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Investigating Lebanese Grade Seven Biology Teachers Mathematical Knowledge and Skills: A Case Study

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Abstract

This paper investigates Lebanese grade 7 biology teachers' mathematical knowledge and skills, by exploring how they explain a visual representation in an activity depending on the mathematical concept "Function". Twenty Lebanese in-service biology teachers participated in the study, and were interviewed about their explanation for the designed activity. The data analysis reveals that teachers refer to different entities as constituting models, and express different way far away from the mathematical concept "Function". Based on the collected data, the findings could not be generalized to all biology teachers, but it is safe to conclude that it would be enriching for students if biology teachers had a background in mathematics and mathematics education, in order to deal with situations of exploration and analysis of the different constraints that might affect biology activities. In addition, the results highlight the need to review the teachers' preparation programs in a way that considers integrating mathematics into sciences, as well as a need to introduce a reform to the Lebanese Biology curriculum, in order to explicitly include all the mathematical competencies required to build up scientific knowledge.

Key words: Biology teacher; Mathematical knowledge; Function; Visual representation

Introduction

"Mathematics is the center of thoughts" (Lamon, 1997, p.35), and the "Queen and Servant of Science" (Bell, 1952, p.11). Mathematical thinking encompasses the capacity to critically use and interpret data summary statistics, graphs and charts. Mathematics has always been closely associated with science. Many biology content areas require mathematics and computer science, for example genetics, ecology, evolution and many other biology subject areas need mathematical algorithms and statistics (Berlingeri & Burrowes, 2011; Fawcett & Higginson, 2012; Kiray & Kaptan, 2012). In fact, mathematical equations are used to describe many biological processes, and some mathematical concepts have arisen directly from the need to study the different processes and phenomena in living systems (Cohen, 2004, as cited in Berlingeri & Burrowes, 2011). Therefore, the proficiency in mathematics and computer science is crucial for biologists for their acquisition, analysis, and understanding of the significance of data (Gross, 2004).

Reserachers such as Bialek and Botstein (2004), Gross (2004), Fawcett and Higginson (2012), and Feser, Vasaly and Herrera (2013), have raised the issue of mathematics integration in biology at a university undergraduate level, and reported deficiencies in quantitative knowledge and skills in biology curricula. Similarly, Lamas, Vila and Sanz (2012) reported the result of a decade-long survey of plant physiology students, which revealed persistent weaknesses in students' abilities to answer quantitative questions. Also, Fawcett and Higginson (2012) investigated the effect of the usage of mathematical equations on the scientific outcomes of studies in ecology and evolution. They reported that biologists lack comfort with mathematics, which may lead to limiting the impact of ideas and findings within their scientific investigations.

Those findings might be the outcome of the fact that mathematics and biology courses are taught separately from one another. This approach often enhances students' knowledge in both content areas, but leaves them unable to understand how each discipline informs and influences the other. Students face difficulty when transferring their knowledge from one discipline to another, and are often unable to mobilize and relate their conceptual knowledge within a cohesive framework.

Feser et al. (2013) suggested that including more quantitative approaches from the onset of the education of biologists would help them in handling mathematical models, by improving their ability to deal with and value

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key approaches within their fields of interest. Thus, it is crucial to address the issue of integration between mathematics and biology early on in stages of education, mainly at intermediate and high school levels, so students would be able to better grasp biology concepts.

The Lebanese Mathematics and Biology (known as Life and Earth Sciences) curricula (1997) in the intermediate level both enable students, in their objectives, to explore the integration of disciplines. One of the objectives of the Mathematics curriculum is "Offering the student an opportunity of practicing the scientific approach, developing the scientific spirit, improving skills in research, establishing relations between mathematics and the surrounding reality in all its dimensions and valuing the role of Mathematics in technological, economic and cultural development", and one of the objectives of the Life and Earth Sciences curriculum is "Permit the student to identify integrated domains within different disciplines and be able to transfer them to different fields".

Generally, in science education, presentations that include both visual and verbal information are widely used in textbooks to display instructional material (Cook, 2006). According to Mathewson (1999) and Buckley (2000), visual representations play a critical role in the communication of science concepts and are used by educators to illustrate abstract ideas and phenomena that cannot be observed or experienced directly. Quantitative graphs presented frequently in biology textbooks, are considered to be visual representations; they display data and process complex information by presenting multiple relationships and processes that are often difficult to describe, in order to promote an understanding of the abstract scientific phenomena (Kozma, 2003).

