Biotechnology / genetic engineering: research on teaching and learning in a critical thinking context

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SUMMARY

The topic of Genetic engineering offers an appropriate context for developing reasoning as it includes many concepts that should be interconnected by the learner and deals with experimental scientific procedures. The objective of this work was the design, implementation and evaluation of a teaching procedure on the basis of previous research on critical thinking in biology education. In particular we attempted to develop a didactic sequence based on the syllabus of Molecular Biology /Biotechnology course offered in the Biology Department of Patras University, Greece. This didactic sequence is consisted of a series of tasks that address specific scientific reasoning skills covering at the same time the topic of genetic engineering. This paper presents the design of the research and the theoretical background of the methodology used.

KEY WORDS: genetic engineering, critical thinking, scientific reasoning

RESUME

Le sujet de la génétique mécanique offre un cadre convenable pour le développement du raisonnement scientifique puisqu'il contient plusieurs notions qui doivent être interconnectes par l'apprenti et en même temps il s'occupe des procédures expérimentales. L'objectif de ce travail était le tracement, l'application et la valorisation d'une stratégie didactique, organisée et basée sur des recherches précédentes pour la pensée critique sur la didactique de la biologie.

Plus précisément, nous avons essayé de développer une séquence didactique basée au programme des cours de la biologie moléculaire/biotechnologie, de la faculté de biologie de l'université de Patras, en Grèce. Cette séquence didactique contient une série des dextralités précises de la pensée scientifique en couvrant en même temps le sujet de la génétique mécanique.

Dans cet article est présenté le soubassement théorique de la méthodologie que nous avons utilisé au tracement de notre recherche.

MOTS CLES : Génétique mécanique, pensée critique, raisonnement scientifique

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The *objectives* of this research were:

- the design of learning environments aiming at developing scientific critical thinking skills while covering at the same time the topic of genetic engineering
- the implementation and evaluation of the teaching procedure, consisted of the designed learning environments.

This paper presents mainly the theoretical background of the methodology used in the design of the study.

Research design

Theoretical background

The basic choice in planning the research was the philosophical approach in the study of critical thinking (Ennis, Paul, Zohar, Tamir). In the philosophical theoretical context in the study of critical thinking, the central role is attributed to the argument that expresses reasoning – higher thinking. In the theoretical context of psychology the central theme is problem solving. In our case we use "problems" with the everyday meaning of the word, which do not require the application of a mathematical formula or thought. The "problems" we use are tasks, learning environments that induce the development of reasoning and expression of arguments.

The skills

Critical thinking skills are considered to be the same with the skills of scientific reasoning or the skills derived from the procedure of the scientific method (Arons, 1984[1]; Kuhn, 1993[2]; Jungrwith &Dreyfus, 1990[3]; Zohar, Weinberger and Tamir, 1994[4]). The examination of the list of critical thinking skills of Norris and Ennis (1989)[5], shows that there is a partial overlap with the skills of scientific method (Tamir and Lunetta, 1978[6]). For example issues like testing of hypotheses, planning of experimental procedures (where test of variables is included) and drawing valid conclusions, can be found in both lists.

According to Zohar et al. (1994)[4], scientific knowledge is developed with the procedure of scientific inquiry and in order to think critically for scientific subjects, someone has to handle the methods by which the scientific knowledge is obtained.

According to Ennis (1969[7], 1989[8]) there is a series of logical fallacies that should be avoided when critical thinking is developed. Other researchers define as basic constituent of critical

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[4] Zohar, A., Weinberger, Y., & Tamir, P., "The effect of the Biology critical thinking project on the development of critical thinking", Journal of Research in Science Teaching, 31(2), 1994, 183-196.

[5] Norris, S. P., & Ennis, R. H., *Evaluating Critical Thinking*, Pacific Grove, California: Midwest Publications, 1989

[6] Tamir, P. & Lunetta, V. N., "An analysis of laboratory inquiries in the BSCS yellow version", *The American Biology Teacher*, 40,1978, 353-357

[7] Ennis, R., *Logic in Teaching*, Englewood Cliffs, NJ: Prentice Hall, 1969

thinking the skill of conceiving causal relationships and the skill of constructing arguments to make decisions and support views (Zohar and Tamir, 1991[9]; Means and Voss, 1996[10]; Pontecorvo and Girardet, 1993[11]).

On the basis of the above and since the subject of genetic engineering that was to be taught with the aim of developing scientific reasoning, includes mainly scientific procedures, where skills of scientific method are applied, we considered *the skill of hypothetical-deductive reasoning as a basic skill in critical scientific thinking*. This skill is practised in tasks concerning the following:

- Testing of hypotheses
- Prediction of experimental results
- Interpretation of experimental data
- Design and evaluation of experimental procedures or experimental choices

The conceptual context of developing the skills

The topic that is used as context for developing the scientific critical thinking skills in the present study is genetic engineering, a subject of central importance in contemporary biotechnology. Genetic Engineering is one of the subjects included in the Molecular Biology / Biotechnology course offered in the Biology Department of Patras University. We think that it offers an appropriate context for developing thinking skills as it includes many concepts that should be interconnected by the learner and deals with experimental procedures as well.

