21st-century skills and their relationship to STEAM learning environments: a review

Habilidades del siglo XXI y entornos de aprendizaje STEAM: una revisión

Wilson Krüger Mariano
Universidad de La Sabana. Chía, Colombia.
wilsonkrma@unisabana.edu.co

Andrés Chiappe
Universidad de La Sabana. Chía, Colombia.
andres.chiappe@unisabana.edu.co

Abstract
The development of the so-called 21st century skills is currently mentioned as one of the key objectives that education systems must achieve throughout the world, so that citizens as a whole can adapt adequately to the labor market and in general, to the future society. The purpose of this review is, given the explosive and growing interest in this topic, to identify the various definitions of the skills of the 21st century and then to recognize the relationships that can be found between these skills and STEAM learning environments, which recently have been proposed as suitable scenarios for developing them. The study was developed as a systematic literature review based on abstracting and in-depth reading of 153 scientific articles published in journals indexed in Scopus and Scielo. The results of the study suggest that, in order to guide the development of 21st century skills, it is convenient to consider when designing STEAM learning environments, issues such as the change in the assessment towards a more formative experience, the inclusion of collaborative and social environments, the use of research-based learning strategies and gamification and games, among others.
Keywords: 21st century skills, STEAM learning environments, gamification, formative assessment, research-based learning.

Resumen
El desarrollo de las habilidades del siglo XXI se menciona actualmente como uno de los objetivos clave que deben alcanzar los sistemas educativos en todo el mundo, para que los ciudadanos en su conjunto puedan adaptarse adecuadamente al mercado laboral y en general, a la sociedad del futuro. El propósito de esta revisión es, dado el explosivo y creciente interés en este tema, identificar las diversas definiciones de las llamadas habilidades del siglo XXI para luego reconocer las relaciones que se puedan encontrar entre estas habilidades y los entornos de aprendizaje STEAM, los cuales recientemente han sido propuestos como escenarios capaces de desarrollarlas. El estudio se desarrolló como una revisión sistemática de literatura a partir de procesos de abstracting y lectura en profundidad de 153 artículos científicos publicados en revistas indexadas en Scopus y Scielo. Los resultados del estudio sugieren que, para conducir el desarrollo de las habilidades del siglo XXI, conviene tener en cuenta al momento de diseñar entornos de aprendizaje STEAM, asuntos como el cambio en la evaluación hacia una experiencia más formativa, la inclusión de ambientes colaborativos y sociales, la aplicación de

estrategias de aprendizaje basadas en la investigación y la gamificación y el juego, entre otras.
Palabras clave: Habilidades del siglo XXI, entornos de aprendizaje STEAM, gamificación, evaluación formativa, aprendizaje basado en investigación.

1. Introduction

The current society, characterized by some as the "society of information and knowledge" (Grijalva & Tapia, 2018; Rončević & Tomšić, 2017), has had as its main source of momentum the evolution of Information and Communication Technologies (ICT). As mentioned by Feshina, Konovalova & Sinyavsky (2019), as a result of this evolution, in recent years has been configured what is understood as the "fourth industrial revolution" also known as "Industry 4.0", which has generated a new and growing space of professional performance composed by new industries that require the development of new competencies usually linked with tasks or jobs related to the evolution of the technological state-of-the-art (Gowripeddi et al., 2021; Koul & Nayar, 2021).

The demand for professionals with differentiated capabilities in the area of the technological application occurs mainly in industries that increasingly become important in our world such as video games, artificial intelligence, computer graphics, virtual reality, augmented reality, Big Data, Cloud computing, 3D printing, collaborative tools, robotics, among others (Feshina et al., 2019). However, the development of technological and digital skills in almost all work areas today has begun to be identified as a differential and competitive factor, both for experienced workers and for those who are just starting their working life.

In this context, a structural category is revealed that allows us to have a better understanding of this phenomenon: 21st-century skills. This category tries to encompass those skills that feel inherent to our century and that seem to be part of the "zeitgeist", in other words, the spirit of this time.

In this regard, it is worth mentioning the importance that this issue has been receiving in the academic community, especially in the last decade, which can be seen in Figure 1, which shows the evolution in the generation of publications on "21st-century skills "or" 21st-century competencies", in journals indexed in Scopus. However, in the literature "skills" and "competencies" are named with some degree of equivalence, we have recognized the relevance of advancing the study of the term "skills", since the competences make up a more complex set that articulates different abilities, with knowledge and ethical and moral values (De Vos et al, 2015). In that sense, it is more consistent for this review to focus on 21st century skills.

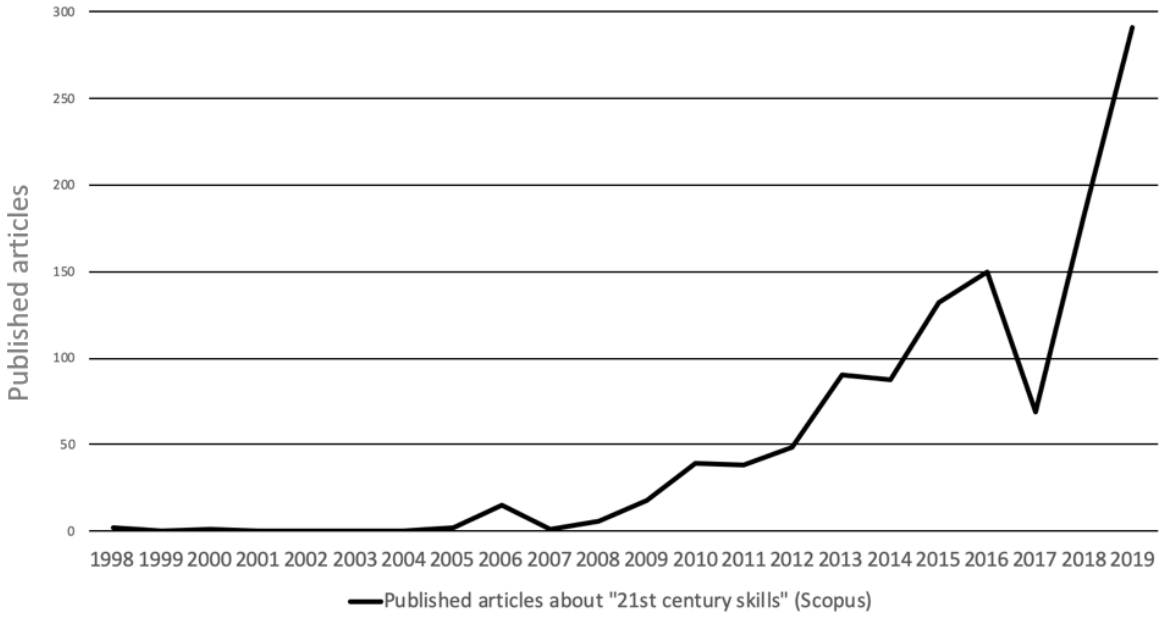

Figure1: Articles published about 21st-century skills in Scopus. Source: own elaboration based on Scopus data

This seems to be a fairly accurate gauge of the temperature of the relevance of this topic in the field of current education. Articles about the future of the professions hardly avoid mentioning the need to develop such skills that will support the good performance of future professionals or those who are currently active in the labor market (Brown III, 2019).

As an emerging and growing issue, it is normal to present various conceptualizations about 21st-century skills. Some organizations, including P21 (2020), OECD (2010) and Delors (1998), refer to these skills linked to the development of creativity, collaboration, communication, critical thinking, and problem-solving, in addition to digital literacy and computational thinking (Tabesh, 2017; Zapata-Ros, 2019). In this regard, Woolf, Lane, Chaudhri & Kolodner (2013) indicate that 21st-century skills are grouped into three categories: cognitive, intrapersonal and interpersonal and that are developed preferably within the framework of digital ecosystems of human interaction or where such interactions are carried out with ICT support.

