Teaching and Learning 21st century Skills: Lessons from the Learning Sciences

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Anna Rosefsky Saavedra, The RAND Corporation
V. Darleen Opfer, The RAND Corporation

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Table of Contents

Introduction

Preparing students for work, citizenship, and life in the 21^{st} century is complicated. Globalization, technology, migration, international competition, changing markets, and transnational environmental and political challenges add a new urgency to develop the skills and knowledge students' need for success in the 21^{st} century context. Educators, education ministries and governments, foundations, employers, and researchers refer to these abilities with terms that include "21st century skills," "higher-order thinking skills," "deeper learning outcomes," and "complex thinking and communication skills." Interest in these skills is not new. For example, researchers at Harvard University's *Project Zero* have been studying how students learn and how to teach these skills for more than 40 years. In this paper, we focus on what research tells us about how students learn 21st century skills and how teachers can effectively teach them.

While all countries believe that the knowledge and skills that students need in the 21^{st} century are different from what they have needed in the past, terminology differs between countries as does the emphasized composition of knowledge, skills and values. We use the term "21^{st} century skills" because we believe it is currently the most widely recognized and used term internationally, though we could just as easily substitute any of the previously mentioned terms for 21^{st} century skills. Critics denounce the term for being vague and overused,[1] for endorsing the idea of teaching skills apart from knowledge and for promoting skills that have been encouraged for centuries, yet are now emphasized with a new sense of urgency that could lead to rapid and unsuccessful reforms.[2]

In the following sections, we briefly summarize current efforts to define 21st century skills and explain the economic, civic, and global rationales for why they are important. We attend to the criticisms leveled against 21^{st} century skills by examining why these skills must be taught primarily through disciplinary content, taking care not to "trivialize subject matter"[3] and then identifying specific ways to do so. The majority of the paper thus focuses on explaining how these skills should be taught, given what we know about how students learn. We then discuss the assessment of 21st century skills and conclude with an overview of the teacher capacity implications of institutionalizing "new" teaching and learning processes.

Defining 21st century Skills

There is no shortage of current definitions of 21^{st} century skills and knowledge. In this paper we do not seek to provide another or choose one over another. Rather we share two well-known examples and pull out several common themes. In a frequently-cited example, the University of Melbourne-based and Cisco- Intel- and Microsoft-funded Assessment and Teaching of 21^{st} Century Skills (AT21CS) consortium—which includes Australia, Finland, Portugal, Singapore, the United Kingdom, and the United States—

organizes 21st century skills, knowledge, and attitudes/values/ethics into the following four categories:

- *Ways of Thinking*: creativity/innovation, critical thinking, problem solving, decision-making, and learning to learn (or metacognition)
- *Ways of Working*: communication and teamwork
- *Tools for Working*: general knowledge and information communications technology literacy
- *Living in the World*: citizenship, life and career and personal and social responsibility including cultural awareness and competence[4]

Another definition comes from the book, *The Global Achievement Gap (2008)*, by Tony Wagner, Co-director of the Harvard Change Leadership Group. Based on several hundred interviews with business, nonprofit, and education leaders, Wagner proposes that students need seven survival skills to be prepared for 21st century life, work, and citizenship:

1. Critical thinking and problem solving
2. Collaboration and leadership
3. Agility and adaptability
4. Initiative and entrepreneurialism
5. Effective oral and written communication
6. Accessing and analyzing information
7. Curiosity and imagination

The Asia Society and the U. S. Council of Chief State School officers specify *global competence* as the core capacity students need for the 21st century, and define it as the capacity and disposition to understand and act upon issues of global significance. Per this definition, globally competent students:

1. Investigate the world beyond their immediate environment
2. Recognize perspectives, others' and their own
3. Communicate ideas effectively with diverse audiences
4. Take action to improve conditions[5]

These 21st century skill definitions (and others not listed) are cross-disciplinary and relevant to many aspects of contemporary life in a complex world. They do not currently have a specific place in most curricula. And most lists of 21st century skills are not entirely composed of skills by any means. They involve aspects of skill and understanding but many of them emphasize inclinations like curiosity, creativity, and collaboration that are not, strictly speaking, skills. Some lists emphasize technology, and others stress attitudes and values more. However, most focus on similar types of complex thinking, learning, and communication skills and all are more demanding to teach and learn than memorization and other types of rote skills.

