved seven major procedures:

1. Meaningful learning orientations of the students were identified using a composite score from student self-reports on the Learning Approach Questionnaire (LAQ) (Donn, 1989; Entwhistle & Ramsden, 1983) and from teacher ratings of their students' learning approach (Robertson, 1984).

2. Student aptitude scores were acquired from the Differential Aptitude Test (DAT) from the school guidance office.

3. An achievement motivation questionnaire was administered to the students (Dweck, 1986; Ames & Archer, 1988).

4. Using open-ended mental model assessments, prior knowledge of meiosis, the Punnett square method, and procedural and conceptual relations was tested. No differences in prior knowledge of meiosis were found. No prior knowledge of the Punnett square method nor of the relation of between meiosis and the Punnett square method was evident.

5. Students were given instruction on meiosis by their classroom teachers. Type-written auto-tutorial instructional packets were administered to students. These packets reviewed meiosis, introduced the Punnett square method, and detailed the relation between meiosis and the Punnett square method.

6. After the instruction, mental model tests were used to assess students' meaningful understanding of meiosis, the Punnett square method, and the procedural and conceptual relations between meiosis and the Punnett square method.

7. Achievement scores on the state biology examination were acquired from the classroom teachers.

SUMMARY OF RESULTS

Differences between males and females on measures of aptitude, need for achievement, and meaningful learning orientation.

Results of t-Tests for aptitude and need for achievement are shown in Tables 1 and 2. Results of a Chi-square analysis for meaningful learning orientation are shown in Table 3.

TABLE 1 t-Test for Differential Aptitude Test Scores for Males and Females (N=140)

	MEAN	SD	t	p
MALES (n=70)	78.18	9.77	3.78	0.0002
FEMALES (n=70)	70.60	13.64		

TABLE 2 t-Test for Need for Achievement Scores for Males and Females (N=137)

	MEAN	SD	t	p
MALES (n=68)	118.28	14.39	2.23	0.0273
FEMALES (n=69)	112.41	16.36		

TABLE 3

Chi-Square Analysis of Students' Rating of Meaningful Learning Orientation (Combined Score of Teachers' Rating and Students' Rating)

	1	2	3	4
FEMALES	19	19	20	12
MALES	9	26	20	15

$X^2 = 4.994$, $p = 0.172$

1 = Rote Learner

2 = Less Rote Learner

3 = Less Meaningful Learner

4 = Meaningful Learner

Analyses of the data from the Differential Aptitude Test and need for achievement questionnaire indicated significant gender differences between males and females. Male students scored higher for achievement than females. Meaningful learning orientation was not significantly different between males and females.

Differences between males and females on the standardized State Biology test.

Results of the t-Test for the State Biology Achievement test are shown in Table 4.

TABLE 4 t-Test for State Biology Achievement Test for Males and Females (N=136)

	MEAN	SD	t	p
MALES (n=66)	77.56	12.46	2.06	0.0411
FEMALES (n=70)	72.94	13.66		

As indicated by the table, males scored significantly higher than females on the state exam.

Differences between males and females in meaningful understanding of meiosis, the Punnett square method, and the procedural and conceptual relations between the topics.

Results of Chi-square analyses for meiosis, the Punnett square method, and the procedural relation of the topics are shown in Tables 5, 6, and 7. T-test results for the conceptual relation between the topics is shown in Table 8.

TABLE 5 Chi-Square Analysis of Meaningful Understanding of Meiosis by Gender

	0	1	2	3
FEMALES	7	23	29	11
MALES	6	24	22	18

$X^2 = 2.749$, $p = 0.432$

0 = No Understanding

1 = Rote Understanding

2 = Intermediate Understanding

3 = Meaningful Understanding

TABLE 6

Chi-Square Analysis of Meaningful Understanding of Punnett Squares by Gender

	0	1	2	3
FEMALES	13	28	17	12
MALES	19	14	19	18

$X^2 = 7.103$, $p = 0.069$

0 = No Understanding

1 = Rote Understanding

2 = Intermediate Understanding

3 = Meaningful Understanding

TABLE 7 Chi-Square Analysis of Meaningful Understanding of the Procedural Relation Between Meiosis and Punnett Squares by Gender

	0	1	2	3
FEMALES	21	36	1	12
MALES	25	38	1	6

$X^2 = 2.402$, $p = 0.493$

0 = No Understanding

1 = Rote Understanding

2 = Intermediate Understanding

3 = Meaningful Understanding

TABLE 8 t-Test for Conceptual Relation of Meiosis and Punnett Squares by Gender (N=140)

	MEAN	SD	t	p
MALES (n=70)	2.24	3.07	0.75	0.4573
FEMALES (n=70)	1.86	3.06		

0 — No Understanding

1 ------------------------ 10

Rote Understanding — Meaningful Understanding

No significant differences were found between males and females on the mental model tests of meaningful understanding.

