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Review

Smartphone Usage in Science Education: A Systematic Literature Review

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Abstract: This article presents a review of research on smartphone usage in educational science settings published between January 2015 and August 2022, and aims to provide an overview of the constructs evaluated and to identify potential gaps in current research for researchers working on this topic. Specifically, the search for publications in the relevant years was narrowed down to such studies that provided empirical evidence for the impact of smartphone usage on teaching and learning in natural science education. The databases used for the search were ERIC, Scopus, and Web of Science. In total, 100 articles were surveyed. The study findings were categorized regarding the type of smartphone usage, as well as the type of educational institution and constructs investigated. Overall, the results from this review show that smartphone usage in educational science environments has the potential for rather positive effects, such as an increase in learning achievements or an increase in motivation, and smartphone usage rarely leads to detrimental effects. Despite the substantial amount of studies to date, more research in these areas would allow for more generalized statistical results and analyses and is therefore desirable.

Keywords: augmented reality; gamification; measurement; science education; smartphone effects; smartphone usage

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1. Introduction

The growing significance of digital learning media 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 mini computers that are popular are handy and readily available and easy to use. They offer quick access to simulations, databases, and other tools of importance in science classrooms.

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., [1–3]). Several factors, such as relief from nomophobia (see e.g., [4–6]) or amplification of distraction due to the use of social messaging apps (see e.g., [7–9]), 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.

Despite the widespread use of smartphones in educational science settings, their impact on psychological constructs has not been systematically reviewed. This literature gap is filled by our review, which qualitatively examines the constructs, measurement methods, and results of studies on educational smartphone use. By providing insights into the documented effects of smartphone usage, our review supports educators and researchers in identifying areas for future study as well as giving them an overview about what has already been assessed.

Specifically, research on the following questions is presented in this article:

1. Which constructs do researchers examine to evaluate the effects of smartphone usage in natural science education?
2. Which types of smartphone usage have been evaluated in research on smartphone usage in natural science education?
3. Which results have been gathered from research on effects of smartphone usage in natural science education?

Prior to setting out the results of this research project, the methodology used to search for, analyze, and cluster the publications deemed suitable will be presented (see Section 2). Thereon, the results of research questions (i) and (ii), namely a summary of the examined constructs and usages will be presented in a joint section (see Section 3). The results of research on smartphone effects (iii), will be presented in Section 4. The paper concludes on baselines drawn from the current body of research and by setting out avenues for future research projects.

2. Methodology

To find articles that fit the required properties for this review, three databases, namely ERIC, Scopus, and Web of Science, were used. We limited the search to articles published within the time span of January 2015 to August 2022, as smartphones in their current form—little computer-like devices that have a user interface and internet access—have only recently been widely used and in the possession of students.

The following query was used to search for articles related to the research questions: (“smartphone” OR “mobile phone”) AND (“students” OR “school” OR “education” OR “learners”) AND ("science" OR “biology” OR “chemistry” OR “physics”). Using this query, 1888 potential articles were extracted and used in further analysis (4568 findings, not accounting for doubles).

From those articles, abstracts were examined and excluded those that: (1) did not have smartphone usage (e.g., articles which focus on general aspects of mobile learning like portable PCs), (2) did not address (natural) science education, (3) only contained meta studies or other reviews, as those included mostly studies from before 2015, and (4) did not explicitly state that they would examine any constructs.

To ensure that the exclusions were conducted reliably, the first 100 articles extracted from ERIC were taken as a sample to test the exclusion criteria. To ensure reliability, this process was done by two different independent researchers. For the 100 articles, no discrepancies in selection were found between the researchers. It was therefore concluded that the selection process worked as intended and the criteria for exclusion were sufficiently well defined.

By using the aforementioned criteria (1–4), 100 articles were extracted from the search results of all databases. Following the search, categories were inductively derived from the articles at hand to find all psychological constructs measured. During the process, the constructs named by the authors were used to create the categories to represent their understanding of the research in the best way possible. This process resulted the list of categories that are presented in Table 1. To ensure the reliability of the coding, an inter-rating process was used: 20 randomly picked examples from the stock of 100 articles were selected and categorized by two independent researchers. The resulting reliability was deemed acceptable (Cohen’s Kappa of 0.97, deemed acceptable by using the measures of Landis and Koch [10]. Similarly, the articles were scanned for reported smartphone usages, resulting in the categories that are presented in Table 2, again characterized by an acceptable inter-rating result (Cohen’s Kappa of 0.89, deemed acceptable by using the measures of Landis and Koch [10]).

