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21st century skills and science achievement among secondary school students: A systematic review

Joel D. Cebrero

De La Salle University-Manila, Philippines, jdcebrero@gmail.com, ORCID ID: 0000-0002-1974-8858

ABSTRACT
This study systematically analysed, evaluated and synthesised published studies on 21st-century skills and science achievement among secondary school students. By scouring 17 well-known online journal databases, 684 related studies were found. After the three-stage screening process, only 17 research papers were included in the study, which were summarised with respect to research needs, aims/objectives, methods, research instruments, participants, results, and implications for teaching and learning. Majority of these studies investigated the development of 21st-century skills and employed a quasi-experimental method. They used questionnaires developed and validated in previous studies while some studies developed and validated their own instruments, data matrixes, observation tools, and concept assessments. Synthesis of findings revealed that constructivist and constructionist pedagogical approaches such as problem-based learning (PBL), project-oriented PBL, context-based, and inquiry-based learning improved student achievement and supported the development of 21st-century skills. Learning modules used under these approaches were designed to encourage active learning through collaborative problem-solving, where students researched for information, deliberated on issues, and proposed solutions to a real-world problem. Moreover, learning activities emphasised the connections of learning contents to real-life scenarios to understand science concepts and principles. Meanwhile, the impact of gender, school location, educated/non-educated parents' job, and teacher outcome expectancy and efficacy on student achievement and 21st-century skills varied depending on the prevailing conditions that directly influenced learning.

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Introduction

Great technological innovations, particularly in the digital economy, have influenced communications, data and information creation, processing and dissemination, thereby affecting consumer behaviour, knowledge transmission, and political practices. Thus, both government and non-government organisations have called for digital inclusions and to take advantage of such innovations by preparing the present and future workforce to cope with the demands of living in the 21st-century digital economy (Martins-Pacheco et al., 2020). The young generation should be prepared to face the challenges of the rapidly changing society by developing the necessary skills and competencies, commonly called Key Skills or 21st-century skills (Bray et al., 2020). The 21st-century skills and competencies refer to a set of abilities and knowledge that are essential for individuals to thrive in today's rapidly changing, technology-driven world (Finegold & Notabartolo, 2016). Skills and competencies are often used interchangeably, but they have distinct meanings, especially in the context of education and workforce development. Skills refer to the specific abilities or proficiencies that individuals possess to perform tasks or solve problems. They can be technical, such as coding or operating machinery, or soft, such as communications or teamwork, and are often seen as the practical application of knowledge and can be developed through practice and experience. On the other hand, competencies encompass a broader concept that includes skills, knowledge, attitudes, and behaviours necessary to perform effectively in a specific context. They involve the ability to meet complex demands by mobilising various resources, including cognitive skills, interpersonal skills, and ethical considerations (Ananiadou & Claro, 2009; Rychen & Tiana, 2004). For instance, effective communication is a competency that requires knowledge of language, practical skills in conveying messages and the right attitude toward the audience. In this view, while skills are specific abilities to perform tasks, competencies are a combination of skills, knowledge, and attitudes that enable individuals to navigate complex situations effectively. In the past decade, several studies have tried to identify and define the skills students require in the 21st century. These skills were assessed based on various characteristics and abilities (Zorlu & Zorlu, 2021). Even though different sets of skills have emerged, they can be categorised into common groups. In particular, the US National Research Council's Committee on Defining Deeper Learning and 21st-Century Skills reviewed frameworks related to 21st-century skills by analysing eight reports and documents that presented research-based arguments on the skills necessary for success in education, work, and other aspects of life (Pellegrino & Hilton, 2012). The committee clarified the concept of 21st-century skills by identifying them, examining their significance, and exploring ways to develop them among students. It found a variety of skills per report and categorised them into cognitive, interpersonal and intrapersonal competencies. Consequently, the skills considered to be 21st-century skills were classified into cognitive and non-cognitive competencies. The committee argued that the development of these competencies is linked to deeper learning processes that support the transfer of both content and procedural knowledge across different contexts. More importantly, the committee's systematic review of correlational studies revealed that these clusters of skills positively influenced educational, career, and health outcomes, as well as civic participation. Accordingly, the committee recommended conducting more research to understand further the relationships between 21st-century skills and successful adult outcomes and to determine effective methods for teaching and assessing these skills (Pellegrino & Hilton, 2012). Building on this notion, this study examined research published in 17 journal databases to provide information to educators, researchers, school administrators, policy-makers, and other education stakeholders on developing 21st-century skills among learners.

Meanwhile, the demand for the blend of cognitive, interpersonal, and intrapersonal skills has been on the rise as the labour market considers this crucial in the quality of job performance and in learning new skills for complex tasks. Specifically, the shift from lower-skilled, manual labour to knowledge-based occupations has created a demand for competencies that go beyond specific technical skills and are essential for success in modern workplaces (Finegold & Notabartolo, 2016). Nowadays, possessing generic or transversal competencies is an advantage to secure employment. For instance, healthcare professionals work in knowledge-intensive and service-oriented occupations wherein providing quality care necessitates them to demonstrate empathy, effective communication, and problem-solving skills. In order to help workers thrive in the evolving labour market, the mechanism by which these skills can be developed, whether through education, training programmes, or workplace practices, should be explored. As mentioned above, the National Research Council's committee viewed these competencies as malleable dimensions of human behaviour, suggesting that 21st-century skills can be developed and enhanced through experience, education and interventions (Pellegrino & Hilton, 2012). When integrated with curriculum content, 21st-century skills are the behaviours and the thinking processes the students should use to collaborate with others, learn, and improve their understanding of the subject area content (Beers, 2011). The challenge now for all science educators is to develop these skills among students through science content and learning activities. Assefa & Gershman (2012) argued that the nature of the relationship between science content knowledge and 21st-century skills is symbiotic or interdependent. The seamless integration of these two factors will provide students with capabilities in content knowledge and allow creative and innovative thinking. In fact, Partnership for 21st Century Skills (2002), one of the pioneering organisations that proposed the 21st-century skills framework, supports the notion of a thematic and interdisciplinary approach to developing these skills. In line with this, a synthesis of studies is needed to reveal the research trends and themes, and to highlight unexplored or less explored issues about 21st-century skills and science education, particularly student achievement in science. This systematic review outlined how the research needs, aims, and objectives were addressed by the selected studies through their methodologies.