It is assumed that, Life and Earth Sciences programs contribute to illustrate some mathematical concepts. It is the product and the process of creation, interpretation and reflection upon pictures and images (Functions, variables, proportionality, statistics...) (Arcavi, 2003). Reversibly, mathematics should be presented as a language and a body of knowledge useful for science, especially for modeling relations between determinants and variables. Therefore, the main challenge for biology teachers is the acquisition of mathematical knowledge and skills, and the right approach that would enable them to accurately deal with quantitative biology activities, and to articulate connections across mathematics and biology in the classroom.

The current study investigates the mathematical competencies and skills that Lebanese grade seven biology teachers should have to resolve some biology activities. The focus is on the teaching and learning processes of quantitative visual representations, which are presented frequently in grade seven Live and Earth Sciences national textbook. Document ***e*** (figure 1) of activity three in the second chapter of the textbook (p 36) was chosen as one of the afore-mentioned representations for the purpose of this study. The instruction for the activity is as follows:

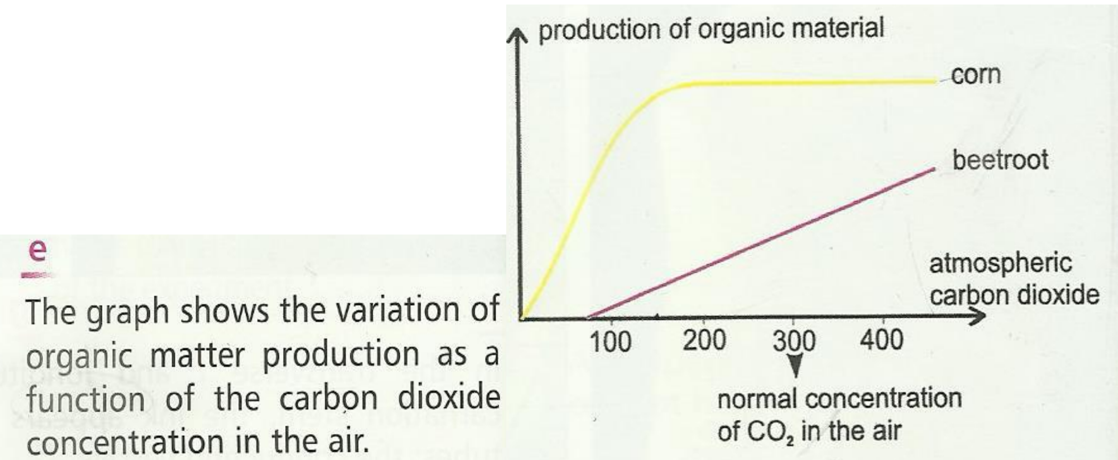


Figure 1. Analysis of the graph of doc e and draw out a logical conclusion

The Lebanese Life Sciences program of grade seven states the following "learning objectives" for the *Production of organic material,* which are related to the activity document **e***:*

> Understand that chlorophyllic plants produce organic materials from inorganic ones (photosynthesis)
> Relate the process of photosynthesis in the presence of chlorophyll, CO_2 and light" (p.265),

The teacher guide proposes the following answer to the question of document ***e:***

> When the quantity of carbon dioxide in the air increases, the production of organic matter increases as well, and when the concentration of carbon dioxide in the air diminishes, the production of organic matter does the same.
>
> Conclusion: production of organic matter or photosynthesis depends on the concentration of carbon dioxide" (p.51).

The answer proposed by the authors of the guide stresses on the visual presentation of the graph. It does not provide any information to the teacher about how to analyze the document. Noting that, the guide gives brief answers and leaves to the teacher the choice to decide how to explain the activity.

Analysis of Document

Since prior knowledge is an important determinant of learning, the analysis of document ***e*** seams important. According to the Lebanese curriculum, the mathematical concept "Function" is taught, for the first time, at grade nine level, which means that grade seven students are totally unaware of this concept; however, they are familiar with a graduated graph and the coordinates of a point. It is the first visual representation in the seventh grade textbook featuring "Function" to model and describe a process.

