Smartphone Usage in Science Education

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The growing significance of digital learning in science education has brought about considerations about various mobile devices. In this respect, the use of smartphones has become a subject of attention in the field of educational research. The popular mini computers are handy, readily available and easy to use. They offer quick access to simulations, databases, and other tools of importance in science classrooms and can be used to improve aspects of science education.

Keywords: augmented reality ; gamification ; measurement ; science education ; smartphones

1. Introduction

As the current body of educational research encompasses a wide range of effectivity-related evaluations, there have been a plethora of undertakings carried out to evaluate the effects that smartphones have on learning processes (see e.g., [1][2][3]). Several factors, such as relief from nomophobia (see e.g., [4][5][6]) or amplification of distraction due to the use of social messaging apps (see e.g., [7][8][9]), that appear to influence the success of smartphone usage, have gained a great deal of attention. Due to the plentiful efforts of researchers, the impact of smartphone usage, which may be positive in one realm and negative in another, is a lot clearer.

2. AR Applications in Smartphone Usage

Learning achievement is the construct that was discussed the most in quantitative research dealing with AR. All evaluated studies found that learning achievement could be supported by using the respective AR applications. In eight of these studies, an EG-CG design (Experimental Group-Control Group) was used to test various AR applications against traditional educational materials. In all these cases, the AR application did net about the same [10][11] or a higher learning achievement [12][13][14][15][16][17].

Attitudes (e.g., towards AR, technology, and subject content) have also been a prevalent topic of research in the context of AR usage. Positive attitudes towards AR were reported by several studies [10][18][19][20]. Both positive and negative attitudes towards AR were found by [21], who named several pros and cons for using the technology. Positive attitudes towards learning were found by [12][22]. In addition, there are reports on neutral [15] and positive [23] effects on attitudes towards the educational content.

The influence of AR applications on *motivation and interest* is not conclusive. There are some studies that show an increase in motivation [12][20][24], with [24] linking the increase of triggered interest to an increased flow experience during AR usage. However, a neutral effect has been shown by [15] and mostly small negative effects have been found by [13]. In the latter case, decreases in attention, relevance, and confidence were reported as well as a slight increase in satisfaction. Though similar results were obtained in the control group, the decrease in confidence was higher in the AR group.

Next to the aforementioned constructs, several smaller aspects of AR usage have been reported on. Positive effects in general and compared to a traditional control group were found by [11][25]. Additionally, the cognitive load was found to be lower during learning using an AR application when compared both to traditional educational materials [16][17][26] and to 3D simulations [16]. Furthermore, it was found by [11] that AR applications do not hinder the usage of representational skills and can help facilitate flow experience [24]. There were positive effects on scientific literacy when compared to a non-AR control group [14] as well as in general [27]. No increases in science learning anxiety were found during the usage of AR by [15]. Lastly, it was found that epistemic justifications have similar effects in both an AR environment and in a traditional one [24].

To summarize, AR applications have a rather positive influence on various constructs that are deemed important for educational contexts.

3. Topic-Specific Smartphone Usage

Topic-specific smartphone usage was reported on in 18 of the articles. In this category, all studies that used smartphones in one very topic-specific case are summarized. One such example is the usage of an application identifying species [28] or birds [29].

As with AR, most of the studies involving a topic-specific use of smartphones were looking at *learning achievement*. Regarding the influence of the usage of smartphones on learning achievement, the general consensus is that smartphone applications for specific teaching units do indeed facilitate learning and lead to an increase in learning achievement. This was reported by 12 studies that dealt with this topic. Of these articles, seven reported on a general increase of learning achievement [27][30][31][32][33][34]. Another six articles looked at learning achievement in comparison to a control group, where outcomes varied: three of these articles reported higher learning achievement with the topic-specific applications compared to “classical” media [35][36][37], two did not show a significant difference when compared to classical media [28][38], and in one case the topic-specific use fared worse (compared to a textbook, [39].

When asked about their *attitudes* on the use of such applications in class, teachers reported feeling pressured by learning and implementing new technologies [40]. Overall, attitudes towards the apps used [20][32][34] and smartphones [29][41] were, however, positive. In the case of [37], the attitudes towards the biochemistry content used as a setting for the study was higher than in a control group. In the case of [33], the applications facilitated positive attitudes towards green chemistry.

Usage of smartphones for specific teaching scenarios netted generally positive motivational affects, such as an increase in enjoyment [20] or general increases in interest when compared to control groups using classical media [28][37]. Additionally, in [28], well-being was shown to be positively influenced by usage of smartphones in certain teaching scenarios, whereas the control group showed decreases with the use of textbooks.

As for *representational skills*, one study showed that increases were facilitated by smartphones [42]. For more general effects on learning skills, smartphones were shown to be able to increase autonomy in general [31] and in comparison with a control group [28], creative thinking [43] as well as critical thinking [42]—difference to control group not significant). Problem solving was also shown to improve in general [43] and when compared to a control group [35].

Other effects of topic-specific use of smartphones were found to be small increases in anxiety in comparison to a control group [36] as well as increases in collective efficacy, though not significantly different to a control group [35]. Moreover, ref. [41] reported wishes for more videos or more detailed information to be used on smartphones to supplement laboratory courses.

4. Games and Gamification in Smartphone Usage

Games and gamification approaches in the classroom via mobile devices showed largely positive effects on *learning achievement*, as documented by [33][44] in general, and by [22][45][46][47][48][49][50] in control design studies. Conversely, ref. [15] found no positive or negative effects of their gamification approach. Moreover, ref. [51] found that learning achievement was independent of students taking pleasure in playing the relevant game.

