Teaching Ninth-Grade Genetics Through Inquiry

M. I. Hadjimarcou, C. P. Constantinou, Z. Zacharia
Department of Educational Sciences, University of Cyprus,
P.O.Box 20537, Lefkosia 1678, Cyprus
hadjim@ucy.ac.cy, *c.p.constantinou@ucy.ac.cy*, *zach@ucy.ac.cy*

Abstract. *This study investigated the effectiveness of using an inquiry-based approach in teaching ninth-grade genetics. The inquiry method enables students to assume an active role in the construction of knowledge and has been shown to positively affect some of the important aspects in the process of learning science, such as conceptual understanding, problem-solving, and scientific method. The study involved teaching a unit of basic genetics to a control and an experimental group in the traditional teacher-centered and the inquiry approach, respectively. The results indicate that the inquiry teaching-method achieved a significantly better learning outcome compared to the traditional method.*

Keywords. Fertilization, genetics, inquiry, mechanisms, Mendelian inheritance, meiosis, mitosis.

1. Introduction

Through fascinating applications such as genetic screening, cloning and the development of genetically modified organisms, genetics is assuming an increasingly more central role in our lives. As a result, today's modern citizen is asked to practice his democratic right, which is also a duty to take critical decisions regarding applications of genetics that affect the individual and the society. For the citizens to be able to carry out these duties responsibly they need to have a certain degree of scientific literacy in genetics. This is normally achieved during formal education.

However, research studies indicate that educational systems fail to achieve an adequate degree of learning of genetics in secondary education [6, 7, 8, 9, 10, 19]. This outcome is usually caused by one or more of three types of problems that characterize the teaching of genetics: a) the teaching methodology traditionally used by science teachers does not utilize the appropriate tools to promote the students' conceptual understanding on the important genetics concepts and the way they relate to each other, b) the school biology books do not clarify the connections between the phenomenon of inheritance and the mechanisms of meiosis, fertilization and mitosis that are responsible for its appearance, and c) the curricula for teaching genetics are too descriptive and contain a large volume of didactic material that is expected to be covered in a short period of time.

The purpose of this study was to investigate the effectiveness of using an inquiry-based approach in teaching genetics at high school level in order to achieve a learning outcome that would approach the scientifically accepted model of inheritance and its mechanisms.

2. The inquiry approach

The term 'inquiry' [13, 16], as it is meant in the context of teaching and learning, refers to the abilities students should develop to be able to design and conduct scientific investigations and to the understandings that they should gain about the nature of scientific inquiry. Also, inquiry refers to the teaching and learning strategies that enable scientific concepts to be mastered through investigations. In other words, the inquiry approach enables students, instead of acting as passive receivers of information as it is usually the case with the traditional teacher-centered methods, to assume an active role in the construction of knowledge by getting involved in processes of inquiry.

Inquiry was chosen as the method of teaching because research has shown it to positively affect some of the important aspects in the process of learning science, such as conceptual understanding, problem-solving, critical thought, scientific method and developing a positive attitude towards learning science [5, 14, 17, 18]. In addition, inquiry takes advantage of the natural curiosity of the students and utilizes it to maintain their interest in learning.

3. Theoretical background

Learning genetics is a complex process that involves not only understanding the basic concepts and phenomena, but also the structuring of strong conceptual connections between the three epistemological aspects that define and describe it, namely, the phenomena, the mechanisms that cause the phenomena and the reason for the existence of the phenomena.

The most basic phenomenon in genetics is inheritance, which in its most simple form, is defined as the transfer of traits from the parents to the offspring through the transfer of genetic material. A trait is a characteristic shared by all individuals of the same species (e.g. eye color) and can exist in a number of variations (e.g. blue, green, brown, etc.)

The phenomenon of inheritance is caused by the combined action of three cellular processes/ mechanisms, namely, meiosis, fertilization and mitosis. Meiosis accomplishes the transfer of genetic material from the mature individual to its gametes. Fertilization brings together one gamete each from a male and a female parent to form the zygote, which contains genetic material from both parents. Finally, the zygote multiplies mitotically to form the body of the new organism. All of the new cells contain the same genetic material as the zygote resulting in an individual who exhibits a combination of traits from both parents.

The reason we observe the phenomenon of inheritance on the planet is because it creates individuals with new combinations of traits within a species. This outcome allows the species more opportunity to adjust to a constantly changing environment increasing its chance for survival. Therefore, the mechanism of natural selection has enabled the species that reproduce sexually and therefore exhibit the phenomenon of inheritance to survive and as a result we can observe this phenomenon.