In recent years, education systems worldwide have also developed frameworks with an increased emphasis on developing the skills, knowledge, and attitudes necessary for success in the 21st century. Table 1 summarizes some of the reforms that have addressed 21st century thinking skills.

Table 1. How national education systems are addressing 21st century skills.

Hong Kong	Japan	China	Finland	Singapore	United States
"Learning to Learn" reform addresses applied learning and "other" learning experiences, including service and workplace learning[6]	"Zest for Living" education reform stresses the importance of experimentation, problem finding and problem solving instead of rote-memorization[7]	Greater emphasis on students' ability to communicate and work in teams, pose and solve problems and learn to learn[8]	New focus on "citizen skills": 1) Thinking skills, including problem solving, and creative thinking. 2) Ways of working and interaction, 3) Crafts and expressive skills; 4) Participation and initiative; and 5) Self-awareness and personal responsibility[9]	New "Framework for 21st century Competencies and Student Outcomes" is intended to better position students to take advantage of global opportunities.[10]	Common Core State Standards Initiative redefines standards to make them "inclusive of rigorous content and applications of knowledge through higher-order skills, so that all students are prepared for the 21st century"[11]
2000	2006	2010	2010	2010	2010

Although the approaches across national education systems differ, they are similar in recognizing the need for more sophisticated thinking and communicating skills.

Why Students Need 21st Century Skills

There are compelling economic and civic reasons for education systems to develop students' 21st century skills. The economic rationale is that computers and machines can cost-effectively do the sorts of jobs that people with only routine knowledge and skills can do, which means the workplace needs fewer people with only basic skill sets and more people with higher-order thinking skills. Further, supply and demand in a global rather than national or local marketplace increases competition for workers who can add value through applying non-routine, complex thinking, and communication skills to new problems and environments.

There is also a strong civic rationale for schools to increase their focus on developing students' 21st century skills. Though students need a foundation of basic civic knowledge, rote learning, recitation of information about government and citizenship is not a sufficient way to promote civic engagement. They also need to learn how and why to be engaged citizens who think critically—so that they can, for example, analyze news items, identify biases, and vote in an educated way. They need to be able to problem-solve so they can propose or review policies to address social challenges. They need to be able to work with others if they are to effectively serve as jurors or participate in political campaigns. They need to be able to communicate effectively orally and in writing so that they can share their opinions publically, defend their rights, propose new policy, etc.[12] In the U.S. context, engagement in the local and national civic sphere is at an all-time low,[13] while increasing inequality—due to the decreasing demand for middle-class jobs that require only routine knowledge and skills—threatens to weaken commitment to democracy.[14]Without 21st century skills, citizens cannot exercise the rights and responsibilities that contribute to a healthy society

Globalization encompasses the third rationale for teaching and learning 21st century skills.[15] Massive global migration, the Internet, long-haul flights, interdependent international markets, climate instability, international wars, and other factors remind us daily that countries, states, and individuals are part of a globally interconnected economy, ecosystem, and political network and that people are part of the human race. This interconnectedness makes it even more urgent for students around the world to learn how to communicate, collaborate, and problem-solve with people beyond national boundaries.[16]

These three rationales each motivate the need for 21st century skills from a different perspective, but they are not at odds. Rather, they complement each other because the skills and knowledge necessary to engage in the economic, civic, and global spheres overlap almost completely.

Why Are Many Students Not Learning 21st century Skills?

The dominant approach to compulsory education in much of the world is still the "transmission" model,[17] through which teachers transmit factual knowledge to students through lectures and textbooks.[18] In the U.S. context, for example, the standards and accountability movement that began in the early 1990s led to the development of standards that have been taught predominantly through the transmission model and tested through recall-based assessments. Even among many national board certified-U.S. teachers, the transmission model dominates.[19] Though many countries are shifting the focus of their educational systems away from this model, it often prevails for two primary reasons—because educational systems are hard to change[20] and because the transmission model demands less disciplinary and pedagogical expertise from teachers than does the contrasting "constructivist" model through which students actively—rather than passively—gain skills and knowledge.[21] Through the transmission model, students have the opportunity to learn information, but typically do not have much practice applying the knowledge to new contexts, communicating it in complex ways, using it to solve problems, or using it as a platform to develop creativity. Therefore, it is not the most effective way to teach 21st century skills.[22]

