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What Works in Education?
Using Evidence to Improve Education

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What do we know about the effectiveness of digital technologies in education?

Mireia Usart Rodríguez

The current pandemic context forces us to make much of the teaching-learning process virtual while also giving greater urgency to the need for evidence on the impact of the use of digital technologies on education, from kindergarten to high school. Many studies have reviewed the role of these technologies in various educational contexts all over, in terms of effectiveness (improvement in learning, development of skills, motivation, etc.) and the key factors needed to implement them (teacher's role, educational basis, types of tools, etc.). This review provides relative evidence to approaches to learning using digital technologies aimed at clearly meeting the current needs of education in Catalonia.

"For too long, education has been subject to inertia and based on traditions, and educational changes have been grounded in unfounded intuitions and beliefs. The 'What Works' movement irrupts into the world of education with a clear objective: to promote evidence based policies and practices. Iválua and the Bofill Foundation have come together to push this movement forward in Catalonia."

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What Works in Education?

Using Evidence to Improve Education

What do we know about the effectiveness of digital technologies in education?

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Motivation

According to the provisions of Articles 58 and 59 of the Catalan Education Law (Law 12/2009, of 10 July, on education) and Article 53.1 of the Statute of Autonomy of Catalonia, both in elementary school and in compulsory high school, students must develop the skills necessary to use digital technologies at the appropriate level [1]. In addition, digital maturity is a defining element of a country's development that is not only achieved with advanced technological infrastructure, but also with digitally competent citizens [2].

The widespread use of digital technologies is present in all areas of people's social development and the implementation of digital technologies in educational contexts is no exception. The social transformation towards digitalization produces new benefits and opportunities. However, the rapid development of educational technology does not prevent many school-age children from lacking an Internet connection at home, which puts them at a disadvantage in terms of homework, access to online resources and the development of their digital competence [3].

Furthermore, teachers' use of digital technologies in the classroom has clearly increased in recent years, though perhaps not steadily. For example, the ratios of students per computer connected to the Internet in the European Union were halved between 2006 and 2012, but the number of compulsory high school teachers who admitted to using the technology in 50% or more of their classes did not increase significantly and is unlikely to reach more than 20% on average [4]. This figure contrasts with the fact that 90% of these teachers use some type of digital technology in the classroom, from which it is inferred that the predominant paradigm continues to relate the use of educational technology to merely the unidirectional presentation of content.

With the closure of schools on 13 March 2020, due to the health pandemic, two circumstances that have shaped the ability to care for students face-to-face have become evident: the digital divide and insufficient development of the digital competence of teachers and students. The main mitigating measures approved urgently by the Government of Catalonia's Ministry of Education were oriented in this direction. Everything we learn from this emergency context should also help us to rethink education when the health crisis ends [5] [6].

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The OECD [7] [8] thinks that progress is being made towards creating appropriate learning environments and that this should lead to the education desired by 2030. Thus, a learning space is not only a specific physical place; virtual spaces also have an impact on learning, because they promote discussion, cooperation and exploration that is established within an educational relationship of this nature [9]. Therefore, the inclusion of digital technologies in education in Catalonia must keep in mind what the evidence says, and the review we present here focuses on filling this gap.

What programs do we look at to understand the impact of the use of digital technologies on education?

Over the last few decades, there has been a wealth of scientific knowledge about the use of digital technologies, not only in remote environments, but in also face-to-face and in hybrid settings. Nevertheless, most scientific texts focus on the effects of technology on higher education, and it has been more difficult to find evidence in high school, elementary school and early childhood education, contexts in which we focus our analysis. In addition, despite the amount of existing evidence, there is a notable lack of impact studies in Catalonia and nearby environments. It is important to explain that the definition of digital technologies as cited in most sources consulted is understood as the variety of digital tools and applications that help to provide learning materials and support learning processes in the classroom for teachers and students alike.

There is a wide variety of possibilities when it comes to implementing digital technologies in schools. The key factors that contribute to the success of this implementation are also diverse and involve actors from the public administration to families.

Ambiguous and inconsistent definitions and the existence of various types of digital technologies can lead to false generalizations of the effectiveness of technology in education.

All these factors have been studied in the specialized literature of the field and summarized in this paper. However, it should be borne in mind that ambiguous and inconsistent definitions and the existence of various types of digital technologies can lead to false generalizations of the effectiveness of technology in education [10].

This review includes educational approaches that incorporate the use of digital technologies in different areas (mathematics, language, science, etc.) and at different educational levels (kindergarten, elementary school, compulsory high school and post-compulsory education), as well as those that deal with strategies or specific digital tools. The references analyzed study the effectiveness of face-to-face approaches using digital technologies, mixed (or hybrid) modality programs and ones that are fully online, albeit to a much lesser degree, due to a lack of evidence regarding pre-university educational levels.

The literature review that underpins this report presents a wide range of experiences and practical evidence. It should be borne in mind that, as several authors [10] [11] say, the variety of modes, models and strategies involved makes it more difficult to unambiguously understand the impact of the key elements that can lead to the success of the programs evaluated. In addition, although we will talk about the effectiveness of different digital tools, it is difficult to find meta-analyses that study the validity of specific tools. The programs under study are structured as follows:

- **Virtualization mode:** according to the degree of virtualization of the program, which can be fully face-to-face, with varying use of digital technologies, fully virtual or online (students do not attend school) or a combination of the two (mixed or hybrid mode) [11] [12].
- **Underlying educational paradigm or approach:** we speak specifically of behaviorism, cognitivism, humanism, constructivism, connectivism, etc. [13] [14].
- **Specific educational strategy for the program studied:** game-based learning (GBL), project-based learning (PBL), inquiry-based learning (IBL), etc.
- **Digital tools implemented:** use of different hardware and software in relation to the model/methodology (mobile devices, robotics, virtual reality, augmented reality, intelligent tutoring systems, educational apps, etc.).
- **Contextual factors:** learning area, duration and intensity of the program, types of programs (to work on the digital divide, family support, special needs, etc.), role and training of teachers, role of the family and environment, demographic factors such as the age of the students, economic factors and characteristics of the school before the implementation of digital technologies.