In view of the above, it becomes clear that teaching genetics and Mendelian inheritance in particular is a very complex and demanding endeavor. In order to achieve an adequate level of learning in the students, it is of utmost importance to facilitate their construction of conceptual connections between the phenomenon of inheritance and the mechanisms that cause it. Only then will the students be able to fully understand the process by which a trait is passed on from a parent to its child. If this is not accomplished, the students might still be able to regurgitate information they have learned but they will not be able to apply it in novel situations they might run into either in the classroom or sometime later in their life.

4. Methods

4.1. Participants and teaching curriculum

The participants of the study were 45 ninth-grade students (age range 14-15) from a suburban secondary school in Cyprus. The students, divided into an experimental (22 students) and a control group (23 students), attended a biology course that involved, among others, a unit focusing on basic genetics and Mendelian inheritance topics. The emphasis was on the understanding of the nature, function and correlations between the basic genetic concepts (e.g. DNA, genes, and chromosomes) and the phenomenon of Mendelian inheritance, in the light of the three biological mechanisms that are responsible for its appearance, namely meiosis, fertilization and mitosis. None of the participants had been taught genetics in the past.

4.2. Study design

A pre-post comparison study design was used for the purposes of this research. Conceptual tests (pre- and post-test) were administered to assess students' understanding of basic genetics and Mendelian inheritance topics both before and after the unit on genetics was taught. The same pre-test items were also included in the post-test (Part A), however, the post-test included some additional items that required a deeper understanding of the topics (Part B).

The pre-test and Part A of the post-test contained open-ended items that asked conceptual questions regarding the phenomenon of inheritance and the mechanisms responsible for its appearance. Specifically, the students were presented with the fact that some traits that appear in the parents also appear in their children and were asked to express their views regarding: a) the nature of these traits, b) the general mechanism that explains this phenomenon, and c) the selection and distribution pattern that these traits follow as they are transferred from parents to offspring.

Part B of the post-test contained closed-ended items that tried to document the degree of conceptual understanding developed in the students on the most important topics they had been taught, such as: a) the nature, role and correlations between the important genetics concepts (e.g. DNA, genes, and chromosomes), b) the nature and role of meiosis, mitosis and fertilization, and the way these three mechanisms collectively cause the phenomenon of inheritance, and c) applications of the first and second laws of Mendelian inheritance.

Furthermore, clinical interviews were conducted with 8 of the students from the experimental group at the end of the study. The interviews provided the opportunity to further enhance understanding of the degree of learning achieved by the students, to recognize the specific topics in genetics that cause learning difficulties to the students, and to collect additional evidence regarding the effectiveness of the teaching approach applied to the experimental group.

4.3. Teaching approach

The participants in the control group followed the traditional approach in studying the basic genetics and Mendelian inheritance topics, a method that is usually used in public schools and which relies heavily on teacher lectures and the school biology book. The participants in the experimental group followed an adaptation of the inquiry approach, which was initially developed for teaching physics [13]. The students in the experimental group worked in groups of four. The school biology book was not used at all and the role of the teacher was reduced to that of a coordinator of the students' work. The students' main learning aid was a set of worksheets, which was specifically prepared for the teaching of the genetics unit. The worksheets complete with short articles as a source of new information, tables, diagrams, pictures, exercises and guidelines for small investigations, facilitated the application of the inquiry approach. Although the basic structure of the worksheets was prepared in advance, several small changes had to be made as the teaching progressed to adjust to the specific needs of the students and to support their investigations.

The teaching of the experimental group was structured according to the following general format. At the beginning of each subunit within the unit of genetics the students were presented with a scientific phenomenon or set of data and were asked to make observations and specify relevant research questions. After selecting an appropriate problem for investigation the students would analyze the available information, propose possible explanations and consider various forms of investigation. They would then proceed with a particular path of investigation. In the process, the students would involve themselves in a variety of activities such as collection and analysis of additional data and information, evaluation of results, re-examination of the initial hypotheses, etc. At the end of the activity cycle the student-groups announced their conclusions to the rest of the class and during the subsequent discussion they would try to defend their positions against criticism from their classmates. The study of the unit would conclude with the adoption of a common position.

