Piagetian Theory of Cognitive Development and the High School Biology Student's Understanding of Basic Genetic Concepts

An Honors Thesis (HONRS 499)

by

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A twenty item (ten pairs of items seeking similar data) survey was conducted to explore the question, "Can tenth-grade introductory biology students learn genetics concepts?" The survey was sent to a sample of biology teachers. The results and conclusions are based on the analysis of the data received from these teachers.

This manuscript includes an introduction to Piaget and his theories, a literature review, discussion of methods (using a survey to gain information), and conclusions and recommendations.

The conclusions made were that tenth grade biology students are capable of learning genetics concepts when taught with consideration to their cognitive thought levels (a la Piaget). For students in the concrete stage of thought the ideas must be taught using familiar objects and ideas. The students in the formal operational thought stage will be able to grasp these concepts easily while the concrete thinkers will be moving on to formal thought.
ACKNOWLEDGEMENTS

Writing my senior honors thesis has been a significant experience in my undergraduate college education.

Working with Dr. Jon R. Hendrix, a skillful, proficient, qualified professional, has made this undertaking absorbing. Dr. Hendrix’s willingness to share his knowledge and mastery in the field of genetics has been continuous and unchanging. My sincere appreciation goes to Dr. Hendrix.
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The importance of understanding genetic mechanisms and recent advances in this area are obvious to scientists and science teachers. Our conceptual understanding in genetics is occurring rapidly. To a science researcher or teacher, the ability to apply and understand genetic terms and concepts comes easily with experience and exposure. But, the average lay person may not have the educational experience to understand basic genetic concepts. The basic concepts of "genetic mechanisms" may include: knowing DNA structure, terms like genotype and phenotype, understanding genotypic and phenotypic ratios in matings, recognizing dominant, recessive, and incomplete dominant modes of inheritance, and finally, understanding the chromosomal theory of inheritance. To illustrate the need for people to understand genetics consider, for example, if a news report states that the location of the gene that causes Cystic Fibrosis has been found on a certain chromosome, then people must have knowledge of basic genetic terminology or the discovery means nothing to them. When a couple runs the risk of passing on a genetic defect because they are "carriers" (i.e.-both people have a hidden or recessive gene for which the trait will only express when two "hidden" genes are paired together) they must know what being a carrier means. In order for DNA
fingerprinting to be admissible evidence in our courts it must first be understood and trusted by the average, non-scientific person.

Genetic mechanisms are often introduced in introductory high school biology courses. The objective of many of these courses is to teach Mendelian principles so that the students can use their knowledge to solve genetic problems when given unfamiliar data (Walker, 1978). In fact many state curriculum guides (Texas, Pennsylvania, California, and Indiana) require that certain genetic content be included in their curriculums. The Indiana Department of Education provides a Course and Curriculum Area Descriptions for Indiana Schools. It contains descriptions that "are to serve as models for school corporations in developing curricula..." The description for Genetics course contents reads as follows:

Genetics should provide students an understanding of the potentials, limitations, and hazards of gene slicing and splicing as well as an understanding of: the mechanisms and laws of heredity in sexual and asexual reproduction; natural, environmental, or chemically produced mutations; and the technology of genetic manipulation. Students should be provided laboratory experiences with the reproductive cycles and genetics of non-pathogenic organisms.

To be able to apply genetic principles to problem-solving requires the ability to think abstractly. It has been proposed that seventy-three percent of tenth grade
biology students are not intellectually ready to understand genetic mechanisms (Adams, Greene 1990). But, according to the Piagetian model of cognitive development, tenth grade students should be ready for abstract thought, and thus, ready to comprehend genetic mechanisms.

The Piagetian model of cognitive development assumes that all people develop mental abilities in the same sequence but at differing rates (Lawson, Renner 1975). The sequential stages are as follows: 1) sensormotor; 2) pre-operational; 3) concrete-operational; and 4) formal operational (Walker 1978). The child in the concrete-operational stage of thought requires familiar objects, actions, and properties for a concepts to be understood. Formal thinkers can perform logical operations on the abstract as well as the real levels. The formal thinker can perform three types of cognitive reasoning:

- propositional logic: the ability to apply proportions, probability concepts, ratios, and analogy analysis (a is to b as c is to d).

- combinatorial logic: the ability to generate combinations by holding all variables constant except one, until all combinations are determined.

- hypothetico-deductive: the ability to consider hypotheses which may or may not be valid, and contemplate what would follow if they were valid.