Within the framework of the development of Industry 4.0, not only the 21st-century skills stand out as a topic of special relevance, but also the term "STEAM" arises, as a content structure that is recognized as having a high affinity not only with educational expectations for the 21st-century (Ge et al., 2015), but with the development of 21st-century skills (Hadinugrahaningsih et al., 2017; Sanabria, 2017). According to Kwon et al, (2011), STEAM is a modification of an integrating curricular concept previously coined as "STEM" (Science, Technology, Engineering, and Mathematics), to which the "A" of Arts has been added.

One of the characteristics of the STEAM educational environments has to do with a notable emphasis on the interdisciplinary and even transdisciplinary approach to learning (Eleni & Fotini, 2018). Such a perspective, added to the approaches of problem-based and project-based learning that characterize STEAM education, are recognized as being related to the very nature of 21st century skills, which is presumed, since the literature on the subject is not very abundant nor conclusively, that STEAM environments seem to be one of the best ways to develop 21st century skills.

Facing such uncertainty and recognizing the importance of this issue for current education, a systematic literature review has been carried out on studies conducted on 21st-century skills, with the purpose of identifying some of its aspects that allow inferring the relevance of STEAM environments as enabling environments for their development.

2. Method

The review was conducted from the stages originally proposed by Kitchenham and Charters (2007) and later revisited by other researchers such as Clear (2015) or López, Méndez, Paz & Arboleda (2016). According to them, the stages have been synthesized and grouped into 3 major phases: Planning of the review, conducting the review and disseminate of the review's results, as shown in Figure 2:

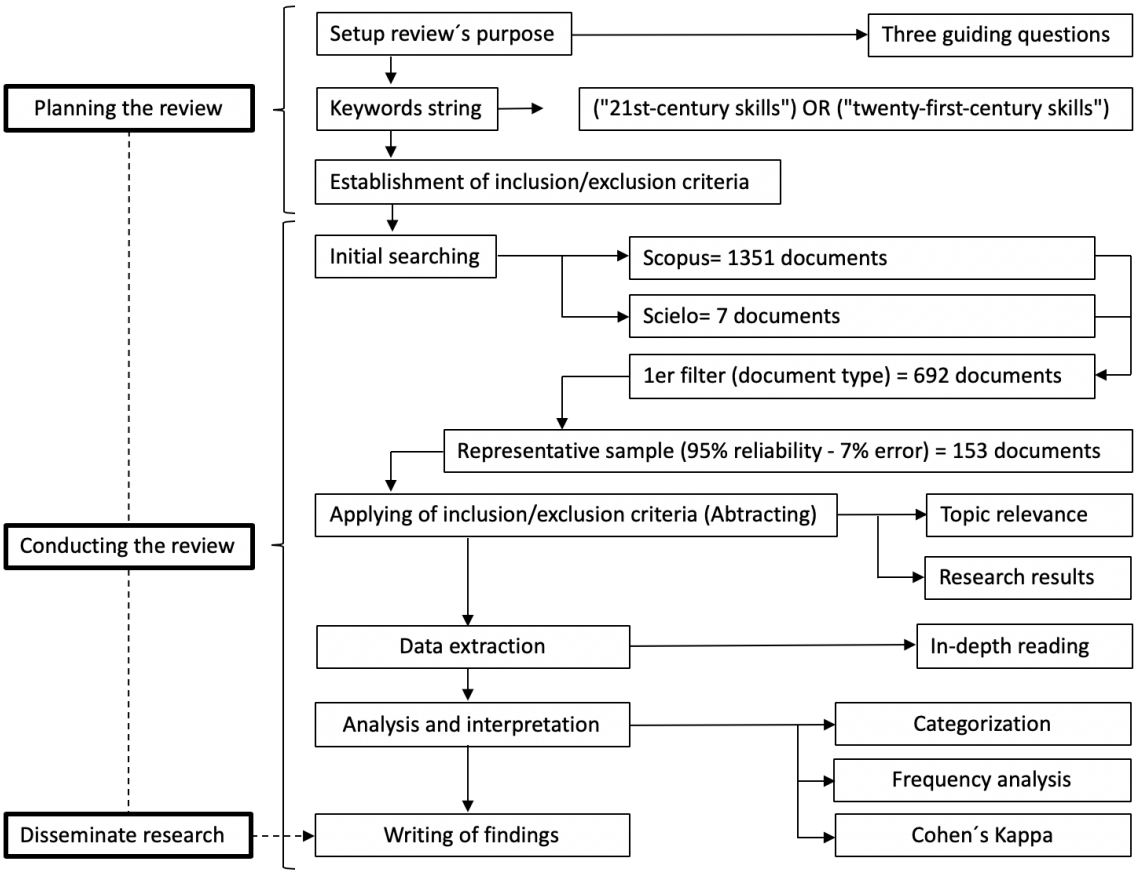

Figure 2: Review method. Source: own elaboration

2.1 Planning the review

As part of this first phase, the purpose for the review was established focused on identifying main key factors for developing 21st-century skills and find out if STEAM as a learning environment was one of the best ways to develop such skills.

For this purpose, three guiding questions were defined: How consistent are the conceptualizations about 21st-century skills? How are 21st-century skills developed? and finally, can they be developed through a STEAM learning environment?

In order to address these questions, a string of searching keywords or descriptors was defined like this: ("21st-century skills") OR ("twenty-first-century skills") which was applied in Scopus and Scielo, which are databases that provide high-quality sources and coverage in English, Portuguese and Spanish.

After these steps, inclusion and exclusion criteria were established, mainly with the purpose of filtering results previously to start the in-depth reading process. Regarding this, only

documents which presented research results about 21st-century skills from 1998 to 2019 were considered for abstracting and further reading.

2.2 Conducting the review

An initial search in databases including title, keywords, and abstract obtained a total of 1358 results. Then, a "document type" first filter was applied reducing the set of results to 692 articles and "articles in press". In order to reduce this set of documents for better handling, a representative sample (95% reliability - 7% error) was found obtaining a final set of documents of 153 items.

The applying of inclusion/exclusion criteria was conducted through a process of abstracting, in which the subsets of documents by year were ordered in an ascending way by the number of citations. Reading the abstract of each document was used as a means to verify that the articles were really relevant by presenting research results or definitions related to the "21st-century skills".

The next process after abstracting was the in-depth reading in which the extraction of data took place and the approach to identify relevant definitions and mentions started. For this purpose, a documentation matrix was created for including information related with the guiding questions: conceptualizations, definitions and key factors for 21st-century skills development. Notes and citations of the articles were also included in the matrix in order to facilitate the retrieval of information related to our search. The final set of documents for in-depth reading was composed chronologically as shown in Figure 3.

