Twenty-First Century Skills

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Chapter 27
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Abstract Since the late 1990s, the term "Twenty-First Century Skills" has entrenched itself in education discourse, reflecting educators' and policymakers' recognition of the evolving workforce landscape and the imperative to equip students with the competencies necessary to excel in the modern era and beyond. This global imperative underscored the need to ready students for success in a progressively intricate and interconnected world. In 1997, the National Academy of Science in the United States released the report, *Preparing for the Twenty-First Century: The Education Imperative*. The papers contained within the report examined challenges in education for the upcoming century. As we entered the twenty-first century, several new reports emerged over the next two decades that set out to define the twenty-first century skills needed to prepare students for success in an increasingly competitive global marketplace. Although the twenty-first century skills listed in these reports varied, there were several overlapping skills deemed essential. At the center of these recommendations was a solid education in science, technology, engineering, and mathematics (STEM). In addition to a strong STEM education, twenty-first century skills identified as essential included several soft skills and dispositions such as cross-cultural communication skills, collaboration skills, critical thinking, and problem-solving. A central theme in the literature was the development of creativity, innovation, and digital literacy to prepare students for the demands of the rapidly changing global economy. Although there is general agreement that twenty-first century skills are essential for all students, there is continued debate surrounding the role of K–12 education on how to help students learn these skills. The COVID-19 pandemic further highlighted the importance of skills like adaptability, resilience, and digital competency, especially in regard to navigating unexpected challenges in education and the workforce. This chapter highlights twenty-first century skills as presented in various international policy documents and discusses implementation strategies as well as the need for implementing "just-in-time" professional development to technologically

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prepare STEM teachers. It is time to move past identifying skills and frameworks by refocusing research and policy efforts on better aligning standardized assessments to include twenty-first century skills, evaluating the level of implementation of twenty-first century skills in the classroom, and building expertise in the pedagogies that support their inclusion.

Keywords Twenty-first century skills (21CS) · Twenty-first century learning · College and career readiness · Project-based learning (PBL) · Problem-based learning (PrBL) · Phenomenon-based learning (PhBL) · STEM

27.1 Introduction

This chapter provides an overview of twenty-first century skills (21CS) as presented in a number of education and policy documents related to science, technology, engineering, and mathematics (STEM) education. Toward the end of the last century, and into the twenty-first century, the education community has been challenged with developing educational programming to keep pace with accelerating change in the economy and persistent advances in technology. The rapid state of change in the workplace continues to increase demands on the education system to prepare students for an evolving workforce. Traditional approaches to education that focus on knowledge acquisition are not typically seen as meeting the needs of employers in the current global information economy context. Promising pedagogies such as Project-Based Learning (PBL), Problem-Based learning (PrBL), and Phenomenon-Based Learning (PBL) help students learn information and address 21CS as described in Chap. 20, Project and Problem-Based Teaching and Learning. PBL, PrBL, and PhBL pedagogies allow students to choose projects, problems, and phenomena to study and produce a product, as described in Chap. 5, Bandura's Social Learning Theory. Promising new frameworks for organizing education, such as through various STEM applications, along with the transdisciplinary approach to science education referred to as STEAM (science, technology, engineering, the arts, and mathematics) as discussed in Chap. 26, STEAM-ED—A Transdisciplinary Teaching and Learning Approach, break down the artificial barriers of disciplines enabling students to understand the connected nature of knowledge utilizing critical skills leading to success in the twenty-first century economy. In addition, integrating new media approaches to teaching and learning, as well as utilizing technological innovations in the science classroom, further connects students to real-life situations and creates opportunities to meaningfully construct concepts and relationships in context (see Chap. 9, Mastery Learning—Benjamin Bloom). Such frameworks allow students to focus on necessary content acquisition as well as 21CS and may provide schools the opportunity to keep pace with the increasing changes occurring in the workplace.

Education is often a reactive institution in regard to responding to the needs of civil society. In the current century, the rapid pace of societial and workforce advancements is creating stress on the education system. Unlike the past, workforce needs change so fast that once education systems update curriculum and technology, they become obsolete without implementing "just-in-time" teacher professional development (Crow et al., 2013). Breaking down traditional disciplinary barriers in education and embracing new pedagogies that include transferable skills to the workplace could help education keep pace with the rapid changes occurring. In other words, education systems, especially those promoting STEM education and supporting education for innovation, must become proactive and focus on meaningful learning (see Chap. 12, Guided Discovery—Robert Gagné). Since it is difficult to predict future change and given that the costs associated with keeping up with technological developments tend to be prohibitive for most schools, focusing on transferable 21CS makes sense. We already know the limitations of "re-active" education policies based on history of education reform efforts. Reactive education policy and practices cannot address the rapid changes that are occurring in the economy. Focusing on 21CS and school models that support twenty-first century STEM learning will allow educators to place emphasis on the future by aligning how students learn using the skills needed to survive and thrive in the modern workplace, rather than focusing on a defined set of knowledge that is quickly out of date (Kennedy & Sundberg, 2020).

27.2 Background

"Twenty-first century skills," "twenty-first century learning," and "college and career readiness" are common phrases in the field of education. Additionally, the tenants of social and emotional learning (SEL), personalized learning, competency-based education (CBE), inquiry-based learning, and the different models of implementing PBL, reflect the evolving priorities and approaches in education as educators strive to prepare students for success in the twenty-first century and beyond. The push to embed workforce-related skills into STEM education can be traced back to the late 1970's. Ultimately, these efforts laid the foundation for the identification and promotion of 21CS into STEM education. Since the early 1980's, academia, government agencies, non-governmental organizations, and industry have invested in research to identify academic skills and competencies needed for the current and future workforce. Although the identification of specific 21CS in need of implementation initiated in the United States, much attention to these goals spread across the globe, prompting educators and policymakers worldwide to prioritize the integration of twenty-first century skills into frameworks and curricula. In addition to efforts in the U.S., a number of reports released by international organizations, such as the Asia Pacific Economic Cooperation (APEC), The United Nations Educational, Scientific, and Cultural Organization (UNESCO), as well as the Organization for Economic Co-operation and Development (OECD), and their Business and Industry Advisory Committee, have made substantial recommendations concerning 21CS. In addition, there have been significant publications from Australia, Canada, New Zealand, and the United Kingdom, among other countries, that emphasize the importance of nurturing twenty-first century skills to ensure students' readiness for the demands of an increasingly globalized and technology-driven world. These publications underscore the need for educational systems to equip learners with competencies such as critical thinking, collaboration, communication, digital literacy, and adaptability to thrive in diverse contexts and succeed in the evolving workforce landscape.

