Pre-service physics teachers' understanding of rates of change in the context of the undergraduate laboratory work

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Abstract. The focus of the study is on how pre-service physics teachers have made sense of rates of change at various points of curved graphs when they analyse experimental measurements in physics lab courses. Forty-eight pre-service physics teachers participated. Data sources were open-ended written tasks, semi-structured interviews and lab reports. When talking about rates of change, the participants proposed to draw a tangent at particular points of the curve but they could not calculate derivatives at corresponding points of curves. In addition, they could not interpret rates of change to give a physical meaning to them.

Introduction and the study

In physics education research various studies looked at the extent to which undergraduate students are able to transfer mathematics knowledge from calculus to the physics context in order to solve problems. The reported study was undertaken in the context of an undergraduate lab course in which the participants conducted experiments, collected measurements, plotted data points and graphs; in particular, curved graphs. They would, then, analyse the experimental results to draw conclusions.

The study was designed to investigate how pre-service physics teachers make sense of rates of change when they plot data points and draw curved graphs to use them in order to analyse experimental data and draw conclusions. Previous studies, for example, the study by Van den Eynde and colleagues [1] reported that inversely proportional functions and graphs are the hardest for students. More studies were undertaken in Mathematics Education [2-4] and Chemistry Education [5] to investigate students' understanding of rates of change and the related co-variational reasoning and understanding.

Methodology and research questions

The context of the study was one laboratory course for pre-service teachers for one semester (13 weeks). The students who joined the study were the ones who registered for one lab course for pre-service physics teachers. Thus, forty-eight pre-service teachers belonging to three (but equivalent) cohorts participated in the study. In the experiments, for example, in the insulation experiment, they would need to calculate some instantaneous rates of temperature change for different regions of the same curved cooling graph. The research question guiding the study are:

(a) How do pre-service physics teachers calculate and interpret rates of change at various points of a curved graph? (when analysing and interpreting experimental data)

(b) To what extent do they connect rates of change with derivatives at particular points of a curved graph?

The sections of analysis and conclusions of lab reports were analysed to identify the difficulties that pre-service physics teachers experience with rates of change. In addition, the participants were given open-ended written questions with secondary experimental data and asked to analyse data, plot graphs and then calculate some changes of rates along a curved graph. For instance, for the case of a P-V graph for an ideal gas, if temperature was kept constant, they were asked to calculate the rate of change *dP/dV* at various points). Many times, semi-structured interviews were conducted to clarify students' answers and reasoning. A fine-grained analysis was undertaken to capture the participants' understandings and reasoning. Apart from insulation, they performed the experiments of discharge of a capacitor and radioactive decay. The steepness of a graph indicates the rate of change. Varying levels of steepness correspond to different rates at different points of a curve. A curving graph indicates the rate is changing.

Results and conclusions.

One major tendency was that the participants were talking about rates of temperature change or of pressure change without being able to calculate the rates by calculating derivatives. Students were restricted to a qualitative answer comparing rates of change to denote at which points rates were bigger and so on. They proposed to draw a tangent at particular points of the curve but they could not calculate any rates of change, because they did not know any "formula" to apply for the calculation of an instantaneous rate of change for a best fit curve. As they explained in the interviews, they could not calculate rates of change at different points of a curved graph because they had not been taught any "formula" for curved graphs. In line with previous studies [i.e. 1, 5], we found that pre-service teachers have difficulties with inversely proportional functions and graphs.

Secondly, although they could write the derivatives of some functions, drawing on calculus Mathematics knowledge, they could not do so when they were given some physics equations with physics symbols. For example, when they were given the function equation $yx= c$ constant, they could write the derivative dy/dx. However, when they were asked to calculate the derivative dP/dV at a particular point of a given graph, they could not give an answer by stating, for example, that they "*could not remember the relevant theory*". They could not relate the rates of change at a point of a curve with the relevant derivative of the graphed function. Therefore, they could not activate their calculus Mathematics. Familiarity with some physics equations (like $PV=nRT$) seems to hinder them from transferring Mathematics knowledge to physics and in particular, to the analysis of experimental measurements. In addition, when asked to interpret a few rates of change, they could not give any physical meaning by referring to the relevant physics theory.

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