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ScienceDirect

Procedia - Social and Behavioral Sciences 228 (2016) 316 – 322

Procedia Social and Behavioral Sciences

2nd International Conference on Higher Education Advances, HEAd´16, 21-23 June 2016, València, Spain

DiffGame: Game-based mathematics learning for physics

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Abstract

Differentiation is a mathematical skill applied throughout science in order to describe the change of a function with respect to a dependent variable. Thus, an intuitive understanding of differentiation is necessary to work with the mathematical frameworks used to describe physical systems in the higher levels of education. In order to obtain this intuition repeated practice is required. This paper presents the development of DiffGame, which consists of a series of exercises that introduce the basic principles of differentiation for high-school students through game-like elements. DiffGame have been tested with 117 first-year students from a single Danish high school, who did not have any prior training in differentiation. The students' learning was assessed by the data obtained directly from DiffGame. The test demonstrated the efficacy of DiffGame, since students at all levels demonstrate a learning gain. In contrast to previous studies demonstrating most learning in the lower tier of students, the middle tier of students (based on overall performance) exhibits the largest learning gains.

Peer-review under responsibility of the organizing committee of HEAd´16

Keywords: gamification; game-based learning; blended learning; e-learning;

1. Introduction

Differentiation is a mathematical skill that determines the change in a function with respect to a change in a dependent variable. Differentiation has a prominent role in the mathematics that describes physical systems. As an example, the resulting force acting on an object at any given time can be determined by differentiating its velocity

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Peer-review under responsibility of the organizing committee of HEAd´16
doi:10.1016/j.sbspro.2016.07.047

with respect to time and thereby obtain the acceleration, which is proportional to the force according to Newton's Second law. Thus, knowing how to differentiate is crucial for any student who wants to proceed with the higher levels of education in science. In order to obtain an intuition about the basic principles of differentiation, repeated practice in solving differentiation-problems is necessary. Students are, however, usually first introduced to the concepts through lectures where the math is presented in an abstract format. Earlier studies have shown an improved learning process by letting students first investigate and try to solve problems within a subject on their own before exposing them to the formal knowledge that enables novices to form an initial understanding of the subject (Kapur et al., 2010).

One way to facilitate students' independent investigation of differentiation-problems is through games. In an educational context games have the ability to make learning more entertaining and motivate students without compromising the learning (Muntean, 2011). Abstract content which could otherwise be incomprehensible can in games be conveyed though simple visual representations and interactions (Bjælde et al., 2014; Magnusen et al., 2014; Pedersen et al., 2016). The simple visual representations combined with the game elements allow students to obtain an intuition even for systems which do not have any analogies to their daily life (Lieberoth et al., 2015).

Games can be designed such that students are presented with problems in an environment that allows them to make mistakes and reflect upon them. The flow-in-game infused learning can be designed to adapt to the individual students' level of skill in order to provide training in the most beneficial areas. Such dynamically differentiated learning (Algozzine & Anderson, 2007) is enabled by giving students, who have troubles with a specific type of problems, extra opportunities to train, while allowing those, who have mastered the problems, to proceed. Thus, students will mostly work in their zone of proximal development (Vygotsky, 1978); continually challenged to the border of their current abilities but with scaffolds like tutoring and feedback in place to keep the learning trajectory moving forward (Wood, Bruner, & Ross, 1976). These elements align well with the visible learning theory (Hattie & Yates, 2014); the games welcome errors as learning opportunities, the students current abilities are assessed and determine the next step in the learning process, the students have a clear goal to fulfill, and the games can be built such that both teachers and students can easily follow the progress.

This paper presents the development of DiffGame, which consists of a series of exercises that introduce the basic principles of differentiation for high-school students through game-like elements. The games were developed and tested in a blended-learning environment, in which the games were deployed in a classroom with a teacher and instructors at hand to help and guide the sessions. The aim was to develop the games such that they required no previous knowledge about differentiation, but it could also be used to refresh students' differentiation knowledge at later stages of their education.

Previous studies (Bjælde et al., 2014; Adams et al., 2008) have showed that it is often the lower tier of students, who learn the most from games. However, it remains an open question whether these results are just a case of diminishing returns (the more you know the less there is to learn), or if gamified teaching appeals to a different segment of students than traditional lectures. Thus, the students are divided into lower, middle, or upper tiers of students based on overall performance in DiffGame and their learning gains are compared.

Another point of interest is how the DiffGame motivated students, and to what degree such motivation predicted performance. Motivation refers to the process whereby goal-directed activities are instigated and sustained by intrinsic or extrinsic dynamics (Lepper et al., 1973; Lieberoth et al., 2014; Ryan & Deci, 2000). Intrinsic motivation refers to motivation to engage in an activity for its own sake. When students are intrinsically motivated, they work on tasks because they enjoy the activity and find it meaningful. In contrast, extrinsic motivation is based on other reasons, such as outside demands or economic and symbolic rewards (Ryan & Deci, 2000). In most cases learning trajectories are supported by a little bit of both. Since intrinsic motivation is thought to have a positive impact on students (Deci et al., 1991), the potential relationship between high levels of intrinsic motivation and higher levels of performance in DiffGame is examined.

2. DiffGame

Differentiation is an important part of the Danish high school curriculum. Differentiation is always introduced through visual interpretation as the slope of a curve at a particular point. However, most teaching on the subject then proceeds quickly to the more formalistic rules for deriving various analytic functions. DiffGame delves much longer