21st Century Skills Frameworks

From the literature, 21st-century skills are a set of skills that students should be equipped with to help them succeed in learning and in navigating today's complex and rapidly changing society (Dede, 2010; Finegold & Notabartolo, 2016; Mishra & Kereluik, 2011; Voogt & Roblin, 2012). Given that students live in a knowledge-based economy amid continuous technological advancements, developing 21st-century skills is an essential curricular element from primary schools to advanced learning institutions to promote lifelong learning. In developing these skills, active learning methodologies that support self-regulated learning should be adopted (Pellegrino & Hilton, 2012) as they not only encourage engagement in learning tasks but also enable students to cope with new challenges and technological changes. Although there are challenges in identifying and defining these 21st-century skills due to differences in perspectives, educational organisations have developed and proposed blueprints to define, characterise, and categorise skills and competencies that comprise the frameworks for 21st-century skills. Specifically, the six relevant frameworks respectively developed by Partnership21 (P21), Assessment and Teaching for 21st Century Skills (ATC21S), North Central Regional Educational Laboratory & Metri Group (NCREL/EnGauge), Organisation for Economic Co-operation and Development (OECD), National Educational Technology Standards for Students (NETS.S/ISTE), and the United Nations Educational, Scientific and Cultural Organization (UNESCO) were the primarily bases of the early review on 21st-century skills done by Dede (2010), Finegold and Notabartolo (2016), Mishra and Kereluik (2011), and Voogt and Roblin (2012). Table 1 presents the common elements across these six frameworks.

Table 1

Comparison of the 21st-century skills frameworks

Skills Domain	ATC21S	P21	NCREL	NETS.S	OECD	UNESCO
1. Creativity & Innovation	✓	✓	✓	✓		
2. Critical Thinking & Problem Solving	✓	✓	✓	✓		
3. Communication & Collaboration	✓	✓	✓	✓	✓	✓
4. Information & Communication Technology	✓	✓	✓	✓	✓	✓
5. Social Responsibility	✓	✓	✓		✓	✓
6. Life & Career	✓	✓				

For descriptive comparison, document analysis was employed to identify the elements common across the six frameworks based primarily on the explicit articulation of the skills. By clustering the skills from each framework, six skills domains were derived and used as the basis of comparison. A framework was only considered to possess an element common with other frameworks if the term for a specific skill domain appeared in the framework document. As such, only ACT21CS and P21 frameworks appeared to be identical with respect to the six skills domains, while the NCREl framework only lacks the life and career domain. The NETS.S framework does not contain a direct term for both social responsibility and life and career domains, while both OECD and UNESCO frameworks have no explicit mention of creativity and innovation, and critical thinking and problem-solving skills. Nonetheless, the framework documents may implicitly include a skills domain by defining or classifying a skill set similar to that of another framework but using a different terminology. As noted by the National Research Council's committee mentioned above, the reports and documents concerning 21st-century skills used different languages to describe the same construct (Pellegrino & Hilton, 2012). Another reason would be defining a terminology encompassing two or more specific skills that directly appear in another framework or may have defined similar terms in different contexts. For example, the NETS.S framework has no direct terminology for social responsibility but highlights technology's legal and ethical use under its digital citizenship domain. Similarly, the OECD framework emphasises creative thinking for innovation that fosters social and economic progress, while the UNESCO framework stresses the role of critical thinking in enabling individuals through a reflective mindset to promote peace, justice, and inclusivity in society. The skills domains shown in Table 1 are not merely derived from the framework documents, but are also supported by the literature, particularly Dede (2010), Finegold and Notabartolo (2016), Mishra and Kereluik (2011), and Voogt and Roblin (2012). Even though this study did not intend for a detailed comparison of the frameworks, a brief discussion provides a foundation for the six skills domains, which served as one of the inclusion criteria for selecting published studies on 21st-century skills and science achievement among secondary school students.

Student Achievement in Science

The US-based National Board for Professional Teaching Standards (2011) defined student achievement as the status of a student's knowledge, understanding, and skills at a specific point in time that is often measured through standardised tests and assessments designed to evaluate curricular mastery in various subjects. Student achievement and student learning are fundamentally different concepts, with the former pertaining to knowledge and skills at a particular point in time, typically assessed through tests. At the same time, the latter encompasses the growth and development of knowledge, understanding, and skills over time. This distinction highlights the significance of the learning process as achievement can indicate what a student knows at a given moment while learning captures the ongoing journey of acquiring and applying knowledge, underscoring the importance of progress and development in education (National Board for Professional Teaching Standards, 2011). According to the OECD (2021), teacher effect, professional development, teaching strategies, school context, and equity and opportunity are the key factors that affect student achievement. The effectiveness of teachers significantly influences student outcomes, wherein skilled teachers can greatly improve students' foundational knowledge and skills, resulting in enhanced academic performance. Also, continuous professional development for teachers is essential as this helps teachers keep abreast with innovative teaching strategies, improving their ability to meet the diverse needs of their students. Teachers who strongly believe in their teaching abilities are more likely to implement engaging and effective teaching strategies, which in turn enhance teaching outcomes (Taştan et al., 2018).

Meanwhile, the school context, which includes school culture, available resources, and support systems, contributes to the overall learning experience by providing an enriching environment and supporting greater student engagement. The educational environment, including both home and school settings, plays a critical role in shaping students' motivation and achievement. Supportive environments that encourage goal setting, self-regulation, and positive reinforcement can foster higher levels of achievement motivation (OECD, 2017). Sibomana et al. (2021) reported that adequate laboratory facilities and instructional materials resources led to better achievement of secondary school students in chemistry. Furthermore, supportive interactions between teachers and students can enhance emotional and cognitive engagement, leading to better academic outcomes (Vilia et al., 2017). As noted by Sibomana et al. (2021), positive teaching strategies can enhance students' motivation and interest in the subject, resulting in improved performance. These suggest that teacher training and professional development should focus on building strong, supportive relationships with students. Conversely, environments that lack support or fail to promote these qualities can lead to declines in motivation, particularly during adolescence, as at this stage, students begin to question the relevance of school and may struggle with their identity and future aspirations, which can be exacerbated by a negative or unsupportive environment, resulting in disengagement from academic pursuits.

Fostering better student achievement requires an equitable educational landscape whereby all students have access to high-quality education and resources regardless of their socioeconomic background or personal circumstances (OECD, 2021). The 2015 Programme International for Student Assessment results revealed the crucial roles of motivation, socioeconomic status (SES), and gender differences in student achievement. Students motivated to achieve their goals tend to exhibit higher self-esteem, cognitive flexibility, and greater study effort, leading to better academic performance. A study by Taştan et al. (2018) found that motivated students were more likely to engage deeply with learning materials, leading to better academic achievement in science. Kumar (2021) found a positive correlation between attitudes toward science and achievement among secondary school students and that their science achievement notably differed across attitude levels. While Sharma and Brahman (2023) found no significant difference in the scientific attitudes between male and female secondary school students, females outperformed the males in science achievement. The study also revealed a significant positive correlation between scientific attitude and achievement in science. These results support the notion that attitudes can influence academic outcomes.