A second barrier to students' development of 21st century skills is that they do not learn them if they are not explicitly taught. These skills are not typically taught in separate stand-alone courses on, for example, thinking. We argue below that students should learn

21st century skills through disciplinary study so view the lack of stand-alone courses favorably. According to the OECD's 2008 Teaching and Learning International Survey (TALIS), teachers in 22 of 23 participating countries—most of which are Northern or Eastern European—favor constructivist pedagogy. However, the TALIS also demonstrates that (in participating countries) 21st century skills are not often clearly highlighted even when teachers use active learning strategies like debate and structured classroom conversations.[23]

A third impediment is that 21st century skills are more difficult to assess than factual retention. When they are not measured on assessments that have accountability or certification high stakes, teachers tend to reduce their classroom prioritization. As we discuss throughout this paper, development of 21st century skills needs explicit attention.

How to Teach 21st century Skills: Nine Lessons from the "Science of Learning"

Decades of empirical research on how individuals learn substantiate critical lessons about the best ways to teach 21st century skills. In this paper we refer to this body of research as the *science of learning*.

In the following sections, we summarize the science of learning as it relates to learning and teaching 21st century skills and recommend general lessons that other education systems can apply to move toward similar outcomes. All of the lessons are about how students learn 21st century skills and how pedagogy can address their needs. Many of the lessons—particularly transfer, metacognition, teamwork, technology, and creativity—are also 21st century skills in themselves.

1. *Make It Relevant*

To be effective, any curriculum must be relevant to students' lives.[24] Transmission and rote memorization of factual knowledge can make any subject matter seem irrelevant. In response to that model, students memorize information for a test, quickly forget it after the test and then simply look up what they need to know on the Internet when they actually need it. This model undermines the possibility of developing students' 21st century skills because lack of relevance leads to lack of motivation, which leads to decreased learning.[25]

Using the Science of Learning

The science of learning served as the basis for educational reforms in Hong Kong and Shanghai in 2000 and 2002. In both systems, reforms address students as holistic learners, mobilize widespread social support and appropriately balanced centralized versus decentralized control. System-level curricular, pre- and in-service training of teachers, and information dissemination policies in both countries also support the implementation of practices derived from the science of learning.[1] Those two sites correspondingly achieved the highest scores in the 2009 Programme for International Student Assessment (PISA), which assesses the extent to which students near the end of their compulsory education have acquired the skills needed to participate fully in society.

To make curriculum relevant, teachers need to begin with *generative topics*, ones that have an important place in the disciplinary or interdisciplinary study at hand and resonate with learners and teachers.[26] Though there are endless generative topic possibilities, broad examples might include climate change, statistics and justice. Students and teachers might study implications of climate change for their local area and other areas with similar geographic characteristics. They might learn how to use their knowledge of basic statistical principles to improve their understanding of statistics used in popular press. They would not, however, study the justice system from the perspective of governmental facts to be memorized, because strong generative topics require student engagement with complex issues.

Choosing a generative topic is the first stage of the well-known Teaching for Understanding curriculum framework, developed through a five-year project by Project Zero researchers and used by teachers worldwide.[27] To choose generative topics, Boix-Mansilla and Jackson[28] recommend that teachers ask themselves questions like, "How does this topic connect to the reality of my students' lives and interests? Am I passionate about the topic myself? If so, why? Are there better ways to frame this topic to make it truly engaging for my students?"