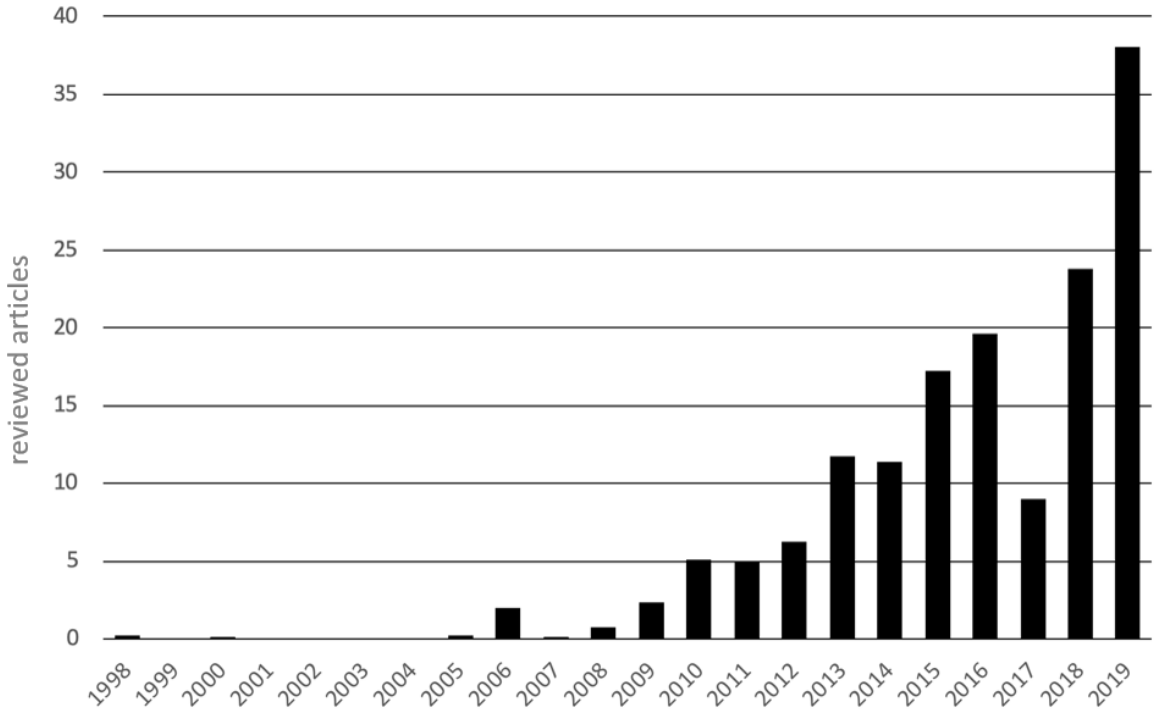

Figure 3: Representative sample for in-depth reading. Source: own elaboration based on Scopus data

2.3 Disseminate of the review's results

In this final phase, data analysis and interpretation were considered following by the writing of findings and conclusions. In detail, data was grouped, categorized and also processed through basic statistical and frequency analysis.

Final analysis and interpretation of data was conducted by two different observers in order to properly manage the viewer's biases. For this purpose, a Cohen´s Kappa coefficient was applied (k=0,607) for 153 reviewed items, which according to Tang et al. (2015), is recognized as an adequate level of inter-rater analysis.

3. Results

3.1 Bibliometric results

The results show a homogeneous approach regarding the contribution of the journals to this review with a total number of 105 journals with an average of 1,48 articles per journal. The quality of the sources consulted is indicated in Table 1, which shows the top 10 of the journals that have contributed the most articles to the review as part of the consultation in

Scopus. The quality of these sources is shown based on their impact factor and location in the SJR quartiles (Scimago Journal Ranking).

Table 1: List of the Top 10 indexed journals with the greatest contribution to the review (Scopus).

Journal	%	SJR ImpFactr	SJR quartile
Thinking Skills and Creativity	4,49%	0,677	Q1
Computers and Education	3,85%	2,323	Q1
Education and Information Technologies	3,21%	0,598	Q1
Journal of Research on Technology in Education	3,21%	0,807	Q1
TechTrends	2,56%	0,448	Q2
Australasian Journal of Educational Technology	1,92%	0,721	Q1
Computers in the Schools	1,92%	0,389	Q1
Educational Technology and Society	1,92%	1,085	Q1
IEEE Engineering Management Review	1,92%	0,132	Q4
Journal of Educational Change	1,92%	1,175	Q1

Source: own elaboration based on Scopus data

3.2 Overall results

The purpose of this paper is to verify studies and experiences around the development of 21st-century skills. As such we came down to the questions: How consistent are the conceptualizations about 21st-century skills? and How can we best develop 21st-century skills? The answers according to the seen literature are not easy ones.

First of all, not many of the articles that were read define the 21st-century skills deeply. Generally, they mention them as if they were very clear and well known by everyone while the truth is that it can be very confusing. Authors care more about one or another specificity of the broad range of competencies that can be considered as a 21st-century skill so that they

could talk about the development of that specific feature through a certain technique - as gaming, mobile learning or robotics, flipped classroom for example: O'Flaherty and Phillips (2015), Gerber and Scott (2011), Eguchi (2016); O'Bannon and Thomas (2014).

Some authors agree to call these set of skills as higher-order thinking skills and complex thinking skills (Saavedra & Opfer, 2012) because of the complexity and thinking processes it takes to reach the invention of a new device for solving a practical problem for example.

The 21st-century skills concept even appears as a keyword for some articles that never mention it within its text (O'Bannon & Thomas, 2014, 2015; Thomas et al., 2014). Such occurrence gives the sense of importance the theme has nowadays that even not being part of the body of the text it is a must to have those concepts in mind when writing a relevant and current article.

Our research has also found the lack of abundance and difficulty of assessing and measuring the 21st-century skills whichever they can be. Not many authors work the issue and very few give tools and options to deal with it. According to Reynolds (2016), we can more easily assess reading literacy, collaboration, information literacy, information technology literacy and media literacy, therefore, they don't consider the other suggested skills for measuring as said by Chu et al (2017).

The ISTE (International Society for Technology in Education), in special, mentions Computational Thinking (CT) for the problem-solving skill; understanding it as a way of dealing with diverse situations and finding solutions through the following: Problem decomposition, recognizing patterns, using abstractions to represent data and automating solutions through algorithms (ISTE, 2016).

Some of the articles that appeared as result using Scopus when searching for the aforesaid expression just mention the 21st Century Skills as any skills the authors think the citizens ought to need to fully engage in the current century. That creates a bit of confusion and misunderstanding on what they refer as such - e.g. Osher et al (2016), Vreeburg Izzo et al (2010), Greenhow (2009) and Dede (2000).

The definition of the term 21st-century skills is currently very difficult to make as many authors, governments and organizations have been using the term indistinctively to refer to whatever they think it is proper to call as such. However, with starting points as the first institutions to name determined competencies and skills like the ones needed to be successfully part of the workforce and citizen of the new century as the aforesaid P21 (Partnership for 21st Century Skills), OCDE, ATCS21s, ISTE, and UNESCO (Care, Scoular & Griffin, 2016). For these entities, the main competencies or skills are technological fluency (National Research Council, 1999), innovation, communication and collaboration, research and information fluency, problem-solving (Sanabria Zafra et al., 2020), and digital citizenship (Greenhow & Robelia, 2009).

Initially the p21 project defined the 21st century skills in 3 categories (Digital literacy, Carrer and Life and 4C's): Collaboration, Communication, Critical thinking and Creativity. Later, that was amplified to 7C. Critical thinking and problem solving, Creativity and innovation Cross-cultural understanding, Communications, information, and media literacy, Computing and ICT literacy, Career and learning self-reliance as said by Trilling and Fadel (2009).

3.3 Concepts related to 21st century skills

How consistent are the conceptualizations about 21st-century skills?
It is found that some authors, organizations and governments that may call indistinctly skills and competences. The OCDE included both in the study of the needs of the 21st century and defined the difference that can be found in many sources: competence is bigger than skill in the sense that it is compounded of cognitive elements, technical skills, and interpersonal attributes being used in a specific context to solve a precise situation while skill is the capability to solve problems and perform tasks (OCDE, 2010).