Relationships between variables of achievement, tests of meaningful understanding and the State Biology Achievement test for males and females.

Correlations for the topics are found in Tables 9 and 10.

TABLE 9 Correlation of the Relationship between Variables of Achievement, Tests of Meaningful Understanding and State Biology Achievement Test

(FEMALES)

	Achievement Variables		
	DAT^	Need for Achievement	Meaningful Learning Orientation
Mental Model Tests			
Meiosis	0.38**	0.19	0.36**
Punnett Squares	0.36**	0.24*	0.44**
Procedural Relation of Meiosis/ Punnett Squares	0.33**	0.09	0.35*
Conceptual Relation of Meiosis/ Punnett Squares	0.45**	0.26*	0.33*
State Biology Achievement Exam	0.52**	0.51**	0.48**

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

^ Differential Aptitude Test

TABLE 10 Correlation of the Relationship between Variables of Achievement, Tests of Meaningful Understanding and State Biology Achievement Test

(MALES)

	Achievement Variables		
	DAT^	Need for Achievement	Meaningful Learning Orientation
Mental Model Tests			
Meiosis	0.32**	0.01	0.20
Punnett Squares	0.27*	0.24	0.18
Procedural Relation of Meiosis/ Punnett Squares	0.14	0.09	0.14
Conceptual Relation of Meiosis/ Punnett Squares	0.37**	0.09	0.20
State Biology Achievement Exam	0.46**	0.15	0.38*

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

^ Differential Aptitude Test

For females, aptitude and meaningful learning orientation were highly correlated with meaningful understanding (mental model test scores) as well as with achievement on the state exam. Need for achievement was highly correlated with females' meaningful understanding of Punnett squares and the conceptual relation between meiosis and the Punnett squares. Need for achievement was also highly correlated with females' achievement on the state exam.

For males, need for achievement was not significantly correlated with any of the mental model tests nor with achievement on the state test. Meaningful learning orientation was correlated only to their achievement on the state exam. Only the Differential Aptitude Test was highly correlated to the mental model tests and the state test.

DISCUSSION

Consistent with past research, males scored higher than females on tests of general aptitude as well as on a state-administered standardized examination. Males also seemed to have a greater desire or motivation to receive favorable judgements for their works (i.e., high grades) than females. Nonetheless, this need to achieve among males did not relate with their actual achievement on the state exam nor on the tests of meaningful understanding. Conversely, though females had a lower need to achieve favorable judgements for their work than males, females' need to achieve was positively related to their achievement on the Punnett square method and the conceptual relation of meiosis and the Punnett square method.

There were no significant differences between males and females in terms of their meaningful learning orientation (meaningful, rote). Thus females did not tend to learn by rote or meaningfully any more than males. This result was reinforced by finding that there were no differences between the genders on their attainment of meaningful understanding (mental model scores) for any of the genetics topics.

Males outperformed females on standardized tests, but this was not the case for performance on open-ended tests used to measure meaningful understandings. Perhaps when students are allowed to express their understandings in a non-restrictive manner, opportunity for success among females is increased and gender differences in achievement are diminished. More research would be needed to explore achievement of females and males on different kinds of tests.

Finally, aptitude generally seemed important for achievement on the tests of meaningful understanding and on the state exam for both males and females. Among females only, the tendency to actively formulate relationships and derive meaning from the information (Meaningful learning orientation) was also important for their achievement on these tests. Thus, meaningful learning orientation seemed important for females' attainment of meaningful understanding and achievement on the state exam. This finding implies that educators should work toward developing a more meaningful learning approach among females in order that they may achieve and form more sound inter-related understandings of science.

Implications for Future Research

Future research could find if the same pattern found in this study exist between males and females on other science topics. Research could also focus efforts on helping students, particularly females, learn to formulate relations between ideas learned in science and become more meaningful in their approach to learning (Novak & Gowin, 1984). The development of a meaningful learning orientation could then be explored in terms of possible improvements in females' understandings of science.

Finally, other variables not researched in this study, such as experience or problem solving abilities, may be differentially related to males' and females' achievement and should be explored in future investigations.

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