As noted in the accompanying text box, the relevance of specific topics or issues is clearer to students if it fits within meaningful, holistic context, i.e. " the big picture." Once it is clear to students what the big picture is, they also need to understand each of the knowledge-, skill- and attitude-based objectives that contribute to understanding the big picture and why they all matter. Developing and conveying to students each of these understanding goals is the second step of the Teaching for Understanding model. Through understanding what the big picture is, why it matters and each of the goals that will get them there, all of the knowledge—concepts, facts, and theories—and skills—methods, tools, and techniques—that students will gain through study of a given generative topic are then relevant.[29]

Help Students See the Big Picture

To appreciate the relevance of a given generative topic, students need to understand the big picture, how pieces fit into the big picture and why the big picture matters. In his book *Making Learning Whole*, author David Perkins uses baseball as an analogy: To play successfully, the players must know how hitting, catching, and running bases contribute to the game. Similarly, students need to understand how, for example, following the order of mathematical operations fits into the bigger picture of mathematical thinking and they must have a sense of the value of mathematical thinking in the first place. Perkins argues for the importance of explicitly relating every lesson to the big picture of the generative topic under study, whatever that topic may be. He also demonstrates that young learners can grasp "junior versions" of the big picture. For example, a junior version of the French Revolution big picture could be understanding what happens when a few people have all of the resources and power at the expense of the rest, a lesson that could be enacted through a classroom role-play game.

Both teachers and students benefit from the use of generative topics and reinforcement of relevance. Teachers like this method because it allows for the freedom to teach creatively. Students like it because it makes learning feel more interesting and engaging, and they find that understanding is something they can use, rather than simply possess.[30] In response to the importance of relevance in fostering student engagement in learning, one of the five goals of Ontario's 2003 *Student Success/Learning to 18 Strategy* specifies provision of "relevant learning opportunities for all students." Through this reform, the Ministry of Education provides a range of vocational, technical and accelerated learning opportunities to students that are intended to "match their strengths and aspirations." [31]

2. Teach Through the Disciplines

Science-of-learning experts concur that learning should take place through the disciplines, including—but not limited to—native and foreign languages, hard and social sciences, mathematics, the arts, and music. As Howard Gardner argues, students

> Need an education that is deeply rooted in… what is known about the human condition, in its timeless aspects, and what is known about the pressures, challenges and opportunities of the contemporary and coming scene. Without this double anchoring, we are doomed to an education that is dated, partial, naïve, and inadequate.[32]

Learning through disciplines entails learning not only the knowledge of the discipline but also the skills associated with the production of knowledge within the discipline. Through disciplinary curriculum and instruction students should learn why the discipline is important, how experts create new knowledge, and how they communicate about it. Each of these steps map closely to the development of 21st century skills and knowledge.[33] For example, through scientific study, students should learn why science is relevant and what kinds of problems they can solve through scientific methods, as well as how scientists carry out experiments, how they reach conclusions, what they do with the knowledge they gain from the process, and how they communicate their findings. Based on this perspective, to foster students' enthusiasm for STEM studies, Japan's *Zest for Living* reform legislation increased emphasis on teaching science and mathematics topics through foundational disciplinary study processes like those described above.[34]

Similarly, through historical study, students should learn how to pose a problem they have realized through familiarity with the historical knowledge base of a given topic. To solve the problem, they must collect, distill, and synthesize information from oral, written, and visual primary and secondary sources. They must know where to look for information, which information will help them to construct an argument, how to interpret the information they find, how to structure complex causal relationships, how to account for source biases, and how to compare and contrast their findings with what has already been presented as historical fact. They must also learn how to communicate their findings and practice communicating them to diverse audiences.

Continued learning in any discipline requires that the student—or expert—become deeply familiar with a knowledge base, know how to use that knowledge base, articulate a problem, creatively address the problem, and communicate findings in sophisticated ways.[35] Therefore, mastering a discipline means using many 21st century skills.[36]

Developing other 21st century skills like leadership, adaptability, and initiative can also take place through the disciplines when teachers explicitly define those objectives and facilitate ways for students to develop them. For example, teachers can design activities in which students practice rotating leadership responsibilities in groups, tutor younger children, or work with their local communities. An evaluation of U.S. students' historical study of the motives and accomplishments of African-American leaders demonstrated that when leadership qualities are explicitly highlighted, students develop their conceptual understanding of leadership and demonstrate leadership skills.[37]

3. *Simultaneously Develop Lower- and Higher-Order Thinking Skills*

In the previous section, we explain why students should learn 21st century skills through disciplinary study. Similarly, students can—and should—develop lower- and higher-order thinking skills simultaneously. For example, students might practice lower-order skills by plugging numbers into the equation like $E=MC^2$ as a way to understand the relationship between mass and energy. To deepen understanding of that relationship, teachers might ask students probing questions that require higher-order thinking to answer. Schwartz and Fischer (2006) provide several example questions including: Why does the formula use mass instead of weight? Can I use my bathroom scale to determine mass, why or why not? While students might find it quite straightforward to plug numbers into equations, addressing these questions successfully, while much more difficult, contributes to flexible and applicable understanding.

