Symposium of GTG Mathematics in Physics Education: Enhancing mathematization in physics education by digital tools

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Abstract. The GTG Mathematics in Physics Education follows the philosophy of supporting physics understanding by the conscious use of mathematical structures. The Symposium discusses the possible roles of digital tools in promoting physics understanding by fostering sensemaking of computations, geometrical visualizations or diagrams in a physics context.

1 Goal and Content of Symposium

In physics besides experiments and theoretical-mathematical methods also digital tools play an increasing role for evaluating data, representing experimental results, numerical calculation of mathematical models (e.g. differential equations) and simulation of physics processes (e. g. by varying parameters). Likewise, the omnipresence of a variety of digital tools in everyday life opens up manifold possibilities to enrich physics education. These might be used for supporting the use of mathematical elements in physics by reducing numerical load or for making realistic processes visible that were not accessible before at school level. Aside from these aspects digital tools show the increasing role of algorithms also in other knowledge areas or everyday life. The symposium intends to give an overview on the different possibilities of using digital tools in the interplay of mathematics and physics. This includes chances as well as obstacles and learning difficulties.

2 Contributions

The focus will lie on the sense-making of mathematical structures in physics contexts with the help of suitable digital tools [1]. As smartphones are a normal tool in everyday life it is important to know how students can handle the resulting diagrams they obtained from using experimenting with the inbuilt sensors (1st contribution). The potential of geometrical tools such as geogebra or visual tools like Algodoo for school are explored in the 2nd contribution. More advanced competences include to be able to work with computational tools such as python [2]. This also requires appropriate preparation of teachers (3rd contribution).

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Interpretation of diagrams from smartphone apps

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Abstract. Smartphones have become an integral part of our everyday life, and different apps for smartphones can also be used as a tool to carry out physical experiments. Many of these apps use graphic representations to display the measured results. In order to investigate how students understand and interpret these graphs, a questionnaire with seven open ended questions has been developed. 113 students from TU Dresden and University of Vienna were asked to analyze and interpret the graphic representations produced by different smartphone apps. The answers were categorized and evaluated quantitatively and these results will be presented in this contribution. The initial results exhibit similar difficulties as with other graphs in physics, with additional difficulties with the offset of coordinate axes, fewer labels on the axes and the presence of noise on the data in the graph.

3 Introduction

We live in a time when digitalization influences almost all areas of our lives and is also becoming increasingly relevant for the school and teaching. Apps for smartphones have been developed that allow data collection from phone internal sensors and facilitate video analysis and stroboscopic recordings. These apps allow the user very quickly to get information about the measurement in form of a graphical representation.

In previous research many student difficulties with graph interpretation were documented and identified in studies that were carried out in physics (mostly kinematics) or mathematics and that are also relevant for the interpretation of graphs from smartphone apps [1-3]. These difficulties include interval-point confusions, slope-height confusions, and iconic confusions, as well as difficulties with the concept of area under a graph.

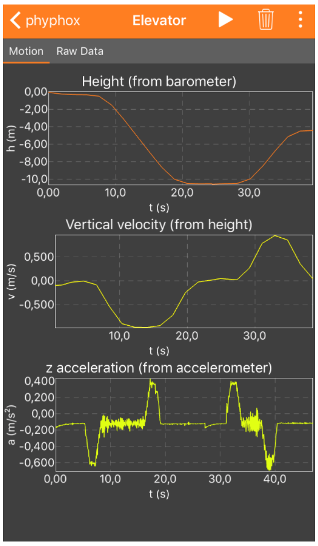
In this study we have investigated the following research questions:

I. What are the main observed student difficulties with graphical representations from smartphone apps?

II. What are similarities and difficulties with the already reported students difficulties with graph interpretation?

4 Methods

To investigate how future physics teachers can deal with graphs and images from smartphone apps, a questionnaire with a total of 7 open-ended questions was developed and given to a total of 58 students from TU Dresden and 55 students from University of Vienna. The allocated time for taking the questionnaire was 45 minutes. The questionnaire contains the graphs from the apps Video Physics, Viana, PhyPhox and Sony Motion Shot. Two questions were related to the graphs from video analysis of the motion (free fall and the ball rolling on the incline), three graphs were generated with the apps PhyPhox [4] using the internal smartphone sensors (elevator, rotational motion and motion of a car) and two representations included stroboscopic images of the motion. The students had to read different physical parameters from the graphs and analyze the graphs. The answers were analyzed and categorized using the framework of qualitative content analysis by Kuckartz [5] to find out the most common difficulties with the representations from smartphone apps. An example of one question is given in Figure 1.



In which time intervals is the elevator speeding up and in which time intervals is it slowing down? How can you recognize when it is speeding up and when slowing down?

Compare the v-t and a-t diagrams. What can you notice?