Genetic Engineering or technology of recombinant DNA, can be considered as a multivalent research instrument for the understanding of the concept of gene. It concerns the manipulation of genes at the level of one species or even between different species and it aims at the genetic analysis or the improvement of specific characters of a species. Gene technology includes in vitro rearrangements of genetic material, leading to the formation of recombinant molecules that consist of at least two different DNA's. These molecules may have a practical value only if introduced to a host cell, where they can be conserved, multiplied, and also expressed under specific circumstances and conditions.
For a typical experiment of DNA cloning the following are required: The piece of DNA that we are interested to clone (DNA – aim), a cloning vector, restriction enzymes, DNA ligases, a host cell of the recombinant molecule.

There are 4 main steps in such an experiment:

- The preparation of the DNA segment that is going to be cloned
- The joining of this segment with the vector (plasmid or phage)
- The introduction of recombinant molecule into a cell host where it will be replicated
- The selection of host cells that have the recombinant DNA, so that this can be isolated and characterized

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[8] Ennis, R., "Critical thinking and subject specificity: Clarification and needed research", *Educational Researcher*, 18, 1989, 4-10.
[9] Zohar, A., & Tamir, P., "Assessing students' difficulties in causal reasoning in biology – a diagnostic instrument", *Journal of Biological Education*, 25(4), 1991, 302-307.
[10] Means, M. L., & Voss, J. F., "Who reasons well? Two studies of informal reasoning among children of different grade, ability and knowledge levels", *Cognition and Instruction*, 14(2), 1996, 139-178.
[11] Pontecorvo, C., & Girardet, H., "Arguing and reasoning in understanding historical topics. *Cognition and Instruction*, 11(3), 1993, 365-395.

Designing of the tasks

The designing of the tasks was based on the theoretical analysis for the development of scientific reasoning skills of Kuhn et al. (1992)[12] The tasks are learning environments for the meaningful approach of both the concepts of Genetic Engineering and the skills of scientific reasoning. The basic principles considered for developing the tasks were:

- The organization of the subject matter of the topic of genetic engineering: constructed tasks covered essential concepts of it (restriction enzymes, plasmids and phages as cloning vectors, gene libraries and cDNA libraries, restriction maps).
- The development of scientific critical thinking skills.

In particular, the series of tasks could be characterized as a wide learning environment for training students in the hypothetical – deductive reasoning and the construction of arguments in specific contexts that concern: hypothesis-testing, prediction of experimental results, interpretation of experimental data, evaluation of particular experimental choices and design of experimental procedures (Ennis, 1989[8]; Means and Voss, 1996[10]; Pontecorvo and Girardet, 1993[11]; Zohar and Tamir, 1991[9]). Each skill was addressed at least twice during the series of lessons. 20 tasks were used. The program covered 4 weeks of the semester. Examples of tasks are given in the appendix.

Theoretical background of group work and development of reasoning

According to Pontecorvo & Girardet, (1993)[11]discussions are collective situations aiming at solving of a problem. Discussions can be conducted by the teacher or autonomously driven by the group peers. Discussion in education can be a very effective context for the training and learning of a new behavior in reasoning. This happens if some particular conditions are met, as for example, starting of from common experiences, the existence of a rather difficult and problematic subject for discussion, and the change of the usual norms of a course –class (Pontecorvo, 1990)[13]. Pontecorvo and Girardet (1993)[11], on the basis of their results from the study of the discussion and reasoning in group discussions of students, suggest that autonomous interactive activities that are developed in the discussion can be very rich situations in producing reasoning of high level. This sort of work lies in a Vygotskian framework. Students can internalize and adapt the cultural processes of a scientific domain (Newman, Griffin and Cole, 1989)[14], when they are supported by the requirements of the task and the social context to apply their general skills of argumentation in a specific problem in a cognitive domain. These discussions in the group can be considered as learning settings of

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[13] Pontecorvo, C., "Social context, semiotic mediation and forms of discourse in constructing knowledge at school". In H. Mandl. E. De Corte, N. Bennet, & H. Friederich (Eds.), *Learning and Instruction*: A publication of the European Association for Research on Learning and Instruction, 2, 1-27. Oxford, England: Pergamon, 1990.

[14] Newman, D., Griffin, P., & Cole, M., *The construction zone: working for cognitive change in school*. Cambridge, England: Cambridge University Press, 1989.