Table 1. Reported constructs. Constructs are sorted by level of targeted educational group and type of research (qualitative, quantitative). Mixed-method approaches are categorized in both of the qualitative and quantitative categories.

Construct		Preschool	Primary School	Secondary School	Higher Education	Total
	Qualitative	-	[11]	[12]	[13,14]	[11–15]
	Quantitative	[16]	[11,17–29]	[12,30–50]	[14,51–67]	[11,12,14–49,51–70]
Learning Achievement Attitudes	Qualitative	-	-	[45,47,48,71,72]	[61,73–79]	[39,45,47,48,61,71–81]
	Quantitative	-	[17,21,23,24]	[33,35,45,46,48,71,72,82–85]	[51,55–57,59,61,63,64,66,75,76,78,86–88]	[17,21,23,24,33,35,45,46,48,51,55–57,59,61,63,66,67,71,72,75,76,78,82–89]
Motivation/Interest	Qualitative	-	-	-	-	-
	Quantitative	-	[17,18,22,25]	[33,34,48,50,84,85,90]	[56,91,92]	[17,18,22,25,33,34,48,56,64,68,69,84,85,89–92]
Additional Affective Constructs	Qualitative	-	-	[93]	[94,95]	[93–95]
	Quantitative	-	[23,96,97]	[30,32,44,80,97,98]	[53,58,81]	[13,23,30,32,34,36,44,53,54,58,65,68,69,80,81,89,96–98]
Behavioral Patterns	Qualitative	-	[26,99,100]	[41,44]	[101]	[26,41,44,99–101]
	Quantitative	-	[99,100]	[41,82]	[51,81]	[41,51,81,82,99,100]
Representational Skills	Qualitative	-	-	[41]	-	[41]
	Quantitative	-	-	[41,102,103]	[53,86]	[41,53,86,102,103]
Learning Skills	Qualitative	-	[104]	[12,93,105,106]	-	[12,93,104,105]
	Quantitative	-	[20,27,28]	[12,40,107–109]	[51,54,65–67,91]	[12,20,27,28,30,31,40,51,54,65–67,69,90,91,101,107–109]
Other	Qualitative	-	[26]	[110]	[87,111]	[26,87,110,111]
	Quantitative	-	[20]	[32,33,43,82,85,98,106,109]	[52,62,79,81,111,112]	[20,32,33,43,52,62,69,79,81,82,85,98,103,109,111,112]

Table 2. Reported usages. Studies that examined more than one usage were sorted into each of the respective corresponding categories.

Type of Usage	Definition	Studies
AR Application	The smartphones were used with an AR application.	[17,21,22,27,28,32,33,35,36,53,54,65,71,75,77,84,88,90,110]
Topic-Specific Use	The smartphones were used in a single lesson or teaching unit without including usage of AR, games, measurements, personal response systems, or communication (e.g., an online textbook).	[19,20,28,38,40,45,52,55,56,61,64,69,74,84,87,102,103,109]
Games and Gamification	The smartphones were used with a gamified application.	[15,16,18,21,23,25,30,31,42,44,55,79,89,92,107,111]
Holistic Use	The smartphones were used holistically over a greater timespan (more than a teaching unit or lesson) without including usage of AR, games, measurements, personal response systems, or communication (e.g., learning diary).	[11,12,26,48–50,76,82,93,96,98,104,105,108]
Measurement	The smartphones were used with a measurement application (e.g., phyphox).	[29,34,41,63,68,72,83,112]
Personal Response	The smartphones were used with a personal response system (e.g., Plickers).	[24,57,67,80,81,94]
Communication	The smartphones were used with a communication application (e.g., WhatsApp).	[14,58,62,73,95]
Other	The smartphones were used in another way (e.g., aiding disabled learners, video conferencing).	[13,37,39,43,47,51,59,60,66,70,78,86,91,97,99–101,105,106]

3. Reported Constructs and Usages

This section provides a summary of the findings from research questions (i) and (ii). Accordingly, an overview of the reported constructs and smartphone usages is given.