Lower-order exercises are fairly common in existing curricula, while higher-order thinking activities are much less common.[38] Higher-level thinking tends to be difficult for students because it requires them not only to understand the relationship between different variables (lower-order thinking) but also how to apply—or transfer—that understanding to a new, uncharted context (higher-order thinking). *Transfer* (which we will discuss in more detail below), tends to be very difficult for most people. However, applying new understandings to a new, uncharted context is also exactly what students need to do to successfully negotiate the demands of the 21st century.

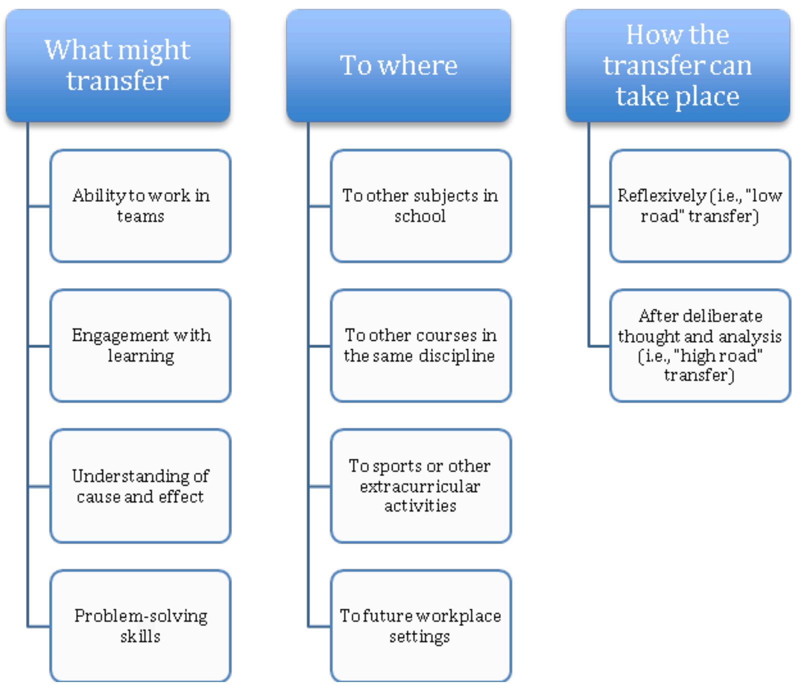
Higher-level thinking skills take time to develop, and teaching them generally requires a tradeoff of breadth for depth.[39] Singapore's national educational success validates this trade-off: Through its *Teach Less, Learn More* education reform, teachers cover far less material than do many other countries, but cover it in depth so that students will master lower- and higher-order concepts.[40] Another approach that is popular in Finland and Singapore is to reverse the way students spend their time in the classroom and on homework at home. Instead of listening to lectures at school and doing problems at home, students can read content as homework and at school work on problems in groups while the teacher poses thought-provoking questions and coaches explicitly on development of higher-order thinking.[41]

4. *Encourage Transfer of Learning*

Students must apply the skills and knowledge they gain in one discipline to another. They must also apply what they learn in school to other areas of their lives. This application—or transfer—can be challenging for students (and for adults as well).[42] Scientific attention to this challenge began in the early 1900s with the work of Thorndike and Woodworth and has led to a large literature and ongoing debate about transfer and the extent to which people can learn to do it.[43] A common theme is that ordinary instruction does not prepare learners well to transfer what they learn, but explicit attention to the challenges of transfer can cultivate it.

Transfer involves three variable components, as shown in Figure 1:[44]
1) What skills, concepts, knowledge, attitudes and/or strategies might transfer?
2) To which context, situation, or application?
3) How can the transfer take place?