"cognitive apprenticeship" (Collins et al. 1989)[15], where reasoning is both a situated and a discursive action that exists in the social reality of the interaction with the others and the task.

Discussions in small groups are considered to facilitate the development of critical thinking on the basis of the assumption that critical thinking is an active procedure that includes construction of arguments. Argumentation is considered to show the way reasoning flows in conversation. Discussion in small groups is considered to have strong influence on the development of critical thinking skills by the peers of the group (Jacques, 1991[16]; Barnes and Todd, 1977[17]; Kuhn, Shaw and Felton, 1997[18]) because it enables subjects to:

1. express their differences concerning both their personal learning styles and their cognitive level
2. interact substantially (Hart, 1990)[19]
3. follow and internalize the process of critical thinking expressed by their peers (Dixson, 1991)[20]

On the basis of the above we made the choice of teaching conditions that were student – centered and included group work:

- The teacher introduced the subject and conducted the whole class discussion. He gave students information when necessary, during the process of solving the tasks
- Students worked in-groups of 3-4. Groups were formed spontaneously but were kept intact during the whole series of lessons.

Evaluation: design of instruments

Questions considered for the evaluation were:

- Are desired skills developed?
- Can we identify argumentation schemes in the conversations between group peers showing the flow of reasoning?
- Is the experimental group better in achievements in the final test (testing knowledge and scientific reasoning skills) than the control group?

The evaluation of the teaching strategy we adopted for the development of scientific critical thinking had to be accomplished at two levels: development of scientific critical thinking skills and learning of desired concepts. Therefore the evaluation included:

- comparison of pre- and post – tests for scientific critical thinking skills that were developed in topics of biology not covered in the teaching procedure
- a qualitative analysis of discussions of two groups, concerning the expression of arguments, reasoning schemes, hypotheses and conclusions, as these could be considered evidence of the active process of development of critical thinking.
- the final exam as a second post –test for critical thinking skills in the context of genetic engineering and as a test for understanding and learning the concepts of the topic, as well.

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[15] Collins, A., Brown, J. S., & Newman, S. E. "Cognitive apprenticeship. Teaching the crafts of reading, writing and mathematics". In L. B. Resnick (Ed.), *Knowing, Learning and Instruction: Essays in honor of Robert Glaser* (pp. 453-494). Hillsdale, NJ: Laurence Erlbaum Associates, Inc. 1989.

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[18] Kuhn, D., Shaw, V., & Felton, M., "Effects of dyadic interaction on argumentative reasoning". *Cognition and Instruction*, 15(3), 1997, 287-315.

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[20] Dixson, M. D., "Group discussion and individual critical thinking processes: An interactive Perspective". Paper presented at the Annual Meeting of the Central States Communication Association. Chicago, IL, April

Some evaluation issues arising from preliminary analysis of the tests and of the discussions

The tasks used in the pre and post – test were not in the context of gene technology but in the wider context of biology and required basic biology knowledge since they had been designed for testing skills of reasoning and not specific knowledge. In the final exam of the course of Molecular Biology we included the final test for the topic of Genetic Engineering. Questions were chosen on the basis of two criteria: testing the knowledge of the included concepts, and the skills that were addressed through the teaching procedure. We shall not present results here, due to lack of space (to be presented at the ERIDOB conference, September 2000). However from the preliminary analysis of the tests we have evidence showing that the tasks constructed were successful in developing the specific skills and that experimental group subjects succeeded better achievements in the final exam compared to the subjects of the control group.

However, when such instruction procedures are implemented, one expects that experimental group will show better achievements than control group. What is really interesting is the active process of development of critical thinking during peer interaction when dealing with the tasks. The analysis of group discussions was based on the method described by Kumpulainen and Mutanen (1999)[21]. According to these researchers the analysis of group discussions can be conducted in three dimensions. The first dimension concerns the character and the aim of the pieces of speech that the members of the group use in order to communicate, and is the *functional analysis*. The second dimension concerns the *cognitive processing* and examines the ways in which students approach and process learning tasks. The third dimension is the *social processing* and concerns the nature of social relationships that are developed in students' social activity.

Our evidence from this sort of analysis of group discussions is particularly interesting as it shows the process of learning and development of the desired skills under the learning conditions applied in the study. The argumentation developed between members of the group contributed to the realization of previous knowledge and to its application as a basis for solving the tasks. Students' conversations during the process of solving the tasks reveal reasoning episodes with argumentation schemes, which show that the nature of the developed tasks led to an exploratory activity, during which the desired skills could be exercised and developed.