Regarding SES, students from families with higher parental education levels tend to perform better academically (Sibomana et al., 2021), and those from disadvantaged families often report lower levels of motivation compared to their more advantaged peers (OECD, 2017). This lower level of achievement motivation can stem from various challenges, such as limited access to resources, less parental support, and negative school environments, all of which can hinder academic success. Similarly, De Silva et al. (2018) examined the factors that influence students' performance in science within developing countries, drawing on sociological and psychological theories, as well as empirical research, and reported that students from higher SES backgrounds tend to perform better academically due to their access to resources, educational materials, and supportive learning environments. This also involves active parental involvement, whereby parenting styles can have varying impacts on student outcomes and the school environment, wherein teacher quality and the availability of school resources affect students' achievements in science. Individual-level factors, including students' motivation, self-efficacy, and engagement, are also crucial for academic success and can mediate the effects of the identified factors.

In another study, analysing the data from the High School Longitudinal Study of 2009 in the US, Alhadabi and Li (2020) reported that students from lower SES backgrounds and certain ethnic groups, such as Hispanic and African American students, tend to have lower initial grade point average across academic classes. In addition, gender differences in motivation can influence how students approach their studies. For example, girls are often more likely to desire top grades and show concern for future opportunities, while boys may describe themselves as more ambitious. For this reason, girls may focus more on achieving high grades and securing future opportunities, while boys may be driven by a desire to outperform their peers (OECD, 2017). Contrary to this, Taştan et al. (2018) found that gender has no significant impact on achievement, but nationality has, with Russian secondary students performing better than their Iranian counterparts. This signifies that socio-cultural factors affect educational outcomes and calls for inclusive learning environments that cater to the diverse needs of students. Recognising these differences is crucial for educators, as it can inform teaching strategies and support systems tailored to the unique motivations of each gender. Overall, academic achievement in science is influenced by multifaceted factors, including scientific attitudes, SES, teacher efficacy, school climate, and student engagement and attitude toward science. Understanding the interplay among these factors, in the light of developing 21st-century skills, is essential for developing effective strategies, practices, and policies to improve science education and cultivate scientifically literate individuals ready to face the issues and challenges at present and in the future.

Significance of the Study

Analysing published works about what has been done and implemented about integrating 21st-century skills in the classroom setting and developing these skills among students is important in understanding how the 21st-century skills frameworks would practically incorporate into the science curriculum to enhance student learning outcomes. This study hopes to contribute to aligning education standards with appropriate 21st-century skills framework, enhancing student learning engagement through 21st-century skills, improving assessment practices that promote 21st-century skills, and advocating for lifelong learning and equity in education. By aligning science education with the 21st-century skills frameworks, educators can ensure that students learn scientific concepts and develop the skills necessary to apply this knowledge in real-world contexts (Voogt & Roblin, 2012). For instance, the OECD framework emphasises the importance of communication and ethical considerations in science, which can motivate students to explore scientific issues that impact their communities and the world (Ananiadou & Claro, 2009). This can make science more relevant and engaging for students, positively affecting their interest and motivation. Likewise, by adopting assessment practices that go beyond traditional testing to evaluate students' 21st-century skills in science, educators can gain a more comprehensive understanding of student achievement, helping them identify areas where students excel or struggle, and allowing teachers to design targeted interventions that can enhance learning outcomes (Griffin et al., 2012).

The frameworks that encourage the development of metacognitive skills, global citizenship, and social responsibility would enable students to reflect on their learning processes and adapt to new scientific knowledge and technologies, and help address equity issues in science education. Gaining an understanding of diverse perspectives, and the ethical implications of scientific advancements, as guided by these frameworks, can prepare students to engage with global challenges, such as climate change and public health (UNESCO, 2020). Additionally, by developing a continuous learning mindset, educators can help students remain relevant and informed throughout their lives (Voogt & Roblin, 2012). Overall, examining the frameworks in relation to students' achievement in science is essential for enhancing educational practices and outcomes. By developing the capacity to align science education with these frameworks and integrate the skills in the teaching-learning process, educators can create a more engaging, relevant, and equitable learning environment that supports academic achievement, prepares students for the complexities of the modern world, and fosters the development of responsible, informed citizens capable of addressing global challenges.

Objectives

This study evaluated and synthesised research on 21st-century skills and student achievement to identify trends, themes, or ambiguities. Answers to the following questions were sought:

1. What are the research needs addressed by the studies?
2. What are the aims/objectives of the studies?
3. What methodologies are used by the studies to achieve their aims/objectives?
4. What are the instruments used by studies to collect data?
5. What does the analysis of data in the studies reveal?
6. What are the implications of the results of the studies on teaching and learning?

Methods

This study employed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) framework. Published studies were searched by scouring 17 online journal databases: ProQuest Dissertations & Theses A&I, ProQuest Central, Education Database, Scopus, Gale Academic OneFile, Academic Search Complete, APA PsycARTICLES, Social Science Database, Sociology Database, Wiley Online Library All Journals, Psychology Database, SAGE Complete A-Z List, Cambridge Journals 2020 Full Package, JSTOR Arts & Sciences, Arts & Humanities Database, Science Database, and Springer Online Journals Complete. A total of 684 articles were found using the keyword "21st-century skills" or "twenty-first century skills" published from 2012 to 2022. This range of years was purposively selected as official reports on 21st-century skills frameworks were published in 2009 onwards, and, more likely, studies relating to 21st-century skills were published several years after this period. To exclusively select studies prior to the onset of the COVID-19 pandemic, the cutoff year was set to 2022. Searching within the 684 articles using the keyword "science achievement" or "student achievement" with full-text copies yielded 331 results. These 331 articles were further subjected to the first-stage screening process in which selection and exclusion criteria were applied. Figure 1. shows the flowchart of the screening process.

Selection Criteria

To further narrow down the 331 search results, the full-text articles were reviewed for appropriate relevancy in alignment with the study topic. The following criteria were applied in selecting the final journal articles:

1. published in peer-reviewed journals from 2012 to 2022;
2. investigated the development of 21st-century skills or the relationship of these skills with student achievement or factors that affect learning;
3. respondents/participants were Secondary School students (Grades 7 to 12);
4. published in English language or have an official English translation;
5. 21st-century skills were clearly specified; and
6. with clear data presentation and analysis of studied variables.