27.2.1 A Nation at Risk

Looking back, in 1981, then U.S. Secretary of Education, Terrel Bell, under President Ronald Reagan, convened the National Commission on Excellence in Education, tasked with examining the overall quality of education in the United States and making recommendations for future educational improvements, including content covered and mastery of skills. The commission issued the report entitled *A Nation at Risk: The Imperative for Educational Reform* (National Commission on Excellence in Education, 1983). This report had a profound impact on education in the United States and, as a result, several reform efforts originated to improve education. A key recommendation stated that educational reform should focus on creating a "Learning Society." The report defined a learning society as follows:

> In a world of ever-accelerating competition and change in the conditions of the workplace, of ever-greater danger, and of ever-larger opportunities for those prepared to meet them, educational reform should focus on the goal of creating a Learning Society. At the heart of such a society is the commitment to a set of values and to a system of education that affords all members the opportunity to stretch their minds to full capacity, from early childhood through adulthood, learning more as the world itself changes. Such a society has as a basic foundation the idea that education is important not only because of what it contributes to one's career goals but also because of the value it adds to the general quality of one's life. Also at the heart of the Learning Society are educational opportunities extending far beyond the traditional institutions of learning, our schools and colleges. They extend into homes and workplaces; into libraries, art galleries, museums, and science centers; indeed, into every place where the individual can develop and mature in work and life. (The Learning Society section, para. 1).

Although a *Nation at Risk* did not address 21CS directly, the report did lay the foundation for future reports and symposia from around the globe issuing similar recommendations while addressing their own context. A sampling of the most influential reports and actions are included in Table 27.1.

While this list is not exhaustive, these reports emphasize various aspects of twenty-first-century skills, including digital literacy, socio-emotional skills, and the importance of continuous learning to adapt to rapid technological and global socio-economic changes.

27.2.2 Comparisons of International Student Assessments

International comparisons of student achievement scores revealing the need for improved academic success were included in many of the reports citing 21CS. Assessments such as the Programme for International Student Assessment (PISA), launched in 1997 by member countries of the OECD (OECD, 2014a; 2014b), were used to

Table 27.1 21CS influential reports and actions 1989–2024

Year	Report title	Author/ Organization	URL
1989	The Hobart Declaration on Common and Agreed National Goals for Schooling in Australia	Australian Education Council	https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Environment_and_Communications/Completed_inquiries/pre1996/arts/report/~/media/Committees/ecita_ctte/completed_inquiries/pre1996/arts/report/e04.pdf
1996	Learning: The Treasure Within	United Nations Educational, Scientific, and Cultural Organization (UNESCO)	https://unesdoc.unesco.org/ark:/48223/pf0000109590
1999	The Adelaide Declaration on National Goals for Schooling in the Twenty-First Century	Ministerial Council on Education, Employment, Training and Youth Affairs (MCEETYA)	https://www.aph.gov.au/parliamentary_business/committees/house_of_representatives_committees?url=edt/eofb/report/appendf.pdf
2002	Learning for the Twenty-First Century	Partnership for Twenty-First Century Skills	https://files.eric.ed.gov/fulltext/ED480035.pdf
2003	Twenty-First Century Skills Realising Our Potential: Individuals, Employers, Nation	Crown Copyright, UK	https://assets.publishing.service.gov.uk/media/5a749939e5274a410efd0e49/21st_Century_Skills_Realising_Our_Potential.pdf
2003, 2005, 2008	Twenty-First Century Learning: Research, Innovation and Policy, Directions from Recent OECD Analyses	Organisation for Economic Co-operation and Development (OECD)	https://www.haiti-now.org/wp-content/uploads/2017/05/21st-Century-Learning.pdf
2007	Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future	National Academy of Sciences, National Academy of Engineering, and Institute of Medicine	https://www.nap.edu/catalog/11463/rising-above-the-gathering-storm-energizing-and-employing-america-for

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Table 27.1 (continued)

Year	Report title	Author/ Organization	URL
2008	Education to Achieve Twenty-First Century Competencies and Skills for All: Respecting the Past to Move Toward the Future	Asia Pacific Economic Cooperation	https://www.apec.org/press/blogs/2008/0115_cn_ednetserminarambcapunay
2011	Quality Science Education and Twenty-First-Century Skills	National Science Teaching Association (NSTA)	https://www.nsta.org/nstas-official-positions/quality-science-education-and-21st-century-skills
2012	Education for Life and Work: Developing Transferable Knowledge and Skills in the Twenty-First Century	National Research Council	https://nap.nationalacademies.org/catalog/13398/education-for-life-and-work-developing-transferable-knowledge-and-skills
2012	A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas	National Academies Press	https://nap.nationalacademies.org/catalog/13165/a-framework-for-k-12-science-education-practices-crosscutting-concepts
2012	Assessment and Teaching of Twenty-First Century Skills	Griffin, McGaw, and Care	https://link.springer.com/book/https://doi.org/10.1007/978-94-007-2324-5
2014	Future Ready: A Framework for Transforming Teaching and Learning	Alliance for Excellent Education	https://futureready.org/future-ready-frameworks/
2015	AAAS Science Assessment	American Association for the Advancement of Science	https://www.aaas.org/programs/project-2061/connections/October-2015
2015	Shifting Minds 3.0: Redefining the Learning Landscape in Canada	C21 Canada	https://c21canada.org/wp-content/uploads/2015/05/C21-ShiftingMinds-3.pdf
2015	The Futures of Learning 1: Why Must Learning Content and Methods Change in the Twenty-First Century?	UNESCO Education Research and Foresight Working Paper (C.L. Scott)	https://unesdoc.unesco.org/ark:/48223/pf0000234807
2016	Global Competency for an Inclusive World	OECD	https://www.oecd.org/education/Global-competency-for-an-inclusive-world.pdf

