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A case study on mathematical routines in undergraduate biology students' group-work

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In this paper, we investigate the mathematical discourse of undergraduate biology students when working on biology tasks. Our data consists of students' and the lecturer's discussion when working on two tasks in an Evolutionary Biology course. In our analysis we make use of the commognitive framework and focus on the use of mathematical routines. We observed that although the overall aim of students' engagement with routines was exploratory, the way they engaged with mathematical routines when working on biology tasks was ritualized. However, students were aware of the need of using construction routines when trying to mathematize a biological phenomenon although the lack of familiarity with relevant construction routines constrained their ability to deal with certain task situations.

Keywords: Commognitive perspective, mathematical discourse, mathematics in biology, routines, rituals and explorations.

Introduction

In the last four decades, the role of mathematics in the science of Biology has greatly increased. This has influenced undergraduate and graduate biology students who need to be mathematically capable to meet the demands of this science (i.e. Labov, Reid & Yamamoto, 2010). Students need to understand and work with contemporary mathematical models and frameworks that are applicable in analysing the overwhelming flow of biological data. However, various studies have shown that biology students face many challenges and difficulties in their biology courses when mathematics is used as an analytical tool (i.e., Speth et al., 2010; Brewer & Smith, 2011). These difficulties can be partly explained by a prevalent epistemological perspective on the connection between mathematics and other disciplines that Barquero, Bosch and Gascón (2011) have called “applicationism”. According to this view, common at the university level, “first mathematical tools are built within the field of mathematics and then they are ‘applied’ to solve problematic questions from other disciplines, but this application does not cause any relevant change, neither in mathematics nor in the rest of disciplines where the questions to study appeared” (ibid, p. 1940). Barquero, Bosch and Gascón argue that such a perspective has problematic effects particularly on mathematical modelling practices, since these require a solid understanding of the connection between the mathematical tools and the context in which they will be used.

This paper, which is based on the pilot study of a doctoral research project aimed at exploring and characterizing the mathematical discourses of undergraduate and graduate biology students, investigates students' group-work in a biology course in a Norwegian university when engaging with biology tasks that use mathematics as an analytical tool. Taking a discursive approach, we

analyse students' and the lecturer's mathematical discourse when working on two tasks aiming to explore the routines that students engage with and the character of this engagement, and to provide insights into the kind of mathematical discourse that the lecturer expected students to engage with.

Commognitive framework

This study is grounded in the commognitive framework (Sfard, 2008). In this framework, mathematical knowledge is conceived through a community's established modes of communication called discourses. A discourse is defined as a "specific type of communication made distinct by its repertoire of admissible actions and the way these actions are paired with reactions" (ibid., p. 297). In other words, discourses are different types of communication set apart by certain characteristic features. In particular, mathematical discourse is described by four features: word use, visual mediators, endorsed narratives and routines.

Our focus in this paper is on the students' use of routines. Sfard (2008) originally defined routines as "repetitive patterns characteristic of the given discourse" (ibid., p. 134). However, recent work by, for instance, Lavie, Steiner and Sfard (2019) elaborates further of the notion of routine. They define routines using the notions of task situation, task and procedure. First, task situation is understood as a setting in which "a person considers herself bound to act – to do something" (ibid., p. 7). Second, a task is "the set of all the characteristics of the precedent events that she (the person) considers as requiring replication" (ibid., p. 9). The task refers to a person's interpretation of a given task situation; and, by precedent event, the authors mean all that happened in the precedent task situation. Third, a procedure is "the prescription for action that fits both the present performance and those on which it was modelled" (ibid., p. 9). The procedure is implemented by the task performer in response to a given task situation. Lastly, a routine which is performed in a given task situation by a given person is the task, as seen by the performer, together with the procedure the person executes to perform the task. Routines are distinguished as practical if the person interprets the task situation as requiring a change, re-organizing or re-positioning of objects; or discursive if the person interprets the task situation as requiring a communicational action (Lavie, Steiner & Sfard, 2019). Moreover, a routine is characterized as exploration if it is oriented towards the outcome; and, as ritual if it is a process-oriented performance. Thus, while an explorative task aims at producing a new "historical" fact about mathematical objects, a ritual is appreciated for its performance and not for its product. Explorations according to Sfard (2008) are divided into three categories: construction (a process resulting in a new endorsable narrative), substantiation (deciding whether to endorse previously constructed narratives) and recall (the process of citing a narrative that was endorsed in the past). According to Lavie, Steiner and Sfard (2019), students participate in unfamiliar discourse in a ritualized way. However, in further learning, their routines are expected to "undergo gradual de-ritualization until they eventually turn into full-fledged explorations" (ibid., p. 2). A person performs a certain mathematical routine in the present task situation because of its "precedents – to past situations which she (the person) interpret as sufficiently similar to the present one to