An opponent to Piaget's model is Joseph D. Novak. He believes that it is misleading to view Piaget's
developmental stages as "unique episodes in the ontogeny of brain development." He holds that it is unlikely that new neural mechanisms can be introduced in a maturing child. He feels Piaget failed to recognize the role language development and frameworks of relevant concepts play in the development of children's patterns of reasoning (Novak, Gowin 1984). Although he has some differing views on cognitive development, Novak does acknowledge the importance of the relationship between children's experiences with objects and events and the role these play in their cognitive development.

If the Piagetian model is accurate then there must be some other factor affecting the seventy-three percent of high school students who are not formal thinkers. The usual teaching strategies of discussing principles, presenting examples, giving similar sets of problems and hoping the repetition of solving many like problems will facilitate the transition from concrete to formal operational thought are not working. The most logical conclusion is that high school biology students are capable of learning and applying basic genetic concepts but they are not being taught in a way which allows them to become formal thinkers. In order to help with this transition educators must recognize that their students may be at different stages of cognitive development and may require concepts to be taught at the
concrete level of thought so that they may grasp abstract concepts in genetics and biology.

Thus, it is important for teachers to determine whether their students are learning genetics. And, if they are not is it really because they are not capable? Or, is it because they are not being taught with consideration to their cognitive abilities? These questions are the basis for my research: to determine whether a group of introductory biology students are formal thinkers and able to use genetics concepts. If not, is it because of something that educators are doing (or failing to do)?

STATEMENT OF THE PROBLEM

A survey was sent to teachers of Biology in the National Network to Implement Human Genetics & Bioethical Decision-Making in to the nations Secondary Schools. The purpose of the survey was to determine the teacher’s opinions and insights as to whether their introductory biology students are able to learn and apply basic genetic mechanisms. Genetic mechanisms can be defined by knowing such terms as genotype and phenotype, genotypic and phenotypic ratios in matings, recognizing dominant and recessive modes of inheritance, and finally understanding the chromosomal theory of inheritance. The teachers were asked to respond to questions concerning
their teaching content and the level of understanding of their students. The results of the survey are summarized and recommendations are made in the final chapter of this manuscript.
In order to determine whether or not Piaget's theory of cognitive development can be useful to educators one must know what his theory includes. There is a vast source of reading material on Piaget's theory and education, pro and con. To understand his theory you must understand the basic ideas underlying his model of cognitive development.

The concepts of mental structures is the backbone of Piaget's work (Lawson, Renner 1975). Lawson and Renner compare them to hypothesized "mental blueprints" that guide a person's behavior. Mental structures organize the environment so that a person can live and function successfully in it. Mental structures, according to Lawson and Renner, are "constructed and reconstructed within the brain throughout a person's cognitive development." Richard Walker (1978) says in his doctoral thesis, "The process of construction of mental structures by the individual's active participation in environmental interaction is evidenced by intellectual or cognitive development." Piaget's view is that the development or construction of mental structures derives from an interaction of an organism and its environment which Piaget calls self-regulation or
equilibration. The structure derives from an organism’s actions within the environment. Piaget suggested four factors which are necessary for the development of mental structures: 1) self-regulation; 2) experience with things; 3) social transmission; and 4) physical maturation (Lawson, Renner 1975).

Self-regulation, according to Lawson and Renner, is the process by which a child’s actions lead to the construction and reconstruction of progressively more complex and powerful mental structures. From birth, a child has structures that allow the child to interact with his environment. As long as the interaction is successful the structures already there will guide the child’s actions. But, eventually a child will meet things that seem to contradict his existing mental structures. These contradictions will produce a state of disequilibrium (Walker 1978). If this occurs then the child’s existing mental structures must be changed or replaced. By investigation or knowledge from others the child accommodates or changes his inadequate mental structure (Walker 1978). Once this occurs, the child can now assimilate the new situation. Then the new structure is developed and tested. If the structure guides behavior that is rewarded or reinforced then the structure will also be reinforced. This is how the child
builds new mental structures to adapt to new situations.

According to Piaget's theory, self-regulation underlies all intellectual development (Lawson, Renner 1975). The process of developing mental structures is a process of self-regulation because the external factors will not "circumvent" the process.

Experience, as well as self-regulation, is a must for learning. If there are no "experiences" or encounters with the environment then no contradictions of structures will occur and no further exploration is possible.