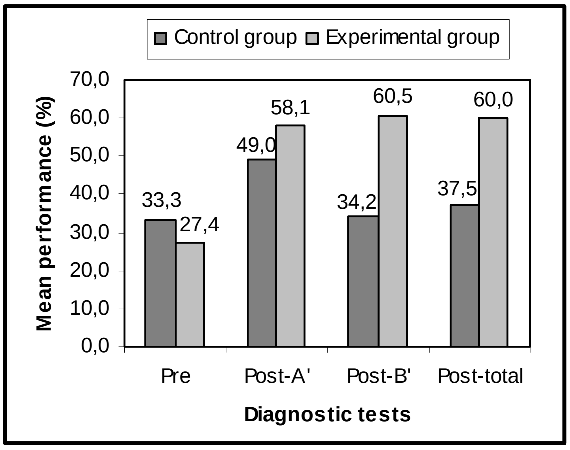
5. Data Analysis and Results

The analysis of the data collected through the use of the pre- and post-tests and the clinical interviews involved both quantitative and qualitative procedures.

5.1. Quantitative analysis

The quantitative data analysis involved the evaluation of students' pre- and post-test scores. To ensure objective assessment, the tests were coded and scored anonymously. Each item in the tests was scored separately; however, a total correct score was derived for each test (Table 1).

Table 1. Diagnostic tests results.



The resulting pre- and post-test scores were used in the analysis to assess the improvement achieved by the students in the experimental and control groups as a possible outcome of having attended the unit in genetics as well as to evaluate the difference in performance between the two groups both before and after the unit in genetics was taught. The statistical procedures used for the two types of evaluation were the paired and the independent samples *t-test*, respectively [15].

The statistical analysis revealed no significant difference in the performance of the two groups in the pre-test, while both groups showed significant improvement ($p<0.01$) from the pre-test to the post-test (only the items that were identical in both tests were compared). The experimental group performed better than the control group in both parts of the post test, but only the difference in Part B was significant ($p<0.01$). In total, the experimental group was found to have significantly higher scores in the post-test than the control group ($p<0.01$). These results indicate that while both the traditional and the inquiry teaching methods succeeded in helping the students acquire basic knowledge in genetics, the inquiry-based method was significantly more efficient.

The difference in the results of the statistical analysis of the students' performance in the two parts of the post-test is due to the nature of the parts themselves. The open-ended items included in Part A did not require extensive knowledge of the topics taught and were relatively easy to answer by students who did not reach this level of knowledge. In contrast, the close-ended items in Part B required a deeper understanding of basic genetics and Mendelian inheritance on behalf of the students and therefore, were more difficult to answer. As a result, the control-group students managed a moderate performance in Part A but failed to reach comparable levels in Part B. On the other hand, the students in the experimental group performed approximately the same in both parts of the post-test (Table 1). Since Part A and Part B weighted 18% and 78% of the total maximum score for the post-test respectively, the much larger contribution of Part B lead to the significantly higher performance observed for the entirety of the post-test for the experimental group compared to the control group.

Internal reliability data were also collected. A second independent coder reviewed the data from the pre-test and Part A of the post-test for both student groups. The items in these tests were of the open-ended type and could therefore take a number of acceptable answers. It was not considered necessary to re-evaluate the data from Part B of the post-test as the items included in it were of the closed-ended type and could therefore only accept one correct answer, or a limited number of different variations of the correct answer. The degree of agreement between the two coders was calculated using the *Pearson Correlation Coefficient* [15]. All the reliability measures were between 0.88 and 0.95. This high correlation suggests that the criteria set for the evaluation of the test items were precise and were applied faithfully in the coding and scoring of the tests.

5.2. Qualitative analysis

The qualitative data analysis focused on identifying and classifying students' concepts/ ideas both before and after the unit on genetics was taught, based on the procedures of phenomenography [11, 12]. Furthermore, it was attempted to decipher the specific difficulties that the students face in their effort to understand basic genetics and Mendelian inheritance topics. The prevalence for each one of the resulting categories of concepts/ideas and difficulties was calculated separately for the students in the control and the experimental group and was used to qualitatively compare the status of the two groups.

The students' responses in the pre-test and Part A of the post-test were analyzed qualitatively and the resulting concepts/ideas were presented in conceptual diagrams of the 'bar' type [1], allowing direct comparison within and between groups, both before and after teaching. The 'bar' type conceptual diagrams present synoptically the concepts and ideas that each student utilizes in his/her effort to answer the test questions. At the same time, they allow parallel observation of the different aspects in the student' s comprehension on specific topics, as these appear as different positions in his/her responses. In this manner, a more complete picture of what each student knows and thinks regarding a particular issue is presented.