Exclusion Criteria

On the other hand, the following articles were excluded:

1. published earlier than 2012;
2. published in non-refereed or fictitious journals;
3. no numerical data or ambiguous data analysis;
4. no specific 21st-century skills enumerated/studied;
5. respondents/participants were or mixed with Grades 6 and below;
6. published in non-English language or without official English translation; and
7. 21st-century skills were just mentioned as part of the literature review or discussion.

After the first-stage screening process, a total of 27 journal articles proceeded through the second stage of screening, through which abstracts were reread, and the results of data analysis were scanned. In the final stage of screening, the articles were read in their entirety, and ten studies were excluded due to the following:

1. only a single skill was investigated, although the key phrase 21st-century skills were considerably present in the article;
2. presented only the results of the survey conducted and no substantial discussion on theoretical or practical explanations; and

3. no results or discussion on the implication of the skills investigated to student learning or achievement in science.

After the three-stage screening of the 331 articles generated from the keyword search in the 17 journal databases, only 17 full-text articles were included in this study. These journal articles were summarised, focusing on research needs, aims/objectives, methods, research instruments, participants, results, and implications for teaching and learning. They were also analysed in terms of scope, general sense, similarities, differences, findings, and general notions to evaluate the trends and themes.

Figure 1

The flow chart in searching and screening of published studies

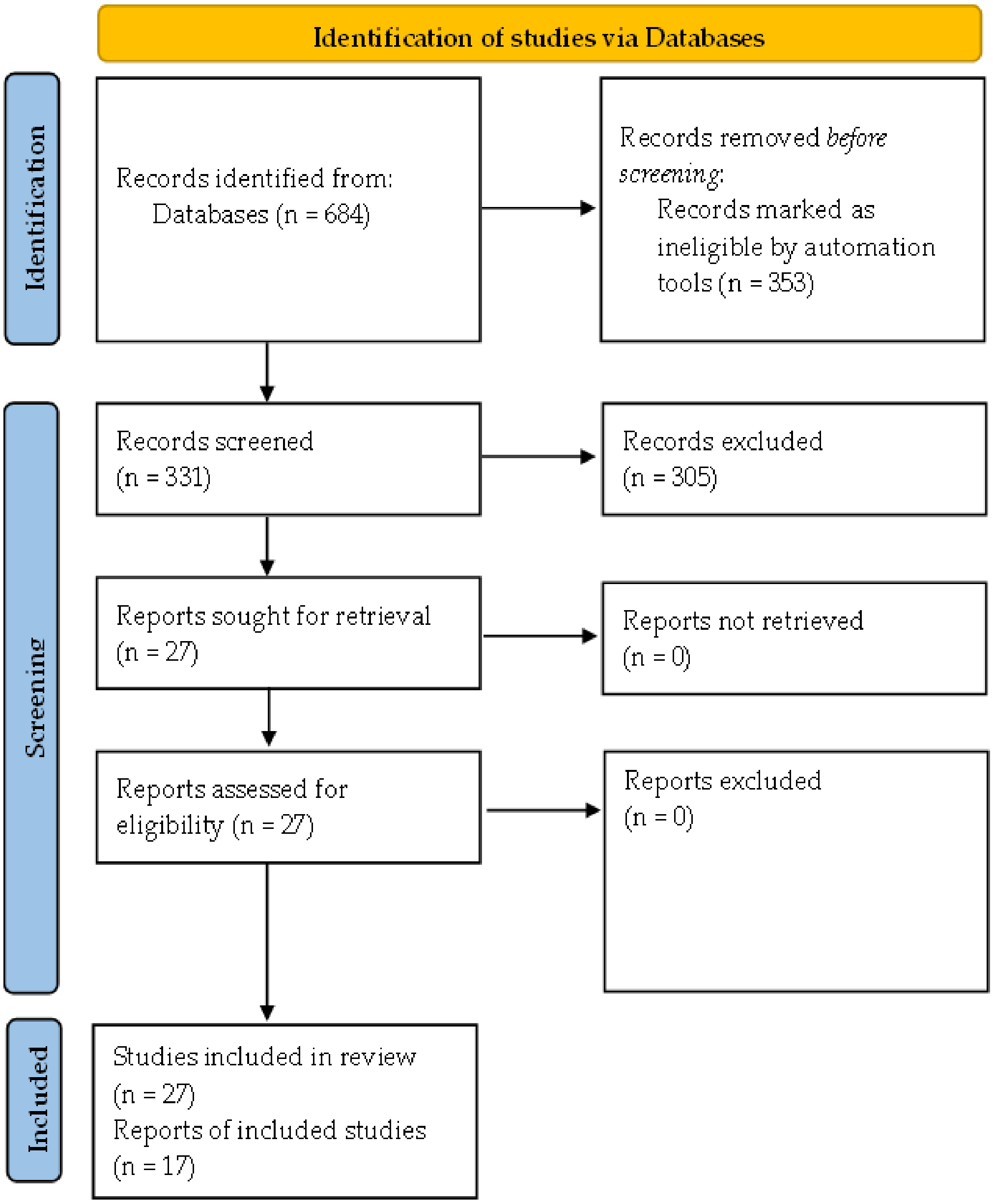

Table 2

The article selection results

Authors	Methods	Country	Grade Level
Arevalo & Ignacio (2018)	Exploratory-Comparative (single group; cumulative linear regression)	Philippines	Grade 10
Asrizal et al. (2022)	Quasi-experimental study (2 groups, post-test only)	Indonesia	Grade 8
Barquilla & Cabili (2021)	Quasi-experimental (2 groups; pre-/post-test)	Philippines	Grade 10
Benek & Akcay (2022)	Nested mixed design (pre/post-test, single group with permanence test and interview)	Turkey	Grade 7
Baran et al. (2021)	Quasi-experimental design (pre/post-test; single group)	Turkey	Grade 10
Diez-Ojeda et al. (2021)	Quasi-experimental (post-test only, single group)	Spain	Ages 15 to 16
Hadinugrahaningsih et al. (2020)	Qualitative (questionnaire, interview)	Indonesia	Grade 10
Han et al. (2021)	Quantitative (SEM – path analysis)	United States	Grades 8 to 12
Huang, et al. (2022)	Mixed-Method (pre-/post-test, interview)	Hong Kong	Junior high school
Kan'an (2018)	Quantitative (Linear regression, student t-test)	Turkey	Grade 8
Khoiri et al. (2021)	Quasi-experimental (2 groups)	Indonesia	Senior Secondary
Kinboon (2019)	Action Research (pre-/post-test)	Thailand	Grade 10
Lay & Osman (2018)	Quasi-experimental (2 groups, pre-/post-test)	Malaysia	Form 4 (Secondary)
Rasul et al. (2016)	Quasi-experimental (single group, pre/post-test)	Malaysia	Lower Secondary
Sekarini et al. (2020)	Mixed-Method (single group)	Indonesia	Grade 8
Semilarski, et al. (2021)	Quasi-experimental (2 groups, pre-/post-test)	Estonia	Grades 10 and 11
Tunkham et al. (2016)	Quasi-experimental (single group, pre-/post-tests)	Thailand	Grade 12

Most of the selected studies (14) were conducted in Southeast and Western Asia, while the remaining three came from Europe and the USA. Eleven of these studies utilised pre-/post-test assessments, of which five only administered such assessments to a single group. The remaining studies used post-test assessment only. As shown in Table 2, the majority of the studies were conducted on specific grade levels, of which six studies were conducted on Grade 10 students, three studies on Grade 8 students, one each on Grade 7 and Grade 12 students, and one study recruited students of ages 15 and 16. The rest of the studies have a mixture of participants based either on age or grade level.

