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Complex modeling: Does climate change really exist? – Perspectives of a project day with high school students

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Introduction

Mathematics is at the core of many areas of everyday life in our society, in science, technology, and the economy. According to the PISA study, the aim of mathematical education is to develop an understanding of the relevance of mathematics in these areas. This should enable high school students to deal with and explain mathematical questions and problems with respect to real world life so that they can act as responsible citizens (cf. OECD, 2014). But process-oriented competences which belong to the educational standards of mathematics are often neglected due to the fact that mathematics lessons are often strongly content-oriented. Therefore, it is essential that the tasks are open, complex, realistic, authentic, problem-oriented and can be solved by carrying out a modeling process (cf. Maaß, 2006, p. 115). This is where the project Computational And Mathematical Modeling Program (CAMMP) intervenes: It offers extra-curricular possibilities for students to participate in modeling events which last between one day and one week. These events show the close connection of several subjects such as engineering, mathematics and computer science. By integrating such questions into interdisciplinary project teaching, mathematical modeling is extended by the dimension of independent experience and practical application. Students solve problems from everyday life or scientific research by using mathematical modeling. Thus, we understand CAMMP as a chance for students to solve real problems by mathematical modeling independently and to develop important future-oriented competencies. Our experiences show that by participating in CAMMP events students discover, among other things, the role of maths in our everyday life. Since the students should not use the modeling cycle as an abstract entity, but as a concrete help for the modeling process, CAMMP presents a simplified variant of Blum's modeling cycle with the four steps *simplifying*, *describing mathematically*, *computing* and *interpreting* (cf. Blum & Borromeo-Ferri, 2009, p. 46). As an example, a workshop lasting one day (CAMMP day) on the topic climate research is introduced.

Didactic reduction and realization of Climate Change Analysis in a CAMMP day

There are various simulations that predict a warming of the average temperature of the earth's surface by up to four degrees Celsius by 2100. Such warming would lead to further effects, from the emergence of deserts to rising sea levels and the disappearance of entire countries. However, many people ignore or deny climate change or the dramatic consequences that inaction would have. The report of the Intergovernmental Panel on Climate Change (IPCC) distinguishes various indicators that point to a climate change. Since climate change is a complex research field with many different forces affecting each other, a good didactical reduction is needed for teaching mathematical models

representing earth climate to high school students. Therefore, the CAMMP day – which we are currently designing – focuses on temperature analysis, an everyday parameter used to describe climate and often used in the media as a yardstick for climate change.

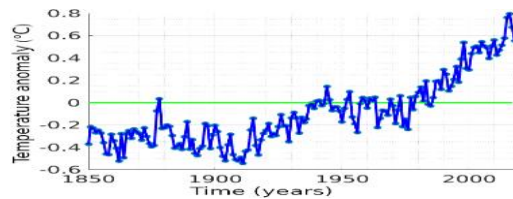


Figure 1: Global average surface temperature

The first step of modeling “Does a climate change exist?” we ask “Has the temperature increased significantly?” To answer this, the global average surface temperature from 1850 to 2018 is examined (see Figure 1). Furthermore, a linear trend is used to describe the trend since it is assumed in the IPCC report (see IPCC, 2013). For this purpose, the students first develop the methodology of regression analysis independently. One possible mathematical description is first to calculate the sum of least squares of the difference between the measured temperature function and the regression, called $e(Y_j)$ for each year $Y_j = 1900, \dots, 2018$. In a second step the sum of the least squares is minimized. The mathematical problem can be written as $\sum_{j=0}^n e(Y_j)^2 = \sum_{j=0}^n (T(Y_j) - TY_j)^2 \rightarrow \min$, where $T(Y_j)$ the measured temperature and $TY_j := mY_j + b$ the modeled temperature value of the regression function with the unknown parameters m and b in the years Y_j are. Here the concept of differentiation is needed. It becomes obvious why the least square method is used: It is easier on high school level to differentiate a polynomial of grade 2; otherwise the absolute value function would be needed. Using real data this results in a linear trend function of $\tilde{T}(Y) = 0.008 \text{ }^\circ\text{C}/\text{year} - 15.578^\circ\text{C}$ which needs to be interpreted with respect to the real-world problem. Here the question of the quality of the adjustment for the data arises. The coefficient of determination is introduced and computed for the given data as $R^2 = 0.8$. As an additional exercise, interested students can prove that in all cases $R^2 \in [0,1]$ holds and find out which R^2 indicates a good adjustment. These results lead to the presumption that $\tilde{T}(Y)$ approximates the data well and that the temperature rises by $0.008 \text{ }^\circ\text{C}/\text{year}$. In order to investigate whether the temperature rises significantly in the last century, the coefficients of the regression function are tested with a so-called t-test. The high school students formulate the null hypothesis (H_0 : the temperature does not rise significantly) on the basis of the question as well as the test statistics. Inserting the corresponding values leads to the acceptance of H_1 . Further steps are to evaluate the influence of human being in this increase. These results do not only lead to a well-founded view on the topic of climate change, but also show the relevance of mathematics in society.

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