There are two kinds of experience: physical and logical-mathematical (Lawson, Renner 1975). Physical experience is the actual physical action on objects in a person's world. Physical experience leads to the development of new mental structures about objects. At some time, a child realizes that there is more to interaction than just objects: "He sees that his actions with objects produce order in themselves", say Lawson and Renner. They use the example of a child realizing that a group of ten objects in a line contains the same number of items whether counted forward or backward. The child realizes that the sum of a set of objects does not change when counted in a different order. The child now has a structure he can use in many differing situations and,
thus, is a logical-mathematical structure. The structure allows a child to function logically within his environment. The behavioral patterns guided by mental structures are called operations (Lawson, Renner 1975). The factor of experience helps children to build operational structures that can eventually lead to abstract thought concerning their world.

Social transmission is also necessary for building mental structures. Young children (and often not so young) are working from an egocentric point of view. A child who thinks this way cannot be objective. In order for the child to change his views he must experience new viewpoints and ideas from other people by interacting with them (Lawson, Renner 1975). Social interaction can cause debate, discussions, and sharing of ideas. These actions cause the child to review his own beliefs. This examination is required for the development of new mental structures. This idea leads to Piaget's belief that data from scientific experiments must be shared and discussed so that the information will be absorbed and understood.

Maturation is the final area that has a role in the development of new mental structures. A child's ability to process information seems to increase with age (Lawson, Renner 1975). Thus, the child's ability to store and utilize information limits the child's ability
to understand complex ideas. Since the maturation of this mental ability is probably dependent on the growth of the central nervous system there is not a lot a teacher can do about it (Lawson, Renner 1975).

COGNITIVE THOUGHT LEVELS

Piaget's theory outlines the major stages of thought that he believes occurs in every child (Lawson, Renner 1975). These stages are sequential, each later stage builds and adds onto the structures of the previous one. There are four stages that occur, according to Piaget: 1) sensory-motor; 2) preoperational; 3) concrete operational; and 4) formal operational.

When a child is born Piaget's theory of cognitive development places them in the sensory-motor stage. This period lasts for approximately eighteen months. "Object performance" is the knowledge that objects continue to be even when they cannot be seen and is typical of the sensory-motor stage.

The second stage, preoperational, indicates that the child has not reached the stages where mental abilities start to appear. This stage occurs until about seven years of age. The child in this stage is very self-centered and perceives only certain aspects of his
environment (Lawson, Renner 1975). The child’s major achievement during this time is learning the language.

At about seven years of age a child reaches the concrete operational stage of thought. The child in this stage is said to be "object-bound" (Walker 1978). Reasoning patterns during this stage require references to familiar objects, actions, and properties that can be seen (Walker 1978). Thus, the concrete operational child can only form and apply mental structures to concrete objects. The concrete thinker cannot think or reason abstractly (Walker 1978).

The final stage of thought is the formal operational stage which usually manifests itself during the early teen years (Lawson, Renner 1975). The formal operational stage is characterized by the child's ability to perform logical operations on the abstract as well as the real levels (Walker 1978). The formal thinker can perform three types of cognitive reasoning: propositional logic, combinatorial logic, and hypothetico-deductive (see introduction for definitions). The formal operational thinker does not need familiar objects to grasp and manipulate abstract concepts such as those included in the content of the subject of genetics.

If Piaget’s theory is accurate then most high school seniors and college freshmen should be able to
perform "higher-order" reasoning patterns that accompany formal thought (Walker 1978). According to Piaget’s theory a child should reach the formal-operational thought stage by his early teens (Walker 1978). But, other studies have suggested that the normal age for the transition to formal thinking occurs much later than fifteen years of age (Walker 1978). These findings would imply that most introductory biology students are still in the concrete operational stage of thought. In fact, research has indicated that a large number of college freshmen are still operating at the concrete level (Walker 1978). This knowledge should suggest the need to provide educational experiences that will start the movement from concrete to formal thought. Many studies have been done that show that a shift from abstract teaching to teaching concretely to reach abstract thought can be successful (Walker 1978).

SUMMARY

A review of the related literature indicates that the Piagetian theory seems to be an accepted idea. But, the question is whether or not educators are using this knowledge to help facilitate cognitive transition from one stage to another. The literature seems to indicate that consideration for a student’s thought level
increases the chances of reaching the point of formal operational thinking processes (Walker 1978).

METHODS

A survey (see Appendix A) was constructed to obtain information from several biology teachers throughout the United States. The questions were written to be as short as possible so the ideas being introduced would be understood. The content validity of the questions was conducted by Dr. Jon R. Hendrix, Professor of Biology. The method used was comparing responses sought to the item's content. The questions were written as ten sets of paired questions. Each pair dealt with the same concept but asked about it in a slightly different way. By doing this I was able to check to see if the questions were responded to with similar percentages. If so, this would indicate that the questions were understood. If answered similarly, the results were validated.