Attitudes towards science learning were shown to positively develop more when compared to non-gamified approaches [22] and positive attitudes towards learning contents were also facilitated [33][51]. The effects of gamified approaches on motivation and interest were reported to be more positive compared to traditional materials by [45][46], whereas [52] reported no significant effects.

Moreover, flow experience was facilitated more effectively with gamified approaches when compared to others [47][53][54], as was engagement [48][55]. Of students with high and mid-level flow, ref. [54] found significant increases in the participants’ scientific literacy. Additionally, ref. [55] found that that gamified approaches in their study worked better than question-based approaches. Generally positive experiences with the gamified material as well as the learning environment were reported by [56][57].

5. Holistic Smartphone Usage

In total, the study survey yielded 12 contributions which address the use of smartphones in a holistic sense, meaning use of smartphones throughout long time spans for various purposes. Taken together, the studies cover each of the categorized constructs with the exception of representational skills. Few of the studies investigate single learning activities or feature an EG-CG design. In contrast, the majority of reported results have been generated from data gathered over prolonged periods of time or from surveys regarding every (school) day smartphone usage.

Most of the studies from this category investigated effects on *learning achievement*. Some of them report positive results [58][59][60], with [58] reporting a greater effect for low ability students. Both positive and neutral effects have been reported by [61][62]. The relevant differences in study outcomes depend on the type of data for learning achievement evaluation in [61] and on the level of media usage in [62]. Investigating perceived learning, ref. [63] finds higher ratings when learning activities are genuine, meet individual requirements, and support student interaction.

Studies investigating the effect of holistic smartphone usage on *learning skills* predominantly report positive results. Using qualitative methods, three studies [64][65][66] reveal its potential to support inquiry learning. Moreover, on the note that adequate directives must be given, its potential to foster self-directed learning is pointed out in [61]. Based on quantitative methods, a positive effect has been reported regarding the development of scientific literacy in [67]. With respect to self-directed learning, a merely neutral effect has been reported in [61].

The studies investigating *attitudes* have evaluated the stakeholders' willingness to adopt mobile devices for educational purposes. Quantitative and qualitative results presented in [60][68] show students' positive views in this regard. As reported in [60], students' outlook on mobile device use for educational purposes is correlated with measures of common usage. Regarding the development of teachers' attitudes, a neutral effect is reported in [69].

In relation to teachers' anxiety and self-efficacy, positive effects in easing the former and strengthening the latter have been reported in [69]. Furthermore, ref. [59] point out that using mobile devices might help teachers to improve their in-class performance regarding communicative processes. Concerning students' subject interest, positive effects have been reported in [60]. Moreover, ref. [59] has found that the use of mobile devices supported participation, especially for low ability students. Researching students' self-efficacy, ref. [70] find higher ratings when learning activities promote autonomy, seem genuine, and reinforce cooperation.

6. Measurement in Smartphone Usage

Using smartphones or tablets for measuring is a fairly new opportunity to approach course content, especially in physics classes. In general, the usage of mobile devices had positive effects on *learning achievement* [71][72] and in comparison with traditional media, showed significantly more positive effects [73][74]. However, ref. [75] reported no significant effects of using mobile devices for measurements on learning achievement.

In general, *attitudes* towards measuring via mobile devices showed positive attitudes towards the activities [34][72][76]. An increase in motivation and interest compared to a traditional control group was documented by [75], although no such increase was found within a similar setting. However, small increases in curiosity were reported by [75] as well. While using mobile devices as tools for measurements, no correlations between behavioral patterns and learning achievement were found by [75].

7. Personal Response in Smartphone Usage

Taken together, studies on personal response applications cover each of the constructs except representational skills. Of the investigated constructs, merely two, namely learning achievement and learning skills, have been investigated with the means of pre- and post-test, EG-CG study designs. Predominantly, the studies from this category report positive results.

The majority of studies investigated students' *attitudes* regarding the usage of the relevant applications. Quantitative results reported in [77][78][79] suggest that students found they benefited from app usage in their learning. This is complemented by the qualitative results reported in [80], which demonstrate that personal response applications add to learning by enabling communicative processes and self-evaluation. Regarding *learning achievement*, there are two studies which feature a pre- and post-test, EG-CG design. Both of them [80][81] report positive effects in both groups, yet significantly higher results in the experimental groups that featured app usage. Another study [77] found that students showed significantly higher achievements on tasks when the relevant content had been taught with the aid of personal response applications.

When *affective constructs* are concerned, there are two studies which investigate effects on engagement. Though both studies report on the use of personal response applications, they are different in nature. The results reported in [79] refer to the use of clicker applications. Using quantitative methods, no evidence was found that their usage enhanced engagement. In a qualitative approach, ref. [82] investigated the use of an answer–response system and found that students' shyness as well as the lecture format hindered students from making contributions on the application.

The remaining studies on personal response applications address learning skills and behavioral patterns. Concerning learning skills, ref. [80] reported positive, yet not significantly differing, effects in both groups of an EG-CG study design. In relation to behavioral patterns, positive effects on student–teacher and student–student interaction as well as collaborative learning have been reported in [79].

8. Communication in Smartphone Usage

Using mobile devices for communication such as messenger apps or feedback tools has been shown to facilitate more positive effects on *learning achievement* compared to a control group by [83] and the same level of positive effects as a control group by [84]. Overall, the *attitudes* toward using mobile devices for communicative purposes were positive [85], and gains in retention [86] and satisfaction [83] were found. Additionally, self-efficacy was shown to be positive in the communicating class [87].

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