3.1. Reported Constructs

The constructs reported most frequently (see Table 1) are learning achievement (59/100 = 59%), attitudes (39%), motivation and interest (17%), additional affective constructs (22%), learning skills (22%), behavioral patterns (9%), and representational skills (5%). There were also some additional constructs such as anxiety, creative thinking, and others.

3.2. Reported Usages

The most frequently reported usages of smartphones are AR applications (20), topic-specific uses (18), games (15), holistic usages (14), usage as measuring devices (8), personal response systems (7), and communicative usages (5). There are some additional usages as well, such as smartphones being implemented for helping learners with disabilities, conferencing, and others. A corresponding overview is given in Table 2. The categories "holistic use" and "topic-specific use" were only chosen when none of the remaining categories were reported in the respective articles. As this review aims to give an overview of the most reported usages, we decided to allow non-disjunct categories. In such instances, the respective studies were put into more than one category (e.g., ref. [21] reports on the usage of an AR game and was thus categorized as both "AR" and "Game").

4. Report of Results

In the following subsections, the usages of smartphones in science education will be detailed by a summary of the findings on reported effects.

4.1. Results in Relation to AR Applications

AR applications are the most documented usage we found, with 20 articles addressing their effects on several constructs.

Learning achievement is the construct that was discussed the most in quantitative research dealing with AR. All of the respective studies found that learning achievement could be supported by using the respective 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 [35,53] or a higher learning achievement [17,22,27,33,36,65].

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 [35,71,75,84]. Both positive and negative attitudes towards AR were found by [77], who named several pros and cons for using the technology. Positive attitudes towards learning were found by [17,21]. In addition, there are reports on neutral [33] and positive [88] 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 [17,84,90], with [90] linking the increase of triggered interest to an increased flow experience during AR usage. However, a neutral effect has been shown by [33] and mostly small negative effects have been found by [22]. 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 [32,53]. Additionally, the cognitive load was found to be lower during learning using an AR application when compared both to traditional educational materials [36,54,65] and to 3D simulations [36]. Furthermore, it was found by [53] that AR applications do not hinder the usage of representational skills and can help facilitate flow experience [90]. There were positive effects on scientific literacy when compared to a non-AR control group [27] as well as in general [28]. No increases in science learning anxiety were found during the usage of AR by [33]. Lastly, it was found that epistemic justifications have similar effects in both an AR environment and in a traditional one [90].

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

4.2. Results in Relation to Topic-Specific Use

Topic-specific smartphone usage was reported on in 18 of the articles. In this category, all studies that used smartphones were placed in one very topic-specific case. One such example is the usage of an application identifying species [69] or birds [64].

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 [19,28,40,45,55,61]. 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 [20,52,56], two did not show a significant difference when compared to classical media [38,69], and in one case the topic-specific use fared worse (compared to a textbook, [42].

When asked about their *attitudes* on the use of such applications in class, teachers reported feeling pressured by learning and implementing new technologies [74]. Overall, attitudes towards the apps used [45,61,84] and smartphones [64,87] were, however, positive. In the case of [56], the attitudes towards the biochemistry content used as a setting for the study was higher than in a control group. In the case of [55], 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 [84] or general increases in interest when compared to control groups using classical media [56,69]. Additionally, in [69], 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 [103]. For more general effects on learning skills, smartphones were shown to be able to increase autonomy in general [40] and in comparison with a control group [69], creative thinking [109] as well as critical thinking [103]—difference to control group not significant). Problem solving was also shown to improve in general [109] and when compared to a control group [20].

Other effects of topic-specific use of smartphones were found to be small increases in anxiety in comparison to a control group [52] as well as increases in collective efficacy, though not significantly different to a control group [20]. Moreover, ref. [87] reported wishes for more videos or more detailed information to be used on smartphones to supplement laboratory courses.