Results and Discussion

Research Needs

Table 3 shows the research needs addressed by the studies. The highest frequency is registered for the development of 21st-century skills, followed by the development of learning materials or the design of learning activities to enhance knowledge or conceptual learning.

Table 3

The research needs identified and addressed by the studies

Research Needs	Frequency
Develop 21st-century skills	13
Develop integrated learning materials (module/learning package)	5
Enhance knowledge acquisition/Conceptual Learning (achievement)	4
Integrate community service learning/socio-scientific issues	3
Assess 21st-century skills	2
Analyse multiple factors affecting learning	1

Research Aims/Objectives

Table 4 presents the aims/objectives specified by the studies. Aligned with the identified research needs, the studies primarily investigated the development of 21st-century skills followed by the development of learning material or design of learning activities and the enhancement of knowledge or conceptual learning.

Table 4

The aims/objectives specified by the studies

Aims/Objectives	Frequency
Develop 21st-century skills	13
Develop integrated learning material (module/learning package)	5
Enhance knowledge acquisition/conceptual learning (achievement)	4
Determine 21st-century skills and science achievement relationship	2
Determine the effect of community service learning/socio-scientific issues	3
Identify factors affecting learning	1
Increase/develop motivation	1

Research Methods

Table 2 and Figure 2 show that nine studies employed a quasi-experimental method, of which five employed a two-group (control and experimental) and four used a single-group design. A mixed-method design was found in two studies, and another three studies utilised modelling/regression analysis. One study employed a qualitative method, one used a nested mixed design, and another was classified as action research. The common skills investigated are critical thinking, problem-solving, collaboration, communication, and information and communication technology (ICT) skills. Three studies considered moral/spiritual values as 21st-century skills (Kan'an, 2018; Lay & Osman, 2018; Rasul et al, 2016), while six studies included creativity in 21st-century skills (Baran et al., 2021; Benek & Akcay, 2022; Hadinugrahaningsih et al., 2020; Kinboon, 2019; Khoiri et al., 2021; Tunkham et al., 2016).

Research Instruments

As presented in Table 5, most of the studies employed instruments adapted from previous studies that established the reliability and validity of the tools for data collection. Other studies included developing and validating instruments, rubrics, observation tools, and concept assessments. Interview forms, reflective journals, and field notes were also used.

Figure 2

Methods employed by the studies

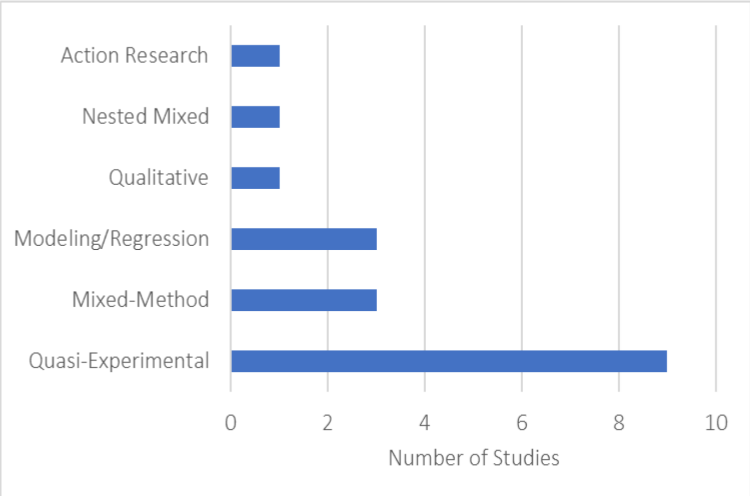

Table 5

Instruments used in the studies

Research Instruments	Frequency
21st CS questionnaire (adapted)	8
Achievement Test (developed/validated)	5
Interview form	6
Observation sheets (attitude, behaviour, collaboration)	5
21st CS questionnaire (developed/validated)	2
Performance sheets (3Cs)	2
Motivation Questionnaire (adapted)	1
Creativity Test (adapted)	1
Rubrics (IMT, Life and Career skills/validated)	1
Creativity Achievement (mind mapping score)	1
Self and Peer Assessment (collaboration)	1
STEM questionnaire- interest and 21st CS (adapted)	1
Achievement test (adapted)	1
Student STEM survey (adapted)	1
Teacher STEM survey (adapted)	1
STEM Knowledge Test (developed/validated)	1
21st Century Skills Rubrics (adapted)	1
Conceptual Learning (critical thinking, communication/developed & validated)	1
Creativity Questionnaire	1
Reflective journal	1
Field notes/informal interview notes	1

Themes and Findings

The 17 studies were analysed and evaluated in their entirety to determine any trends or themes. Based on the aims/objectives, findings, and implications, the studies were classified into Learning Modules, Pedagogical Approaches, and Learning-Related Factors.

Learning Modules

After implementing a learning module or learning activities package, the post-test scores of the group that received the treatment had significantly improved in 21st-century skills. In one study, only the high productivity domain (Lay & Osman, 2018) had improved, while in other studies, spiritual values (Rasul et al., 2016), responsible citizenship, and changeability of scientific knowledge skills (Semilarski et al., 2021), and cross-cultural skills, global awareness, and humanitarianism (Diez-Ojeda et al., 2021) did not have a significant improvement as these skills were less promoted during the intervention. Notably, in the study by Baran et al. (2021), the learning activities that were structured around project-based learning principles, emphasizing hands-on, collaborative, and real-world problem-solving experiences, failed to enhance students' cognitive and innovation skills significantly. This result can be attributed to factors such as the project focus, information access, project design, and time limitation. Since the projects were designed for practical applications and collaboration over fostering deep cognitive engagement and innovative thinking, the activities mainly revolved around executing predefined solutions or utilizing existing knowledge without promoting exploration or creativity, restricting the development of cognitive and innovation skills. In the same manner, students' dependence on the Internet for information can sometimes result in a passive learning experience as it favours searching for ready-made solutions instead of engaging in critical thinking or original problem-solving. Also, the timeframe allotted for project preparation may have been inadequate to compel the students to engage thoroughly with cognitive and innovative processes.