The visual presentation must emphasize the information related to the data, and "Graphs can have various purposes, such as: (i) to let us perceive and appreciate some broad features of the data, (ii) to let us look behind these broad features and see what else is there" (Anscombe, 1973, p. 17). Hence, the graph of document ***e*** displays the variation of organic matter as *function* of carbonic dioxide concentration in the air. Our study of the document shows that:

1. the origin point of the orthonormal graph is not specified;
2. two labels are present on the x-axis: *atmospheric carbon dioxide* and *normal concentration of* CO_2 *in the air*;
3. two different terms are used: *matter* and *material* to label the dependent variable;
4. the main keys of a conceptual presentation in a graph representing a function are missing: the values on the y-axis, contrary to those of the x-axis;
5. the scale of x-axis is not coherent, since between the first 2 values (100 and 200) a point is allocated, however no allocated points appear between the other sets of consecutive values.
6. the unit of *concentration of* CO_2 *in the air* is not mentioned on the x-axis, and the unit of *production of organic material* is also missing on the y-axis.
7. the starting point of the production of organic material for corn is the origin, whereas for beetroot, it is 100. However, the document does not provide any explanation about this difference.

Concept-wise, in quantitative representation, data provided should be identical to the information assigned in the context. Otherwise, it may lead to confusion during the analysis, and affect the "logical conclusion" desired. Regardless of the inaccurate representation and information of document ***e***, the main challenge for a grade seven biology teacher is to figure out how to tackle this activity that displays different data by including two new processes: *Function* and *Production of organic matter.*

Model Plan

Since visual representations are critical in the communication of science concepts (Mathewson, 1999), and graphics are used to present relationships between too variables, it is crucial to illustrate how this activity could be explained. The explanation requires conceptual mathematics knowledge followed by its application in the context of biology. Given the fact that the Lebanese biology teacher is not a mathematics teacher, and to connect between mathematics and biology, it is advised that the explanation of the concept "Function" covers the core of the mathematical concept, as illustrated below.

In this study, two variables will be adopted: *concentration of* CO_2 *in the air* and *production of organic matter,* following the title of chapter 2 in the textbook, and the data provided in the text of document **e**.

1. Mathematical introduction

- Explain the relationship between two variables to describe, predict, compare and analyze their variation. The teacher has to propose different situations in order to help students eventually reach the mathematical concept "Function". Hence, modeling is required by tables and also by simple graphs to stress on the "axis and scales", "input and output values", and "coordinates of a point".
- Elaborate on the definition of "Function" in mathematics: "Function is a relation between two sets in which one element of the second set is assigned to each element of the first set" (http://www.mathwords.com/), so, a function is a relationship where each input (element of the first set) has a single output (element of the second set). The teacher is to also give some examples

Input	**Relationship**	**Output**
x	f →	f(x) = y

- Function *f* is a relation between two numbers presented as *x* (*input*) and *y* (*output*)

Input	**Relationship**	**Output**
x= 2	f (x) = 3x →	y = 3 ✕ 2 = 6

2. Apply the concept of function in the context of biology.

- Identify the variables of the experiment presented in the graph: the *input* variable is the x variable, which is in a scientific activity called *independent* variable. The output variable is the y variable, which is in a scientific activity called *dependent* variable (Grade 7 students are familiar with the meaning of dependent and independent variables). Since in a function, if *x* changes, *y* changes, then the *dependent* variable varies with the *independent* one correspondently in a specific trend.

Input	**Relationship**	**Output**
x	f →	f(x) = y
Independent variable		Dependent variable

- Identify that the independent variable is *concentration of CO_2 in the air*, and the dependent variable is *the production of organic matter.*
- Adopt that the value (0,0) as a coordinate of the origin of the orthonormal graph.
- Adopt a logical scale on the y -axis from 0 to 100, based on the scientific representation of the rate of production of organic materials.
- Choose arbitrary units (a.u) for both variables, since the unit of the *concentration of CO_2 is* ppm (per million in volume), and that for the *production of organic material* is µmole CO_2/m^2/sec.
- Identify the trend between the two variables:
  - ➢ For beetroot: a straight line represents the function y = ax + b. The production of the organic matter beetroot increases with the increase of the concentration of CO_2 in the air.
  - ➢ For corn: The curve represents an increased function. The production of the organic matter corn increases with the increase of the *concentration of CO_2 in the air*, till the *CO_2* reaches a concentration of 150, and then the production of organic matter becomes constant with the increase of concentration of CO_2.
- Highlight that one output may be the result of many inputs, which is illustrated in the corn case.

