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HOW CAN DRAWINGS HELP US TO SUPPORT STUDENTS IN MEANINGFUL LEARNING? CONNECTING MATHEMATICS AND BIOLOGY THROUGH GRAPHS

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ABSTRACT. Graphs are considered as one of the most often used data visualizations in science and math. It is a diagram showing the relation between variable quantities, typically of two variables, each measured along one of a pair of axes at right angles. The data or values should be represented in an organized manner. The ability to display data in a form of a graph is also a part of basic scientific skills. According to many educational policy documents, science, and mathematics teachers are expected to foster students' ability to interpret data and construct and interpret graphs in their classrooms (Bowen & Roth, 2005). Despite that fact, students are facing numerous difficulties with constructing and reading graphs (e.g. Taylor & Swatton, 1990; Whitaker & Jacobbe, 2017). At the same time, researchers are calling for more ''authentic'' practices that can resemble the way scientists routinely do when asked to interpret data or graphs (Bowen & Roth, 2005; Nicolaou et al., 2007). The presented article is an example of a sequence of activities on the usage of graphs in a biology lesson – on the topic of the variability of the human body – that can be considered as a good practice resembling scientific practice also from a philosophical perspective (semiotic, epistemic and epistemological practices).

INTRODUCTION: GRAPHS AS THINKING TOOLS FOR SCIENTIFIC PRACTICES

A picture (and a drawing) can be understood as a designed message. It is usually created in the process of social interactions. That has particular consequences in a process of this visual communication. The situation, culture, and other contexts can stimulate and/or block visual communication acts. Another problem can be found when we will take into account that the individual perception of a recipient also plays a role in understanding the information being presented. On the other hand, while teaching and learning science and math we would be willing to a large extent to avoid multiple meanings that can be assigned to the visual representation.

The use of images in teaching and learning supports students' understanding, retention, and application of personal knowledge. For example, we combine the use of images with spatial intelligence, students' motivation to learn, and learning conditions (including instructions) (Bobek & Tversky, 2016; Dunlosky et al., 2013). Especially graphics generated by the student to explain the phenomenon or the object, are powerful learning tools. As Prain and Tytler (2012) claim constructing a representation helps in learning from three perspectives, which include:

i) semiotic – students are using particular features of symbolic and material tools to make meaning;

ii) epistemic – how this representational construction relates to the broader picture of science;

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iii) epistemological – how and what students can know through engaging in the challenge of representing casual accounts through this semiotic tool.

Graphs and the construction of graphs can serve as a perfect example of an embodiment of these 3 perspectives of graph construction. Graphs are one of the basic tools in scientific language and communication, thus the ability to construct, read, interpret, make predictions, and make meaning on the basis of this form of visual display of information seems to be one of the basics in science and math education. It is not a new discussion. Wavering (1989) argued that "in order for students to be thinking participants in society, they need to understand graphs" (p. 373), Brasell (1990) elaborated, that graphs have a powerful value due to the possibility of presenting quantitative information as a visual display, in a way that makes relationships between data visible. From this perspective, they are a perfect medium for many tasks from showing data, describing them, and revealing relationships between them to communicating and making comparisons. This perspective indicated that graphs as a visual display of information are carries of messages but they do not have to be the final product while learning (Rogers, 1997). As Russel and co-workers (2004) highlighted – the formation of scientific ideas might not be achieved by simply exposure to the information, (despite the modality of communication of this information) such formation can and should take place in the process of analyzing and interpreting the data. Such formation should allow the learner perception of the possible implication of the designed message (in the form of e.g. a graph, table, or a model), allow for predictions, and involve in scientific practices.

Science education standards require students to use visualizations to understand relationships, to reason about scientific phenomena and models, and to communicate data to others (National Research Council, 2013). Interpreting and creating graphs play a critical role in scientific practice. But at the same time, students quite often find textbook representation too challenging to understand, poorly designed, or located in a place where integration with text provided in order to help is impossible (see e.g. Nistal et al., 2009).

Graph construction and comprehension are generally taught in mathematics classrooms, where students typically graph only linear functions (Cobb, 1999; Watson, 2008). Science teachers rarely teach about the graph features needed in science, so it is assumed that students already possess the knowledge and skills that are required to understand graphs and construct them (Gal, 2002; Galesic & Garcia-Retamero, 2011; Gallimore, 1991; Jarman et al., 2012).