In the game design module MyKimDG by Lay & Osman (2018), students were given opportunities to represent macroscopic concepts and experiences at the sub-microscopic and symbolic level by designing and modifying a PowerPoint game about a Chemistry topic. This allowed students to share their ideas, which may induce cognitive conflict and lead to reconstructing an existing schema, resulting in an improved understanding of concepts and principles. The students also used the PowerPoint game to help their peers who experienced learning difficulties, increasing their self-efficacy as they experienced success. In the learning module developed by Tunkham et al. (2016), the significant difference in the achievement scores of Grade 12 students in favour of the post-test was primarily attributed to the integration of the subject matter (protein) into technology, engineering, and mathematics through the learning activities. Students' creativity and skills in information, media, technology, and life and career skills improved as they tried to solve problems, formulate solutions, and design, create, and improve products for use in the classroom and real-life situations. The students also used technology to search for information necessary for creating products and making product presentations.

In the ICT-based thematic teaching module implemented using the 5E model, Asrizal et al., (2022) reported a significant difference in Grade 8 students' attitudes toward learning in favour of the experimental group. Based on the observation and performance sheet data, this group obtained a higher attitude score than the control group. The same result was noted for communication, creative thinking, and critical thinking skills. Those in the experimental group scored higher in these skills and there was a significant difference between the achievement scores of the two groups in favour of the experimental group. This positive performance can be attributed to active learning by connecting content with real-world contexts (Asrizal et al., 2022). The module encouraged students and motivated them to construct knowledge and experience meaningful learning by conducting investigations, writing reports, and solving problems through critical and creative thinking. Meanwhile, Barquilla and Cabili (2021) implemented an enhanced learning module on gases among Grade 10 students and found that although both control and experimental groups had better scores during the post-test, students in the experimental group doubled their pre-test scores after the treatment. In addition, there was a significant difference in the 21st-century skills of students from both groups in favour of the experimental group (Barquilla & Cabili, 2021).

Pedagogical Approach

Inquiry-based, problem-based, problem-oriented, or context-based learning encouraged students' active learning that led to improved 21st-century skills (Asrizal et al., 2022; Baran et al., 2021; Barquilla & Cabili, 2021; Han et al., 2021; Lay & Osman, 2018; Tunkham et al., 2016; Rasul et al., 2016). Under such approaches, students involved themselves in role-play, argumentation, and other activities as they can relate to the interdisciplinary connections among the learning contents based on common life/real-world scenarios (Semilarski et al., 2021). They took responsibility for their learning, brainstormed to generate solutions, and collaborated and communicated with group members to finish their projects (Baran et al., 2021). While doing the learning activities, the students expressed and defended their ideas and opinions, which helped them adapt and formulate solutions in real-life situations (Tunkham et al., 2016). Furthermore, sharing ideas may induce cognitive conflict, leading to a reconstruction of an existing schema and improving understanding of concepts and principles (Lay & Osman, 2018). In particular, Sekarini et al. (2020) reported that problem-based learning (PBL) with mind mapping improved students' creative thinking and collaboration skills as they systematically expressed their ideas into images, colours, and symbols while working together during experiments and learning activities. Generally, the project-based learning approach allowed students to exchange ideas collaborate with peers, share tasks, and resolve disagreements. The students' active engagement also contributed to developing their autonomous skills, as they learned to work independently and make decisions. As the projects offered the students real-life challenges requiring them to think critically and develop solutions, this enhanced their problem-solving skills as they navigated obstacles, explored various sources of information, and sought practical solutions.

The inquiry-based activities on chemical products produced by the local chemical industry, implemented through the 5E teaching model, favoured the development of critical thinking, self-direction, disciplinary knowledge, self-confidence, interpersonal communication, and organisation management among 15 to 16 years old secondary students (Diez-Ojeda et al., 2021). However, cross-cultural skills, global awareness, and humanitarianism were less observed. Nonetheless, the results were positive, with no significant differences observed between male and female students, both even scoring high in contents. In the context-based learning approach by Semilarski et al. (2021), which was implemented for 1.5 years, the perceived self-efficacy of Grade 10 students toward their 21st-century skills was significantly higher in the experimental group than the control group, particularly in cognitive and problem-solving skills, critical thinking, and mindset for scientific research. On the other hand, there was no significant change in responsible citizenship and changeability of scientific knowledge as these skills were less promoted during the intervention. Huang et al. (2022) integrated community service learning with science, technology, engineering, and mathematics (STEM) so that junior secondary school students may apply human-centred design in proposing a solution to housing problems in Hong Kong. The results of a paired sample t-test indicated that the students significantly improved scores in creative thinking, collaboration, perseverance, and career interest, with career interest and creative thinking as the most improved dimensions (Huang et al., 2022).

After undergoing socio-critical and problem-oriented learning processes, the 21st-century skills expressed the most by Grade 10 students, as measured by an adapted questionnaire coupled with direct observation, were communication and collaboration, social and cultural interaction, and information and ICT literacy (Hadinugrahaningsih et al., 2020). Also significantly observed were creativity and innovation, leadership and responsibility, critical thinking and problem-solving, and flexibility and adaptability. Less significantly expressed skills were self-regulation, productivity and accountability, and media literacy (Hadinugrahaningsih et al., 2020). In the study on the use of project-based learning STEM applications involving waste materials, pre-and post-test scores showed a significant increase in the 21st-century skills of Grade 10 students, including autonomous skills, and cooperation and flexibility were observed, along with their environmental sensitivity levels (Baran et al., 2021). In addition, the analysis of data from structured and semi-structured questionnaires and focus group interviews revealed that the students also developed creativity and increased their levels of concretising science concepts as they brainstormed and planned for the design and carried out their STEM projects (Baran et al., 2021). However, as discussed earlier, there was no significant change in the student's cognitive and innovation skills.