justify repeating what was done then, whether it was done by herself or by another person” (ibid., p. 8). The precedents are chosen with the help of “precedent identifiers – to those features of the current task situation that a person considers as sufficient to view a task situation from the past as a precedent” (ibid., p.8). The analysis in this paper examines this relation focusing particularly on the following research questions: “What characterizes students’ mathematical discourse when engaging with biology tasks?” and “How does students’ mathematical discourse relate to the lecturer’s intended solutions of the tasks?”

Method

This research is a case study of the course Evolutionary Biology, an undergraduate biology course at a large Norwegian university. The study was conducted during the spring semester of 2018. All students enrolled in the course were required to have taken at least one course in Calculus and one in Statistics. The aim of this course is to provide students with a deeper insight into the evolutionary processes that can explain the genetic composition of populations, form, behaviour and distribution of organisms, and to acquaint students with the basic methods of analysing evolutionary relationships between species. Moreover, students are introduced to different mathematical models of evolution. During the course, three sessions are dedicated to students’ group-work. In these sessions, students are asked to work on different questions related to the topics that have been presented by the lecturer in the lecturing sessions. In this paper, we present data from one of these group-work sessions. In this particular session, students were asked to work in groups on a quiz with multi-choice questions. Students had 30 minutes available to finish the quiz. They were first to work individually for 10 minutes, then discuss their answers in small groups. The lecturer also handed out an answer sheet, enabling the students to check if the proposed alternative was the right one. After the small group discussion, the group had to agree upon a correct answer, which was then evaluated using the answer sheet. As students were working on the quiz, the lecturer circulated among the groups, providing help if needed. At the end of students’ group-work, the lecturer discussed each question of the quiz in front of the class.

In our analysis, we focus on two questions: *Heritability Equation* and *Genetic Correlation*. The first question (see Figure 1) requires students to find the correct formula of heritability (h^2) which is given as a proportion of response (R) to selection (S).¹ This formula derives from the definition of heritability as the degree to which a certain trait in individuals is genetically (rather than environmentally) determined when the genetic construction of an individual and the environmental factors have a normal distribution. This equation had been introduced in a previous lecture. The second question (see Figure 2) requires students to reason about negative and positive correlation between variables. Although this specific question had not been previously discussed, the lecturer had previously introduced the theoretic background on genetic correlation between variables.

¹ R - is the response to selection for certain trait, S - is the selection differential, defined as the mean phenotypic difference between selected individuals and the population mean (see, Falconer and Mackay, 1996).

For the purpose of this study, we video and audio-recorded two groups of five students each (in total there were 32 students in the class, divided into groups of five or six) and the lecturer's discussion afterwards. The two groups of students were chosen randomly. All collected data was transcribed. Students' and lecturer's discussions were conducted in English. When analysing the data, we focused on the identification of students' and lecturer's mathematical routines. We analysed separately the transcripts of each students' group-work and the lecturer's discussion, looking for instances where they were engaged in mathematical routines. Then we compared the findings from each students' group work with the lecturer's discourse. In the process of data analysis, we also looked for signs of exploratory or ritualized engagement, for instance, whether students' routine use was aimed at producing or justifying mathematical claims, or if they appeared to be engaging in routines without a regard for their relevance for the task at hand.

Results

In this section, we will analyse each question separately, considering both the students' group-work and the lecturer discussion where he presented his expected solutions.

4. One way to calculate heritability is by looking at the response to directional selection. Which equation is correct?

a) $h^2 = \frac{S}{R}$; b) $h^2 = \frac{R}{S}$; c) $h^2 = \frac{R^2}{S^2}$; d) $h^2 = \frac{R^2}{S}$

Figure 1: Heritability equation

Analyzing students' work on the Heritability Equation task, we observed that as the first step toward finding the correct response, students would engage with recall routines – trying to recall the equation given during the lectures or written in their textbook. Of the two groups of students that we video-recorded, only one student was able to remember the correct form of the equation, and she still expressed some doubt concerning her choice: “I think the right answer is *b*). I'm just trying to remember what was written in the book but I'm not sure about it”. After failing to recall the correct equation, students tried engaging in construction routines. They started discussing what the variables in the equation stood for and how they were defined. Although students were able to identify them biologically, they could not recall the meaning behind these variables: ‘I think *h* is everything that is heritable, and *R* is of course response and *S* the selection, but I don't remember what they mean or how you actually use them’. Being unable to explain what these variables represent biologically urged students to look for other solutions. They tried reasoning mathematically using the properties of ratio and squared numbers. As shown in the dialogue below, through the use of these mathematical routines, the students tried to construct a new endorsable narrative (the equation of heritability).