APPENDIX

Examples of tasks follow:

Task 1: *Hypothesis- testing skill*
Phage _K grows inside the bacterium E. coli , strain K and phage _C grows inside the bacterium E. coli, strain C. Phage _C is 100% successful in re-infecting strain C (possibility of plaque formation = 1), but almost totally incapable of infecting strain K (possibility of plaque formation = 10^{-3}).
What could possibly cause this failure of phage _C when changing host?
Hypothesis 1: Phage _C cannot introduce its DNA into the bacterial strain K, because the latter does not have the specific receptors on its surface needed for the adsorption of the former.
Hypothesis 2 : Phage _C does introduce its DNA into the bacterial strain K where -for some reason- it is destroyed.

Question :
In order to test these hypotheses
(a) propose an experiment
(b) what are the predicted results of the experiment you proposed, assuming that the the hypotheses are correct ?
(c) what result would show that hypotesis 1 is propably wrong ?
(d) what result would show that hypotesis 2 is propably wrong ?

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Aims of the task

1. Organization of subject :

The task serves as an introduction to the phenomenon that led the scientists to the discovery of the existence of restriction enzymes, the phenomenon of restriction & modification.

2. Development of scientific reasoning skills :

[21] Kumpulainen, K, & Mutanen, M. "The situated dynamics of peer group interaction: an introduction to an

The task was designed according Lawson's quizzes of hypothesis-testing and requires the generation of ' if – and – then – therefore' hypothetico-deductive arguments, which would allow the rejection of the two hypotheses formulated to explain a specific observation.
Students are expected to propose an experiment similar to that of Hershey & Chase:

- grow E. coli, strain C, in a medium containing radioactive phosphate
- infect these bacteria with phage _
- the phage _C growing in these bacteria have their DNA labeled with radioactive phosphate
- try to infect E. coli, strain K, by these labeled phage _C
- and finally 'search' for radioactivity in the bacteria

Answering sub-questions (b), (c) and (d) gives them the opportunity to develop the desired thinking pattern:

If hypothesis 1 is right (phage cannot introduce its DNA in the bacteria) *(hypothesis)*
and the proposed experiment is conducted *(proposed test)*
then there will be no radioactivity in the bacteria *(predicted result)*
But if the experiment is conducted and radioactivity is found in the bacteria
Therefore we could conclude that hypothesis 1 is propably wrong. *(conclusion)*

If hypothesis 2 is right (phage's DNA is destroyed after being introduced in the bacteria) *(hypothesis)*
and the proposed experiment is conducted *(proposed test)*
then there will be radioactivity in the bacteria *(predicted result)*
But if the experiment is conducted and radioactivity is not found in the bacteria
Therefore we could conclude that hypothesis 2 is propably wrong. *(conclusion)*

Task 4: *designing experimental procedures*

A plasmid, which has genes responsible for resistance to antibiotics kanamycine and ampicilline, is digested with restriction enzyme Bgl lI which cuts inside the sequence of the gene giving resistance to ampicilline. Furthermore, the cut plasmid DNA is incubated with a segment of Drosophila DNA already digested with Bgl II. The recombinant product is used to transform E. coli cells.

a. What antibiotic would you use to make sure that you would find all the colonies of bacteria with plasmid?
b. Which bacterial phenotypes resistant to your antibiotic do you expect to find?
c. How can you find alive the bacteria with the recombinant plasmid?

Aims of the task

Organization of subject : the task is a part of a wider unit which examines the characteristics of plasmids that are necessary for their use as a cloning vectors.
The specific characteristic studied here is the existence of 'indicators' , genes that offer resistance to antibiotics and include recognition sites for restriction enzymes, helping us to find the bacteria with the recombinant plasmid.
Development of scientific reasoning skills : Question (a) requires the generation of an argument which will be based on the identification of the assumption included and will lead to a conclusion concerning the specific experimental choice.
1st claim: the assumption that attempting to form recombinant plasmids is not a 100% successful procedure
2nd claim: bacteria with recombinant plasmids are sensitive to amp, since the gene that would offer resistance to amp is inactivated by insertion of Drosophila DNA segment
3rd claim: bacteria with recombinant plasmids are resistant to kan, since recombination does not influence the relevant gene (kan^R amp^S)
4th claim: bacteria with non recombinant plasmids are resistant to both antibiotics (kan^R amp^R)
5th claim: **if** amp is added to the petri disc, **then** bacteria with the recombinant plasmid will not survive
6th claim: **but if** kan is added, **then** bacteria with plasmid, recombinant or non, will survive.
Conclusion: therefore, the proper antibiotic here is kan.

Question (b) aims at helping students to identify the assumption mentioned above and it is actually explored in the context of (a). Question (c) requires the design of an experimental procedure which would allow for the detection of alive bacteria with the recombinant plasmid.
1st claim: if amp is added, then we will detect the bacteria with recombinant plasmid by killing them
2nd claim: the aim here is to have them alive
Conclusion: therefore, we should have a replica of the culture before adding the antibiotic, so that we could have alive in replica the bacteria killed in the original culture.