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Table 27.1 (continued)

Year	Report title	Author/ Organization	URL
2016	Education 2030: Incheon Declaration and Framework for Action: Towards Inclusive and Equitable Quality Education and Lifelong Learning for All	UNESCO	https://unesdoc.unesco.org/ark:/48223/pf0000245656
2017	The Fourth Industrial Revolution	World Economic Forum (K. Schwab)	https://www.weforum.org/about/the-fourth-industrial-revolution-by-klaus-schwab
2017	Digital Skills Toolkit	G20	https://www.oecd.org/g20/topics/employment-and-social-policy/G20-OECD-Digital-Skills-Toolkit.pdf
2018	OECD Learning Compass 2030	OECD	https://www.oecd.org/en/data/tools/oecd-learning-compass-2030.html
2018	Future of Education and Skills 2030: OECD Learning Compass 2030	OECD	https://www.oecd.org/en/about/projects/future-of-education-and-skills-2030.html
2018	PISA 2018 Global Competence Framework	OECD	https://www.oecd.org/education/Global-competency-for-an-inclusive-world.pdf
2018	Transforming the Future: Anticipation in the Twenty-First Century	UNESCO	https://unesdoc.unesco.org/ark:/48223/pf0000264644
2018	World Development Report 2018: Learning to Realize Education's Promise	The World Bank	https://www.worldbank.org/en/publication/wdr2018
2020	The Future of Jobs Report	World Economic Forum	https://www.weforum.org/reports/the-future-of-jobs-report-2020
2020	STEM Education for the Future: A Visioning Report	National Science Foundation (NSF)	https://www.nsf.gov/edu/Materials/STEM%20Education%20for%20the%20Future%20-%202020%20Visioning%20Report.pdf
2020	Education for Sustainable Development: A Roadmap	UNESCO	https://unesdoc.unesco.org/ark:/48223/pf0000374802
2020	The Condition of Education 2020	National Center for Education Statistics (NCES) Institute of Education Sciences	https://nces.ed.gov/pubs2020/2020144.pdf

(continued)

Table 27.1 (continued)

Year	Report title	Author/ Organization	URL
2020	Education in a Post-COVID World: Nine Ideas for Public Action	UNESCO	https://unesdoc.unesco.org/ark:/48223/pf0000373717
2021	Futures of Education: Learning to Become	UNESCO	https://unesdoc.unesco.org/search/5aa83ab7-2289-4051-abc4-35a7d5358eec
2021	Reimagining our Futures Together: A New Social Contract for Education	UNESCO	https://unesdoc.unesco.org/ark:/48223/pf0000379707
2021	Digital Learning in the Twenty-First Century	OECD	https://www.oecd.org/education/online-learning-and-the-future-of-education.htm
2023	The Future of Jobs Report 2023	World Economic Forum	https://www.weforum.org/reports/the-future-of-jobs-report-2023
2023	OECD Skills Outlook 2023	OECD	https://www.oecd.org/en/publications/oecd-skills-outlook-2023_27452f29-en.html
2023	Evidence for System Transformation: twenty-first Century Skills	Global Partnership for Education	https://www.globalpartnership.org/content/evidence-system-transformation-21st-century-skills
2024	Global Skills Report 2024	Coursera	https://www.coursera.org/skills-reports/global
2024	Putting Skills First: Opportunities for Building Efficient and Equitable Labour Markets	World Economic Forum	https://www.weforum.org/publications/putting-skills-first-opportunities-for-building-efficient-and-equitable-labour-markets/

monitor if students had acquired the knowledge and skills necessary for full participation in society. PISA scores became an increasingly important tactic to draw attention to the case that students in other countries may be outperforming students in their own country. Given the competitiveness of our global economy, PISA results have been used as an indicator of how well education systems are preparing students in mathematics and science, STEM subjects that are critical to the innovation economy.

In addition to assessing students' knowledge and skills, the OECD examined student competencies and identified three "Competency Categories" (OECD, 2003, 2005, 2008). These categories included: (1) using tools interactively, (2) interacting in heterogeneous groups, and (3) acting autonomously. "Using tools interactively" was defined as acquiring and using language, information, and knowledge, including using the tools of technology. Simply having access to technology does not guarantee students have the technical skills to use the technology. For example, many schools provide students with computers but do not equip teachers and students with the skills to use them in a meaningful context.