The original sample size was fifty teachers. Twenty-four teachers responded out of this original sample. Due to the low number of responses a second set was sent (of the same survey) to twenty-five additional teachers. The second mailing yielded thirteen returned answer sheets. The two samples were combined to make a larger sample size to draw conclusions from. All
conclusions are based on the combined results of the survey.

The surveys were sent with an answer sheet including five choices for responding to the questions. A represented strongly agree; B-agree; C-no opinion; D-disagree; and E-strongly disagree. A glossary was included with the survey to define any ambiguous terms within the survey questions.
CHAPTER 3

RESULTS AND DISCUSSION

The survey used in this study was designed with paired questions. I will discuss the results by using results from the pairs of questions that are related and the percentages obtained. (See Table I)

Questions five and twelve are the first set of paired questions. These questions dealt with the educators' opinions about intellectual autonomy and whether they feel it is an important part of a student becoming a formal thinker. Piaget does believe it plays an important role in developing formal operational thought. Seventy-five percent and fifty-six percent, respectively, of the teachers who responded agreed or strongly agreed that intellectual autonomy is important for formal thought to occur. They also indicated by agreeing that they tried to encourage working alone and thinking things through. Thus, these teachers seem to be encouraging formal thought by their students according to the results of these two questions.

The next set of paired questions are thirteen and two. Question two asked if the instructor's lectures are geared toward formal operational thinkers. Sixty-four percent agreed that their lectures are taught assuming their students are formal thinkers. But, when asked in
TABLE I: CHECK FOR INTERNAL ACCURACIES

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<th>%Disagree</th>
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<td>2.70, 32.43</td>
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<tr>
<td>4, 19***</td>
<td>43.25, 91.89</td>
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</table>

* Agree percentages include strongly agree and agree responses. Disagree percentages include strongly disagree and disagree. No opinion was not included, thus the percentages do not add up to one.

** These questions are worded in opposite ways. One in the negative (do not) and the other positive (can). Thus, the agree percentages are very skewed as are the disagree.

*** These questions dealt with the hypothetico-deductive reasoning which has not been closely linked to the learning of genetics (Walker, 1978).
question thirteen if their teaching strategies are dependent upon their students being formal thinkers they disagreed (sixty-seven percent.) There seems to be a disparity between the responses to basically the same question. Their lectures are taught at an abstract level, but they also say their strategies are not dependent on the students being formal thinkers. A possible reason for the inconsistency could be that the questions were misunderstood. Or, that the teachers are not familiar enough with Piaget's theory of cognitive thought levels to ascertain their own students level of thought.

Questions eighteen and ten dealt with discussing lab data to increase formal thought. Seventy-five percent and ninety-seven percent, respectively, agreed that, indeed, discussing data derived from concrete experiences (i.e.- labs) is an important part of developing formal thought. They also said that they used this technique to foster formal thinking in genetics by agreeing with such high percentages.

Survey questions three and twenty questioned the students' ability to understand what a DNA model represents. Question number three was phrased as "cannot understand." Eighty-one percent disagreed, meaning they do believe their students understand the abstract idea
that a DNA model represents. On question twenty, eighty-one percent agreed that their students understand the DNA model. To be able to comprehend what a DNA model actually represents could possibly indicate that the students are able to understand an abstract concept which requires formal thought processes. Thus, according to the results of these two questions the teachers believe their students seem to be capable of formal thought processes with respect to genetics.

Numbers six and fourteen asked whether the educators' feel that their students have reached the formal operational stage of thought. Question six stated that the majority of their students cannot learn genetics because they are not formal thinkers. Ninety-seven percent disagreed with this statement. These results seem to indicate that their students are learning genetics because they are formal thinkers. But, question fourteen asks whether their students have reached the formal operational thought stage. Fifty-five percent disagreed which seems to show that the teachers feel their students are still concrete thinkers. A possible reason for the contrasting results could be that in question number six the teachers do believe the students can learn genetics but they are not all formal thinkers. Perhaps they must be taught using concrete ideas to allow
them to understand more abstract concepts. Question fourteen only stated that the majority of students are formal thinkers, which probably is not true but does not mean they are not capable of learning genetics.

Paired questions sixteen and nine dealt with laboratories preceding an abstract concept. The teachers were asked whether they feel concrete experiences (labs) before an abstract concepts is introduced help build formal operational thought processes. Eighty-one percent on both questions agreed that a lab is helpful and that they try to precede their teaching strategies with concrete experiences. These results could indicate that their students are being helped out of the concrete operational stage of thought and on to abstract thought.