Figure 1. Example of one question from the questionnaire

5 Preliminary results

Results indicate that students have a lot of difficulties interpreting the graphs from the smartphone apps. These include difficulties determining the slope of the graph, slope-height confusion, inadequate use of formula, difficulties determining and interpreting area under the graph. In addition in the problem with an elevator students had a difficulty to determine when the elevator is speeding up and slowing down. They also had a problem finding the function that relates the variables from the graphs. More specifically in the problems with the video analysis students had a problem determining where is the origin of the coordinate system for the analysis and also the presence of the noise in the data was causing the problems. More detailed results of the study and possible implications for teaching will be presented in the talk.

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Two functions of visualization tools: the case of GeoGebra

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Abstract. In this paper, we identify two functions that interactive digital visualization tools fulfil in facilitating mathematization in physics education: namely, (1) bridging physical phenomena and formalisms and (2) bridging idealized models and formalisms. To illustrate these two mathematization functions, we present the case of GeoGebra, a flexible visualization tool which can exemplify both functions depending on how it is implemented in physics teaching and learning.

6 Introduction

In the discipline of physics, physical relationships are often systematically described using mathematical elements (i.e., formalisms) such as numbers with units, diagrams, vector arrows, and/or functions. These formalisms are often quite removed from physics students' everyday experiences and learning how to use them in the context of physics typically presents a challenging step in the process of learning physics. Digital visualization tools are technologies that can facilitate the transition from experience to formalisms and vice-versa by visually rendering the abstract formalisms of physics potentially making them more intuitively accessible.

The utility of visualization tools to facilitate students' understanding of science has been explored by researchers ranging from, for example, cognitive science [1] to physics education research [2]. Relevant to our discussion of how visualization tools make formalisms more intuitive, diSessa [3] highlighted how digital technologies could perform the role of *semi-formalisms*. With the term semi-formalism, diSessa meant to capture how technologies can constitute environments, wherein the experiential and formal features of physical phenomena are comingled with one another, providing students with alternative access to rigorous formalisms in intuitively familiar ways.

7 Two mathematization functions of visualization tools

In reviewing the literature on visualization and mathematization (an ongoing larger project), and building on diSessa's notion of semi-formalisms [3], we have identified two distinct functions that visualization tools may serve in facilitating mathematization:

- *Function I.* Bridging physical phenomena and formalisms—i.e., by (a) linking physical phenomena to formalisms and/or (b) augmenting physical phenomena with formalisms.
- *Function II.* Bridging idealized models of physical phenomena and formalisms—i.e., by (a) linking models to formalisms and/or (b) augmenting simulations with formal representations.

To illustrate these two mathematization functions, we present the example software of GeoGebra, which, unlike many other visualization tools used in physics education, can flexibly exemplify both mathematization functions depending on how it is implemented.

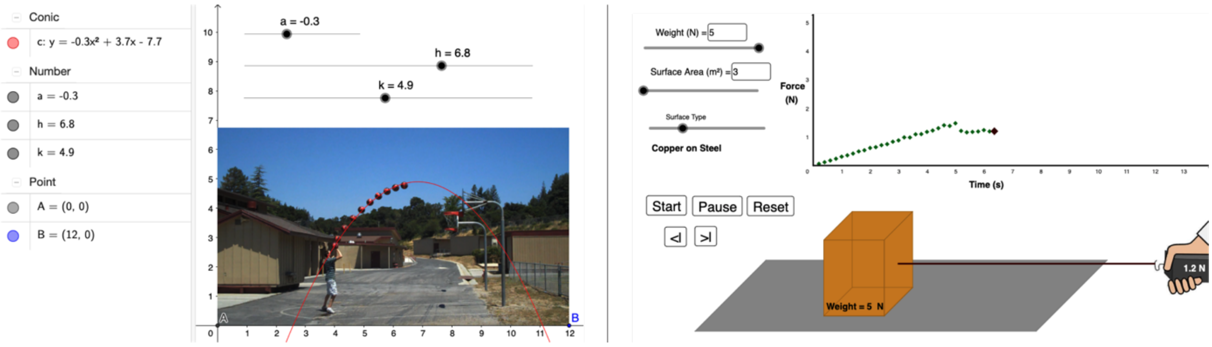

Fig. 1 (left) GeoGebra sim of projectile motion showing the augmenting and linking of physical phenomena with formalisms, and (right) sim of friction showing the linking of idealised models to formalisms (from [4]).

8 How GeoGebra exemplifies the two mathematization functions

GeoGebra is a software which can be used by physics educators (with or without prior programming knowledge) to create simulations, to augment real experiments, and/or to involve students in the process of modelling physical phenomena [4]. Researchers have identified that GeoGebra's editability as a visualization tool is valuable insofar as it 'makes the mathematical models behind the simulations completely transparent and easily accessible to the user, and avoids producing the impression that complex and exotic algorithms are at work' (p. 18) [5].