In addition, the information from the conceptual diagrams was used to construct summary tables, which present the positions held by the group of students as a whole. Table 2 for example presents the percentage of students that hold specific ideas about the mechanism that is responsible for the appearance of the phenomenon of inheritance. The first three statements represent partial but scientifically acceptable descriptions of this mechanism. The last two responses can not be considered adequate explanations. According to the data, although both groups show marked improvement after having attended the unit on genetics, the percentage of students from the experimental group that express one or more of the first three positions in their answers is much higher compared to that from the control group. What is of most importance is the fact that almost half of the students in the experimental group (45%) consider the processes of meiosis and mitosis as part of the mechanism of inheritance, whereas none of the students in the control group do so even after having been taught genetics.

Table 2. The mechanism of inheritance.

Students believe that heredity is caused by:		Contr. (%)		Exper. (%)	
		Pre	Post	Pre	Post
1	The transfer of DNA, genes, or chromosomes	10	57	14	82
2	The processes of fertilization and / or reproduction	32	57	5	68
3	The processes of meiosis and/ or mitosis	0	0	0	45
4	The transfer of characteristics	9	0	0	5
5	The living habits and/or the social environment	5	0	29	0

Furthermore, the examination of the data from the pre-test revealed students' naive ideas about basic genetics and Mendelian inheritance topics. Students seem to believe that: a) the acquired characteristics are inherited, b) inheritance is controlled by either God or the living habits of the individual, c) the distribution of the characteristics inherited from parents to offspring depends on the sex of the parent or the offspring, and d) the only type of characteristics inherited are the important, the strongly expressed or those selected by God. These ideas appeared at approximately the same frequency in the control and the experimental groups. Similar ideas were also reported in other research studies [2, 3, 4] with the exception of the role played by God in heredity.

The students' answers in the post-test items and the clinical interviews from the experimental group revealed a number of difficult learning areas that students encounter in their effort to understand genetics. These are: a) the construction and interpretation of diagrams representing Mendelian inheritance, b) the structure, function and correlations between DNA, genes and chromosomes, and c) the way meiosis, mitosis and fertilization collectively cause the appearance of the phenomenon of inheritance. Similar results also appear in other research studies [6, 7, 8, 9, 10, 19]. What is important to emphasize is that although these difficult learning areas were common for both student groups, the magnitude of the problem was significantly reduced in the experimental group.

6. Conclusions and implications

The research results indicate that the inquiry method, in the form that was applied in the teaching of the genetics unit in the experimental group, was able to achieve a significantly better learning outcome compared to the traditional teacher-centered method, in the form that was applied in the teaching of the control group.

In all but one of the 11 items included in the post-test the experimental group performed better than the control group. The biggest difference was observed in Part B items. When comparing the items in the two parts of the post-test, the open-ended items in Part A could be answered correctly in a variety of different ways and could be considered less demanding on behalf of the students. On the other hand, the items in Part B were of the close-ended type and could accept only one or a limited number of different but specific answers. Therefore, these items could be considered highly demanding with regard to the level of knowledge and understanding required for a correct response to be provided by the students.

The above hypothesis works well with both the quantitative and qualitative results recorded for the two groups. The performance of the control group was considerably higher in Part A than in Part B. On the other hand, the students in the experimental group performed equally well in both parts. These results suggest that the methodology applied to the teaching of the control group did not succeed in equipping the students with the appropriate learning tools that would allow them to achieve an in-depth understanding of the topics taught. In contrast, the inquiry method used in the teaching of the experimental group managed to achieve a high degree of conceptual understanding in the students. Also, the difference in the level of knowledge and understanding between the students in the two groups becomes evident when comparing the quality of the responses they provided in the post-test. For example, almost half of the experimental-group students gave responses that showed an adequate degree of understanding of the conceptual connections between the phenomenon and the mechanisms of inheritance. None of the control-group students exhibited this level of understanding in their responses.

The above findings can be best explained when considering the basic characteristic features of the inquiry method. The students construct their own knowledge through their active participation in the process of learning. In addition, their interest is constantly stimulated through a variety of activities in which they are involved. The students are the ones to decide what there is to learn and in an effort to acquire that knowledge they ask the questions, propose the answers and carry out the investigations to test their proposals. In other words, the students are responsible for their own learning.

The implications from the findings of this study are more than obvious. If educational systems are to improve the degree of learning genetics in secondary education they need to adopt teaching methodologies that can achieve better learning results. The inquiry teaching-method is one such example.

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8. References

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