Figure 1. How Transfer Works



Examples of "What" might include ability to work in teams, engagement with learning, understanding of cause and effect, problem solving through trial and error, and so forth. Examples of contexts include to other subjects, to other courses within the same general discipline, to sports, to future workplace settings, etc. And transfer can take place in one of two general ways. "Low-road" transfer functions reflexively. Students might apply what they know about using the equation *distance=rate*time* to using the equation $E=MC^2$. "High-road" transfer requires deliberate abstraction and generalization about a particular concept.[45] Through the example provided previously of provocative questions about mass and motion, teachers ask students to engage in high-road transfer by making conceptual connections between scientific laws and situations they may encounter in their lives.

There are a number of specific ways that teachers can encourage low- and high-road transfer.[46] To encourage low-road transfer, teachers can use methods like the following:

- Design learning experiences that are similar to situations where the students might need to apply the knowledge and skills
- Set expectations, by telling students that they will need to structure their historical argument homework essay in the same way that they are practicing in class
- Ask students to practice debating a topic privately in pairs before holding a large-scale debate in front of the class
- Organize mock trials, mock congressional deliberations, or other role-playing exercises as a way for students to practice civic engagement
- Talk through solving a particular mathematics problem so that students understand the thinking process they might apply to a similar problem
- Practice finding and using historical evidence from a primary source and then ask students to do the same with a different primary source

The purpose of each of these activities is to develop students' familiarity and comfort with a learning situation that is very similar to a new learning situation to which they will need to transfer their skills, concepts, etc.

Teachers can use other methods to encourage high-road transfer. For example:

- Explicitly ask students to brainstorm about ways in which they might apply a particular skill, attitude, concept, etc. to another situation
- Ask students to generalize broad principles from a specific piece of information, such as a law of science or a political action
- Ask students to make analogies between a topic and something different, like between ecosystems and financial markets
- Ask students to study the same problem at home and at school, to practice drawing parallels between contextual similarities and differences
- Ask students to think explicitly about their own thinking, (a process known as metacognition, which we discuss below)

Transfer is hard and students need support from teachers and practice at school to ensure that it happens.[47] Fortunately, we know enough about how to develop students' ability to transfer and we have a common sense understanding of its power. For example, Shanghai university entrance examinations ask students to apply knowledge and skills addressed through their secondary syllabus-based courses to problems not covered in their courses. Shanghai education experts believe that training students to transfer their knowledge and skills to real problems contributed to their success on the 2009 Programme for International Student Assessment (PISA).[48] The importance of transfer brings us back to the fundamental rationale for learning 21st century skills in the first place—so that students can transfer them to the economic, civic and global 21st century contexts that demand them.

5. Teach Students to Learn to Learn

There is a limit to the skills, attitudes, and dispositions that students can learn through their formal schooling. Therefore, educating them for the 21st century requires teaching them how to learn on their own. To do so, students need to be aware of how they learn. Though the history of this concept is long, Flavell first coined the modern label *metacognition* in 1976 to describe learning to learn and defined it as, "one's knowledge concerning one's own cognitive processes or anything related to them…For example, I am engaging in metacognition if I notice that I am having more trouble learning A than B; if it strikes me that I should double check C before accepting it as fact."[49]

Not only is learning to learn a critical skill in itself, activities that develop metacognition also help students to learn skills, knowledge, strategies, and attitudes more effectively. For example, a study of 79 Swiss eighth grade classrooms, incorporating video recordings, student and teacher surveys, and student achievement demonstrated a positive relationship between metacognition and student achievement on the Third International Mathematics and Science Study.[50] In Finland, beginning in first grade, teachers place a major emphasis on students' metacognition development. Students set their own educational objectives and evaluate their progress. The goal of this practice is "to increase pupils' curiosity and motivation to learn, and to promote their activeness, self-direction, and creativity by offering interesting challenges and problems."[51] In Hong Kong, in accordance with the aptly titled 2000 *Learning to Learn* reform, teachers are integrating strategies designed to develop students' metacognition into their teaching practice.[52]