Table 27.2 Organization for economic cooperation and development competency categories

Using tools interactively	Interacting in heterogeneous groups (Soft skills)	Acting autonomously
Utilizing technology	*Relating to Others*	*Fitting into Society*
• Language • Symbols • Texts • Information • Knowledge • Technology	• Be cooperative • Work in teams/groups • Manage conflicts • Resolve conflicts • Use effective communication skills	• Form and conduct life plans • Conduct personal projects • Define projects and set goals • Identify and evaluate resources • Prioritize and refine goals • Balance resources/meet goals • Monitor progress/make adjustments • Learn from past actions • Defend/assert one's rights, interests, limits, needs

Interacting in "heterogeneous groups" refers to relating well to others. These skills are often referred to as "soft skills" and include the ability to be cooperative and work in teams. In addition, they also require students to manage and resolve conflicts, which involves using advanced communication skills. The final category is "acting autonomously," which includes knowing how the individual fits within the greater context of society. Acting autonomously is important, since unlike the past where one's position was well-defined, that is no longer the case today. The ability to plan and carry out life plans and coordinate personal projects is especially important, but it also has implications for science education. Similar to the project-based learning approach (PBL, PrBL, PhBL), this competency assumes individuals are able to: (a) define projects and set goals, (b) identify and evaluate both the resources they have access to as well as the resources they need, (c) prioritize and refine goals, (d) balance resources to meet multiple goals, (e) learn from past actions and plan future outcomes, and (f) monitor one's progress, adjusting goals as the project unfolds. Acting autonomously also addresses the need to defend and assert one's personal goals and needs (OECD, 2005). See Chap. 3, *Bildung* Theory and Chap. 11, discovery learning in a cultural context. Table 27.2 lists the three OECD competency categories and their associated skills.

27.2.3 Defining Skills for Success

The National Education Association (NEA) of the United States, working in cooperation with educators, education experts, and business leaders in the U.S., defined the skill sets necessary for success in work, life, and citizenship in 2002 known as the *Framework for Twenty-First Century Learning* (National Education Association, 2012). The report highlighted 18 skills that schools could refer to when building standards, professional development, and assessments. Ten years later, many believed the framework was too long and complicated, and therefore these skills were further refined into four primary skills termed the "Four C's": critical thinking, communication, collaboration, and creativity (Partnership for Twenty-First Century Skills, 2010; 2015).

In 2012, the U.S. National Research Council (NRC) categorized the 21CS to more clearly show the relationships between skills, as well as summarized evidence collected in support of 21CS development. One of the concerns that the NRC addressed was the lack of specific definitions for the terms used to describe each skill. They further organized the skills into three broad competency domains: (1) the cognitive domain, including thinking and reasoning; (2) the intrapersonal domain, involving self-management and the ability to regulate one's behavior and emotions; and (3) the interpersonal domain, focusing on self-expression, interpretation of messages, and appropriate response (NRC, 2012). A content analysis of the existing lists of 21CS was completed and the skills were further grouped within the three domains. Table 27.3 displays the three NRC domains and their associated competencies/skills. The four C's (critical thinking, communication, collaboration, and creativity) are clearly visible within this framework, and highlight the importance of developing transferable knowledge and skills, including cognitive, interpersonal, and intrapersonal skills.

The World Economic Forum's report a *New Vision for Education: Unlocking the Potential of Technology* highlighted the growing deficit in 21CS development in our youth and included strategies focused on addressing this gap through technology. Sixteen skills were identified for student success in the twenty-first century and emphasized the need for "lifelong learning" (World Economic Forum, 2015, p. 3). These 16 skills were divided into three categories, (1) Foundational Literacies, defining how students apply core skills to the tasks they are faced with on a day-to-day basis; (2) Competencies, defining how students solve complex problems and challenges; and (3) Character Qualities, defining how students react to the environment around them. Table 27.4 shows the World Economic Forum 21CS. Once again, the Four C's emerge.

The Queensland Curriculum and Assessment Authority (2017) assembled an explanation of 21CS providing teachers with a clear picture of supportive student expectations. Creative pedagogy is crucial for twenty-first century learning and skill development. Instructional interventions and techniques such as team-teaching, social constructivist game design/game play, as well as uses of social media including wikis and online communications, help to equip students with 21CS (Chu et al., 2017). See Chap. 7 regarding new media technologies, and Chap. 28 describing spacial learning in digital-augmented and virtual learning environments.

The Four C's are present in a number of 21CS policy documents from around the globe in one fashion or another, often times including social and emotional intelligence, technological literacy, and problem-solving skills (see Chap. 23, Multiple Intelligences and Chap. 24, Systems Thinking). Application of knowledge and moving beyond rote memorization is required, thus PBL/PrBL/PhBL approaches push students to be more creative, use multiple technologies in their projects, and develop the higher-level thinking skills needed in higher education and the workplace (Kennedy & Fields, 2023, 2024; Odell & Kennedy, 2020). Creativity acts as a

Table 27.3 National research council competency categories

Cognitive domain	Intrapersonal domain	Interpersonal domain
Cognitive processes/Strategies	*Intellectual openness*	*Teamwork/Collaboration*
• Critical thinking • Problem solving • Analysis • Reasoning and argumentation • Interpretation • Decision-making • Adaptive learning	• Flexibility • Adaptability • Artistic and cultural appreciation • Personal and social responsibility • Appreciation for diversity • Continuous learning • Intellectual interest and curiosity	• Communication • Collaboration • Cooperation • Teamwork • Coordination • Interpersonal skills
Knowledge	*Work Ethic/Conscientiousness*	*Leadership*
• Information literacy • ICT literacy • Oral and written communication • Active listening	• Initiative • Self-direction • Responsibility • Perseverance • Grit • Career orientation, ethics • Integrity • Citizenship	• Responsibility • Assertive communication • Self-presentation • Social influence with others
Creativity	*Positive Core Self-Evaluation*	
• Creative thinking • Ideation • Design thinking • Innovation	• Self-monitoring • Self-evaluation • Self-reinforcement • Physical and psychological health	

Table 27.4 World economic forum competency categories

Foundational literacies	Competencies	Character qualities
Applying core skills to everyday tasks	*Approaching complex challenges*	*Approaching their changing environment*
• Literacy • Numeracy • Scientific literacy • Information and communications technology literacy • Financial literacy • Cultural and civic literacy	• Critical thinking/ problem-solving • Creativity • Communication • Collaboration	• Curiosity • Initiative • Persistence • Grit • Adaptability • Leadership • Social and cultural awareness

powerful catalyst for learning, driving students to engage deeply with material and fostering a passion for exploration and innovation (see Chap. 2 discussing the theory of motivation).