Lower secondary students who underwent project-oriented PBL improved their 21st-century skills, as shown by their pre-test and post-test scores, with the exception of the spiritual values domain (Rasul et al., 2016). The highest increase was observed in high productivity, followed by digital age literacy and, respectively, effective communication and inventive thinking. The inventive thinking improved as the students collaborated in small groups to deliberate on possible solutions to a given problem. This collaboration resulted in an artifact design that supported high productivity skills. Further, technology was used to search for information related to students' tasks, particularly project creation (Rasul et al., 2016). In the same manner, PBL with mind mapping applied in motion and force topics improved the creative thinking and collaboration skills of Grade 8 students as they expressed their ideas in images, colours, and symbols in a systematic manner while working together during experiments and learning activities (Sekarini et al., 2020). Similarly, Grade 7 students' pre-and post-test scores, in favour of the latter, indicated that socio-scientific activities had improved the 21st-century skills of students (Benek & Akcay, 2022). There was no significant difference between the students' post-test and reassessment scores, signifying permanent gains in 21st-century skills. Moreover, there was no significant difference in students' pre-test and post-test scores among the cognitive, affective, and sociocultural sub-dimensions of the 21st-century skills scale (Benek & Akcay, 2022). The same findings were found between the post-test scores and the student's scores in reassessment four months after the intervention.

Learning activities developed using Web 2.0 tools like Pawtoon, Kahoot, and other ICT applications can enhance learning and improve students' achievement (Demirezer & İlkörücüi, 2023). As such, in the study by Kinboon (2019), by implementing information technology media in activity-based teaching, the Grade 10 students' post-test scores became significantly higher than the pre-test scores (Kinboon, 2019). That is, the student's academic achievement, technology skills, creativity and innovation skills, global awareness, and bilingual communication skills were found at high to the highest level. This signified that students' achievement and 21st-century skills improved through the ICT-interdisciplinary pedagogical approach based on STEM education. According to Kinboon (2019), to address real-life problems such as packaging a fermented fish, students used technology to search for accurate and relevant information, collaborated and shared ideas with their groups, and planned and created packaging designs. They also showcased their creativity and innovation in designing a webpage and their global awareness in presenting their outputs to a multi-religious and cultural community. This was also noted in the study by Baran et al., (2021), wherein Grade 10 students used the internet to get information about the process of conducting their STEM projects, and in the study by Rasul et al. (2016) and by Tunkham et al. (2016) in which students used technology to search for information relating to project creation, as well as in the study by Huang et al., (2022) where junior secondary school students learned the internet of things for community service-STEM integration.

Learning-Related Factors

Seven studies included socio-demographic factors in investigating either 21st-century skills or student achievement in science. These are gender, school location, and educated/non-educated parents' job (Arevalo & Ignacio, 2018; Benek & Akcay, 2022; Diez-Ojeda et al., 2021; Han et al., 2021; Huang et al., 2022; Kan'an, 2018; Khoiri et al., 2021). These studies concluded that, with the exception of school location and gender, the rest of the factors have no significant effect on 21st-century skills. In terms of career, Huang et al. (2022) reported that males tend to have a higher interest in STEM careers than females. Using a simple linear regression analysis, Kan'an (2018) revealed that students' 21st-century skills score is a predictor of their science achievement and a higher level of students' 21st-century skills are related to higher interest in physical science, mathematics, and engineering careers as suggested by Yerdelen et al. (2016), drawing from the results of their canonical correlation analysis involving middle school students. Similarly, in the modelling done by Han et al. (2021), the path analysis revealed significant direct effects of teacher self-efficacy on students' STEM knowledge achievement which was also significantly influenced by student STEM attitudes. The teacher outcome expectancy indirectly influences students' STEM knowledge achievement by affecting student STEM attitudes. When mediated by student STEM attitudes, 21st-century skills, and STEM career awareness have indirect effects on STEM knowledge. The teacher outcome expectancy showed a significant direct effect on student STEM attitude, while the teacher self-efficacy showed a significant direct effect on student STEM career awareness. On the other hand, both teacher outcome expectancy and self-efficacy have no significant effects on students' 21st-century skills (Han et al., 2021).

Arevalo and Ignacio (2018) found that although the majority of the Grade 10 students have an average level of science achievement and 21st-century skills, there was no statistically significant difference between male and female science achievement, while Kan'an (2018) found a significant difference between male and female students' 21st-century skills in favour of female students. In the STEM integration study involving a community service-learning model with human-centred design, Huang et al. (2022) found that there was no significant difference between males and females in terms of collaboration, creative thinking, and perseverance, and gender was not significantly related to these factors. Furthermore, Arevalo and Ignacio (2018) reported that technology integration could affect students' skills and achievement. In their study, the performance of high-achieving and low-achieving Grade 10 students in science was attributed to digital age literacy and inventive thinking. According to Kinboon (2019), students used technology to search for accurate and relevant information to solve real-life problems. This was also reported in the study by Baran et al. (2021) and by Rasul et al. (2016) wherein the students used the internet to get information about STEM projects. In the study by Huang et al. (2022), junior secondary school students learned the Internet of Things to design a community service-STEM integrated project.

In the analysis of 21st-century skills of Grade 12 students, Kan'an (2018) found that students from urban areas have statistically higher 21st-century skills mean scores than those from rural areas. Also, there was no significant difference between the jobs of educated and non-educated parents with respect to students' 21st-century skills. Due to cultural restrictions, Jordanian female students usually stay at home; thus, they may focus more on their studies and develop more 21st-century skills than their male counterparts. Moreover, technology and access to information and learning resources may be easier in urban areas, giving an advantage to students in urban schools than in rural schools. The jobs of both educated and non-educated parents have no direct bearing on science achievement as students, given their age, may have developed the ability to study with less parental support (Kan'an, 2018). In investigating the differences in communication, collaboration, creativity, and critical thinking skills, Khoiri et al. (2021) noted that there was no significant difference in the critical thinking of students from experimental and control groups. The researchers claimed that critical thinking is not influenced by students' backgrounds because problem-solving is a complex process that depends on the thinking habits of every individual. On the other hand, students from middle and rural areas have higher creativity and communication than those from urban areas, while students from rural areas have higher teamwork and collaboration than students from the two other groups (Khoiri et al., 2021). The researchers argued that creativity is independent of school background and mainly depends on the individual's previous experiences in producing new ideas. Students from urban areas have an advantage in communications due to access to technology and training (Kan'an, 2018; Khoiri et al., 2021).

Implications to Teaching and Learning

The significance of the 17 studies was grouped in the same manner as their results were classified. That is the implications of learning modules/packages, pedagogical approaches, and learning-related factors to the development of 21st-century skills and the improvement of science achievement.