ISTE defines their standards of the today's students based on the needs seen by this organization that sets the foreseen future of education and for this future is needed that the students are empowered learners, digital citizens, constructors of the knowledge, innovative designers, computational thinkers, creative communicators and global collaborators. These are somehow coincident with other definitions and nomenclatures given but with the same ideas where the students must be active in the learning process, independent, free to build their own knowledge and make meaningful learning experiences.

One of the main studies on the subject and cited by many of the articles seen here is of Binkley et al (2012) which is based amongst others in the core project ATC21S that is per se one of the pioneers in the definition of such skills together with UNESCO, OECD and ISTE. The article seems to be the main source of definitions of the 21st-century skills for articles that resulted in our research: e.g. Niemi and Multisita (2016), Qian and Clark (2016), Redecker and Johannessen (2013), Wilson et al. (2015), Ras et al. (2014) and Van Laar, Van Deursen, Van Dijk and De Haan (2017).

3.4 Development of 21st Century skills

How are 21st-century skills developed?
Almost all studies that mention 21st-century skills are trying to give a recipe to develop these competencies but very few of them specify what exactly they refer to as being the 21st century skills. It is a very generic term that is taken as something everyone can understand as a set of skills needed to succeed in the current century.
Of the articles reviewed, 15% made no mention of the ways in which it was possible to strengthen the skills of the 21st century. From the rest of the articles, 28 different ways of

doing it were identified, although it should be mentioned that several of them have similarities or very close relationships with others. Figure 4 shows those that exceeded 1.5% of the total identified, among which are: with 12,2%, the assessment change to formative (Sahlberg, 2011), with 11,6% the collaborative and social environments (Kale & Goh, 2014), 9,1% for research and inquiry-based learning (Wright & Lee, 2014), 8,5% for gamification and gaming (Kingsley & Grabner-Hagen, 2015; Gerber & Scott, 2011) as well as online communities of practice (Dede, 2000; Wright & Lee, 2014), 7,9% for social networking (Black, 2009), 5,5% for Mobile learning (Zheng et al., 2016), 3,0% for goal-oriented learning (Anderman, Sinatra & Gray, 2012), interactive web content (van Laar et al., 2017) and situated learning (Pazey et al., 2016) , 2,4% for challenge-based experiential learning (Parker et al., 2013), cross-discipline learning (Saavedra & Opfer, 2012), learning analytics (Gobert et al., 2015), STEM learning environments (Eguchi, 2016; Jang, 2016; Unfried et al., 2015; Sahin, Gulacar & Stuessy, 2015) and 1,8% for robotics (Eguchi, 2016).

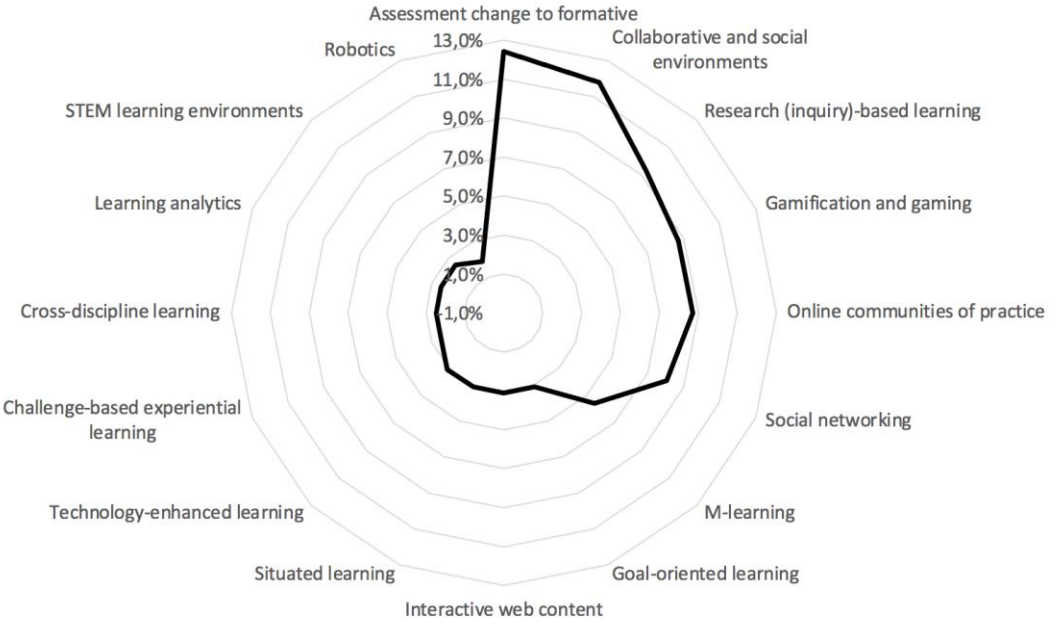

Figure 4: ways to foster 21st Century skills. Source: own elaboration.

The rest of the results show a lower participation in relation to the total, among which are: with 1.2% the authentic learning (Putnam et al., 2016), entrepreneurship (Zhao, 2015), flipped classroom (Hodges & Weber, 2015) and self-directed learning (Bullock, 2013). Finally, with 0.6% each one, we found affective and social approach to learning (Tan, 2016), computational thinking (Zapata-Ros, 2019), cross-cultural learning (Ghaith, 2010), digital storytelling (Niemi & Multisilta, 2016), internet-enabled services (Kong, Chan, Griffin, Hoppe, Huang, Kinshuk, Looi, Milrad, Norris & Nussbaum, 2014), mastery learning (Anderman et al., 2012) and job-study environments (Jang, 2016).

3.5 Relation between 21st-century skills and STEAM

STEAM education or STEAM learning environments are not easy defining because many authors characterize them differently. Predominantly we see that is agreed upon the original concept of STEM (content and careers) as said by Unfried at al. (2015), but there is some controversy on the meaning or representation that the "A" stands for. Primarily it stands for Arts as the creative bit but it does not mean the other subjects lack creative thinking or creative problem-solving (Perignat & Katz-Buonincontro, 2019; Grecca et al. 2021; Leroy & Romero, 2021; Hsiao & Su, 2021).

On one hand, STEAM learning environments is understood like the environment that combines the application of PBL (both project-based learning or Problem-based Learning) strategy, or other constructivist or progressive strategy where students are the active subjects of their learning, with a mix of at least 2 out of the 4 four possible variables from STEAM and with that build up a problem or set an objective that would conjugate diverse knowledge and result in the construction of new knowledge for the students (Perignat & Katz-Buonincontro, 2018). Students as said by John Dewey should face real-world problems under the supervision/guidance of a tutor and through the PBL (Project-based learning) method first worked by William Kilpatrick solve those problems. "In classrooms, students should be motivated to solve integrated, interdisciplinary sets of complex problems collaboratively using critical thinking and knowledge of STEM disciplines" (Jang, 2016).

Can the 21st century skills be developed through a STEAM learning environment?

Despite the fact that, as mentioned above, very few studies directly mention STEM (or STEAM) environments as suitable settings to develop 21st century skills, also we found that most studies relate some of the STEAM components with the development of these skills compelling us to affirm positively to the question.

In this sense, some studies are focused in developing of critical thinking and problem solving, mainly through Project-based Learning (PBL) and associated with the engineering and math components of STEAM. Those studies are: (McCreery et al., 2011), (Woolf et al., 2013), (Gerber & Scott, 2011), (Sahin et al., 2015), (Ras et al., 2014), (Siddiq et al., 2017), (Ahonen & Kinnunen, 2015), (Seifert, 2015), (Wilson et al., 2015) and (Redecker & Johannessen, 2013).