Method

The question of how teachers' mathematical knowledge affects the learning and teaching of biology is the active field of this study. The biology teacher is supposed to use his/her mathematical modeling skills or modeling competencies (Maaß, 2006) to go through the phases of the activity in document ***e***. This study suggests that biology teachers use various mathematical tools and approaches in their teaching. The central question of the study is: How do grade seven biology teachers deal with quantitative visual representations, presented by a "Function" graph, in their teaching/ learning process?

To answer this question, sub-questions are addressed

1. How do grade seven biology teachers connect between mathematics and biology in their teaching and learning process?
2. Do seventh grade biology teachers have the required mathematical tools and approaches that enable them to illustrate mathematical concepts embedded in visual representations?

The current study is a case study based on interviewing twenty grade seven biology teachers in service, in Beirut official schools, about

1- how they would explain document ***e*** to know
   - i) how they perceive the word "Function"?
   - ii) how they connect between mathematics and biology?
   - iii) which mathematical tool(s) they would use in their explanation.

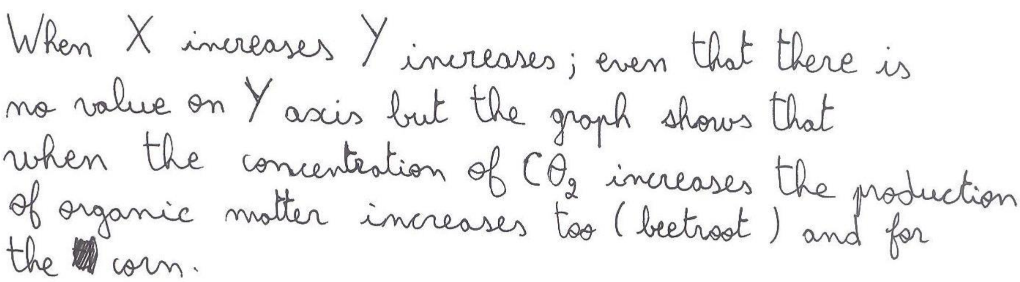
2- the credibility of document ***e***. In other words, asking if they pay attention to the difference between data provided by the graph and the information provided by the accompanied text; and if so, how would they deal with it?

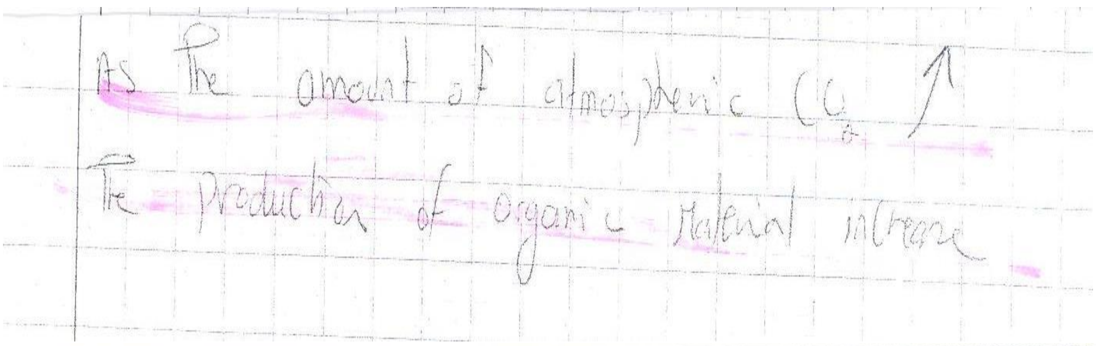
Participants are selected based on their motivation and availability. They teach Biology in English and French language. All teacher-participants hold a minimum of two years teaching experience, and have a Bachelor Degree in Biology from the Faculty of Sciences, and a Master Degree in Science Education-Teaching Biology from the Faculty of Education at the Lebanese University.
Participants answered in writing. Data was collected and analyzed to answer the research questions. A sample of the data is presented in the results discussion section.