Table 1.

Educational modalities using digital technologies (DT) and their relationship with educational paradigms, strategies and types of digital tools

	Face-to-face, without the use of DT or with little use of DT	**Face-to-face, with intensive use of DT**	**Mixed or hybrid**	**Online**
Definition	The teaching-learning process is facilitated by the teacher, who makes limited use of digital technologies in time and frequency and focuses action on the classroom.	The teaching-learning process is facilitated by the teacher, who implements digital technologies during the year in the physical classroom.	The teaching-learning process takes place both through the teacher and technology. The student learns at least part face-to-face and part outside the physical classroom (>25%), with some degree of student control over the time, place, and rhythm.	The teaching-learning process only takes place through technology. The teacher and student interact remotely, outside of the physical classroom. An Internet connection and the use of digital devices are usually required.
Paradigm	Behaviorism, humanism, cognitivism (and metacognitive theories), constructivism (social, mixed and online).			
Models and strategies	GBL, PBL, IBL, cooperative, collaborative	GBL, PBL, IBL, cooperative, collaborative	FC, CSCL, GBL, PBL, IBL	GBL, PBL, IBL, CSCL
	Physical devices such as computers or the use of computer rooms.	All kinds of devices: computers, mobile/tablet, interactive whiteboards, projectors, etc.	All kinds of devices: computers, mobile/tablet, interactive whiteboards, projectors, etc.	Devices provided by the school (one-on-one) or by the students themselves..
	They are classified according to the type of instructional design and functionalities.			
	• "Practice and repetition" programs, quizzes • Simulations/video games/graphic applications • Robotics • Hypermedia systems (AR, VR, apps, etc.)		• Digital learning platforms • Tutoring systems • Intelligent tutoring systems (bots)	

Source: author's creation based on Means et al. (2013) [11]; Zheng et al. (2018) [15]; Delgado et al. (2015) [16]. PBL: project-based learning. GBL: game-based learning. IBL: inquiry-based learning. CSCL: computer-supported collaborative learning. FC: flipped classroom. AR: augmented reality. VR: virtual reality. DT: digital technologies.

Questions influencing the review

Digital technologies have been introduced in a very heterogeneous way in education, often making technology itself prevail over pedagogy or students' different educational needs. This review on the use of digital technologies in education seeks to provide topics for discussion, while answering the following questions: 1. How has education using digital technologies improved student learning? 2. Which mode or degree of virtualization has the most significant impact on students? 3. What types of educational methodologies and strategies using digital technologies are related to an improvement in terms of learning, competence improvement or attitudinal aspects? 4. Is there a specific type of digital tool that is related to a significant improvement in learning, in terms of academic performance, involvement and motivation? Finally, we discuss the conditions of implementation under which these proposals are most effective as well as the practical implications for Catalonia.

Reviewing the evidence

To conduct the review of evidence presented in this paper, 58 references from the last 10 years have been analyzed, 23 of which are directly experimental or quasi-experimental and provide success stories that may be useful in the context. The 16 literature reviews and 19 meta-analyses cover more than 1,600 primary studies from around the world on the effects of the use of digital technologies in elementary and high school.

How effective are these programs generally on the learning outcomes and other key dimensions identified?

To answer this question, we focused on five meta-analyses (see Table 2), six literature reviews and 12 experiments and quasi-experiments that evaluate the effectiveness of digital technologies on learning in general. The evidence is described as extensive and has increased in recent years. [17] [18] [19] We note that the areas of mathematics, science and language have historically been studied more in relation to the use of digital technologies. The lack of research on the humanities is noteworthy.

There is a positive, albeit modest, impact on the use of digital technologies on learning.

In general, we can say that there is a **positive, albeit modest, impact** on the use of digital technologies on learning that is very similar between the different areas of knowledge, and where **the training of teachers in technology plays a key role** [19] [21]. The impact has remained positive over time, from the 1980s until now, when the positive influence is starting to rise (see Table 2). Digital technologies also help to increase positive attitudes in elementary and high school regarding specific subjects such as mathematics and science. [18] [21] However, there are many factors involved that make it difficult to develop specific approaches if we do not analyze the type of technology in greater detail.

Studies that evaluate the general results of international tests such as PISA and TIMMS give us very useful information regarding the use of digital technologies in general by students. Neither the attitudes of students towards digital technologies, nor the time of use, nor access to them observably help to improve learning. However, the frequency of use of digital technologies is a key factor in improving learning [22] [23]. The amount of use of digital technologies at both school and home is not a predictor of improved learning.

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In the field of **language**, the evidence has focused mainly on the literacy process. Statistically significant, although, again, very uneven improvements, have been found, especially in early childhood education and elementary school, and specifically in basic and reading skills [20] [24] [25]. The use of digital technologies generally has a more positive effect on language learning than traditional approaches

The use of digital technologies generally has a more positive effect on language learning than traditional approaches.

Mathematics with digital technologies provide a pair of success stories. In both elementary and high schools, digital technologies provide statistically significant improvements in learning, but do not reflect a dramatic step forward [17] [18]. Although positive results are found at all levels of education [19], there is less evidence focused on early childhood education. However, studies that cover it do find a positive impact [26]. Studies focused only on elementary school evaluate fewer groups and care must be taken when drawing conclusions from secondary outcomes. Studies focusing on high school conclude that the use of digital technologies has a positive effect on students' learning outcomes and attitudes [19].