Student1: I'm guessing *b*) or *d*) ... because that would be response squared divided by selection, so the higher the response, the higher is the heritability; the higher the selection, less heritability.

Student2: Yeah, but you can also see that there is only one answer where is the opposite which leads to one of these to be right.

Student1: Yeah, but the question is which one should we square?

Student2: They can both be squared.

.....

Student3: Why would you have it squared?

Student2: To negate the possibility of a negative answer. Just square something and it cannot be negative.

Despite engaging in construction routines, the students in the first group were unable to come up with an answer, since these routines were not helpful enough for justifying any of the proposed alternatives. Thus, they decided to postpone the question. They had a further reason for this: since the following question was directly asking for the definition of heritability, they believed that the alternatives given there would help them to find the expected definition of heritability. After students had spent some minutes working on the quiz, the lecturer asked them if they needed help with the questions. He suggested using another definition of heritability given during lectures, but the group still felt lost and, in the end, the group gave up and just skipped the question. Meanwhile, the second group, after some discussion, agreed upon alternative (*d*), arguing that if you have a higher selection in the numerator then the response is higher in the denominator, although without explaining why that would make sense biologically. Checking the answer sheet and realizing that they had selected the wrong answer, they merely exchanged this for the correct answer. Thus, we can observe that in this exercise, although students used construction routines with the overall aim of formulating a new endorsable narrative, they engaged with the mathematical routines in a ritualized way – employing the routines without much regard to their relevance for the problem at hand, and consequently failing to come up with a meaningful narrative.

In the follow-up discussion of the first question, the lecturer began by saying: “I told you, you have to learn these equations and some of you didn’t”. Although the lecturer was laughing as he said this, suggesting that he was perhaps not entirely serious, it still implies that he was not really expecting students to come up with the correct alternative from scratch. Rather, he just expected them to remember it. In other words, he expected them to use recalling routines rather than construction routines. However, he also explained how the model could be constructed and how the form of the equation could be justified using the graph of normal distribution which describes the relation of differential selection and response. Hence, during his explanation of the task, he used construction routines that differed from the ones the students used in their solution attempts. Neither normal distribution nor the alternative definition suggested by the lecturer to the first group, were mentioned by any of the students.

The second question (see Figure 2) focused on genetic correlations of three different variables. This question, unlike the first one, could not be solved using only recalling routines. Since the task required actions for deciding whether to endorse previously constructed narratives, the

solution will involve substantiation routines. Working on this task, both groups struggled with the same issue as in the first question: converting variables into their biological context. However, in this case, students were able to come up with the meaning of genetic correlation, but as shown in the

7. Here, are two questions dealing with genetic correlations, using a real-world example. Pick the alternative which has the correct answer for both questions.
The genetic correlation between %_Fat and Kg_Food/Kg_Gain (Feed Conversion Ratio) is positive, +33. (Hint: Think of Kg_Gain as 1, and Kg_Feed getting higher or lower). The genetic correlation between %_Fat and Days_to_Market (how long it takes to reach the weight at which the pig is sold) is negative, -20.

7A) What will be the effect of selecting for leaner pig (less fat) on Days_to_Market?

7B) What will be the effect of selecting for leaner port on feeding costs?

a) 7A) Days_to_Market will be longer; 7B) higher feed costs.
b) 7A) Days_to_Market will be longer; 7B) lower feed costs.
c) 7A) Days_to_Market will be shorter; 7B) higher feed costs.
d) 7A) Days_to_Market will be shorter; 7B) lower feed costs.

Figure 2: Genetic Correlation

dialogue below, they struggled with making sense of the biological interpretation of their result.

Student2: But if there is a negative ratio between fat and days to market, that means that if fat increases then days to market decrease, right? ... Then, that would mean that less fat, more days to market? And if we apply the same logic to the first one, then fat decreases, then we need less food.

Student3: Yeah, I thought that when I read it. I thought it was the amount of fat correlates to the Days to Market so that means that the percentage of fat...the amount of days at the market would lower the percentage of fat by a factor of 0.2.