Results and Discussion

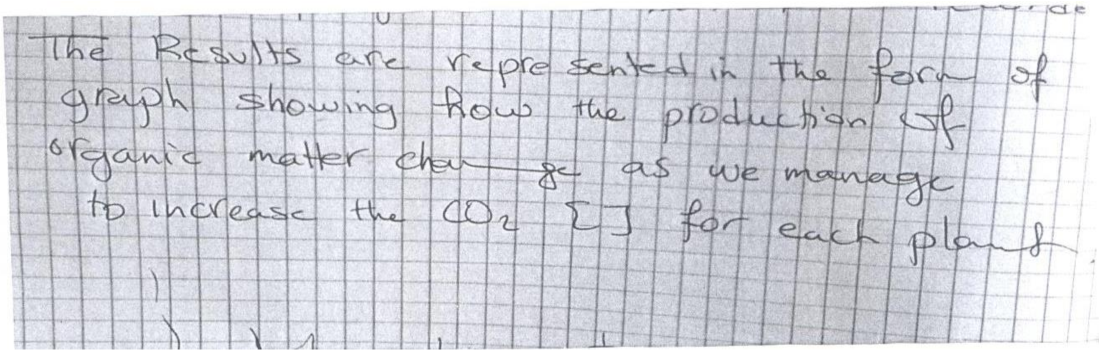
After analyzing data, we found that mathematics pose a major challenge for biology teachers. All participants used direct teaching, and the majority of them described the activity without using mathematics; they simply followed the teacher's guide explanation. None of them paid attention to the difference between the data presented in the graph and the information provided by document ***e***. They had cognitive difficulties a) to translate back and forth visual and analytic representations of the graph, which is at the core of understanding mathematics, and b) to choose appropriate mathematical tools and to represent situations graphically.

- Twelve teachers explained similarly to the content of the teacher guide. They outlined the absence of the Y scale, and mentioned that the absence of scale has no effect on the visual analysis.


When X increases Y increases; even that there is
no value on Y axis but the graph shows that
when the concenteation of CO_2 increases the production
of organic matter increases too (beetroot) and for
the corn.

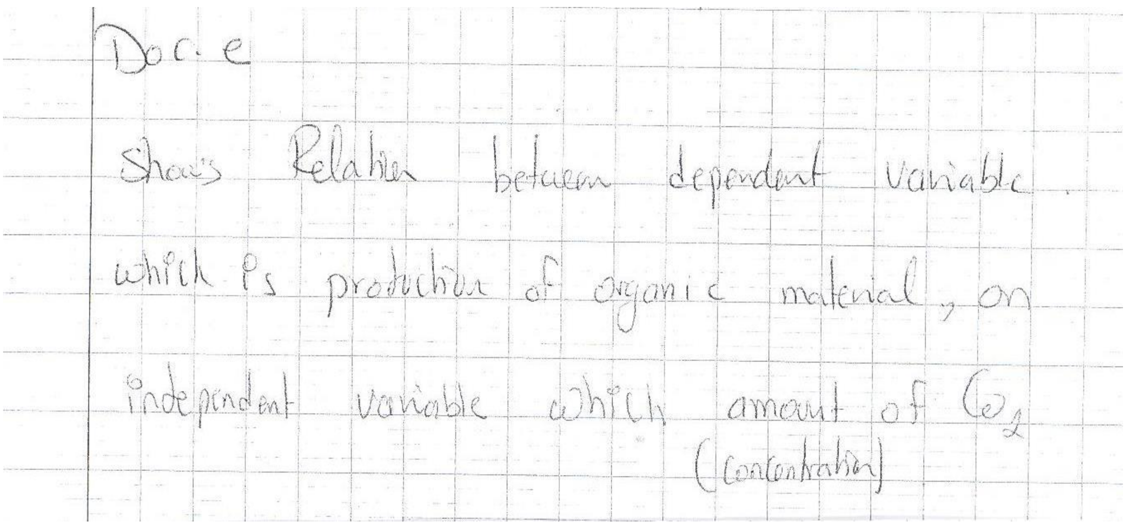


As the amount of atmospheric CO_2 ↑
the production of organic material increase



The Results are represented in the form of graph showing how the production of organic matter change as we manage to increase the CO_2 [ ] for each plant.