Table 2.
Results of meta-analyses that measure the effectiveness of the use of digital technologies in educational settings compared to those that do not use them

Outcomes related to students' academic dimension						
Reference (date)	**Dates of the studies**	**Number of studies included**	**Level of education**	**Type of technology or program**	**Results**	**Measurement of the effect**
Cheung et al. (2012) [18]	2000-2010	74	Elementary and high school	Intensity of hardware use	*Improves learning outcomes in mathematics*	SE g=0.15 p<.01
Cheung et al. (2013) [20]	2000-2010	84	Elementary and high school	DT implementation level	*Improves reading outcomes*	SE g=0.16 p<.01
Grynszpan et al. (2014) [27]	1998-2013	22	Elementary school	Innovative interventions with DT (robotics, virtual reality, etc.)	*Improves learning in different subjects for students with autism*	**ME** d=0.47 p<.01
Hershkovitz et al. (2018) [21]	2014-2016	7	All	One-on-one programs in the classroom and online	Teacher-student relationship *Improves the end results of learning*	SE d=0.36 p<.05
Hillmayr et al. (2020) [19]	2000-2018	108	High school	Use of DT in the classroom and teacher training in DT	Role of teacher training *Improves learning math and science* *Improves student attitudes*	**ME** g=0.65 p<.01 g=0.45 p<.05

Source: author's creation. DT: digital technologies. The duration of the programs is variable and not indicated in most studies. The size effect of the meta-analyses reports the standardized mean difference: g = Hedges' estimator; d = Cohen's estimator. The size of the effect is expressed as: small effect (SE): 0.2; medium effect (ME): 0.5; large effect (LE): 0.8.

What mode or degree of virtualization has a more positive impact on education?

Research on the different modes began by measuring the differences between online and hybrid educational programs as opposed to face-to-face ones that did not make use of technologies [28]. However, the current consensus on the feasibility of fully online education has made it possible to go beyond comparisons and move towards the study of concrete differences within digital modes [29]. Six meta-analyses and a systematic review specify this part of the evidence (see Table 3).

The **mixed or hybrid mode** (one that combines face-to-face and distance learning) is the one that presents the most evidence for elementary and high school, even though some studies focused on fully online programs [29] provide us with some lessons applicable in the current pandemic context.

The findings of the meta-analyses and reviews suggest an overall effectiveness in terms of learning for the mixed mode over the face-to-face mode. However, the great variability of results indicates that this effectiveness depends on the context and how the model is applied: the introduction of the mixed mode requires a rethinking of instructional design, as well as an investment in additional time and effort towards a more active and student-centered approach. The mixed mode enhances learning outcomes, combining the advantages of face-to-face mode and online mode. For example, it allows for more authentic and varied instructional materials, as well as innovative learning activities. However, this mode also combines the disadvantages of both: **students often have more difficulty with time management, the self-regulation of learning and the complexity of tasks** [30].

The findings of the meta-analyses and reviews suggest an overall effectiveness in terms of learning for the mixed mode over the face-to-face mode.

The effectiveness of mixed mode is also influenced by the extent to which the activity is synchronous. These activities offer high spontaneity, allow for a sense of cohesion among students and promote collaboration. Yet at the same time, students in some cases feel pressured to respond without having the time to reflect or indicate that they have more technical problems than if the activity is asynchronous. Asynchronous design offers the most flexibility in terms of location and time. It also allows for more reflective student involvement [11] [12].

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The flipped classroom: a fad or a truly effective model?

In hybrid mode, we find one of the most widespread models: the flipped classroom [12]. Here, the teacher provides the content to the class in advance and through pre-recorded videos and spends class time immersing students in activities that involve collaboration and interaction [31], changing the pace of learning, style and the level of difficulty to which students are accustomed. Recently, many studies have investigated the effective implementation of this model across a wide variety of subjects and educational levels, although the bulk of research focuses on higher education.

In the flipped classroom model, digital technologies help by providing faster feedback, which results in greater student satisfaction. Tools of assistance are more effective than tools based on trial and error [25]. However, the results of meta-analyses focused on high school indicate a moderate improvement in learning outcomes that is independent of the duration of the program, but is related to the area of knowledge: to properly plan the flipped classroom, it should be recalled that this model is not suitable in areas of an applied nature such as architecture and engineering. Furthermore, if the specific content requires frequent interaction or very hands-on learning, students may have trouble proceeding during learning that occurs before class activities [32].

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We cannot close this section without talking about the online mode which, despite being mostly implemented at the university, has also been used as a stopgap measure in Catalonia in elementary and high school [6]. It has become popular for providing more flexible access to content and instruction anytime, anywhere. It must be differentiated from the broader category of distance learning, which has historically included correspondence courses, educational television and videoconferencing [14].

Authors studying online mode indicate that it can be as effective as face-to-face mode, specifically for independent study, and provided that the methods and technologies used are appropriate for the learning objectives [11] [33] [34]. When comparing different online high school programs, virtual environments designed to facilitate collaboration and cooperation between students are found to be the most effective for learning, especially if the teacher acts as a guide [29] [35]. Specifically, high school science students are satisfied with the online program and improve their achievement in science. Despite these positive results, students with learning difficulties benefit the least [36] [37]. All students need constant help and feedback in online environments to achieve the expected results and start cognitive and metacognitive processes, beyond trial and error learning. Online help programs, meaning those that support students outside of subjects and school hours, are the most common when implementing an online mode in elementary school [38] [39] [40].

Virtual environments designed to facilitate collaboration and cooperation between students are found to be the most effective for learning, especially if the teacher acts as a guide.

Studies comparing mixed and online modes indicate that the former provides better outcomes in terms of learning and motivation, less cognitive load and less feeling of loneliness for students [11] than the fully online mode.

Table 3.
Results of the meta-analyses that compare the effectiveness of the different modes or degrees of virtualization of the learning environments.