One simulation made in GeoGebra, which exemplifies the first function of visualizations, presents a composite image of a basketball as it arcs through the air (Fig. 1, left). Users can visually fit a parabolic curve to the path of the basketball by manipulating sliders for the relevant parameters. In this simulation, GeoGebra augments a physical phenomenon (i.e., a basketball shot) through a superimposed formalism, and students can intuitively manipulate the formalism by 'grabbing' and moving skeuomorphic sliders. Another simulation made in GeoGebra, which exemplifies the second function of visualizations, presents an idealized visual model of a block being pulled across a frictional surface (Fig. 1, right). Here, students can manipulate the relevant parameters of the block and surface model and observe a dynamically generated plot of force vs. time. In this second example, GeoGebra links an idealized model of physical phenomena to a formalism by coupling the animation of a sliding block to a simultaneously generated graph.

In both examples above, the GeoGebra visualization tool ostensibly facilitates students' transition between relatable physical phenomena and the formalisms that the discipline of physics uses to mathematize those phenomena as part of problem solving and analysis.

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Accommodating to teachers' concerns: integrating computation into inquiry-based learning

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Abstract.
Solving motion equations computationally using "step-by-step" numeric methods allows even 9th grade students to model a wide range of phenomena. While these computational methods are within the reach of students, their teachers usually refrain from using computation in their lessons. We present a sequence of computational modeling activities accompanying an inquiry-based physics module. The activities were designed to develop teachers' confidence by focusing on assigning meaning to a readymade program rather than writing its code. Each activity was structured in three steps: *Exploring* an existing program, *Sense-making* through guiding questions and *Application* - modification of the program. We describe the design, based on teachers' feedback, of the different versions of the activities, as well as teachers' views on them.

Rational

Research in physics consists of the construction of an experimental model along with producing a theoretical model based on laws of nature. In frameworks that engage students in open-ended inquiry, secondary-school physics students are mainly involved in the experimental aspects of research [2]. Learning resources have been developed that enable students to model phenomena otherwise beyond their mathematical competence, in an approach that integrates computational modeling with the scientific content [3]. While performing simple computational tasks is within the reach of students, their teachers do not feel proficient enough to manage the computational activities in the classroom [4]. We present a sequence of activities that were introduced as part of an inquiry workshop for 9th grade physics teachers and refined following their feedback. We focus on two research goals: (1) Characterizing design guidelines for computational modeling activities that enable teachers with no programming background to successfully complete them in a limited time frame. (2) Examining teachers' perceptions of the activities.

Research approach

Goal 1 was addressed via examination of two designs of the activity. The "pilot" design was tried out in the summers of 2017-2018, and the "final" design considered the feedback from the pilot versions and was implemented in the summers of 2019-2020. The versions were tested based on two main measures - teachers' ability to complete the activities in the limited PD time frame, and the extent of classroom implementation. Goal 2 was investigated through questionnaires and open-ended reflection questions.

Context and design of pilot activities

“Gateway to physics” is an inquiry-based program intended to motivate 9th graders to choose physics as a major by raising their interest and self-efficacy. Two learning modules were developed, the 1st investigates oscillations of a mass on a spring and the 2nd objects falling through air (both systems involve non-linear equations). The modules were introduced in summer workshops (30h along 4 days for each module), the computational activities lasting half a day (~4h).

The computational activities were carried out using Trinket.io - a free, online tool for coding activities and courses. This platform runs Vpython - a 3D graphical package for python, a widespread coding environment for scientific modeling. The activities were designed as a middle ground between using ready-made models and constructing models from scratch: students 'opened the hood' and observed a working model and then changed its features according to their needs. Instruction given in the pilot versions was minimal: Participants learned the meaning of the different parts of the program through hands-on tasks. The activities did not address the algorithmic considerations of the program.

The sequence consisted of 4 activities: (1) Creating and placing objects. (2) Constant velocity motion - using the "while" loop. (3) Motion under a constant force - participants apply Euler's method to model motion using Newton’s 2nd law. (4) Comparing model and to experimental findings. For example, in the ‘constant velocity’ activity they were asked to cause a body moving from the right of the screen to the left to move the opposite way (which requires changing the direction of velocity and the initial position).

Empirical investigation

53 teachers participated in the pilot activities. We witnessed a high drop-out rate: ~20% of teachers did not complete the whole sequence, mostly teachers without background in programming or in physics. Only a few implemented them in their classes - either due to external constraints or due to lack of confidence to adapt such innovative curriculum.

We revised and scaffolded the activities: Each activity was broken down to the following steps: (a) *Exploring* an existing program by running it, making guided manipulations and describing their outcome. (b) *Sense-making* of the program through guiding questions. (c) *Application*: modification of the program to meet different tasks. In addition, instead of using an external platform, the activities were incorporated into the same learning management system of the other workshop activities, to help teachers view the unit as an integral part of the workshop.

67 teachers experienced the final design. Previous research [6] showed that the 2019 teachers appreciated the activities and reported higher programming self-efficacy after completing them. In the 2020 PD workshop, teachers from different backgrounds successfully completed the activities (only 1/18 drop-out). However, most of the teachers (~75%) stated they still do not feel confident enough to implement the activities in their classrooms.

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