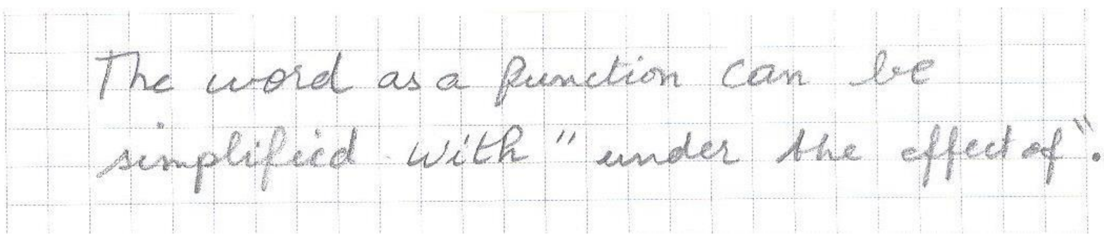
- All participating teachers did not perceive the word “Function” in its mathematical meaning. Rather, they used the scientific approach in their explanation by mentioning the dependent and independent variables of the experiment presented in the graph: “*function of which is in reality the variation of Y which is the dependent as X varies which is the independent*”. They dealt with “Function” as being a visual description. They considered that the variation between the variables is determined visually by the trend presented in the graph, ignoring the mathematical tools.



Doc e

Shows Relation between dependent variable which is production of organic material, on independent variable which amount of CO_2 (concentration)

Five of them went beyond the common scientific approach described above and used the expression “*under the effect of*” to explain the concept “Function”. They considered that



The word as a function can be simplified with "under the effect of".

- One teacher claimed:

> It took me a while to explain how I explain the function activity because I never thought of it as a function word related to a mathematical subject.

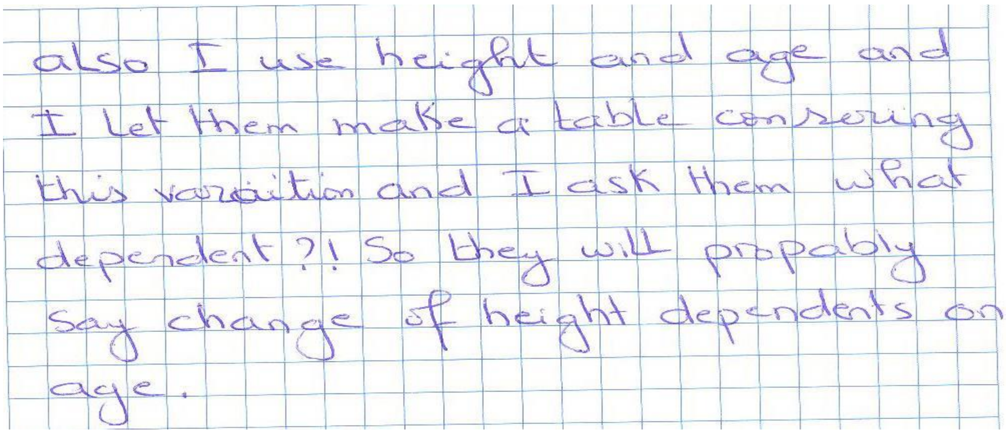
This teacher faced difficulties to accept "Function" as a mathematical concept. The word "Function" carries with it a stress and stands for her only in the vocabulary of biology. The integration between mathematics and biology is absent.

Considering the mathematical tools that teachers would use to help students understand the concept of "Function", linear functions; daily live examples, proportionality and arbitrary units were proposed.