Reference (year)	Dates of the studies	Number of studies included	Level of education	Type of technology and comparison	Results	Measurement of the effect
Cook et al. (2008) [34]	1990-2007	63	All	Effectiveness of distance mode compared to face-to-face	*Improves learning outcomes*	SE g=0.12
Means et al. (2013) [11]	1996-2012	50	High school	Effectiveness of online mode compared to face-to-face Effectiveness of hybrid mode compared to face-to-face	*Improves learning outcomes* *Improves learning outcomes*	SE g=0.05 g=0.35
Bernard (2009) [33]	1985-2002	74	All	Effectiveness of distance mode compared to face-to-face	*Improves learning online, depending on the types of interactions*	**ME** g=0.38
Spanjers et al. (2015) [30]	1985-2002	69	Elementary and high school	Effectiveness of mixed mode compared to traditional, use of tests and quizzes	*More effectiveness measured as a result of the post-test in the program* *More subjective effectiveness* *More student satisfaction* *More investment in education*	SE g=0.34 g=0.27 g=0.11 g=-1.04
Mahmud et al. (2018) [10]	1990-2007	59	All	Mixed environments compared to face-to-face ones Studies the effects on learning and students' attitudes/motivation	*Use of hardware and software in language learning* *Improves language learning outcome + AT/MOT*	**ME-LE** g= 0.55-3.00 g=-0.48-1.20
Borokhovski et al. (2012) [29]	2000-2011	74	Elementary and high school	Online learning: Studies the types of interactions between the agents involved	*Improves learning outcomes:* *student–student* *student–teacher* *student–content*	**ME** g=0.49 g=0.32 g=0.46
Cheng et al. (2019) [32]	2013-2016	55 (115)*	Elementary and high school	Studies the flipped classroom model compared to the traditional one	*Improves cognitive outcomes* *Depending on the duration of the program:* Less than a semester More than a semester	SE g=0.19 g=0.35 g=0.15

Source: author's creation. DT: digital technologies. FC: flipped classroom. FF: face-to-face. MM: mixed mode. OL: online mode. AT: attitudes. MOT: motivation. All: from elementary school to the university. Improved learning: various learning measures such as final grade, GPA or standardized grades for different subjects and courses. The size effect of the meta-analyses reports the standardized mean difference: g = Hedges' estimator; d = Cohen's estimator. The size of the effect is expressed as: small effect (SE): 0.2; medium effect (ME): 0.5; large effect (LE): 0.8. *number of studies (number of size effects).

Therefore, all the modes that involve the intensive use of ICTs present great challenges for schools, including changes to schedules, teaching tasks and activity design. Changes are also important for students and must be taken into account: the implementation of hybrid and online modes, especially in elementary school, must give students enough time to adapt to the change it entails, a period of time that sometimes exceeds the program itself (between five and 12 weeks) presented by most of the programs reviewed. All these factors make it necessary to assess the extent to which a mode other than face-to-face mode needs to be implemented, unless it is for an emergency such as confinement, which has taken place in 108 countries around the world [6].

Which digital learning strategies are most effective?

The most evidence-based strategy for using digital technologies is **game-based learning** (GBL). Studies that study its effectiveness (see Table 4) show a positive relationship between it and learning outcomes. In particular, if applied with a cognitive pedagogical basis with interaction, it improves the acquisition of content [13] [41] [42] and skills, while improving student involvement [43]. In contrast, the increase in motivation and retention is not as high [13] [43]. GBL is more effective in elementary school than in high school, and single-player games are more effective than multiplayer games [42]. Finally, this strategy is more effective when using video games compared with simulations and virtual worlds [44]. Elementary and high school students find this methodology useful for learning math, social science, and vocabulary. In addition, they feel motivated to do so. However, there is no evidence that games are the right strategy for all educational situations [13].

The most evidence-based strategy for using digital technologies is game-based learning.

Moreover, the strategy called **computer-supported collaborative learning** (CSCL) presents a broad body of study, although the evidence outside university settings is very limited and focuses on extracurricular activities [26] [45]. The main positive results of this strategy are found when learning science and STEM, provided that clear guidance and constant support are provided to students [15].

Project-based learning (PBL), along with collaborative and cooperative learning approaches, have also been the focus of study in the field of digital technology education. Explicit collaboration and cooperation improve student-student interaction in online modes compared to other strategies that do not explicitly facilitate this interaction. The relationship between students and content is also improving, although not significantly [29].

Finally, we need to focus on **inquiry-based learning** (IBL). The evidence in elementary and high school indicates that it is a widely used strategy in mixed and online modes [14] [46] for working on STEM subjects [47]. This strategy is related to the concept of communities of inquiry (CoI) [24] [48] [49]. Within these communities, providing students with clear course objectives, syllabi, planned dates and timely feedback and helping them to collaborate effectively with their classmates helps them to interact productively both with content and with other students, which assists efforts to build knowledge together [24].

Table 4.

Results of meta-analyses evaluating digital strategies and tools.

Reference (year)	Dates of the studies	Number of studies included	Level of education	Type of tool and strategy	Results	Measurement of the effect
Wouters et al. (2013) [41]	1990-2012	39	All	Educational games (strategy, GBL)	*Better end-of-year grades* *Better retention* *Better motivation*	SE d=0.29 d=0.36 d=0.26
Merchant et al. (2014) [44]	Until 2012	69	All	Study of the different types of tools in the GBL strategy	*Improves learning outcomes in:* Educational games Simulations Virtual worlds	**ME** g=0.51 g=0.4 g=0.36
Huang (2018) [51]	2011-2018	30 (34)*	High school and university	Studies the use of social media compared to learning outcomes	*Improves learning outcomes according to:* Use of social networks Usage time Frequency of use	SE r = -.07 r = -.06 r = -.01
Jeong et al. (2019) [45]	2010-2018	143	All	Examines the impact of CSCL on STEM education	*Improves learning outcomes in STEM*	**ME** g=0.49
Steenbergen-Hu & Cooper (2013) [37]	1997-2011	26 (34)*	Elementary and high school	ITS Mathematics *ITS vs. FF*	*Improves learning outcomes in mathematics*	SE g=0.05**
Fang et al. (2018) [52]	2005-2015	15 (24)*	High school and university	Intelligent tutoring system (ALEKS) compared with face-to-face tutoring	*Improves learning of mathematics*	SE g=0.10 p<.05
Xu et al. (2019) [53]	2000-2018	19 (88)*	Elementary and compulsory high school (ESO)	Intelligent tutoring systems compared with other types of tutoring	*Improves reading comprehension:* General ITS vs. human tutor online ITS vs. tutor in the classroom	**LE** g=0.60 g=0.20 g=0.86
Donnelly-Hermosillo et al. (2020) [54]	1980-2018	13	Elementary and high school	Graphic representation technologies in IBL strategies	*Improves hypothesis generation, predictions, analysis and interpretation of data and reflection*	**ME** g=0.59** (0.55-0.62)
Tsai & Tsai (2020) [42]	2000-2018	26	Elementary and compulsory high school (ESO)	GBL strategy with compared to the traditional strategy and type of games by level of education	*Improves the acquisition of scientific knowledge:* Elementary school Compulsory high school (ESO) Individual Multiplayer	**LE** g=0.68 g=0.51 g=0.75 g=0.49