Crockett et al. (2011) further sought to refine the classification of 21CS. Based on New Zealand's Ministry of Education (2007) definition for the five key competencies for living and lifelong learning (thinking; using language, symbols, and text: managing self; relating to others; participating and contributing), along with the International Baccalaureate Program (2010) desired student outcome skills (inquirers; knowledgeable; thinkers; communicators; principled; open-minded; caring; risk-takers; balanced; reflective), Crockett, Jukes and Churches contend that students need to develop transparency-level skills in the following six areas: problem-solving; creativity; analytical thinking; collaboration; communication; and ethics action and accountability. Further to this, Crockett and Churches (2018) push for schools to play a significant role in preparing students for life beyond the classroom. They postulate that purposefully teaching skills that focus on effective and ethical participation in online and offline communities promotes critical thinking and the development of global digital citizenship (GDC) practices, resulting in students who are contributors and valuable citizens.

STEM education intersects with 21CS to include rigorous core content with critical thinking skills (Bybee & Fuchs, 2006). For the purposes of this chapter, we are interested in and will focus on 21CS for STEM Education. STEM is a critical component supporting our technology-rich global economy. To maintain technological development, there is a need to prepare students in the STEM disciplines within a twenty-first century context. The definition and emphasis of twenty-first-century skills have continuously evolved in response to rapid technological changes, including the rise of artificial intelligence, automation, and advancing digital communication tools. Now more than ever before, our students must develop strong skills in digital literacy, computational thinking, and adaptability in navigating a technology-driven world. Without these competencies, they will not be equipped to thrive in a digital age characterized by constant innovation and disruption. Mastering the tenants of 21CS ensures the next generation of leaders can use technology effectively, critically evaluate information, solve complex problems, and adapt to changing circumstances.

27.3 Twenty-First Century STEM Education: A Second Renaissance?

Driven by economic forces and global competition, refocusing education on the development of skills required for success in our rapidly changing digital society has become an international quest. Many of these skills are associated with inquiry learning described in numerous STEM education reform documents. These documents also place priority on mastering skills in analytic reasoning and complex problem-solving (see Chap. 9, Mastery Learning), along with working collaboratively as a team player, rather than solely developing traditional academic skills based on content knowledge. 21CS and effective STEM pedagogy appear to have a number of related goals.

Historians generally date the first Renaissance in Western culture to have occurred around the eleventh century (Montgomery & Kumar, 2015). Descriptors for the First Renaissance typically involve the convergence of the arts with science, technology, engineering, and mathematics (STEAM), as described in Chap. 26. However, traditional education has isolated STEM subjects into distinct disciplines. The artificial barriers between STEM disciplines are disappearing, as each of the components of science, technology, engineering, and mathematics are necessary for innovation. In this sense, we see a resurgence of the convergence of STEM disciplines, non-STEM disciplines, and 21CS such as the Four C's. For example, stereotypes of engineers as expert loners promulgated by the media are counterproductive. In stark contrast, high tech multimedia cartoonists and science fiction illustrators function as teams of artisans, musicians, and technicians (Disney, 2018). Science educators assert the importance of the role of science in today's society. From the WWII Generation to the Baby Boomers, Generation X, Millennials (Generation Y), Generation Z, and now Generation Alpha, our global society continues to be united by technology, and thus, we experience continuous life-long education mediated by the latest gizmo technology, from tweeted homework reminders, cell phones, and tablet-based educational games and apps, to self-driving vehicles and multiple platforms of AI. Emerging technologies, such as Virtual Reality (VR) and Augmented Reality (AR) as described in Chap 28, further transform lifelong learning by offering personalized, immersive, and collaborative educational experiences that increase engagement, retention, and accessibility for learners of all ages and backgrounds.

In the STEM context, what is meant by the term 21CS? Essential skills in STEM education include rigorous core content (biology, chemistry, Earth sciences, engineering, mathematics, physics, and technology) combined with critical thinking skills (Bybee & Fuchs, 2006). These disciplines also play a crucial role in marine education, which integrates STEM principles to address complex Ocean-related challenges and foster Ocean Literacy (Kennedy, 2024; Kennedy et al., 2024). Additionally, business and education leaders increasingly emphasize the importance of *soft skills* (effective verbal and written communication, career readiness, and emotional intelligence) for success in a global, high technology economy (Broadening Advanced Technological Education Connections, 2013). Members of today's workforce require teamwork and collaboration skills, as well as the ability to apply critical thinking and problem-solving skills within day-to-day scenarios (The Conference Board, Inc., 2006).

A central barrier to reform is the dichotomy between the importance of *hard skills*, referring to rigorous core content, and the need for soft skills, such as collaboration, creativity, and work ethic. Student success relies on "greater connection between traditional core courses, hard skills, and soft skills like social skills and workforce readiness" (Voogt et al., 2013, p. 410). In addition, Silva (2009) valued not only cognition of core constructs but emphasized the essence of 21CS to increase students' capacity for applying knowledge to real-world scenarios. PBL/PrBL/PhBL provide an inquiry-based pedagogy for the inclusion of 21CS. These pedagogical approaches promote student-centered opportunities for deeper learning. Collaboration is essential for problem-solving because the complexity of real-life problems require a variety of skills. Özdemir (2019) postulated entrepreneurship often begins with a problem from an individual who seeks out collaboration from others with diverse expertise, which Özdemir termed *soloborative learning, solo thinking, collaborative tinkering* (see Chap. 6 Connectionism, Edward Thorndike).

PBL/PrBL/PhBL also embed critical thinking, problem-solving, and many of the soft skills included in the Four C's into the STEM classroom. Beers (2016) listed creativity and innovation as crucial skills involved in the processes of problem-solving and the creation of new products and services. In addition to academic skills, Beers noted twenty-first century students need cultural awareness to succeed in the global economy.