In the presented article we would like to show how these three perspectives are revealed while engaging students in the construction of a graph on biology lessons. This is a research and philosophy-inspired instructional activities sequence that is meant to help in improving students' understanding of scientific knowledge. To fulfill this requirement we present a sequence of activities.

1. CHALLENGES IN GRAPH CONSTRUCTION AND UNDERSTANDING OF A GRAPH

Students of different ages face some problems with graph construction and most often with graph interpretation and adequate usage of this visual display of data.

The Guidelines for Assessment and Instruction in Statistics Education (GAISE) Report: A Pre-K–12 Curriculum Framework (Franklin et al. 2007) outlines three developmental levels—A, B, and C—through which students should develop and mature. Level A – describes beginning awareness of the statistics question distinction, for example, the students should be familiar with bar graphs, or use particular properties of distributions in the context of a specific example. At B level – called Increased awareness of the statistics question distinction – students learn to use particular properties of distributions as tools of analysis, so they for example should be able to compare bar graphs and histograms or quantify variability within a group. Level C – Students can make the statistics question distinction – students understand and use distributions in the analysis as a global concept; measure variability within a group and between groups, compare group to group using displays and measures of variability; describe and quantify sampling error, so, for example, students are able to make a prediction on the basis of graphs. All of these levels are associated with statistical topics. In different situations, students show difficulties with constructing graphs, interpreting, and reading the information presented in a form of a graph.

Students' conceptual understanding of a graph and data displayed this way can be also a challenge for them. Bright and Friel (1998) revealed that a common misunderstanding before intervention was interpreting each bar as representing a single value rather than using the height of the bar to determine the number of values represented.

Elementary school students encounter difficulties while interpreting relationships between variables and constructing and interpreting bar charts or line graphs or histograms (Swatton & Taylor, 1994; Taylor & Swatton, 1990; Whitaker & Jacobbe, 2017). Additionally, Whitaker and Jacobbe (2017) report in their article that the same problems can be observed also among college students. They also reported that in the literature they analyzed the most widely reported misunderstanding about bar graphs and histograms is that the variability in the data is represented in a histogram by variability in the heights of the bars.

Linda L. Cooper and Felice S. Shore (2008) have reported that students' notions of the variability of data represented in histograms are tenuous. They have observed that 50% of examined students judged variability by focusing on the comparing heights of the bars, implying variability in frequencies, rather than data values. As a possible source of this misunderstanding, the authors indicate the problem with differentiation between visually similar graph types – frequency bar charts and time plots that use bars, and histograms. As a consequence, students do not notice the dramatically different methods that are used to evaluate the variability of these different representations.

Problems with visualizations in the form of graphs are also related to linking the result of data visualization in the form of graphs with a bigger picture of knowledge. In other words, students show difficulty linking graph features to science concepts, especially when asked to critique or construct graphs – even in middle school students as reported by Lai and co-workers (2016).

The ability to construct graphs is a challenge in itself for students. During final exams in biology conducted in Poland, only 1/3 of students in 2008 were able to correctly construct a graph (Przybył-Prange & Rybska, 2008). In the analyzed sample, the reason for the failures of high school graduates in many cases can be attributed to a lack of basic skills associated with:

a) constructing a chart (applying units, describing axes, scaling),

b) reading instructions with understanding and analyzing the content of the task.

Nicolaou and co-workers (2007) highlighted the need for creating instructional scaffolding for students where they would be challenged with "key questions by which the graph is considered as a resource and a starting point for thinking activity rather than an end product" (p. 92). Matuk and co-workers (2019) showed in their research that critiquing graphs helped students improve their scientific explanations within the taught topic while constructing graphs led students to connect key science ideas in constructed explanations – within and beside the analyzed topic. Such results indicate that both activities play their role in learning science.

Constructing a good graph as a proper visual display of given data helps in communication and understanding patterns, relationships, etc. Contrary, ineffectively designed visualizations can cause confusion, misunderstanding, or even distrust (Franconeri et al., 2021).

2. THE SEQUENCE OF ACTIVITIES ON THE USAGE OF GRAPHS IN BIOLOGY LESSON – VARIABILITY OF THE HUMAN BODY

1) First step is asking a general question: Are all people the same? How do they differ? And this discussion leads to a general introduction to variability and its types. Variability is understood as the differentiation of the characteristics of individuals within a population or

species. There are two major types of variability: environmental (modification, fluctuation, non-hereditary), and genetic variability that comes as a result of recombination or mutations. Diversity is the measure of variability and can be seen in genotypes as well as in phenotypes.