Source: author's creation. GBL: game-based learning. AR: augmented reality. SLR: systematic literature review. ITS: intelligent tutoring systems. IBL: inquiry-based learning. All: from elementary school to the university. Improves learning: various learning measures such as final grade, GPA or standardized grades of subjects and courses. The size effect of the meta-analyses reports the standardized mean difference: g = Hedges' estimator; d = Cohen's estimator; or alternatively with r = mean correlation coefficient. The effect size is expressed as: small effect (SE): 0.2; medium effect (ME): 0.5; large effect (LE): 0.8. *number of studies (number of size effects). **does not report significance level (p), but intervals.

Is there a type of digital teaching tool or resource that is related to better learning?

Technological progress provides different digital tools depending on the type of instructional design. Their impact on learning is also diverse [17] [50]. Apps and videogames are the most commonly studied tools in systematic reviews [55]. Other tools studied and discussed below are virtual reality and augmented reality and collaborative and assessment and support tools, including artificial intelligence and social media (see Table 5).

For any digital tool, overly difficult content can quickly lead to a loss of student interest and motivation [39].

For any digital tool, overly difficult content can quickly lead to a loss of student interest and motivation.

Table 5.
Digital tools included in the review of evidence

Devices or hardware:	Digital tools (software):	Allow:
• Computer • Mobile phone/tablet • Mixed devices • Robots and robotic toys • Interactive whiteboards • Multimedia equipment	• Platforms/websites/ virtual laboratories, etc. • Video games, simulations, etc. • Intelligent tutoring systems and social bots • Social media and spaces for CSCL • Virtual reality • Augmented reality • Apps • Drawing/graphics software • 3D design technologies*	• Acquisition/exchange of information • Acquisition/practice of skills • Feedback, reflection • Motivation/involvement • Collaboration, competition • Joint creation of knowledge • Evaluation

Source: author's creation, based on Zheng et al. (2018) [15]; Cheung & Slavin, (2012) [18]; Mahmud (2018) [10]; Huang (2018) [51]; Jia et al. (2013) [25]. *The latter are very specific and we have no clear evidence about them.

We find few impact studies that explore children's technological acceptance of mobile applications and technologies, and even less focus on the learning outcomes involved in their use. However, tablets have an important place in education due to their convenience of use, low cost and attractiveness for students [56] [57]. They allow students to write on the screen with a digital stylus and are suitable for learning penmanship, which provides a useful learning environment for early writers [57]. However, regulatory pressures and intrinsic motivations for the use of mobile learning technologies in elementary school could oppose their implementation [58].

Box 1.

An example of a tablet intervention, specifically with a multilingual app for learning math aimed at early ages: Onebillion [59]

Onebillion: An app for teaching math and language to children

This program provides basic math, reading and English skills to children at risk of exclusion. It does this with technological educational solutions, specifically apps, which reduce costs and reach many children.

These solutions are based on the fact that educational math apps, available in several languages, are becoming increasingly popular, and that emerging evidence demonstrates the benefits of math apps to aid boys and girls develop mathematical skills.

To understand "what works" in the use of math apps, we need to consider factors that can affect outcomes, including the children's mastery of the language of instruction.

In this project, teachers started with the initial app, Math 3-5, and then moved on to the more advanced app, Math 4-6.

Results: Students who used Onebillion advanced an additional three months in math compared to the control group.

The formative assessment suggests that the impact of the program could be influenced by the amount of educational support given to students during the program sessions. Students performed better when supervised by teachers (who thought their role was to teach concepts when students had difficulties).

Tutors reported that students enjoyed Math 3-5 app more and needed less educational support to use it.

More information is needed on the **type of educational support that works best in app sessions** and on the effects of improving math for struggling students.

For further information:

Onebillion project website: https://onebillion.org/

Examples of experience-based evaluations of this program:
Outhwaite, L. A., Faulder, M., Gulliford, A., & Pitchford, N. J. (2019). "Raising early achievement in math with interactive apps: A randomized control trial". *Journal of Educational Psychology*, 111(2), 284-298. [60]

Outhwaite, L. A., Gulliford, A., & Pitchford, N. J. (2020). "Language counts when learning mathematics with interactive apps". *British Journal of Educational Technology*. doi:10.1111/bjet.1291 [61]

Self-administered tests and questionnaires have a positive effect on student's achievement and attracting students in hybrid contexts.

In mixed mode, messaging, blogs and forums are the tools that significantly facilitate peer interaction [62]. Moreover, commonly used digital tools like self-administered tests and questionnaires have a positive effect on student's achievement and attracting students in hybrid contexts. Specifically, the most effective tools are those that include online questions or tests in videos (Quizzes, Socrative, etc.). In contrast, the use of Facebook and other social media has negative results: the use of social media is not directly linked to improvements in learning [51].

In hybrid and online environments, we find another effective tool in terms of learning that especially helps to increase the presence and feedback of teachers: **intelligent tutoring systems** (ITS). In mathematics and language [37] [52] [53] it is a viable option for providing constant accessible training to geographically spread out populations that would otherwise be unable to access educational assistance. **Combined with graphical representation tools** (those that allow us to visually and mathematically represent numerical results, such as Geogebra), they improve learning outcomes [19]. In fact, graphical representation tools improve the acquisition of math and science skills compared to environments that do not use its type of software. Through immediate feedback, they help students to generate hypotheses and predictions, collect, analyze and interpret data and reflect on them. They are therefore suitable in IBL strategies and for STEM subjects [54].