On the other hand, regarding creativity, innovation, adaptability, ingenuity, curiosity and imagination, other studies as (Woolf et al., 2013), (Reese, 2015), (Sahin et al., 2015), (Ras et al., 2014), (Siddiq et al., 2017), (Ahonen & Kinnunen, 2015), (Wilson et al., 2015) and (Redecker & Johannessen, 2013), are focused in the "Art" component of STEAM environments.

Continuing with the analysis, (Woolf et al., 2013), (Reese, 2015), (Sahin et al., 2015), (Ras

et al., 2014), (Siddiq et al., 2017), (Ahonen & Kinnunen, 2015), (Jang, 2016), (McCreery et al., 2011), (Anderman et al., 2012), (Seifert, 2015) and (Wilson et al., 2015), through student-centered class techniques or methods, focus their studies on Communication, mainly in active listening, speaking, writing effective oral and written communication.

Regarding Collaboration (and adaptability), social perceptiveness and collaborative problem solving, (Jang, 2016), (Häkkinen et al., 2017), (Care et al., 2016), (McCreery et al., 2011), (Anderman et al., 2012), (Sahin et al., 2015), (Ras et al., 2014), (Siddiq et al., 2017), (Ahonen & Kinnunen, 2015), (Seifert, 2015), (Niemi & Multisilta, 2016) and (Redecker & Johannessen, 2013) focus their estudies on group and team work, basically through PBL (project based learning).

In relation to Creative non-routine problem-solving, some studies as (Jang, 2016), (Woolf et al., 2013), (Anderman et al., 2012), (Sahin et al., 2015) and (Ras et al., 2014), address the science, engineering and technology components of STEAM.

In addition to the above, (Ras et al., 2014), (Jang, 2016), (Yadav et al., 2016), (Woolf et al., 2013), (Anderman et al., 2012), and (Zapata-Ros, 2019), highlight the importance of the "science", "engineering" and "technology" components of STEAM and associate them mainly with systems and computational thinking and decision making.

Regarding self-management/development, active learning, time management and lifelong learning, (Jang, 2016), (Häkkinen et al., 2017), (Niemi & Multisilta, 2016), (Woolf et al., 2013), (Reese, 2015), (Anderman et al., 2012), (Sahin et al., 2015), (Ras et al., 2014), (Wilson et al., 2015), (Siddiq et al., 2017) and (Redecker & Johannessen, 2013), make special emphasis in the combination of PBL (project based learning) and student-centered class techniques as the way to strengthen these 21st century skills.

Finally, (Niemi & Multisilta, 2016), (Siddiq et al., 2017), (Ahonen & Kinnunen, 2015), (Wilson et al., 2015), associates ICT and digital literacy development with the technology component of STEAM environments, while (Woolf et al., 2013), (Sahin et al., 2015), (Wilson et al., 2015), (Redecker & Johannessen, 2013) and (Reese, 2015) focus their studies on science, art and technology regarding information literacy, accessing and analyzing data, leadership, risk-taking, initiative and entrepreneurialism and cultural and global awareness.

4. Discussion

The STEM movement appeared from the present and moreover the future "shortage of STEM workers" (National Research Council, 2011); furthermore, the definition of leadership in areas as energy, health, environmental protection, and national security and therefore the need to adapt the education in order to fuflil these positions (Jang, 2016); the final proposition of the whole movement is to generate competent well-prepared engineers for the difficult task of working with the ever-changing technology for the industry and new ICT branches.

In primary or secundary school we should try the "true STEM education (that) should increase students understanding of how things work and improve their use of technologies" (Bybee, 2010).

The immediate reason we see an increasing interest on STEAM education development in schools is that "Workers with science, technology, engineering, and math (STEM) skills and competencies are in demand in the United States (Carnevale et al., 2011) and around the world, and researchers and economists predict that this demand will continue for years to come (Unfried et al., 2015).

That moves the market towards a new trend and countries all over the world start being aware of it and follow the same trend. The worker and citizen of our time should have both hard and soft skills. Develop their subject knowledge - desirebly in STEAM - and their notorious 21st-century skills. They go hand in hand towards the new age worker and citizen.

The "entry into Science, Technology, Engineering, and Mathematics careers is often determined by children and adolescents' experiences with science" (Anderman et al., 2012).

The STEM movement appeared from the present and moreover the future "shortage of STEM workers" (National Research Council, 2011); furthermore, the definition of leadership in areas as energy, health, environmental protection, and national security and therefore the need to adapt the education in order to fuflil these positions (Jang, 2016); the final proposition of the whole movement is to generate competent well-prepared engineers for the difficult task of working with the ever-changing technology for the industry and new ICT branches. In primary or secundary school we should try the "true STEM education (that) should increase students understanding of how things work and improve their use of technologies." (Bybee, 2010).

With foundations on the Delors report for UNESCO in 1996 referring to the skills needed to face the 21st century society and work market. Despite the discourse about the need of the "society" in the new era of knowledge of citizens with contemporary abilities to face modern challenges we see the urge of fulfilling the profiles emerged from the industry 4.0, industry automation, computer science and engineering and others like the thriving ICT industry. That is almost the same origin of the incentive demanded by the economy for STEM workers as we face a shortage of engineers and other related professionals.

Another actor that has played an important role in defining the skills needed in the current and future education is the ISTE-NETS. Starting to set their vision on the matter in 2007, today they define their standards for students as: Empowered Learner, Digital Citizen, Knowledge Constructor, Innovative Designer, Computational Thinker, Creative Communicator and Global Collaborator. These are very ambitious concepts and seem to cover a whole lot not to say a great number of very different dimensions as says the ISTE.

The so-called 21st-century skills are not new in History, - their intentional development to everyone through the educational system in recent years is new (Rotherham & Willingham, 2009); the idea that one should know a bit of everything and be able to integrate the knowledge is also as old as great thinkers that would make great inventions, discoveries, pieces of art and so on. Just to mention some names of more recent times we could remember of Leonardo Da Vinci, Nikola Tesla, Benjamin Franklin, Santos-Dumont, Guglielmo Marconi, James Watt amongst many others transdisciplinary minds.

During the industrial era and until not long ago, an age of hyper-specialization, when the best thing the worker could do was to get a very specific knowledge in order to be the only one able to perform a certain task, was set.

The difference nowadays is that the ever-changing economy (and at some extent the society) demands a different kind of citizen and worker instead of a specialized one who manages to see the big picture, relate things, collaborate, criticize, produce, create, perform mental processes that the machine still cannot do (at least not well).

The idea of this work is not to establish whether the curriculum as we know right now should disappear or be relegated to a secondary role in education. It is rather about the inclusion of the meta-curriculum and meta-knowledge (Scott, 2015) called 21st-century skills and the possibility of reaching these competences and skills through an emergent vision of STEAM education. So, we would use both the subject curriculum and the STEAM subjects intertwined with the assurance of empowering people with the modern but not new competences and skills necessary for the 21st century citizen according to the forecast done so far. As Resnick (2010) says “[...] thinking abilities have to develop in the course of reasoning about specific information and knowledge.” That idea is complemented by Kong et al. (2014) when they talk about the assessment of those: “The assessment of 21st century skills should therefore be linked with the assessment of domain knowledge, so that teachers can better understand the interrelationship between learners’ gains in these two types of learning outcomes."