Position statements issued by the National Science Teaching Association (2011, 2024, 2025 indicate science has many inherent connections to 21CS including complex communication skills and unique problem-solving scenarios/strategies. In an analogous manner, Beers (2016, p. 5) reported the emphasis on STEM intersects with 21CS, stating that STEM is "inherently cross-curricular." Almost all STEM professions utilize a team approach to solve complex problems and, often, workable solutions are mediated with technology. STEM professionals use a wide variety of technology tools and software applications while problem-solving. For example, spreadsheets are used to mine and analyze data. Data collecting technologies, such as satellite imaging of atmospheric phenomena, are submitted to large databases, analyzed by computer software, and the information gleaned from the analyses is utilized in the building of complex models and hypotheses, such as weather forecasting (Sundberg, Kennedy, & Odell, 2013). See The GLOBE Program, https://www.globe.gov, for more information about involving students in large-scale international data collection activities (Kennedy & Henderson, 2003; Kennedy & Odell, 2000; Kennedy, Odell, & Klett, 2001), and refer to Chap. 7, New Media Technologies and Information Processing Theory—George A. Miller and Others.

A landmark research study conducted in 2015 in the U.S. by the Research Consortium on STEM Career Pathways, surveyed high school students in STEM classes and concluded that "creativity is an essential skill for twenty-first century students" (Educational Research Center of America, 2016, p. 3). The study provided evidence that increasing student efficacy for confidence in the ability to learn and select a career in STEM strongly correlates with a creative component in STEM classes in primary and secondary schools. While this study noted that males were consistently more confident of their STEM abilities than females, it also determined that when including a creative component in the curricula, students, both female and male, were approximately twice as likely to report confidence in their ability to learn STEM. Results of the study concluded that "creative learning matters," further suggesting that "greater access to STEM learning environments which students themselves see as creative might boost the STEM confidence of a generation" (Educational Research Center of America, 2016, p. 6).

This same study also noted that in addition to the gender gap described above, historically marginalized groups in the U.S. (women, African Americans, Hispanics, and Native Americans) often did not plan to pursue a STEM career, despite students acknowledging STEM is important for future career aspirations. According to these data collected by the Educational Research Center of America, female students were 38% less likely to select a STEM profession and historically marginalized groups were not provided with an adequate number of advanced courses in STEM. Gender and equity in STEM must be a priority (Kennedy & Sundberg, 2013, 2017, 2019). To address equity, the Educational Research Center of America recommended including creativity learning in all STEM courses and increasing access of advanced STEM courses for historically marginalized students, significantly underrepresented in STEM professions. To augment the traditional classroom, after school STEM clubs, maker spaces, and camps can provide opportunities for increased representation of historically-marginalized students in STEM professions (Educational Research Center of America, 2016, p.8). Additionally, initiatives such as the Future Ready Schools Framework (All4Ed, 2024), provide structured approaches to integrate technology and digital learning strategies into schools and districts "to overcome challenges and succeed in unimaginable future careers" (para. 2) through personalized learning, community engagement, providing flexible learning environments, and focusing on the four C's (creativity, collaboration, communication, and critical thinking), the foundational skills for success in work and life. See Chapter 29 for additional information addressing the gender gap in STEM education.

27.3.1 What Makes an Effective Twenty-First Century STEM Education Program?

According to the National Research Council Committee on Highly Successful Schools or Programs for K–12 STEM Education (NRC, 2011), one factor for achievement in highly successful schools for students ages 5–18 is the implementation of a STEM blueprint, guiding a college preparatory curriculum with focused emphasis on college readiness for all students. Along with committed educators and community leaders, the curricula should involve active student learning linking prior knowledge to new knowledge in learning tasks where students are engaged in the practices of science. STEM capabilities are nurtured from the early years, starting with the development of manipulative skills, understanding safety protocols, and adhering to safety rules and instructions, and includes recognizing problems, planning solutions, identifying necessary resources, executing designs, evaluating outcomes, and adapting strategies (Kennedy & Tunnicliffe, 2022; Prieto & Kennedy, 2022). This iterative process celebrates successful discoveries and facilitates redirection to tackle new challenges as they arise.

Many effective programs promoting twenty-first century STEM skills have been functioning for years in countries around the world. In addition to the International Baccalaureate program previously mentioned, Montessori Schools and their K–12 Academies, Reggio Emilia Schools, and schools within the Waldorf Education System, have also earned global reputations. Short descriptions of each follow.

Montessori Schools adhere to a method of early childhood education building on the way children learn naturally. Developed in 1907 by Italian physician, educator and innovator Maria Montessori, the schools encompass a child-centered educational philosophy involving multi-age grouping in the classroom, mirroring real-world interactions between people of all ages. The Montessori methods congruent with 21CS include encouraging students to think critically, work collaboratively, and act boldly (American Montessori Society, 2018).

The North America Reggio Emilia Alliance (NAREA), based on the early childhood education philosophy termed *Reggio Emilia*, was developed by Loris Malaguzzi in 1945 in Italy. The NAREA early childhood education approach centers on the philosophy that intelligent children deserve intelligent teachers (NAREA, 2018). twenty-first century STEM skills supported by NAREA schools include relating to others in cooperative experiences and *Progettazione,* projects that follow a similar guiding format of PBL/PrBLPhBL, and are designed by teachers in cooperation with their students who in turn share the results of their projects with the larger group to promote learning from one another (Reggio Emilia Australia Information Exchange, 2021).

Waldorf Education, established by Rudolf Steiner and Emil Molt in 1919, has its foundations in Anthroposophy, the belief that humanity has the wisdom to transform itself and the world, through one's own spiritual development (Waldorf Education, 2018). Waldorf schools integrate arts into all curricular areas. Currently there are more than one thousand Waldorf/Steiner schools and nearly 2000 Waldorf kindergartens in over 70 countries. The education philosophy of Waldorf schools support 21CS, and reports have shown "94% of Waldorf graduates attended college or university with almost half selecting a STEM major" (Mitchell & Gerwin, 2007; Montgomery & Kumar, 2015, p. 16).

