FROM A CAUSAL QUESTION TO STATING AND TESTING HYPOTHESES: EXPLORING THE DISCURSIVE ACTIVITY OF BIOLOGY STUDENTS

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ABSTRACT

This paper aims at exploring the discursive activity of one group of second year biology students during their collaboration on a task of stating and testing hypotheses to answer a causal question. The specific task is a part of a didactic sequence that was developed in the context of genetic engineering considering aspects of situated-learning theory, with the aim of providing students the opportunity to 'talk science' with their peers as participants of a hypothetical gene cloning project. Our focus is set on certain cognitive aspects of peers' discourse. Hence, this paper is concerned with the construction of arguments, particularly on the level of argumentative operations (e.g. claims, justifications, challenges) and the context-bound epistemic operations (e.g. abducting, appealing to instances) activated by peers in order to produce a joint answer to the task's causal question. Furthermore, it is concerned with the development of the *'if...and...then'* hypothetical-deductive reasoning pattern potentially involved in peers' hypothesis-testing process.

1. INTRODUCTION

Recent research in science education focuses on the study of students' argumentation in various contexts (Mason, 1996; Desautels & Larochelle, 1999; Jimenez, 2000; Driver et al., 2000; Simonneaux, 2000). Our study attempts to build on this body of research work by focusing on the construction of biology students' arguments while interacting in the context of genetic engineering for the formulation of a hypothesis and the development of *'if... and...then'* reasoning patterns to test their hypothesis.

Stating hypotheses (tentative explanations to causal questions) constitutes, in general, a complex process of combining empirical evidence, previous knowledge, and intuition (Lawson, 1995). The role of argument in this process seems to be crucial. Partial scientific claims towards an explanatory framework do need to be well grounded in warranting structures that are built on reliable epistemic criteria (Driver et al., 2000). Furthermore, the possible formulation of more than one alternative hypothesis for the same causal question, activates a process of comparative evaluation of their explanatory efficacy to decide which one is the

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fittest (Giere, 1991) and therefore should be experimentally tested. Argument is also a necessary tool when designing the experimental tests to be used in hypothetical-deductive reasoning. Stating, justifying, and evaluating scientific claims remains a prerequisite for making predictions about the expected outcomes of the test, assuming the hypothesis' validity, and for defining the conditions of the hypothesis's rejection by comparing the expected and the potentially observed outcomes of the proposed test (Lawson, 1995).

Our focus is set on the process of formulating and testing hypotheses and the employment of argumentative and epistemic tools in this process. Thus, the question framing our study is *'how do collaborating students formulate and test hypotheses in the context of genetic engineering?'*. More specifically, *'what kind of argumentative and epistemic operations do students activate in the process of stating and testing hypotheses?'* and *'to what extent do they follow the hypothetical-deductive reasoning pattern to explore the validity of their hypotheses?'*. In summary, the objective of this paper is to highlight students' reasoning patterns on hypothesis stating and testing by analyzing both the argumentative process towards its construction and the resulting construct itself.

2. METHODS

The task and the setting

A didactic sequence of genetic engineering was developed on aspects of *situated-learning theory* to provide biology students with an *authentic* context for practicing scientific reasoning and discourse. In a student-centered setting, peers collaborated in small groups to create joint answers to tasks embedded in a hypothetical gene cloning mission as its meaningful and purposeful steps. Peers who were supposed to be responsible for cloning a medically useful plant gene were faced with choices, predictions, experimental proposals, and stating/testing hypotheses. The teacher's role was limited to introducing themes, giving hints, and conducting whole class discussions after the group work.

The participants of the group discussion presented here are three female students who volunteered to be tape-recorded while interacting as they stated and tested tentative explanations of the cloned gene's inability to synthesize its protein in bacteria (see Appendix). Lawson's hypothesis-testing quizzes (Lawson, 1995) were taken into account for the task's development, resulting in the insertion of a scaffolding device which explicitly requires that peers predict the expected outcomes of their experimental test regardless of the adequacy of their hypothesis. The task aims at encouraging students to practice scientific reasoning through argumentative discourse. It does this by engaging peers in a process of developing hypothetical-deductive reasoning to answer a causal question which derives its meaning and purpose from a hypothetical cloning mission, and which also challenges the application of peers' background declarative and procedural knowledge.