There are certain authors that are convinced about the openness and incertitude of these competences and skills of the 21st-century as concept. “While there is no single definitive list of these skills, most lists focus on expanding traditional concepts of knowledge, skills, and abilities to encompass concepts such as critical and innovative thinking, systems-thinking, interpersonal communication and collaboration skills, digital networking and operation skills, intra- and intercultural awareness and identity, and cross-cultural sensibility." We would like to highlight the coincidence of some of the most mentioned interpersonal communication and collaboration skills (Rupp et al., 2010).

The need for more students and future professionals in the STEM areas was determined and pointed out by former President Obama in 2009. Although many efforts have been made throughout the world it seems that we still don’t understand well the importance of such careers for the future of science, industry and society as a whole. Furthermore, this is not an

over discussed issue in our education and should be more often related as STEAM education for enabling STEM students equipped with all the 21-st century skills needed for our current and future careers.

Acknowledgment

We want to thank the Universidad de la Sabana for the support in the preparation of this article and in the research processes that gave rise to it.

Received: February, 5, 2021
Accepted: May 30, 2021
Published: November 30, 2021

Krüger, W., & Chiappe, A. (2021). 21st-century skills and STEAM learning environments: a review. *RED. Revista Educación a Distancia*, *21(67)*. http://dx.doi.org/10.6018/red.470461

Funding

This research has not received any specific grant from funding agencies in the public, commercial or non-profit sectors.

References

Ahonen, A. K., & Kinnunen, P. (2015). How Do Students Value the Importance of Twenty-first Century Skills? *Scandinavian Journal of Educational Research*, *59*(4), 395–412. https://doi.org/10.1080/00313831.2014.904423

Anderman, E. M., Sinatra, G. M., & Gray, D. L. (2012). The challenges of teaching and learning about science in the twenty-first century: Exploring the abilities and constraints of adolescent learners. *Studies in Science Education*, *48*(1), 89–117. https://doi.org/10.1080/03057267.2012.655038

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2012). Defining Twenty-First Century Skills. In P. Griffin, B. McGaw, & E. Care (Eds.), *Assessment and Teaching of 21st Century Skills* (pp. 17–66). Springer Netherlands. https://doi.org/10.1007/978-94-007-2324-5_2

Black, R. W. (2009). English-Language Learners, Fan Communities, and 21st-Century Skills. *Journal of Adolescent & Adult Literacy*, *52*(8), 688–697. https://doi.org/10.1598/JAAL.52.8.4

Brown III, W. (2019). Guiding the path: Identified skills for educating the next generation of workers. *Journal of Education for Business*, 1–8. https://doi.org/10.1080/08832323.2018.1541854

Bullock, S. M. (2013). Using digital technologies to support Self-Directed Learning for preservice teacher education. *The Curriculum Journal*, *24*(1), 103–120. https://doi.org/10.1080/09585176.2012.744695

Bybee, R. W. (2010). What Is STEM Education? *Science*, *329*(5995), 996–996. https://doi.org/10.1126/science.1194998

Care, E., Scoular, C., & Griffin, P. (2016). Assessment of Collaborative Problem Solving in Education Environments. *Applied Measurement in Education*, *29*(4), 250–264. https://doi.org/10.1080/08957347.2016.1209204

Carnevale, A., Smith, N., & Melton, M. (2011). *STEM: Science Technology Engineering Mathematics. Executive Summary*. Georgetown University Center on Education and the Workforce.

Chu, S. K. W., Reynolds, R. B., Tavares, N. J., Notari, M., & Lee, C. W. Y. (2017). Assessment Instruments for Twenty-First Century Skills. In S. K. W. Chu, R. B. Reynolds, N. J. Tavares, M. Notari, & C. W. Y. Lee, *21st Century Skills Development Through Inquiry-Based Learning* (pp. 163–192). Springer Singapore. https://doi.org/10.1007/978-981-10-2481-8_8

Clear, T. (2015). "Follow the moon" development: Writing a systematic literature review on Global Software Engineering Education. *ACM International Conference Proceeding Series*, *19-22-Nov-2015*, 1–4. https://doi.org/10.1145/2828959.28350190

Dede, C. (2000). Emerging influences of information technology on school curriculum. *Journal of Curriculum Studies*, *32*(2), 281–303. https://doi.org/10.1080/002202700182763

Delors, J. (1998). *Learning: The treasure within*. Unesco. http://lllp.iugaza.edu.ps/Files_Uploads/635087182222401677.pdf

De Vos, A., De Hauw, S., & Willemse, I. (2015). An integrative model for competency development in organizations: the Flemish case. *The International Journal of Human Resource Management*, *26*(20), 2543-2568. https://doi.org/10.1080/09585192.2014.1003078

Eguchi, A. (2016). RoboCupJunior for promoting STEM education, 21st century skills, and technological advancement through robotics competition. *Robotics and Autonomous Systems*, *75*, 692–699. https://doi.org/10.1016/j.robot.2015.05.013

Eleni, N., & Fotini, P. (2018). "Developing Interdisciplinary Instructional Design Through Creative Problem-Solving by the Pillars of STEAM Methodology." In M. E. Auer & T. Tsiatsos (Eds.), *Interactive Mobile Communication Technologies and Learning* (Vol. 725, pp. 89–97). Springer International Publishing. https://doi.org/10.1007/978-3-319-75175-7_10

Feshina, S. S., Konovalova, O. V., & Sinyavsky, N. G. (2019). Industry 4.0—Transition to New Economic Reality. In E. G. Popkova, Y. V. Ragulina, & A. V. Bogoviz (Eds.), *Industry 4.0: Industrial Revolution of the 21st Century* (Vol. 169, pp. 111–120). Springer International Publishing. https://doi.org/10.1007/978-3-319-94310-7_11

Ge, X., Ifenthaler, D., & Spector, J. M. (2015). *Emerging technologies for STEAM education: Full STEAM ahead*. Springer.

Gerber, S., & Scott, L. (2011). Gamers and gaming context: Relationships to critical thinking: Gamers and critical thinking. *British Journal of Educational Technology*, *42*(5), 842–849.

https://doi.org/10.1111/j.1467-8535.2010.01106.x

Ghaith, G. (2010). An exploratory study of the achievement of the twenty-first century skills in higher education. *Education + Training*, *52*(6/7), 489–498. https://doi.org/10.1108/00400911011068441

Gobert, J. D., Kim, Y. J., Sao Pedro, M. A., Kennedy, M., & Betts, C. G. (2015). Using educational data mining to assess students' skills at designing and conducting experiments within a complex systems microworld. *Thinking Skills and Creativity*, *18*, 81–90. https://doi.org/10.1016/j.tsc.2015.04.008

Gowripeddi, V. V., Bijjahalli, M. C., Janardhan, N., & Bhimavaram, K. R. (2021). Role of Education 4.0 Technologies in Driving Industry 4.0. In M. E. Auer & D. May (Eds.), *Cross Reality and Data Science in Engineering* (Vol. 1231, pp. 576–587). Springer International Publishing. https://doi.org/10.1007/978-3-030-52575-0_48

Greca, I. M., Ortiz-Revilla, J., & Arriassecq, I. (2021). Diseño y evaluación de una secuencia de enseñanza-aprendizaje STEAM para Educación Primaria. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias*, *18*(1), 1-20. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2021.v18.i1.1802

Greenhow, C., & Robelia, B. (2009). Informal learning and identity formation in online social networks. *Learning, Media and Technology*, *34*(2), 119–140. https://doi.org/10.1080/17439880902923580

Grijalva, R. D. R., & Tapia, M. G. A. (2018). The prevalence of the knowledge society or the information society as structuring elements of the social system [La prevalencia de la sociedad del conocimiento o la sociedad de la información como elementos estructurantes del sistema social]. *Prisma Social*, *20*, 333–346.