2) When describing types of variability students might observe among themselves that some of the traits show as discrete variables and some as continuous variables. Discrete variables refer to qualitative traits, usually with a simple genetic background – that is encoded by one or more genes, e.g.: blood groups; earlobes. While continuous variables concern quantitative traits encoded by cumulative genes, e.g. height, or body weight.

3) Introduction of a Gaussian curve – that shows what is called a normal distribution and is a type of continuous probability distribution. Students are explaining what can be read out of this curve, and can some human trait distribution fit into this curve.

4) Then students are asked to perform a short experiment, with the research question: Do people of the same age have the same body size? They state their hypothesis and start their measurements in groups. Group work tasks are:

    a) taking all measurements and entering them into tables,

    b) ordering the results of measurements of the assigned body part from the smallest to the largest,

    c) determine classes/ranges of results and count how many people are in a given range (a single result cannot be treated as a range, ranges should be created containing a narrow range of results),

    d) presentation of results: in the table and in the form of a bar graph.

5) Students are supposed to measure:

    a) Ear – we measure from the hem to the petal = the distance from the highest to the lowest point as in the photo on the right (they should use a thread and a ruler, bring the thread to the ear from top to bottom and measure with a ruler).

    b) Nose **–** bring the thread to the nose so that one end touches the tip of the nose and the other connects to the eyebrows (by using also a thread and a ruler).

    c) Upper limb - feel through the skin the head of the humerus and measure from it to the end of the longest (middle) finger of the hand. By using a tape measure.

    d) Lower limb - measure from the iliac spine to the ankle (it is easy to find: palpable through the skin, in slim people visible "bumps" near the hips in front, on both sides of the abdomen, slightly below the navel are the protrusions of the hip bones).

    e) Index finger - measure from the trapezius bone below the toe to the tip of the toe.

    f) Height - Measure from the top of the head to the ground, in the anatomical position (straightened, heels together, head slightly raised). You can do it against the wall: Put a book or ruler on your head touching the wall and measure the distance from this point on the wall to the floor.

6) Students are analyzing their data and create a graph. Examples of such graphs are presented in Figures 1A and 1B.

7) Comparing graphs with each other, and again with a Gaussian curve.

8) Searching for possible mistakes, omissions, or misunderstandings.

9) Searching for differences in data presentation, for example, ranges can be created by dividing the whole spectrum into 5 ranges, or accordingly to the frequency – and this influences the shape of a graph) – first reflection on data visualization.