An overview of the analysis process

The peer group discussion was tape-recorded, transcribed and segmented to message units, each expressing a single idea in possibly more than one linguistic clauses (Kelly et al., 1998; Mason, 1996). Sequences of message units were then identified on the basis of the different levels at which they were carried out. Thus, we identified sequences on the levels of:

- Constructing a joint answer to the task (*on-task sequences*);
- Re-establishing intersubjectivity as a necessary condition for an effective shift to the previous level (*repair sequences*) (Roth, 1995);
- Evaluating the constructed answer or part of it (*meta-sequences*);
- Gaining hints and/or clarifications from the teacher (*teacher-help sequences*).

The segmented discussion was coded for argumentative and epistemic operations and finally analyzed on the levels of the argument constructions and hypothesis-testing reasoning pattern development.

The analytic tools

Concerning the argumentative operations, we mainly drew on the framework proposed by Pontecorvo and Girardet (1993), and additionally on that proposed by Resnick et al. (1993). The derived coding scheme, summarized in Table 1, incorporates typical claims and justifications, as well as non-typical structural elements of the argument (oppositions, concessions, challenges). So, it is considered adequate for approaching both the individual and the social aspect of students' argument constructions, namely adequate for identifying the contribution of the *'other'* to the construction of one's own arguments. For example, a justification request carried out through the socially oriented operation of challenge may be a condition that leads to providing grounds for a spontaneously non-justified claim, thus to constructing a new argument. Similarly, opposition to a stated claim may be the trigger for more complex, sufficient, or persuasive justification structures on which to ground the claim. Furthermore, this scheme may highlight the dynamic process of argument construction, since – considering argument as *any* justified claim, concession, or opposition – it becomes possible to probe all intermediate arguments formulated towards the final answer. Following these arguments, we can also reconstruct the argumentative patterns employed in peers' discourse as persuasive strategies.

After considering several coding schemes proposed for the domain-bound epistemic operations (Pontecorvo et al., 1993; Mason, 1996; Jimenez et al., 2000), we constructed a new scheme that emerged to a large extent from our own data. The derived scheme, presented in detail elsewhere (Ergazaki & Zogza, 2002), makes it possible to identify the 'micro' cognitive procedures in which students are engaged in the specific context in order to construct their reasoning strands. In the case of the specific task, categories like 'abduction', 'prediction', or 'interpretation of outcomes' may permit us to follow peers' hypothetical-deductive reasoning, while others, like 'referring to' experimental handling or to background knowledge, may be useful in outlining the peer design process which moves students towards the experimental test of their hypothesis. Finally, the several kinds of 'appeals' incorporated in the scheme, make it possible to define which criteria (i.e. experimental goals, background knowledge, authority) do count among students as warranting tools throughout the process of hypothesis formulation and testing in the context of genetic engineering.

Table 1. The coding scheme for the argumentative operations

ARGUMENTATIVE OPERATIONS	DEFINITION
Claim	Any clause stating a position without necessarily constituting an answer to the task
Justification	Any clause providing grounds to a standpoint
Concession	Any clause admitting a point claimed by another peer (confirming a claim or a justification)
Opposition	Any clause denying a point claimed by another peer (rejecting a claim or a justification)
Challenge	Any clause requesting either justification or inquiry of specific issues

3. RESULTS

An overview of peers' discourse

From the outset of the discourse, Fani (*F*) seems to have figured out one plausible explanation for the failure of the cloned plant gene to synthesize the MRT protein in bacteria. Thus, employing a series of challenges, she facilitates her peers to explore key issues in the formulation of the hypothesis, 'failure cause: no mRNA splicing in bacteria', which is finally contributed by Vasso (*V*). Nevertheless, the third peer of the group, Elsa (*E*), doubts the plausibility of the hypothesis by appealing to the *fact* that known eucaryotic proteins are indeed synthesized in bacteria.

F, insisting on her standpoint, attempts to propose a hypothesis testing procedure, but she only comes up with a procedure 'testing' the datum of the MRT synthesis failure in bacteria: '*if* the cancer cells of the culture continue their division after the bacterial MRT protein is added, *then* the MRT protein is not actually produced in bacteria'. The proposed experiment is evaluated in a meta-sequence as inappropriate for testing the hypothesis. This becomes, in turn, the focus of a series of adversarial exchanges among peers.