Hadinugrahaningsih, T., Rahmawati, Y., & Ridwan, A. (2017). Developing 21st century skills in chemistry classrooms: Opportunities and challenges of STEAM integration. *AIP Conference Proceedings*, 0300080–0300089. https://doi.org/10.1063/1.4995107

Häkkinen, P., Järvelä, S., Mäkitalo-Siegl, K., Ahonen, A., Näykki, P., & Valtonen, T. (2017). Preparing teacher-students for twenty-first-century learning practices (PREP 21): A framework for enhancing collaborative problem-solving and strategic learning skills. *Teachers and Teaching*, *23*(1), 25–41. https://doi.org/10.1080/13540602.2016.1203772

Hodges, T. S., & Weber, N. D. (2015). Making Heads or Tails of Classroom Flipping. *Kappa Delta Pi Record*, *51*(2), 57–63. https://doi.org/10.1080/00228958.2015.1023135

ISTE. (2016). *Redefining learning in a technology-driven world: A report to support adoption of the ISTE Standards for Students*. ISTEC, Inc. https://cdn.iste.org/www-root/Libraries/Documents%20%26%20Files/Standards-Resources/ISTE%20Standards_Students-2016_Research-Validity%20Report_final.pdf

Hsiao, P.-W., & Su, C.-H. (2021). A Study on the Impact of STEAM Education for Sustainable Development Courses and Its Effects on Student Motivation and Learning. *Sustainability*, *13*(7), 3772. https://doi.org/10.3390/su13073772

Jang, H. (2016). Identifying 21st Century STEM Competencies Using Workplace Data. *Journal of Science Education and Technology*, *25*(2), 284–301. https://doi.org/10.1007/s10956-015-9593-1

Kale, U., & Goh, D. (2014). Teaching style, ICT experience and teachers' attitudes toward teaching with Web 2.0. *Education and Information Technologies*, *19*(1), 41–60.

https://doi.org/10.1007/s10639-012-9210-3

Kingsley, T. L., & Grabner-Hagen, M. M. (2015). Gamification: Questing to Integrate Content Knowledge, Literacy, and 21st-Century Learning. *Journal of Adolescent & Adult Literacy, 59*(1), 51–61. https://doi.org/10.1002/jaal.426

Kitchenham, B., & Charters, S. (2007). *Guidelines for performing Systematic Literature Reviews in software engineering* (Version 2.3; EBSE Technical Report, pp. 1–65). Kelle University and University of Durham.

Kong, S. C., Chan, T.-W., Griffin, P., Hoppe, U., Huang, R., Kinshuk, Looi, C. K., Milrad, M., Norris, C., & Nussbaum, M. (2014). E-learning in school education in the coming 10 years for developing 21st century skills: Critical research issues and policy implications. *Journal of Educational Technology & Society*, *17*(1), 70–78.

Koul, S., & Nayar, B. (2021). The holistic learning educational ecosystem: A classroom 4.0 perspective. *Higher Education Quarterly*, *75*(1), 98–112. https://doi.org/10.1111/hequ.12271

Kwon, S. B., Nam, D., & Lee, T. W. (2011). The effects of convergence education based STEAM on elementary school students' creative personality. *Proceedings of the 19th International Conference on Computers in Education, ICCE 2011*, 783–785. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84860464127&partnerID=40&md5=2b60fd0fee41d815b2fd84679ec5dc53

Leroy, A., & Romero, M. (2021). Teachers' Creative Behaviors in STEAM Activities With Modular Robotics. *Frontiers in Education*, *6*. https://doi.org/10.3389/feduc.2021.642147

López, A., Méndez, D., Paz, A., & Arboleda, H. (2016). Desarrollo e Instrumentación de un Proceso de Vigilancia Tecnológica basado en Protocolos de Revisión Sistemática de la Literatura. *Información Tecnológica*, *27*(4), 155–164. https://doi.org/10.4067/S0718-07642016000400017

McCreery, M. P., Schrader, P. G., & Krach, S. K. (2011). Navigating Massively Multiplayer Online Games: Evaluating 21st Century Skills for Learning within Virtual Environments. *Journal of Educational Computing Research*, *44*(4), 473–493. https://doi.org/10.2190/EC.44.4.f

National Research Council. (1999). *Being fluent with information technology*. National Academy Press.

National Research Council. (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. National Academy Press. https://www.nap.edu/resource/13158/dbasse_071100.pdf

Niemi, H., & Multisilta, J. (2016). Digital storytelling promoting twenty-first century skills and student engagement. *Technology, Pedagogy and Education*, *25*(4), 451–468. https://doi.org/10.1080/1475939X.2015.1074610

O'Bannon, B. W., & Thomas, K. (2014). Teacher perceptions of using mobile phones in the classroom: Age matters! *Computers & Education*, *74*, 15–25. https://doi.org/10.1016/j.compedu.2014.01.006

O'Bannon, B. W., & Thomas, K. M. (2015). Mobile phones in the classroom: Preservice teachers answer the call. *Computers & Education*, *85*, 110–122. https://doi.org/10.1016/j.compedu.2015.02.010

OCDE. (2010). *Working Paper 21st Century Skills and Competences for New Millennium*

Learners in OECD Countries (EDU Working paper no. 41). OCDE. http://recursostic.educacion.es/blogs/europa/media/blogs/europa/informes/Habilidades_y_competencias_siglo21_OCDE.pdf

O'Flaherty, J., & Phillips, C. (2015). The use of flipped classrooms in higher education: A scoping review. *The Internet and Higher Education*, *25*, 85–95. https://doi.org/10.1016/j.iheduc.2015.02.002

Osher, D., Kidron, Y., Brackett, M., Dymnicki, A., Jones, S., & Weissberg, R. P. (2016). Advancing the Science and Practice of Social and Emotional Learning: Looking Back and Moving Forward. *Review of Research in Education*, *40*(1), 644–681. https://doi.org/10.3102/0091732X16673595

P21. (2020). *Battelle For Kids*. P21's Frameworks for 21st Century Learning. https://www.battelleforkids.org/networks/p21

Parker, J., Maor, D., & Herrington, J. (2013). Authentic online learning: Aligning learner needs, pedagogy and technology. *Issues in Educational Research*, *23*(2 SPL), 227–241. Scopus.

Pazey, B. L., Schalock, R. L., Schaller, J., & Burkett, J. (2016). Incorporating Quality of Life Concepts Into Educational Reform: Creating Real Opportunities for Students With Disabilities in the 21st Century. *Journal of Disability Policy Studies*, *27*(2), 96–105. https://doi.org/10.1177/1044207315604364

Perignat, E., & Katz-Buonincontro, J. (2018). *From STEM to STEAM: Using Brain-Compatible Strategies to Integrate the Arts* ,: by David A. Sousa and Tom Pilecki. (2013). Thousand Oaks, CA: Sage. 280 pp. *Arts Education Policy Review*, *119*(2), 107–110. https://doi.org/10.1080/10632913.2017.1300970

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. *Thinking Skills and Creativity*, *31*, 31–43. https://doi.org/10.1016/j.tsc.2018.10.002

Putnam, C., Dahman, M., Rose, E., Cheng, J., & Bradford, G. (2016). Best Practices for Teaching Accessibility in University Classrooms: Cultivating Awareness, Understanding, and Appreciation for Diverse Users. *ACM Transactions on Accessible Computing*, *8*(4), 1–26. https://doi.org/10.1145/2831424

Qian, M., & Clark, K. R. (2016). Game-based Learning and 21st century skills: A review of recent research. *Computers in Human Behavior*, *63*, 50–58. https://doi.org/10.1016/j.chb.2016.05.023

Ras, E., Krkovic, K., Greiff, S., Tobias, E., & Maquil, V. (2014). Moving towards the Assessment of Collaborative Problem Solving Skills with a Tangible User Interface. *Turkish Online Journal of Educational Technology-TOJET*, *13*(4), 95–104.