4.3. Results in Relation to Games and Gamification

Games and gamification approaches in the classroom via mobile devices showed largely positive effects on *learning achievement*, as documented by [15,55] in general, and by [18,21,25,30,44,92,110] in control design studies. Conversely, ref. [33] found no positive or negative effects of their gamification approach. Moreover, ref. [23] 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 [21] and positive attitudes towards learning contents were also facilitated [23,55]. The effects of gamified approaches on motivation and interest were reported to be more positive compared to traditional materials by [18,25], whereas [16] reported no significant effects. Moreover, flow experience was facilitated more effectively with gamified approaches when compared to others [30,31,107], as was engagement [44,89]. Of students with high and mid-level flow, ref. [107] found significant increases in the participants' scientific literacy. Additionally, ref. [89] 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 [79,111].

4.4. Results in Relation to Holistic Use

In total, the study survey yielded 12 contributions which address the use of smartphones in a holistic sense. 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 [11,26,48], with [11] reporting a greater effect for low ability students. Both positive and neutral effects have been reported by [12,49]. The relevant differences in study outcomes depend on the type of data for learning achievement evaluation in [12] and on the level of media usage in [49]. Investigating perceived learning, ref. [82] 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 [93,104,105] 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 [12]. Based on quantitative methods, a positive effect has been reported regarding the development of scientific literacy in [108]. With respect to self-directed learning, a merely neutral effect has been reported in [12].

The studies investigating *attitudes* have evaluated the stakeholders' willingness to adopt mobile devices for educational purposes. Quantitative and qualitative results presented in [48,76] show students' positive views in this regard. As reported in [48], 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 [98].

In relation to teachers' anxiety and self-efficacy, positive effects in easing the former and strengthening the latter have been reported in [98]. Furthermore, ref. [26] 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 [48]. Moreover, ref. [26] has found that the use of mobile devices supported participation, especially for low ability students. Researching students' self-efficacy, ref. [96] find higher ratings when learning activities promote autonomy, seem genuine, and reinforce cooperation.

4.5. Results in Relation to Measurement

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* [41,63] and in comparison with traditional media, showed significantly more positive effects [34,112]. However, ref. [68] 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 [61,63,72]. An increase in motivation and interest compared to a traditional control group was documented by [68], although no such increase was found within a similar setting. However, small increases in curiosity were reported by [68] as well. While using mobile devices as tools for measurements, no correlations between behavioral patterns and learning achievement were found by [68].

4.6. Results in Relation to Personal Response

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 [57,80,81] suggest that students found they benefited from app usage in their learning. This is complemented by the qualitative results reported in [67], 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 [24,67] report positive effects in both groups, yet significantly higher results in the experimental groups that featured app usage. Another study [57] 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 [81] refer to the use of clicker applications. Using quantitative methods, no evidence was found that their usage enhanced engagement. In a qualitative approach, ref. [94] 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. [67] 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 [81].

4.7. Results in Relation to Communication

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 [62] and the same level of positive effects as a control group by [14]. Overall, the *attitudes* toward using mobile devices for communicative purposes were positive [73], and gains in retention [58] and satisfaction [62] were found. Additionally, self-efficacy was shown to be positive in the communicating class [95].

4.8. Results in Relation to Other Usages

Studies from this umbrella category are of various types. Thus, the amount of research conducted on each type is comparably small.

The study survey yielded four studies that research the use of mobile devices to compensate for learning disabilities. Two of them investigated its impact on learning achievement. One of those studies [37] found that assignments read aloud by mobile devices had a similar effect in supporting students with reading disabilities in test situations as did the teachers' assistance. The other [39] found that knowledge of content matter in students with disabilities noticeably improved when they learned with tangible mobile applications. In addition, ref. [39] investigated students attitudes towards device use and found high rates of satisfaction. Another two studies used mixed methods approaches and found that students benefited from the use of mobile devices to improve in-class activities [99] and learning strategies [101].

Three studies have been identified that address the use of videos in teaching and learning. Notably, they focus on different types of video use. Whereas [91] reports on students' use of videos as databases, ref. [13] reports on their use as a source of information. In turn, ref. [70] reports on teachers managing the presentation of videos via their phones. Each of these studies reports positive effects of application use on various constructs: Both [13,70] report positive effects on students' learning achievement. In addition, [13] reports a significant effect on students' self-efficacy. While [91] reports positive effects on motivation and scientific literacy that were significantly higher compared with the effects generated in a traditional control group. Two studies have been found that address the use of visualization applications. Both of them measure its effect on learning achievement. Specifically, ref. [86] reports a positive and significantly higher effect when comparing post-test results from an experimental group with those from a control group. Moreover, ref. [60] reports a higher learning success in students with higher usage intensities regarding the relevant application.