Box 2.
An example of an Intelligent Tutoring System (ITS) for high school math: ALEKS [52]

ALEKS (intelligent tutoring system based on knowledge space theory, created by McGraw Hill)

ALEKS (Assessment and Learning in Knowledge Spaces) is a web-based assessment and learning system using artificial intelligence. It uses adaptive questioning to quickly and accurately determine what a student knows and does not know about a topic. ALEKS instructs the student on the topics they are prepared to learn. As the students work through a school year, there are periodic evaluations to ensure they have meaningfully learned the topics studied. When it comes to assessment, it avoids multiple choice questions. It also provides the benefits of individual, asynchronous and ubiquitous instruction, accessible from virtually any computer connected to the Internet.

Results:
ALEKS has no negative effect and a **very small positive effect on student learning, compared to other types of instruction**. ALEKS was **more effective when used for one semester compared to a full school year** in the same way as a support and as a main tool. ITS had no effect on elementary and high school students' learning of mathematics compared to regular classroom instruction [37]. They generally benefited more from the use of ITS than their low-performing peers, which calls into question the potential of ITS in these cases.

For further information:
ALEKS project website: https://www.aleks.com

Examples of experience-based evaluations of this program:

Fang, Y., Ren, Z., Hu, X. & Graesser, A.C. (2018). "A meta-analysis of the effectiveness of ALEKS on learning", *Educational Psychology*, DOI: 10.1080/01443410.2018.1495829 [52].

Virtual Reality and Augmented Reality Tools: A Good Option to Increase Student Motivation

Mixed reality-based pervasive games (reality and use of virtual reality and/or augmented reality) [63] expand the gaming experience outside the device and bring it to the physical world [26] [43]. They are considered tools to be used in the constructivist perspective and Grynszpan et al. [27] measures their effectiveness in girls and boys with autism spectrum disorders.

Augmented reality (AR) [46] helps **active participation and makes learning more immersive** [50]. Educational AR focuses primarily on providing additional information on topics of interest through games and experiments. Despite the amount of existing practices, there is a lack of evidence to study AR's potential in elementary school [50].

The main advantages of learning experiences based on games with AR include improved knowledge, motivation, interaction and collaboration.

The combination of AR and the GBL strategy across mobile devices integrates real-world environments with dynamic and interactive digital content. Science and social studies are the areas of education where AR has been applied the most in elementary school. For learning STEM, it offers exploration and simulation activities, based on discovery mechanisms, though few provide help to students. The main advantages of learning experiences based on games with AR include improved knowledge, motivation, interaction and collaboration. Students can improve their performance due to positive attitudes and motivation towards the learning process. Most studies find positive effects, such as increased students' conceptual understanding, followed by affective learning outcomes [49]. In addition, the combination of GBL, PBL and virtual reality enhances interpersonal relationships and mutual aid in online environments [43].

Programming, robotics and robotic toys: the future of digital tools in school?

Educational robotics is a valuable tool for developing students' cognitive and social skills from an early age.

We have left these types of tools for the end, which have a hardware part (the robot, arduino, etc.) and a software part (like Scratch). The reason for this is because despite their popularity, there are still few meta-analyses and systematic reviews focused on elementary and high school. These tools also have a high cost and their application needs constant updating [27]. The evidence shows that educational robotics is a valuable tool for developing students' cognitive and social skills from an early age. Students are not limited to learning programming or technology-related aspects; they are applied in various disciplines, from science to foreign language learning. Bee-bot, for example, is used in preschool education [64] and in the elementary school classroom. When students learn to program a robot, they also learn mathematical concepts, literacy and the arts, as well as logical thinking, problem solving and metacognitive skills [66].

What needs to be considered to launch educational programs using technologies to make them effective?

It has become clear that despite being increasingly present in classrooms everywhere, educational programs using digital technologies need to present several specific features in order to enhance student learning. Beyond the results presented so far, we must specify how these programs are implemented in terms of pedagogy, the teacher's role, the role of technology, the type of interaction and temporal factors that must be taken into account. There are also barriers that can diminish the effectiveness of digital technologies in the classroom such as access to them by students and the training of everyone involved. We have seen that making large investments solely in technology provides a rather modest result [16] [21] if these aspects are not considered.

Are classical educational paradigms taken into consideration in studies or are we building castles in the air? Unfortunately, most of the studies reviewed do not explicitly address the educational approach or paradigm from which the program is designed [13]. Instead, we know that **that theoretical basis is key** to the effectiveness of any educational program that takes educational technologies into account.

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According to the few reviews and meta-analyses that study educational paradigms in digital environments, GBL strategies are pursued the most often in educational paradigms [13]. Specifically, cognitivism and metacognition should be mentioned as effective approaches to learning how to use digital technologies [67] [68] (see Table 6).

Developing high-order **cognitive and metacognitive** processes through intelligent tutoring systems, simulations, programming, educational games, collaborative learning environments and virtual reality [26] as early as in early childhood education helps children to plan, monitor, control and reflect on basic mathematical activities. Learning math from a constructivist approach and using digital technologies leads to better learning outcomes than traditional classrooms. If we also enrich these environments with metacognitive education, we will obtain positive results [55]. Students must actively relate to the educational content to understand new information [69] [70] using **self-regulated** learning. This confirms the key role of educational figures, especially in fully online environments. In online contexts, **social presence** is necessary to improve learning outcomes and involvement, rather than in hybrid or face-to-face environments.

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Table 6.
Meta-analyses that evaluate the use of educational theories

Reference (year)	Dates of the studies	Number of studies included	Level of education	Type of mode and comparison	Results	Measurement of the effect
Darabi et al. (2013) [67]	2000-2012	72	Elementary and high school	Interaction in online environments, according to the cognitivist paradigm	*Better learning outcomes in strategic discussions compared to conventional discussions*	**ME** d=0.50 p<.01
Zhou & Lai (2019) [68]	1995-2017	29 (36)	Kindergarten and elementary school	Metacognitive scaffolding in online educational search processes	*Scaffolding strategies* *Improves search process* *Improves search result*	**ME** r = .33 r = .34 p<.001

Source: author's creation. Improves learning: various learning measures such as final grade, GPA or standardized grades of subjects and courses. The size effect of the meta-analyzes reports the standardized mean difference: d = Cohen's estimator; or alternatively with r = mean correlation coefficient. The effect size is expressed as: small effect (SE): 0.2; medium effect (ME): 0.5; large effect (LE): 0.8

A second key moderating element is **teachers**, as well as their training in specific technologies and tools [19] and especially how they use them. Specifically, their constant help and feedback, whether supplementary or central, is key to helping the student to feel supported and motivated to continue learning [4] [56]. To properly include technologies in the classroom, schools should not assume that teachers are ready to use them, but should actively create the appropriate opportunities for professional development. The lack of specific training, technical support and clear policy can prevent them from being used regularly [56]. It is essential that proper support is given to teachers and that technology is integrated naturally into the school's educational approach [71]. As internal factors, the literature highlights teachers' beliefs, attitudes and expectations toward digital technologies [24] [55] [72].