Redecker, C., & Johannessen, Ø. (2013). Changing Assessment - Towards a New Assessment Paradigm Using ICT: European Journal of Education. *European Journal of Education*, *48*(1), 79–96. https://doi.org/10.1111/ejed.12018

Reese, S. A. (2015). Online learning environments in higher education: Connectivism vs. dissociation. *Education and Information Technologies*, *20*(3), 579–588. https://doi.org/10.1007/s10639-013-9303-7

Resnick, L. B. (2010). Nested Learning Systems for the Thinking Curriculum. *Educational Researcher*, *39*(3), 183–197. https://doi.org/10.3102/0013189X10364671

Reynolds, R. (2016). Connecting student information resource uses to learning outcomes in guided discovery-based game design. *IConference 2016 Proceedings*, 1–12.

Rončević, B., & Tomšić, M. (Eds.). (2017). *Information Society and its Manifestations: Economy, Politics, Culture*. Peter Lang AG. https://doi.org/10.3726/b10694

Rotherham, A. J., & Willingham, D. (2009). 21st century skills: The challenges ahead. *Educational Leadership*, *67*(1), 16–21.

Rupp, A. A., Gushta, M., Mislevy, R. J., & Shaffer, D. W. (2010). Evidence-centered design of epistemic games: Measurement principles for complex learning environments. *The Journal of Technology, Learning and Assessment*, *8*(4), 1–48.

Saavedra, A. R., & Opfer, V. D. (2012). Learning 21st-Century Skills Requires 21st-Century Teaching. *Phi Delta Kappan*, *94*(2), 8–13. https://doi.org/10.1177/003172171209400203

Sahin, A., Gulacar, O., & Stuessy, C. (2015). High School Students' Perceptions of the Effects of International Science Olympiad on Their STEM Career Aspirations and Twenty-First Century Skill Development. *Research in Science Education*, *45*(6), 785–805. https://doi.org/10.1007/s11165-014-9439-5

Sahlberg, P. (2011). The Fourth Way of Finland. *Journal of Educational Change*, *12*(2), 173–185. https://doi.org/10.1007/s10833-011-9157-y

Sanabria, J. C. (2017). Enhancing 21st Century Skills with AR: Using the Gradual Immersion Method to develop Collaborative Creativity. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(1), 487–501. https://doi.org/10.12973/eurasia.2017.00627a

Sanabria Zafra, E., Rodríguez Rodríguez, N., Zerpa Pérez, A. E., Prieto Marañón, P., & Alonso Rodríguez, M. Á. (2020). El Pensamiento computacional: ¿Una nueva forma de entrenar la memoria de trabajo?: Computational thinking: A new way to train working memory? *Revista de Educación a Distancia (RED)*, *20*(63). https://doi.org/10.6018/red.401931

Scott, C. L. (2015). *El futuro del aprendizaje 2?` Qué tipo de aprendizaje se necesita para el siglo XXI?* UNESCO. http://unesdoc.unesco.org/images/0024/002429/242996s.pdf

Seifert, T. (2015). Pedagogical Applications of Smartphone Integration in Teaching: Lecturers, Pre-Service Teachers and Pupils' Perspectives. *International Journal of Mobile and Blended Learning*, *7*(2), 1–16. https://doi.org/10.4018/ijmbl.2015040101

Siddiq, F., Gochyyev, P., & Wilson, M. (2017). Learning in Digital Networks – ICT literacy: A novel assessment of students' 21st century skills. *Computers & Education*, *109*, 11–37. https://doi.org/10.1016/j.compedu.2017.01.014

Tabesh, Y. (2017). Computational Thinking: A 21st Century Skill. *Olympiads in Informatics*, *11*, 65–70. https://doi.org/10.15388/ioi.2017.special.10

Tan, L. (2016). Confucius: Philosopher of twenty-first century skills. *Educational Philosophy and Theory*, *48*(12), 1233–1243. https://doi.org/10.1080/00131857.2016.1182416

Tang, W., Hu, J., Zhang, H., Wu, P., & He, H. (2015). Kappa coefficient: A popular measure of rater agreement. *Shanghai Archives of Psychiatry*, *27*(1), 62–67.

Thomas, K. M., O'Bannon, B. W., & Britt, V. G. (2014). Standing in the Schoolhouse Door: Teacher Perceptions of Mobile Phones in the Classroom. *Journal of Research on Technology in Education*, *46*(4), 373–395.

https://doi.org/10.1080/15391523.2014.925686

Trilling, B., & Fadel, C. (2009). *21st century skills: Learning for life in our times*. John Wiley & Sons. http://shorturl.at/lnqIN

Unfried, A., Faber, M., Stanhope, D. S., & Wiebe, E. (2015). The Development and Validation of a Measure of Student Attitudes Toward Science, Technology, Engineering, and Math (S-STEM). *Journal of Psychoeducational Assessment*, *33*(7), 622–639. https://doi.org/10.1177/0734282915571160

van Laar, E., van Deursen, A. J. A. M., van Dijk, J. A. G. M., & de Haan, J. (2017). The relation between 21st-century skills and digital skills: A systematic literature review. *Computers in Human Behavior*, *72*, 577–588. https://doi.org/10.1016/j.chb.2017.03.010

Vreeburg Izzo, M., Yurick, A., Nagaraja, H. N., & Novak, J. A. (2010). Effects of a 21st-Century Curriculum on Students' Information Technology and Transition Skills. *Career Development for Exceptional Individuals*, *33*(2), 95–105. https://doi.org/10.1177/0885728810369348

Wilson, M., Scalise, K., & Gochyyev, P. (2015). Rethinking ICT literacy: From computer skills to social network settings. *Thinking Skills and Creativity*, *18*, 65–80. https://doi.org/10.1016/j.tsc.2015.05.001

Woolf, B. P., Lane, H. C., Chaudhri, V. K., & Kolodner, J. L. (2013). AI grand challenges for education. *AI Magazine*, *34*(4), 66.

Wright, E., & Lee, M. (2014). Developing skills for youth in the 21st century: The role of elite International Baccalaureate Diploma Programme schools in China. *International Review of Education*, *60*(2), 199–216. https://doi.org/10.1007/s11159-014-9404-6

Yadav, A., Hong, H., & Stephenson, C. (2016). Computational Thinking for All: Pedagogical Approaches to Embedding 21st Century Problem Solving in K-12 Classrooms. *TechTrends*, *60*(6), 565–568. https://doi.org/10.1007/s11528-016-0087-7

Zapata-Ros, M. (2019). Computational thinking unplugged. *Education in the Knowledge Society*, *20*, 1–29. https://doi.org/10.14201/eks2019_20_a18

Zhao, Y. (2015). A World at Risk: An Imperative for a Paradigm Shift to Cultivate 21st Century Learners. *Society*, *52*(2), 129–135. https://doi.org/10.1007/s12115-015-9872-8

Zheng, B., Warschauer, M., Lin, C.-H., & Chang, C. (2016). Learning in One-to-One Laptop Environments: A Meta-Analysis and Research Synthesis. *Review of Educational Research*, *86*(4), 1052–1084. https://doi.org/10.3102/0034654316628645