Student2: Which does not make sense.

.....

Student4: I understand your point. I just guessed something because I was thinking about what is the effect of selecting leaner pork on feeding costs. If you think logically, then it would take shorter time to get a leaner pork than a fat pork which means lower feeding costs, right? So, I just kind of started thinking without the mathematics.

After some discussion, both groups came up with the right answer. Still, the second group first tried drawing a conclusion through reasoning biologically, rather than considering the quantitative relations between variables. However, due to a mistake in their biological reasoning, they ended up with the wrong answer. Realizing that, they started re-examining the correlation between the variables, noticing that just considering the relation between variables would lead to the right answer. In his discussion of the solution to this question, the lecturer suggested that it should have been based on the meaning of genetic (negative or positive) correlation, which fits with what the students did. Thus, his expectation on the kind of routines that students should

have used during the exercise were fulfilled (despite the fact that the second group failed in their first attempt).

Discussion

In this paper we have analysed students' and the lecturer's discourse when working on two biology tasks involving mathematical elements: *Heritability Equation* and *Genetic Correlation*. These two tasks set by the lecturer in a group-work session differ from each other concerning the expected routines that students were required to use when solving them. In the second question, the mathematization of the problem had already been done, meaning that the relation between variables was given, and the students just needed to use that relation. Thus, they were expected to use substantiation routines in order to endorse previously constructed narratives. In the first question, on the other hand, the mathematization of the problem was not given. Students had two possibilities in this case – use recall routines to remember the correct form of the equation from previous lectures or use construction routines to construct a mathematical model for the problem.

Working on *Heritability Equation*, when the students were unable to remember the correct equation, they used construction routines. However, considering that they did not remember the biological meaning of any of the variables, students were not left with many choices other than identifying other features of their current task situation that would allow them to repeat precedents from their past situations. The choice to use properties of ratio and squared numbers as a step to overcome the constraints of the task, shows that they were trying to apply familiar routines in unfamiliar task situations aiming at innovation. However, we observed that students employed these mathematical routines – by identifying precedents that allowed them to use properties of ratio and squared numbers – without any apparent regard for their relevance for their task situation. Rather, they appeared to engage in familiar routines in a purely process-oriented manner and not towards a specific goal. This is in accordance with the findings of Viirman and Nardi (2019) where biology students were seen to employ mathematical routines in a ritualized way, even when their engagement with the biological content of the tasks was exploratory.

On the other hand, from the lecturer's discourse we can observe that his expected solutions to the task build primarily on recall routines. This fits with the aims of the course, which focused on learning how to use mathematical models rather than constructing them (although he did show the construction of the models during his discussion). Still, we do not exclude the possibility that the lecturer expected students to explore the exercise mathematically using construction routines since he gave a hint on how the problem can be modelled using the alternative definition of heritability. We note that when the lecturer gave the hint to the first group, he assumed that students knew the meaning of variables (h^2 , R and S), which was not the case. However, as Lavie, Steiner and Sfard (2019) suggest, although the lecturer's own mathematical discourse can be a model for the students to follow, it is necessary to put a conscious effort into establishing whether the explorative nature of the task gets through to the students clearly enough (ibid., p. 20). We suggest that helping students with the biological meaning of the variables might have

supported their engagement with construction routines. This being said, the lecturer was unaware of the students' difficulties since they did not mention that they were struggling with understanding the variables. Concerning *Genetic Correlation*, despite some struggles in the beginning, students were able to use substantiation routines in accordance with the lecturer's expectations. It is worth emphasizing that, contrary to the second task, the nature of the *Heritability equation* encouraged students to engage in explorative participation. The mathematization of the first task required engagement with an unfamiliar task situation, as suggested by the students' inability to use the hint that the lecturer gave them during group-work, and by the absence in the students' discourse of any of the routines used by the lecturer in his construction of the heritability model.

We are aware of the limitations of our study, and that the limited amount of data does not allow us to draw any general conclusions. Still, we find it noteworthy how the students' engagement with the tasks corresponded well with the lecturer's expectations, and that difficulties mainly occurred when they failed in invoking the kind of routines he had expected. We claim that relying purely on recall routines can be potentially problematic for students. We suggest that providing students with some opportunities for working with construction routines can be helpful for their learning. In the continuation of this doctoral project, it is our intention to observe a greater number of biology students' over a longer period of time, investigating what happens to their mathematical discourse as they participate in a course more closely connecting mathematical modelling with biology.

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