Questions fifteen and eleven were designed to see if the teachers were using concrete ideas and objects to teach genetics. Sixty-two percent and eighty-six percent, respectively, agreed that they did use concrete concepts and objects to facilitate the transition from concrete to formal thought.

Questions one and seventeen asked whether students are able to apply combinatorial logic to genetics problems (i.e.- determining the number and type of gametes produced in a dihybrid cross.) Seventy-eight percent agreed on number one and ninety-four percent on
number seventeen that their students are capable of using this type of logic when solving genetics problems. These results seem to show that the majority of their students are using and applying formal thought while solving genetics problems. But, if they are simply doing repetitive problems by memorization they are not really thinking formally.

One possible explanation for some of the results may be the lack of knowledge of the Piagetian model of cognitive thought. This should have been a question addressed in the survey. Without proper training or schooling a teacher may have never encountered Piaget's ideas. In this case, my survey would probably have not been very clear to the teachers.

Another reason may be in how I constructed the survey. Some of the questions may have been ambiguous or not worded to get the points across I was trying to make. Table II illustrates the raw data upon which Table I was based.
Table II: Research Raw Data; Number answered on each question and percentage totals for each question

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SUMMARY AND RECOMMENDATIONS

The survey results (See Table II) seemed to show that the majority of the sample of biology students in the study may not all be formal thinkers and most likely are not. But, the teachers seem to be using concrete experiences to allow their students to comprehend abstract ideas. Whether or not the teachers are aware that they are promoting formal thought cannot be properly assessed by these survey results.

Using the data obtained from the survey, it seems that tenth-grade biology students are capable of learning genetic mechanisms. But, they must be taught with consideration to their level of cognitive thought. They may not all be formal thinkers, but can probably be taught genetic concepts by using concrete objects in order to foster a transition to formal operational thought.

RECOMMENDATIONS

Based upon the results of my survey, I offer the following recommendations to educators of biology:

1. Teachers and future teachers of biology courses
should have a better knowledge of the ideas and applications of the Piagetian theory of cognitive thought. This knowledge should come from college education classes and should be required for all teaching majors.

2. Laboratories should be used to create concrete experiences that will foster the understanding of abstract concepts. The students who might already be formal operational thinkers will easily comprehend the ideas while the concrete thinkers will have an easier time understanding the ideas presented.

3. Educators need to recognize that students are in different stages of thought at different ages. If they would teach assuming everyone is a concrete thinker then the concrete and formal thinkers could all learn abstract concepts.
REFERENCES


APPENDIX A

Please respond to the following statements using the scale below and the enclosed answer sheet. A glossary is included to eliminate any ambiguous terms. Reminder: this survey pertains to your introductory biology classes. Thank you.

A----------B----------C----------D----------E
strongly agree no opinion disagree strongly disagree

1. The majority* of my introductory biology students are able to apply combinatorial logic (i.e., determining the number and type of gametes given a dihybrid cross) to genetic problems.

2. My genetics lectures are geared toward formal operational thinkers.

3. When shown a model of DNA, my students do not understand what it explains.

4. The majority of my students are capable of hypothetico-deductive reasoning when solving genetics problems.

5. Intellectual autonomy is important in order for a student to obtain formal operational thought abilities.

6. The majority of my introductory biology students cannot learn genetics because they are not yet formal thinkers.

7. My formal-thinking students can perform all three elements of cognitive reasoning: propositional logic, combinatorial logic, and hypothetico-deductive.

8. By learning genetic mechanisms, my students have increased their formal operational thought abilities.

9. I believe, as does Piaget, that students attain formal operational thought processes through concrete experiences.
10. I often ask my students to discuss lab data in order to increase their level of formal thought in genetics.

11. My students in the concrete operational thought stage can be taught to be formal thinkers in genetics by using familiar objects and properties to introduce abstract concepts.

12. Encouraging students to work alone and think things through for themselves helps develop formal thought.

13. My teaching strategies are dependent upon the students being formal thinkers.

14. The majority of my students have reached the formal operational stage of thought.

15. For students who are in the concrete operational thought stage, I use familiar objects and properties to introduce them to abstract ideas.

16. When introducing an abstract concept, I precede my teaching strategies with a concrete experience (i.e., a lab).

17. Students, who are capable of formal operational thought, can analyze a problem dealing with a dihybrid cross (AaBBxaAbB) and determine number and type of gametes produced.

18. Exchanging points of view and discussing data derived from concrete experiences is necessary for logical, formal thinking.

19. My formal-thinking students can contemplate the consequences of hypotheses which may or may not be true.

20. The majority of my students understand what a DNA model represents.

*Consider a majority to be at least 75 percent or more.