Mobile Devices as Experimental Tools: Five Empirical Studies on Students' Learning in Mechanics

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Abstract. In this contribution we present an overview about the experimental possibilities of mobile devices (smartphones, tablets) in the context of learning introductory mechanics, and summarize the findings of five empirical studies. The studies cover the specific subjects of the physics pendulum (acceleration sensor, video analysis), one-dimensional motion processes (video analysis), and a long-term video analysis intervention in experimental physics courses (1st year university). All studies have in common that they involve a contrast between students who did use mobile devices as experimental tools and students who did not, establishing a fair comparison in terms of time-on-task, demands and other conditions.

1 Mobile Devices (MD) as experimental tools

During the last decade the development of modern mobile digital media, such as smartphones and tablet computers (MDs), has triggered an experimental revolution in STEM education. These devices include numerous sensors covering different physical quantities and have been successfully established as portable mini-labs for the use in schools and in university courses in the last years [1]. Today integrated sensors allow performing experiments in almost all fields of physics, e.g., mechanics, optics, acoustics or even nuclear physics. Recently, video-based motion analysis (short: video analysis) has also become available on MDs due to special applications [2]. Thus, short video sequences can be recorded and analyzed subsequently, and most of the features commercial video analysis software offer can be used on the MD. The high availability of MDs, in addition, is a huge advantage, which opens new possibilities for, e.g., informal learning settings, ubiquitous learning, and recording videos from everyday experiments.

In contrast to a broad basis of conceptual developments, little is known about the effectiveness of such devices concerning learning outcomes. Our research program aims to close this gap. During traditional classroom settings or university courses, we investigate students learning (and other variables) with MDs. We use an instructional approach (work sheets, exercises, and problems) to guide students through experimental activities involving MDs as experimental tools.

2 Hypotheses and Objectives

Based on the theoretical and conceptual framework of multimedia learning [3], including cognitive load theory, as well as Cognitive Theory of Multimedia Learning resp. Cognitive Affective Theory of Learning with Multimedia, we formulate hypotheses and study research questions concerning learning, and moreover concerning affective variables (motivation, epistemic curiosity) as well as workload and perceived stress. In this contribution, we present results concerning learning variables (conceptual understanding of mechanics and representation competency). The hypothesis reads: "Students working with MDs will show larger learning gains compared to students working with traditional methods, if and only if MDs are employed in a beneficial way of learning". A beneficial way of learning is given when the possibilities of the MDs are exploited according to the theoretical considerations of learning theories. This involves, e.g., establishing active engagement and reducing cognitive load during experimentation. We use manipulation checks to ensure this condition.

3 Methods and empirical studies

For the purpose mentioned above, both groups, intervention group (with MD) and control group (without MD), were held identical in their learning contents and differed only in the use of MDs as experimental tools. In each study, we examined the dependent variables by using well-established and well-validated paper-and-pencil tests as pre- and post-measures, and controlled for covariates. Table 1 provides an overview about the studies which will be discussed. Studies 3 and 4 will be presented in more detail, including all materials and the full study design.

Table 1: Overview of the studies

<table>
<tr><th>Study No.</th><th>Subject</th><th>Sample (matched) and time span of intervention</th><th>Contrast</th><th>Learning variable(s)</th></tr>
<tr><td>1</td><td>pendulum oscillations</td><td>Upper secondary (N=154)
4 hours experimentation</td><td>Smartphone acceleration sensor vs. traditional equipment</td><td>Conceptual understanding</td></tr>
<tr><td>2</td><td>pendulum oscillations</td><td>Upper secondary (N=60)
4 hours experimentation</td><td rowspan="3">Video motion analysis (tablet PC) vs. traditional lab equipment</td><td rowspan="4">Conceptual understanding, representational competence</td></tr>
<tr><td>3</td><td>uniform motion: v=konst.</td><td>Upper secondary (N=109)
4 hours experimentation + 2 hours problem-solving</td></tr>
<tr><td>4</td><td>uniform motion: a=konst.</td><td>Upper secondary (N=70)
4 hours experimentation + 2 hours problem-solving</td></tr>
<tr><td>5</td><td>University mechanics</td><td>1st year students (N=76)
4 weeks (16 recitation problems)</td><td>Video-based problems in recitations (tablet PC) vs. traditional problems</td></tr>
</table>

4 First results

From study 1, we obtain evidence that *simple replacement* without reducing cognitive load during experimentation of traditional lab equipment by smartphones is not sufficient to achieve better learning gains compared to the control condition. However, working with smartphones had positive impact on interest ($p=0.015$, $d=0.4$) and curiosity ($p=0.002$, $d=0.25$). From studies 3 and 4 we found that mobile devices facilitate learning *during experiments* better than traditional equipment ($p<0.05$, $d=0.31$-0.64), but the control catches up this deficit during problem-solving exercises. Study 5 proofed that also university students can benefit from video-based motion analysis with mobile devices in the framework of traditional mechanics courses. After solving 8 problems as homework assignments, students' representation competence and conceptual understanding was more pronounced when employing video analysis ($p<0.001$, $d=0.72$; $p<0.05$, $d=0.34$). After this instruction period, both groups switched their role and the positive impact of MDs on students' conceptual understanding was confirmed ($d=0.40$). Study 2 is still ongoing, but results will be available in June 2018.

References

[1] Kuhn, Relevant information about using a mobile phone acceleration sensor in physics experiments, *Am. J. Phys*., **82** (2014), 94.

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[3] Mayer, Cognitive theory of multimedia learning. In The Cambridge Handbook of Multimedia Learning. Cambridge University Press, 2014.