Many charter and private schools in the U.S. take on specific disciplinary themes such as STEM and other content areas. For example, High Tech High (HTH), an integrated network of thirteen charter schools in San Diego, California, serves students aged 5–18. HTH has its own teacher certification program, and focuses on curricula involving PBL supported by state-of-the-art technology. While the numbers of total alumni attending and/or completing a university education are impressive, 30% of HTH graduates enroll in a STEM field compared to 17% of high school graduates across the U.S., with 35% of their graduates attending university as first-generation college students (HTH, 2016). Why is HTH so successful? HTH's philosophy centers on the concept of *Teacher as designer*, involving teacher teams designing the courses they teach and providing students with opportunities to work on real-life problems that are meaningful and important to them in order to increase student engagement (Cernavskis, 2015; HTH, 2016).

Another public charter school STEM network, the Denver School for Science and Technology (DSST), includes fourteen schools on eight campuses in Denver, Colorado, and utilizes similar philosophies related to project and problem-based pedagogies. DSST schools increase student achievement for all students at a significantly faster rate than comparable schools (Carroll, 2015).

Critics of traditional high schools often recommend competitive enrollment for effective STEM schools. One unique facet of DSST is the policy of open enrollment, which is often atypical for other STEM-focused schools (Cernansky, 2013).

However, despite the open enrollment policy, Cernansky reported student achievement on state assessments is high, citing that students graduating from DSST enroll in STEM programs at three times the national average, with a diverse student population (high percentage of traditionally marginalized students in STEM, girls, and low-socioeconomic students). What makes the difference in achievement? School culture is cited as one factor for the success of DSST. In addition, students in their junior year at DSST are required to complete a STEM-focused internship offering students a needed conceptual bridge from school into higher education and the work force.

In the U.S., there are several emerging STEM school models that promote twenty-first century STEM skills. Manor New Technology High School (MNTH) in Texas was created as part of a statewide STEM initiative entitled *The Texas High School Project*, which created inclusive STEM high schools where students were accepted in the program based on interest in STEM as opposed to traditional acceptance criteria, high aptitude or prior achievement (Lynch et al., 2017). Opportunity structures are built into the design of the MNTH curricula, providing students with support in pursuing STEM opportunities and careers. Evaluation of program success cite almost 100% of MNTH students graduated high school and have been accepted into post-secondary programs. In addition, scores on the 8th grade assessment conducted during the 2007 school year indicated that the students enrolled at MNTH scored above average in science, 65% students meeting standard, compared to 53% their peers meeting standard in other schools in the district (Lynch et al., 2017).

The Texas High School Project was established by the 79th Texas Legislature, allowing students in high school to complete two years of college concurrently with completion of a high school diploma (Chapa et al., 2014; SRI International, 2018). STEM academies emerged as a result, transforming schools into twenty-first century learning communities where students engaged in interdisciplinary, hands-on learning experiences that integrate STEM with real-world applications. These experiences provided students with the requisite knowledge, skills, and mindset to excel in the present era as well as in the evolving landscape of the future (Kennedy & Odell, 2023, 2024).

The foundation of the Texas High School Project model was supported through four pillars: (1) effective teachers; (2) supportive and knowledgeable educational leaders; (3) learning systems (curricula, scheduling, and classroom design); and (4) streamlined data analysis of performance (Haney et al., 2013, p. 25). All Texas Education Agency T-STEM academies followed and implemented the same *Design Blueprint,* serving as a guide to produce college and career-ready students. The T-STEM model has since evolved, and many have now become either Early College High Schools (ECHS) that lead to an associate's degree or Pathways to Technology Schools (P-TECH) which focus on industry-based certificates.

The University of Texas at Tyler University Academy opened in 2012 and extended the Design Blueprint to encompass K–12 students, engaging students in PBL/PrBL/PhBL experiences as the primary pedagogy for learning, resulting in a shift from a teacher-centered learning environment to a student-centered learning environment (Odell et al., 2019). Twenty-first century STEM skills development is an important part of the school assessment model. Students not only receive grades for content achievement but are also evaluated on acquiring twenty-first century STEM skills. Incorporating these skills into the curriculum ensures that students are not only knowledgeable but also capable of applying their learning to real-world problems on a global scale.

For example, one PhBL challenge that was created and implemented into the University Academy curriculum in March of 2020 involved identifying and designing solutions to societal issues related to the COVID-19 pandemic. A broad collaborative invitation that was disseminated by the International Council of Associations for Science Education (ICASE) to schools around the world. This project resulted in over 1000 students from 14 countries creating and sharing their engineering designs by the end of December 2023 (Kennedy, 2021), and many of the participating schools continue to implement this PhBL. Through engaging in the COVID-19 Engineering Design Challenge, students refined their abilities in STEM and developed twenty-first-century skills such as creativity and communication, while also cultivating adaptability, resilience, and digital competencies, particularly in response to navigating an unforeseen and unwelcome real-world scenario. Refer to Chap. 20 for more information about implementing PBL.

Evaluation of dual enrolment in the Texas High School Project revealed students who completed college courses during their high school years, attended and completed an Associate's degree or higher during their college experience. These findings, along with findings of the Central Texas Student Futures Project, were particularly significant for completion rates held for traditionally marginalized groups, racial minorities, and students from low-income families (Cumpton & King, 2013; Struhl & Vargas, 2012), and showed that students from diverse backgrounds attending STEM academies outperformed their counterparts at traditional high schools (Kennedy & Odell, 2014). There are many STEM schools emerging in the U.S. and across the globe that provide access to all students interested in STEM. These schools implement twenty-first century pedagogies involving students in real-world projects.