So, *E* doubts once more the plausibility of the hypothesis, based on the *fact* of eucaryotic proteins' synthesis in bacteria. This time *V* is persuaded, while *F* grounds her opposition by appealing to the handling of cDNA cloning. The dialogue is shifted again to the meta-level, which allows for a better definition of the cloning goal apart from protein synthesis.

After requesting the teacher's clarification on whether the failure of protein synthesis in bacteria represents a broad problem solved through cDNA cloning, peers develop another test for the stated hypothesis. *F* suggests the elimination of the proposed cause in order to examine the deriving consequences on the cause's potential effect. Thus, she produces the strand '*if* the MRT protein is indeed synthesized in bacteria by an mRNA cloned in bacteria but already spliced elsewhere, *then* the cause of the previous failure of its synthesis must have been the inability of the mRNA splicing in bacteria'. So, once more the validity of the hypothesis is predicted upon the experimental outcomes and not vice versa.

Following the scaffolding device of the task, peers use this last experimental test to develop a hypothetical-deductive reasoning pattern. The resulting reasoning strand is: '*if* the hypothesis is right, *then* the synthesis of a functional MRT protein is expected'. This *'if…then'* pattern is enriched with information about the testing procedure: *'if* the hypothesis is right *and* the test of cloning spliced mRNA in bacteria is conducted*, then* the propagation of the cancer cells in the culture will be inhibited*'*. It is also worth noticing that the group does not proceed to comparisons between expected and 'observed' outcomes to reach a final conclusion about the rejection of the hypothesis. The dialogue is ending while peers summarize their reasoning strand to the teacher.

Argumentative and epistemic operations

The results of our analysis on the level of the argumentative and epistemic operations indicate that peers are engaged in a highly argumentative discourse using a rich set of epistemic tools (Table 2). Apart from activating the operation of justification (29 times) to support (20) claims directly, (7) oppositions and (2) concessions, peers also employ higher-order justification structures for (5) claims and (1) concession. These structures may be either 'subsequent' or 'complex'. Subsequent warrants (Kelly, 1998) consist of a whole argument (a justified claim, opposition, or concession) in support of a premise, while complex ones may include more than one argument or several combinations of arguments and claims, oppositions, or concessions in support of a premise.

The number of explicitly unjustified operations in the discourse is similar to the number of operations that were justified in various ways (35 in each case, unjustified and justified), showing peers' tendency to leave things implicit while carrying out discussions on common ground. In fact, the character of the unjustified operations may account for the latter's non-warrantability. Confirmatory concessions, claims implicitly grounded in shared knowledge, common sense, and given data; or predicative counter-oppositions against oppositions to already thoroughly justified premises, may indeed be excluded from the justification rule without undermining the discourse's argumentative character.

Table 2. The epistemic operations activated by the peer-group

Epistemic operation	Times of activation in the discourse
Appeal to	
- experimental handling	(2)
- background knowledge	(3)
- task data	(3)
- instances	(1)
Refer to	
- experimental handling	(9)
- background knowledge	(4)
- experimental goal	(2)
Abduction	(2)
Prediction	(5)
Interpretation of outcomes	(1)
Task reframing	(1)
Recognition of assumption	(1)
Definition of concepts	(1)
Evaluation	(12)

The process of stating a hypothesis by the peer group is facilitated through the argumentative operation of challenge, not as a direct request for justification but as a request for exploring specific key issues by applying background knowledge. So, the contribution of challenge to the process of 'abduction' concerns its use as a scaffolding tool mobilizing epistemic operations like 'refer to/appeal to background knowledge' about introns, cDNA, and mRNA splicing. On the other hand, the process of reaching consensus on the plausibility of the thus formulated hypothesis is actually hindered by the employment of complex warranting structures (each consisting of two claims justified by 'appealing to' background knowledge or to experimental goals) based on the *'counterfactual strategy'* (Pontecorvo & Girardet, 1993). Undermining the stated hypothesis by considering its implications as contradictory with real *facts*, is attempted repeatedly in the discourse: *'if we accept the hypothesis 'cause of protein-synthesis failure: cloned gene's introns', then we must accept that there is no way of producing eucaryotic proteins in procaryotic cells / that it is not possible for the recombinant DNA technology to function / that we shouldn't have been given instructions to carry out the cloning procedure up to* *this point using DNA; which we know that it is not really the case. Thus, the hypothesis cannot be accepted'*. Nevertheless, the oversimplified generalization behind the counterfactual mechanism of these warrants is rebutted with a direct justification through the epistemic operation of 'appealing to' the handling of carrying out the cloning procedure with cDNA instead of DNA. It is worth noticing that background knowledge on cDNA when creatively applied to the construction of a simple argument, not only resolves peers' disagreement on the hypothesis plausibility and unblocks the discourse towards the proposal of an experimental test, but also provides peers with a framework for disconnecting the cloning goal from the protein synthesis through the epistemic operation 'definition of concepts'.