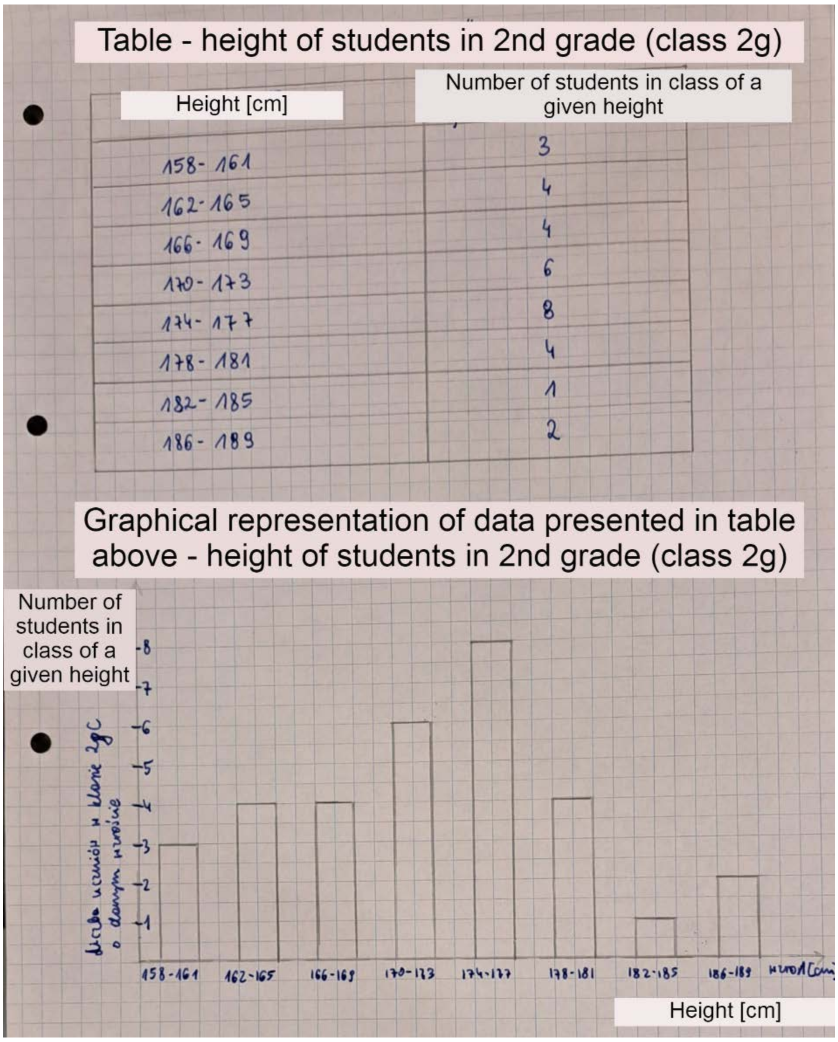

FIGURE 1A. Table with data of students' height and graphical representation of these data

Typical mistakes observed by teachers during this activity include:

– Not precise measurements

– Not precise data collection (e.g. the length of a nose or ear is quite often rounded to an integer number, which makes the volatility data shallower)

– determine classes/ranges of results are arbitrarily assigned (e.g. every 0.5 cm) despite what data shows

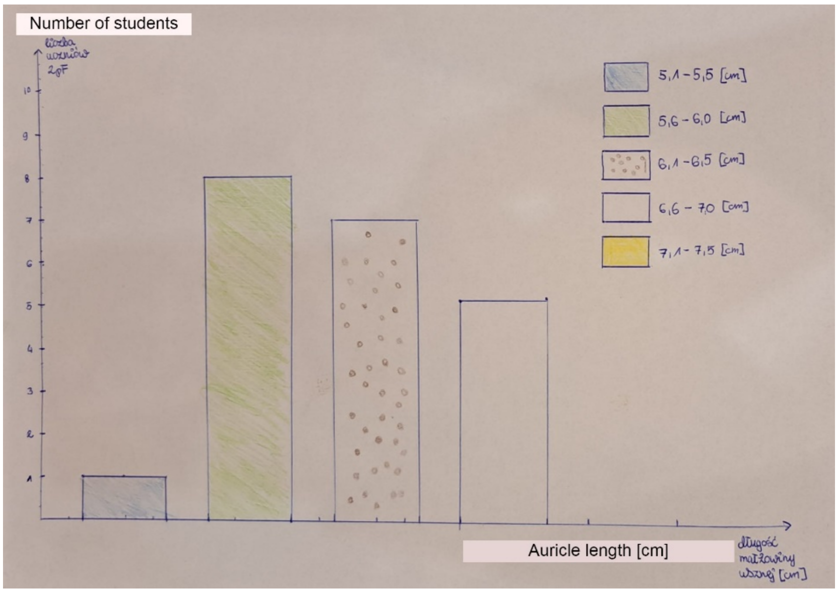

FIGURE 2B. Graphical representation of the distribution of auricle length among students in one class

10) Meta-reflection activity – why do these types of data visualization differ? Why data from class does not always fit perfectly into the shape of the Gauss curve? In which type of data visualization it fits and why? Where and when do they meet data visualization that fits perfectly into a Gauss curve? Why the distribution of the data collected in the classroom do not match perfectly the ideal shape of a Gauss curve?

CONCLUSIONS

Data visualization is a skill required in everyday life – not only in science. To construct meaning or a response, students need to make sense of the features of graphs—including labels, scale, shape, noise, and patterns—to describe, depict, and evaluate claims regarding scientific phenomena. This can help them to make connections between evidence and scientific reasoning, or to construct arguments, or to make predictions. But visualization is not a goal per se. It is a tool that helps in thinking, learning, reasoning, and many other scientific practices.

In a presented sequence of activities, all three perspectives are applied. While constructing a graph that represents some data students apply a semiotic perspective in that process. As Prain and Tytler (2012) claim students participate in this aspect through "developing capacity to recognize and use key functional features of generic and science-specific material and symbolic tools to construct an account of phenomena" (p. 2755)

By constructing different graphs, comparing their representation among themselves and with scientific ways of representing the same idea or phenomenon, they participate in symbolic practices for undertaking and reporting science inquiry. This activity belongs to epistemological practices.

And while comparing each other graphs, ask questions like how do they differ? why do these types of data visualization differ? What is variability and in which group was bigger? Students are able to construct their knowledge and reason while engaging in this process. Thus they participate in epistemological practices.

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