Learning Modules

According to Usman et al. (2023), instructional materials designed based on the PBL principles promote and improve students' learning and achievement. In particular, the student as a game designer approach to learning chemistry can increase students' achievement, motivation, and 21st-century skills (Lay & Osman, 2018). In addition to integrated/interdisciplinary/thematic design, learning modules should allow students to learn and discover ideas/concepts through activities designed for collaboration and engagement through which they share or defend their ideas and formulate decisions based on their consensus. Learning modules should also encourage students to represent macroscopic concepts and experiences at the sub-microscopic and symbolic levels through learning activities. Learning activities should involve solving problems, formulating solutions, and designing, creating, and improving products for use in classroom and real-life situations (Tunkham et al., 2016). The activities should support students to connect learning contents with the real-world context (Asrizal et al., 2022) expressing and defending their ideas and opinions while constructing new knowledge and learning new skills by active participation in a meaningful learning experience. In line with this, Barquilla & Cabili (2021) suggested that any existing science modules should be evaluated using the 21st-century learning design rubrics to ensure that contents and activities, as well as the module design itself, support the development of 21st-century skills. Furthermore, Diez-Ojeda et al. (2021) argued that the development of the skills is more related to how the teacher implements the activity than the activity itself. Hence, teachers should be trained on how to develop and implement learning activities that would help students develop the targeted skills.

Pedagogical Approach

Pedagogical approaches that support the development of 21st-century skills while improving conceptual learning, such as PBL, project-oriented PBL, inquiry-based learning, and context-based learning, involve collaborative activities among students where they express their ideas and deliberate on possible solutions to a given problem. They also integrate life-related scenarios, along with mind mapping and inventive thinking, in learning activities to help students understand the connections of concepts and principles to real-life context applications (Khoiri et al., 2021). One such strategy is the STEM-based community service-learning model by Huang et al. (2022), which promotes 21st-century skills, particularly creative thinking, collaboration, and perseverance among students by researching and proposing solutions to a community problem. Thus, teachers should emphasise the connections of learning contents to everyday life scenarios and involve students in collaborative problem-solving where they will formulate ideas and express them into images, colours, and symbols in a systematic manner while working together (Sekarini et al., 2020), deliberating on proposed designs for a project that will resolve the given problem (Rasul et al., 2016). Completing such a project would reflect students' level of academic knowledge and 21st-century skills (Kinboon, 2019). Sharing of mental representations of a phenomenon, such as in the mind mapping by Sekarini et al. (2020), allows the students and their teacher to provide constructive criticism and offer suggestions during collaborative learning. This sharing and receiving of feedback enable students to improve their output, clarify thoughts, or correct their misconceptions (Demirçalı & Selvi, 2022). Similarly, teachers should employ socio-critical and problem-oriented learning processes (Hadinugrahaningsih et al., 2020) and socio-scientific STEM activities (Baran et al., 2021; Benek & Akcay, 2022; Hadinugrahaningsih et al., 2020) to help students realise interdisciplinary connections among the learning contents and understand science concepts and principles as they appear in nature, which in turn promotes the development of 21st-century skills.

Learning-Related Factors

Since 21st-century skills are predictors of students' achievement in science, integrating these skills into the science curriculum is beneficial (Kan'an, 2018). By assessing students' level of 21st-century skills at different time points within the academic year, teachers can see the student's progress in acquiring these skills, which may serve as a basis for a pedagogical approach to support student development. As Arevalo and Ignacio (2018) attributed the performance of high-achieving and low-achieving Grade 10 students in science to digital age literacy and inventive thinking, technology should then be integrated with pedagogical instruction to develop 21st-century skills and improve student achievement. Consistent with the literature, the results of path analysis by Han et al. (2021) revealed that teachers' efficacy and success beliefs are strong predictors of students' self-efficacy, motivation, and achievement. Teachers with strong self-efficacy are likelier to implement engaging and effective teaching strategies (Taştan et al., 2018). Hence, teachers should be continuously trained on content and pedagogical strategies. Although socio-demographic factors such as sex, school type, location, and parental involvement may affect the acquisition of 21st-century skills, the impact of these factors on students may vary depending on the prevailing conditions that directly influence learning. For instance, Diez-Ojeda et al. (2021) and Huang et al. (2022) did not find any significant differences in 21st-century skills between male and female students, while Kan'an (2018) found a significant difference in favour of female students. On the other hand, Arevalo and Ignacio (2018) attributed students' science achievement to digital age literacy and inventive thinking, which is supported by Kan'an (2018) and by Khoiri et al. (2021) asserting that access to technology, information, and learning resources may be easier in urban areas, giving advantage to students in urban schools than in rural schools. Teachers then should be aware which among these factors hinder students' progress and which factors support learning so that proper intervention can be given.

Conclusion

Seventeen studies were included in this systematic review, in which 13 primarily investigated the development of 21st-century skills among secondary school students, followed by the development of learning materials to enhance skills and knowledge acquisition. Nine of these studies employed a quasi-experimental method, followed by mixed-method (3 studies), and modelling/regression analysis (3 studies) while the rest are qualitative, nested mixed design, and action research. Eight of the 17 studies adapted a questionnaire on 21st-century skills with established reliability and validity by previous studies. These studies also developed and utilised achievement tests (5 studies), interview forms (6 studies), and observation sheets (5 studies) to attain their objectives. The remaining studies developed and validated their own instruments, rubrics, observation tools, and concept assessments. Reflective journals and field notes were also used.

The studies described teaching and learning modules as integrated, interdisciplinary, thematic, context-based, inquiry-based, inquiry-aided, problem-based, and problem-oriented learning, improved student achievement, and supported the development of 21st-century skills. Likewise, the studies that employed constructivist and constructionist pedagogical approaches have positive effects on student achievement and the development of 21st-century skills. Meanwhile, the studies that include socio-demographic factors in the investigation of either 21st-century skills or student achievement in science involved gender, school location, educated/non-educated parents' job, and teacher outcome expectancy and efficacy, suggested that, with the exception of school location and gender, the rest of the factors have no significant effect on 21st-century skills. Hence, the impact of these factors on students may vary depending on the prevailing conditions that directly influence learning.

Students who develop 21st-century skills such as critical thinking, communication skills, problem-solving, and ethical awareness are expected to be capable of discussing information and formulating creative decisions. They can use technology and social media to communicate effectively and achieve their aims. These notions are supported by inquiry-based, problem-based, problem-oriented, socio-critical/socio-scientific, or context-based learning approaches that encourage active learning where students involve themselves in role-play, argumentation, and other collaborative learning activities. Students are actively and pro-actively participating in knowledge construction and skills acquisition as they realise the interdisciplinary connections among the learning contents with real-life scenarios and research for information, deliberate on issues and propose solutions to a real-world problem. These entail the integration of chemistry topics with science, engineering, and technology, along with appropriate ICT, through learning activities in order to improve student achievement and support the development of 21st-century skills. Thus, teachers should be trained on how to develop and implement interdisciplinary/thematic learning activities that would help students develop the targeted skills and improve achievement.

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