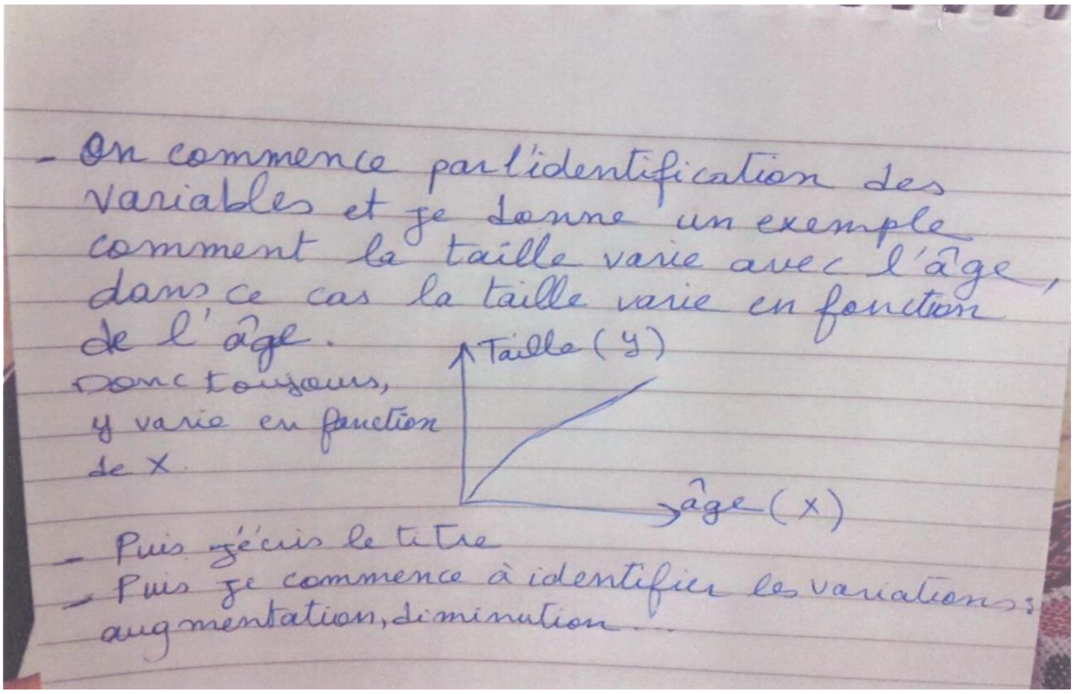
- One teacher, in order to exploit the potential of the activity, considered that the "*aim of the experiment is based on the idea of equation of a straight line: y = ax*". She introduced "*the title of the graph as: y = f(x)".* In her explanation, she stated that *"Organic material (y) is a function (f) of atmospheric CO_2 (x)*". But, the goal to sketch this graph is for the presentation of the function y = ax + b and not y = ax.

> The aim of the experiment is to observe the result based on controlled condition. Based on such "principle" and the idea of equation of straight line (y = ax) I can introduce the title of the graph as: y = f(x); ⇒ The variation of production of organic material as a function (f) of atmospheric CO_2 y (x)

- Three teachers illustrated the purpose of the activity by a daily life example, to engage students. They used a very common example: the variation between "*age*" and "*height*" in order to facilitate the aspect of knowledge about function process without declaring it. One of them used a graph and represented this variation as a linear function (she drew the line representing the function y = ax), and the others used a table to let the students note the variation by numbers. Noting that data used for "*age*" and "*height*" is not reliable, teachers used proportional numbers for the purpose of their explanation.



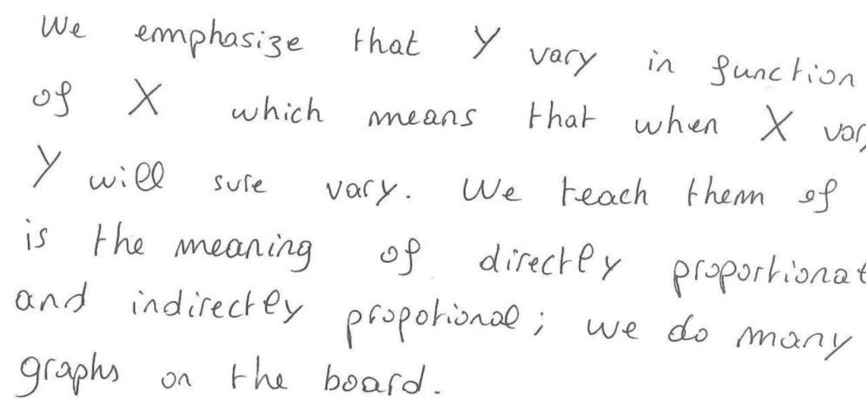
also I use height and age and I let them make a table conserning this variation and I ask them what dependent ?! So they will propably say change of height dependents on age.



- On commence par l'identification des variables et je donne un exemple comment la taille varie avec l'âge, dans ce cas la taille varie en fonction de l'âge.
Donc toujours, y varie en fonction de x.

- Puis j'écris le titre
- Puis je commence à identifier les variations : augmentation, diminution...