The argument remains a significant tool in the process of testing the shared hypothesis through the epistemic operations of 'referring/appealing to experimental handlings', 'evaluating', 'predicting', and 'interpreting outcomes'. Specifically, the initial proposal is rejected with a direct justification 'evaluating' negatively its effectiveness in testing the hypothesis. The next attempts are shaped by subsequent warranting structures in support of experimental handlings, like having the mRNA spliced elsewhere or adding the new protein to a culture of cancer cells. So, the idea of transferring mRNA into a system where the splicing process will be possible is warranted by an argument stressing the opportunity to remove the factor that possibly causes failure in protein synthesis in order to test the effect on the resulting protein. Similarly, the idea of having the new protein added to a culture of cancer cells is supported by another argument based on the assumption of the protein's anti-cancer function and the possibility of interpreting the outcome of this in regard to the hypothesis validity. Peers develop their hypothesis-testing reasoning pattern through the epistemic operations of 'prediction' and 'interpretation of outcomes': the group predicts – although not deductively – the expected outcome and subsequently interprets it as the hypothesis confirmation.

Hypotheses' testing reasoning patterns

The causal relationship of variables *A* (cause: no splicing in bacteria) and *B* (effect: no plant-protein synthesis in bacteria), is explored through an experimental intervention on *A* (cloning a spliced gene) and a subsequent examination of its implications on *B* (what happens to the MRT protein). In other words, peers' reasoning, while proposing a test to establish or not a potentially causal relationship, is shaped by exploring the co-variation of the possible cause *A* and its effect *B*. Coming to a conclusion about the validity of the tested hypothesis leads to a further elaboration: '*if* the proposed experimental handling which aims at eliminating the 'possible cause *A* – no splicing', alters the 'possible effect *B* – no protein synthesis', *then* it may be concluded that the *A* is indeed a valid cause for the effect *B*'.

The character of peers' spontaneous, hypothesis-testing reasoning pattern is confirmatory. In fact, peers are interested in confirming the hypothesis despite the rejection-oriented scaffolding device embedded in the task. This is rather fallacious, since the confirmation of a hypothesis might be claimed only in the case that the hypothesis remains unrejected after many appropriately designed tests (Lawson, 1995). Reasoning in a confirmatory context, peers encounter the following pitfall:

they claim the hypothesis validity based on the experimental outcomes of the proposed test, instead of predicting the latter on the basis of the former. So, they substitute the deductive reasoning '*if* hypothesis X is valid, *then* the expected outcomes of the proposed test are x' with the inductive reasoning, '*if* the proposed test for hypothesis X gives the outcomes x, *then* the hypothesis X is valid'. The pitfall in question may be associated with the invalid assumption that the relationship 'cause-effect', and consequently the relationship 'hypothesis-predicted testing outcomes', are unidirectional. Thus, it indicates that peers seem to ignore the fact that the same hypothesis may be the source of more than one (different) prediction, as well as the fact that the same prediction may derive from different hypotheses. A second assumption possibly associated with peers' fallacies is the one of absolute trust in the appropriateness and reliability of the proposed test. In other words, peers seem not to consider the possibility of an experimental outcome deriving from a bad experimental handling or a procedural mistake and not necessarily from the validity of the tested hypothesis itself.