Another key factor in the use of digital technologies is **peer support and online collaboration** [29]. Environments designed intentionally for students to interact have a much more positive effects on learning.

Environments designed intentionally for students to interact have a much more positive effects on learning. ↗

There are two key aspects that have been studied regarding **timing**: the synchrony and the duration of the programs. Asynchronous interaction shows better learning outcomes, especially in more advanced courses and forums [67], although synchrony helps with involvement [21]. On the other side, short-term programs (less than a semester) already show positive results [73], even though the effort in preparation time and in investment of means and money makes programs lasting less than one semester unviable at most institutions.

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Finally, we must also talk about **access** to digital technologies as a mediating factor between them and learning. One-on-one programs have become increasingly common in schools and aim to provide laptops to children for use at school and at home. They have been implemented in 36 countries and distributed more than two million computers [74] [75]. There is no theoretical or empirical consensus on whether having a home computer is directly related to academic achievement. The reviewed studies show both positive and negative impacts. In general, having one does not improve academic achievement, class attendance or motivation [21] [76]. But cognitive skills do improve, as does the amount of computer use at home. Most importantly, teaching practices change and students' digital cognitive gap narrows [77]. We can conclude that access to technology for the most vulnerable students who often go to schools with fewer resources complements the teaching role, although they do not ensure academic improvement.

Access to technology for the most vulnerable students who often go to schools with fewer resources complements the teaching role, although they do not ensure academic improvement.

Box 3.

Example of one-on-one program in the United States. Lessons learned for elementary school [74]

The main objective of this experimental study is to **provide direct evidence on the one-on-one program in the United States**, using the largest random sample among students aged 6 to 10.

Results: The program substantially increased access to and use of the computer at home, but no positive or negative effects on education were seen, including final grades, attendance and disciplinary action. Having a computer at home does increases its total use for school work, but also for playing, accessing social networks and other recreational uses. There are also no observable positive effects such as spending time getting help with tasks, using software or other aspects related to digital competence. On the other hand, we also find no evidence of more time spent doing homework.

Conclusions: For schoolchildren in the United States and possibly in other developed countries, the negative educational effects of using computers for games, social media and other forms of entertainment are not very significant, but computers are also not used to communicate with teachers and schools, or to provide parental supervision of students through specific software. Therefore, we must be careful with this type of aid if it is not accompanied by other actions: the mere fact of having a computer with Internet at home should not in itself imply improvements in academic results for children with a low socioeconomic level.

Programs to reduce the digital divide in the United States and other countries should not only focus on helping to obtain computers and hardware, but also on showing students and families how to use these devices for the teaching-learning process.

References:

Fairlie, R. W., & Robinson, J. (2013). "Experimental evidence on the effects of home computers on academic achievement among schoolchildren". *American Economic Journal: Applied Economics*, 5(3), 211-40 [74].

Fairlie, R. W., & Robinson, J. (2013). *Experimental Evidence on the Effects of Home Computers on Academic Achievement among Schoolchildren.* National Poverty Center Working Paper Series# 13-02. National Poverty Center, University of Michigan [75].

Are educational programs mediated by ICTs equally effective for all students?

As we have seen, the educational transformation towards digitalization produces new benefits and opportunities. However, the rapid development of digital technologies is taking place in a context of deep and persistent inequality. There is little evidence on groups with special educational needs (SEN). We also know that educational technologies can alleviate or exacerbate existing disparities depending on how programs are designed, how they are used and who can access them. While access to digital devices and the Internet is becoming more common, many school-age children do not yet have an Internet connection at home, which puts them at a theoretical disadvantage compared to students who can access online resources [3].

Students with SEN are at risk of digital exclusion. The evidence shows that they need to be involved in hands-on reading and writing classroom activities using digital tools that students already know from outside school, such as virtual reality [24] [27]. In this group, the use of digital technologies becomes an option to promote interaction and collaboration, which results in improved reading and writing skills, as well as the ability to work with others [36]. In general, individual programs achieve lower academic outcomes than those working in small groups and elementary school students benefit more than high school students. Math and writing are the areas where improvement is the most evident, and problem solving the least.

Programs using digital technologies to help migrants with low socioeconomic status increase students' interest, trust and interest in school [36] [78]. The inclusion of digital technologies in environments with a lack of technological infrastructure and institutional support especially helps younger, reluctant and more difficult children to learn basic writing. In fact, digital tools can help students in these contexts in terms of teacher presence and feedback. Without these factors, the results lose meaning [76] [78].

The inclusion of digital technologies in environments with a lack of technological infrastructure and institutional support especially helps younger, reluctant and more difficult children to learn basic writing.

Summary

While the implementation of digital technologies in the classroom represents a challenge for all educational actors, and particularly for teachers, it can also provide an opportunity for improvement, not only in direct relation to digital or technological aspects, or in terms of academic performance, but also in students' other attitudinal aspects such as motivation, involvement and interest in science, language and math subjects. Collaboration and interaction between students, as well as teachers' monitoring and guiding role, are critical in hybrid or online environments. Yet to implement this successfully, we need to consider different key factors such as the educational basis underlying each program, educational strategies, instructional design and necessary changes in both schools and educational

Therefore, the question is no longer whether digital technology should have a place in the classroom, but how it can be integrated effectively.

policies related to the necessary investment in digital tools and technologies. Therefore, the question is no longer whether digital technology should have a place in the classroom, but how it can be integrated effectively.