Another two studies investigated the use of mobile devices in writing notebooks and portfolios. Both of them [59,78] investigated students' attitudes towards the mobile activities and found positive results. Moreover, ref. [59] investigated the applications' effects on learning achievement in a pre- and post-test EG-CG design and found a significantly greater positive effect in the experimental group. Two further studies have been found that research the use of mobile devices in institutions for informal learning. Notably, both of them use quasi-experimental designs to investigate effects on learning achievement and learning skills, however, they yielded differing results. Whereas [66] reports significantly higher learning achievements in the experimental group, ref. [51] reports no statistically significant difference. In relation to learning skills, ref. [51] reports significantly larger stay times in the experimental group, whereas [66] reports that time spent learning was significantly lower. In addition, both studies investigated participants' attitudes regarding mobile device usage and found positive responses.

Of the remaining studies, there is one [43] that researched the effects of video conferencing and found that it significantly improved students' subject knowledge as well as their metacognitive awareness. Addressing the use of text messages in learning, ref. [47] likewise reported a positive effect in learning achievement and additionally positive attitudes towards application usage. In relation to the use of intelligent personal assist applications, ref. [97] reports a neutral effect on engagement. Used as a tool for visualisation, ref. [106] did not find effects on spacial thinking and reasoning skills. Also, the effects on learning achievement and interest were reported to be most positive when smartphones were used with collaborative and student-led functions [50]. Lastly, concerning the use of learning management applications, ref. [100] investigated students' behavioral patterns using mixed methods and found that participation depends on a variety of activity factors.

5. Limitations and Recommendations

Though the amount of papers reporting on effects and usages of smartphones in science education is not small, several points need to be recognized when looking at the results:

1. Next to the prominent constructs (learning achievement, attitudes, and motivation/interest), many constructs were found that did not have many papers attending to them. The reported effects on these constructs have to be taken with caution, as they might not be transferable. We recommend more research to be done in these areas to get sounder statements on the effects.
2. The data collection instruments used in the various studies differed in depth and complexity. This makes comparing the results more difficult on a qualitative basis and should be considered when looking into the articles. We recommend the use of more unified instruments to make results more comparable in the future.
3. The grouping of constructs was organized by the labels that the articles used. This means that some of the groupings might be more surface-level: several constructs, though carrying the same label, had either varying or no definitions given by the re-

searchers of the respective article (e.g., [31,33]. We recommend that in future research, the definitions for constructs used (e.g., for interest, motivation, or engagement) should be similar or the same and briefly outlined in the respective articles to make comparisons more valid.

6. Summary and Conclusions

Within the reviewed articles, several constructs were found that are commonly evaluated. These include evaluations of effects on learning achievement, attitudes, and motivation/interest. Additionally, cognitive constructs such as representational skills were examined. Most of the studies were conducted with roughly equal distribution in primary and secondary schools as well as university courses. Additionally, most of the instruments used to evaluate the constructs were of a quantitative nature. Smartphones in the studies were mostly used with AR applications, topic-specific applications, or in a holistic way. Gamified approaches to learning via smartphones as well as their usage for measurements were also reported on several occasions.

All usages of smartphones did show that they can facilitate learning in science education, either directly, by facilitating an increase in learning achievement, or indirectly, by increasing motivation or attitudes. Though these results are positive, the effects were not always significantly higher than those reported in control groups using traditional approaches. Nonetheless, the negative effects of smartphone usages—especially in comparison with control groups—were only reported in three studies [22,74,77]. Although a large amount of research was done on several types of smartphone usages, there are many left unregarded: very few studies were found on the usage of smartphones for supporting learners with disabilities (which has important potential for making the classroom more inclusive), communication via applications regarding educational content, videos, and video conferencing (which is especially needed now that distance learning has become somewhat more widely used).

Overall, the examined studies reported that smartphones may be used in a variety of ways in science education and rarely lead to detrimental effects on learning achievement and other relevant constructs and—when compared to traditional materials like textbooks—sometimes even facilitate learning.

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