27.4 Recommendations

This review of preceding reports and STEM program descriptions is not exhaustive but provides sufficient evidence of clear commonalities among 21CS frameworks, learning documents, and successful STEM school models from around the world. However, nearly 25 years into the twenty-first century, we are still struggling to define 21CS with precision due to the dynamic and ever-evolving nature of the skill sets required for success. These definitions will undoubtedly continue to evolve as we progress toward the twenty-second century.

In many countries, including the U.S., educational policies and accountability systems continue to rely heavily on standardized tests structured around memorization of facts and procedures. As long as accountability systems reward scores on achievement tests, schools will focus on maximizing test scores rather than on developing 21CS. Of particular importance today is the need to evaluate the actual level of penetration of 21CS into classroom instruction.

The U.S. Bureau of Labor Statistics estimated "that employment in STEM-related fields will increase by one million between 2012 and 2022" (Educational Research Center of America, 2016, p. 3; Vilorio, 2014, p. 3). However, according to the U.S. National Center for Science and Engineering Statistics (NCSES), the size of the STEM workforce grew between 2011 and 2021 by 5.9 million, representing a 20% increase during this time period (National Science Foundation, 2023). Current projections cite an 11% increase in STEM occupations will occur from 2022–2032, highlighting occupational growth in the following areas: computer and mathematical, architecture and engjneering, and life and physical science, along with managerial and postsecondary positions associated with these areas as well as sales occupations requiring scientific/technical knowledge (U.S. Bureau of Labor Statistics, 2024).

Advancements in technology, innovation, and the growing demand for skilled workers in these areas require a continuous commitment to education, training, and professional development. Teaching students to be creative producers of knowledge and innovation supports the development of twenty-first century STEM skills. Specialty Schools, especially those that focus on skills rather than test scores, can foster future STEM leaders and immerse students in high-quality STEM education aimed at developing 21CS. These environments, flexible in design, can also provide a venue to test teaching materials and provide professional development to prepare teachers ready to immerse their students in environments rich in PBL/PrBL/PhBL. In addition, open enrollment STEM schools, such as those described earlier, can serve as a transition to STEM majors and careers for all students.

The 22nd Century may seem distant, but the rapid pace of change demands forward-thinking today. The constant reoccurrence of the Four C's implies that the most critical skills for students of all ages are represented through a continuing thread throughout most of the 21CS documents. Developing 21CS begins in the early years and progresses through secondary school, requiring educators to align how students learn through concept acquisition and development while promoting students to use the skills needed to survive and thrive in the modern workplace. Learning about scientific practice, through Problem and Project-based Learning, Phenomenon-based Learning, and other transdisciplinary STEM approaches to teaching science education, promotes student engagement in scientific inquiry for and by themselves. 21CS is a vehicle for promoting socio-political activism, assisting students to become active citizens in addressing science and technology issues at local, national, and global levels. Twenty-first century STEM skills are more important than ever as industry advances and places greater importance on preparing students for the world of work.

27.5 Summary

- The U.S. National Education Association and the Partnership for Twenty-First Century Skills Four C's (critical thinking, communication, collaboration, and creativity) appear equivalent to international descriptions of desirable 21CS, as well as with the NRC and World Economic Forum competency categories.
- An examination of curriculum documents from multiple countries shows the inclusion of 21CS, and that the goals encompassing twenty-first century competencies have been included in many standards and curriculum documents.
- Project-Based Learning (PBL), Problem-Based learning (PrBL), and Phenomenon-Based Learning (PhBL), along with transdisciplinary approaches to teaching science education such as STEM (science, technology, engineering and mathematics), STEAM (science, technology, engineering, the arts, and mathematics), as well as marine and environmental education programs, break down the artificial barriers of disciplines enabling students to understand the connected nature of knowledge and utilize critical skills leading to success in the twenty-first century economy.
- Successful schools provide technology tools for classrooms and equip teachers and students with the skills to use them in a meaningful and equitable context, thus promoting the development of the technical skills supporting twenty-first century STEM skills.
- 21CS have evolved in response to rapid technological changes (AI, automation, digital communication tools) and will continue to evolve as technologies progress requiring increased digital literacy, proficient computational thinking, and adaptability in navigating a technology-driven world.
- There is broad recognition that twenty-first century STEM skills are important, but there is little research to indicate the level of implementation in the classroom.
- Classroom implementation of the 21CS, and the pedagogies that support them, may not come to fruition until standardized assessments are reformed to include measurements related to 21CS and professional development for teachers is designed to include 21CS across the primary and secondary school experience.

Further Information on Model 21CS STEM Schools

Denver School for Science and Technology, Colorado: https://www.dsstpublicschools.org/

High Tech High Charter School, San Diego, California: https://www.hightechhigh.org/

Manor New Technology High School, Texas: https://mnths.manorisd.net/

University of Texas at Tyler University Academy: https://www.uttua.org/

Reflective Exercises

Identifying Essential Skills

Objective: Reflect on the key 21CS necessary for your students' success.
Instructions:

1. Review the various 21CS highlighted in the chapter (e.g., critical thinking, collaboration, creativity, communication).
2. List three skills you believe are most crucial for your students and explain why.
3. Describe how your current teaching practices support the development of these skills.
4. Reflect on how well these skills are currently being addressed in your teaching practice. Provide specific examples and outline the changes you could implement to better integrate these skills into your classroom?

Evaluating Pedagogical Approaches

Objective: Evaluate the effectiveness of different pedagogical approaches in fostering 21CS.
Instructions:

1. Review the pedagogical approaches discussed in the chapter (e.g., Project-Based Learning, Problem-Based Learning, Phenomenon-Based Learning).
2. Identify which approach you currently use most frequently and describe a specific lesson or project that utilized this approach. If you have not used these approaches, create a PBL experience for your students.
3. Analyze the impact of this approach on your students' development of 21CS.
4. Describe how the approach facilitated the development of 21CS? (Include evidence demonstrating that the approach was effective in enhancing your students' skills).

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