Table 7.
Strengths and weaknesses of the use of digital technologies in the classroom

Strengths	Weaknesses
The use of digital technologies in the classroom brings the digital world closer to the school.	The lack of teacher training in digital technologies, the lack of technical support and the lack of policies on certain devices can prevent the use of technologies. Schools should not assume that teachers are prepared to use digital technologies. On the contrary, opportunities for professional development in the digital realm need to be created.
Most of the programs evaluated show positive aspects on students, specifically in terms of learning and student attitudes.	The effects are highly variable and the gains in learning are often small and dependent on multiple factors. To assess the actual impact, we must focus on the whole learning process and not just measure final evaluation data.
The mixed mode in general, and the flipped classroom model in particular, have been extensively studied and the outcomes on learning are positive.	It is necessary to go into detail about the theoretical elements, foundations and concrete methodologies that make this model truly achieve better results. In this regard, the teacher's presence and the instructional design adapted to the needs of each context are key.
The success of the use of digital technologies is already in its infancy. It is greater in elementary school and more discreet in high school. The most frequently studied areas of knowledge are mathematics and language.	Unfortunately, there is no clear concretion in these aspects in all the meta-analyses and reviews. Furthermore, there is a lack of research in areas such as the humanities, art, physical education and more.
Cognitive and metacognitive approaches are directly related to better learning outcomes.	There is a lack of solid theoretical approaches in most studies that do not adopt any specific paradigm or do not reflect on it properly.
Online environments that promote collaboration and interaction between students are more effective for learning and motivation.	More evidence is needed on the timing of this interaction and on the duration of the programs.
The relative effectiveness of education with the use of digital technologies must be studied in accordance with the wide range of existing resources or tools. These can facilitate complex learning. GBL strategies combined with social aspects and interaction in mixed modes give the best results.	Digital games cannot be the solution for all contexts or educational needs and teachers and designers need to work together.
Intelligent tutoring systems (ITS) are one of the digital tools that present more positive effects in elementary and high school and help to supplement the teacher's presence in mixed and online environments.	We recommend quantifying the costs associated with implementing ITS (acquisition price, configuration, implementation, maintenance, teacher training, etc.) in order to perform a cost-benefit analysis of ITS compared to other educational programs, including traditional ones.
The use of different apps, and particularly those that incorporate Augmented Reality technologies, improves the learning, motivation and satisfaction of students of all ages and vulnerable students.	Constantly updated digital tools are necessary for teaching and it is more advisable to invest in training and support for students than in devices for one-on-one models.

Implications for practice

The educational context in Catalonia has historically been involved in educational innovation and the application of digital technologies. Specifically, as the responsible official body, the Catalan Ministry of Education has recently presented the Digital Education Plan of Catalonia 2020-2023, which goes beyond the use of technology to promote learning and skill development in a digital world.

The evidence shows that this is a complex situation and that further research is needed on specific educational approaches, strategies and tools, taking vulnerable students into account and without overlooking the digital divide, not only in terms of connectivity, but also in terms of digital competence at a cognitive level. The design of programs using digital technologies is effective, but also raises some limitations regarding its scope.

In order to obtain positive outcomes for student learning, motivation and involvement, teachers must think about the educational approach, plan, make a cost-benefit analysis and adapt teacher training and practice prior to the introduction of DT [21]. When teaching, the teacher must be helped and the students supported with constant follow-up so that the initial motivation does not decrease. Finally, evaluation of the whole program and of the actors involved (teachers, technicians and students) is critical in order to learn and improve on the different aspects.

We will end with some specific reflections to ensure that public activity to implement digital technologies naturally has the desired effect:

Active approaches and methodologies are needed that place students at the center.

- **Which strategies should be prioritized for which students?** Active approaches and methodologies are needed that place students at the center. Guiding students and prioritizing online and face-to-face collaborative mechanical tasks is key. Student-centered models such as the flipped classroom not only help to relatively improve content acquisition, but also to improve students' skills. Thus, a hybrid mode is recommended, where students are offered a balance between face-to-face tasks and the teacher's guidance, complemented with work to acquire content and practice skills, with some student control over the time, place and rhythm. These hybrid environments adapt to the current post-pandemic needs in terms of mobility and access to schools in Catalonia.
- **Which measures encourage students to access technology?** There are three key aspects here: supporting families who will, in turn, support students, changing teaching practices and not simply focusing on the type or amount of devices. The underlying educational paradigm must be considered when designing educational programs that implement digital technologies. Specific digital tools should not be the goal, but a means to achieve a better teaching-learning process. A fully online mode in our context is only recommended for high school. Faced with a potential new period of confinement, interactive environments should be designed that allow students to communicate better with each other

and with materials and work collaboratively to increase the model's effectiveness from a distance.

- **Which measures do we have to support teachers and schools?** We must create opportunities for professional development in the digital field. Without teachers mediating in the relationship between technologies and students during the teaching-learning process, there is no possibility of success in applying any technology. That is why the teachers of Catalonia are a key asset in the success of these programs. We refer here to specific training in digital technologies and tools, increased specialized technical support and policies on specific devices, such as tablets. We must know teachers' digital competence and establish programs for their development within the framework proposed by the teaching department.
- **What assessment should be made of the measures taken?** In our context, we can use different ways of assessing students that are part of our educational culture, such as interviews, concept maps, peer assessment and different aspects related to cognitive educational paradigms or theories. There is also a need to differentiate between learning and assessment, as many studies focus on students' final assessment, but not on their learning process. We need to look beyond learning as a result and focus on the process and attitudes. Evaluating programs does not make sense if done only quantitatively. There is a need to train students and teachers and train them on specific technology.

Finally, we want to invite the reader to understand and adapt all indications prudently. We must remember the limitations that we have explained throughout the report regarding the wide variety of results, types of analysis and specificities of each context. However, we want to encourage all those involved to rethink the challenge and opportunity presented by the current pandemic context in the school agenda in Catalonia, especially in the digital field.

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