Finally, when attempting to adapt their reasoning to the scaffolding-device, peers shift from the problematic inductive pattern to the deductive one, but they do not proceed to the required predictions of those outcomes or to a rejection of the hypothesis. Instead, they remain consistent with their confirmatory context, since they only follow the first steps of proposing a test and predicting its outcomes, while leaving out of focus the critical step of defining the conditions of hypothesis rejection.

4. DISCUSSION

Our analysis indicates that peers, being engaged in a symmetrical and mainly adversarial interaction, produced an argumentative discussion based on a rich set of epistemic tools to accomplish their collaborative goal of stating and testing a hypothesis for the cloned gene's failure to synthesize its protein in bacteria.

Peers managed to formulate the appropriate hypothesis by applying systematically their background knowledge concerning the introns of eucaryotic genes and the resulting need of mRNA splicing, the absence of splicing mechanisms in procaryotic cells, and also the cDNA synthesis from spliced mRNA.

Combining, elaborating, and synthesizing ideas in a group discussion to come up with a commonly accepted explanation is much more demanding for peers than reproducing a ready-made statement in a typical 'triadic dialogue' led by the teacher (Lemke, 1990). The role of argumentation in this process is two-fold, since it is employed as a reasoning tool and also as a persuasive one. This is quite clear in peers' adversarial exchanges while attempting to reach consensus on the hypothesis plausibility before proceeding jointly to its experimental test. Complex warranting structures synthesizing a counterfactual strategy are employed as a persuasive device against the stated hypothesis, while one direct justification that invokes background knowledge is contributed in favor of it. Peers' commitment to the proving power of 'real facts', which is expressed in the counterfactual persuasive strategy, loses ground when confronted with valid knowledge resources. Thus, argument seems to be more than a rhetorical device in peers' discourse towards a joint hypothesis. Furthermore, it is worth noticing the social character of argument construction that is stressed by the role that argumentative operations like challenge and opposition, as well as epistemic operations like evaluation, do play in the discourse.

The hypothesis-testing reasoning constructed in peers' argumentative discourse does not follow the hypothetical-deductive reasoning pattern. It seems that peers prefer inductive to deductive reasoning, as well as hypothesis confirmation to hypothesis rejection. Thus, they infer the hypothesis validity based on the outcomes of the proposed experimental test, when they are actually requested to do the opposite. Moreover, when finally adapting their reasoning to the task's scaffolding device, they shift to the deductive pattern, but they are still focused on confirming the hypothesis, since they do not define the required hypothesis-rejection conditions. This invalid preference needs to be explicitly stressed by the teacher so that peers can recognize this pitfall in hypothesis testing. Grasping the need to deductively predict instead of inductively infer is a significant task, since it might save students from fallacies, such as making hasty generalizations, when reasoning in scientific and in everyday contexts. It is also associated with understanding the key idea that confirming a hypothesis is a much more demanding task than rejecting one, since confirmation requires coming up with a series of different predictions based on the potential validity of the hypothesis as well as thinking of a series of appropriate experimental tests. Finally, a purposeful teaching goal might be to support peers in recognizing that, despite the multiple predictions and tests confirming a hypothesis, there is always the possibility that the next prediction's test will break the confirming sequence irreversibly, dictating, therefore, rejection of the hypothesis. In summary, the implications of the differences between peers' hypothesis-testing reasoning and the hypothetical-deductive pattern, may serve as a fruitful basis for improving peers' hypothesis-testing skills.

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APPENDIX

You have already accomplished the goal of completing successfully the cloning procedure of the *MRT* plant gene in bacterial cells. Nevertheless, your co-researchers have gained promising results from the continuing preliminary studies on the potential anti-cancer effect of *MRT* protein, and thus your team is assigned to the task of synthesizing this protein massively in bacterial cells. So, continuing to grow the cell culture having the *MRT* gene, you are surprised to realize that the *MRT* protein is not in fact synthesized in the bacterial culture.

- How could you explain this observation? Why is the *MRT* protein not produced in the bacteria by the cloned *MRT* gene? Can you give a tentative explanation for this? In other words, can you formulate a so-called hypothesis?
- To develop a testing-reasoning for your hypothesis, follow the next steps:

1. Propose an experimental procedure: how could you experimentally explore the validity of your hypothesis?
2. What are the outcomes of the proposed test that would show you that your hypothesis is probably right?
3. What are the outcomes of the proposed test that would show you that your hypothesis is probably wrong?