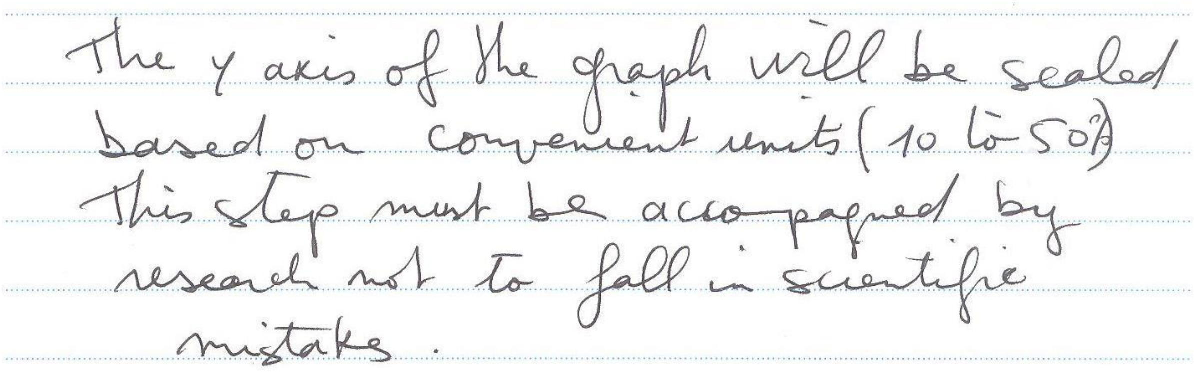
- Two teachers recalled the mathematical concept of proportion. They mentioned the direct and indirect proportion, which does not apply at all to document e.



We emphasize that Y vary in function of X which means that when X vary Y will sure vary. We teach them of is the meaning of directley proportional and indirectley propotional; we do many graphs on the board.

When asked to elaborate their idea about proportionality, they were confused and unable to express their thought pattern.

- One teacher, to help student to analyze the graph, scaled the Y-axis. But, she did not explain why she had chosen the units she chose. For her, those units are *the convenient units*


The y axis of the graph will be scaled based on convenient units (10 to 50%) This step must be accompagned by research not to fall in scientific mistaks.

Discussion and Conclusion

The results show that mathematics can function as a toolkit for use in biology, since mathematics, as a human and cultural creation, deals with objects and entities, quite different from physical phenomena, that rely on visualization in its different forms. The difficulty arises from the need to attain a relation between visual in biology and analytical representation of the same situation, which is at the core of understanding of mathematics.

The findings show clearly that Lebanese seventh grade biology teachers who participated in this study need to acquire mathematical knowledge that allows them to teach such kinds of biology activities. It is crucial to recognize that mathematical skills are important cognitive skills that will ultimately impact a biology teacher's performance. This finding is in line with that of Fawcett and Higginson (2012) who reported that biologists lack comfort with mathematics, which may lead to limit the impact of ideas and findings within their scientific investigations.

The visual information disables the participants to engage with mathematics concepts and the meaning of "function". It is obvious that all of them are trying to connect between mathematics concepts and biology activities by replacing the mathematical language related to "Function" by scientific indicators such as "dependent and independent variables; under the effect of". So, mathematics is presented as a language for modeling the relations between the determinants variables and not as knowledge useful for science. Furthermore, some teachers illustrate the concept "Function", by using, wrongly, the linear function y = ax instead of y = ax + b, and examples from student's daily life, namely "age" and "height". Those teachers contrary to the suggestion of Feser et al. (2013), by providing false quantitative approaches not related to the situation of Document **e**, not only are not helping students to handle mathematical models, but are also reinforcing the development of students' mathematical misconceptions. It is obvious that all participants are adhering to the content of the teacher guide. They did not make any effort to evaluate this content and to elaborate comprehensive answers. Visualization offers a method of seeing the unseen" (McCormick, De Fantim & Brown, 1987, p. 3), but our participant teachers *see what they know.*

Recommendations

A reform in the Lebanese school Biology curriculum is required in order to include explicitly all the mathematical competencies required to build up scientific knowledge. So the cross-curricular activity will support the development of skills that transcend traditional curriculum areas. Also, the results shed the light on the need to integrate mathematics in biology programs offered at the Faculty of Sciences, and consider this integration in teacher's preparation programs at the Faculty of Education.

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