Building Metacognition

The *Visible Thinking* project, which provides education tools to a network of schools in Australia, Belgium, the Netherlands, Scotland, Sweden, and the United States, helps students develop metacognition through disciplinary study and explicit examination of thinking processes. In the "Think-Puzzle-Explore" reasoning routine, teachers might ask students (or students might ask their peers or teachers), "What do you think you know about subtraction? What makes you say that? What are you puzzling over about subtraction? How will we explore our puzzles about subtraction?" With the "Perspective-Taking" routine, teachers ask students to consider who might have different viewpoints about a controversial topic like Internet regulation or stem cell research or social safety nets. Students would then divide up and voice the different viewpoints and then reflect as a class. Using the "Headlines" summarization routine, at the beginning of class, teachers might ask their students to write a newspaper headline about the Pythagorean theorem. And then at the end, they might ask students how the headline they might write then differs from what they would have written before the class began. All of these routines work in the full class setting and in pairs or small groups, in which each student practices vocalizing their thinking and also learns how their peers think (Richhart & Perkins, 2008).

Teachers can develop students' metacognitive capacity by encouraging them to explicitly examine how they think. Researchers studying the use of concept maps in a school in Melbourne, Australia, found that a practice in which students wrote "thinking" in the middle of a blank piece of paper and then recorded their ideas about thinking, was an effective way to make them more self-directed learners and better thinkers.[53] In a debate setting, teachers might ask students to prepare their own argument and prepare to rebut the other teams' arguments in an organized way that considers different arguments and potential responses. Then students can explicitly document why it was helpful to develop their own argument and rebuttals in advance.[54] Teachers can also reinforce students' metacognition by modeling it on a regular basis and talking through their own thinking as they address an example problem and then asking students to reflect on the teachers' model.

In addition to developing metacognitive skills, it is also important for students to develop positive mental models about how we learn, the limits of our learning, and indications of failure. While some cultures view intelligence and learning capacity as innate rather than effort-based, others believe that effort overrides innate limitations.[55] Students benefit from believing that intelligence and capacity increase with effort (known as the "incremental" model of intelligence) and that mistakes and failures are opportunities for self-inquiry and growth rather than indictments of worth or ability.[56]

In Singapore and Shanghai mathematics classrooms, teachers ask students to work on problems at the board, not expecting all students to get the right answer. The purpose is for the effort of those at the board to help students understand the problem and to develop their broader mathematical understanding, rather than to focus on getting the right answer.[57] An effective way for teachers to cultivate the incremental model includes praising students for their effort and how they learn rather than for their intelligence as well as discussing mental models as part of other metacognition building activities.[58]

6. Address Misunderstandings Directly

Another well-documented science-of-learning theory is that learners have many misunderstandings about how the world really works, and they hold onto these misconceptions until they have the opportunity to build alternative explanations based on experience.[59] This process generally requires explicit guidance and takes time.[60] For example, children believe that the world is flat until they learn otherwise, and even college students who have studied the solar system may still hold onto an incorrect explanation of why seasons change. Misconceptions develop from the process of creating explanations based on what we see and hear, and while many of these explanations may be correct and serve as useful building blocks, others are incorrect and do not take into account complicated causal relationships.[61]

To overcome misconceptions, learners of any age need to actively construct new understandings. Think of how many times you have thought you were absolutely certain of something, even if someone told you the contrary was true. It is human nature to need to "find out for ourselves." Textbooks rarely explicitly speak to misunderstandings, leaving the challenge of addressing them to the teacher.[62] Thus, teachers face the important challenge of identifying misunderstandings and giving students opportunities to learn the facts for themselves.

There are several ways to counter misunderstandings, including teaching generative topics deeply (which has many benefits as discussed throughout this paper), encouraging students to model concepts and providing explicit instruction about misunderstandings.

Teaching topics deeply gives students time and space to familiarize themselves with ideas that contradict their intuitive misconceptions. Deep attention also facilitates learning about topics in ways that engage different learning styles and therefore have a better likelihood of turning around the misconception.[63] For example, to understand historical relationships, students can read and discuss biographies, analyze demographic data, interpret art, debate controversial issues, and so forth.[64]

Modeling misunderstandings and explicitly addressing them also helps to improve and deepen students' understanding.[65] For example, in a U.S. middle school setting, researchers studied specific instructional methods designed to improve students' understanding of ecosystems. Teachers instructed the class to model an ecosystem by assigning each student to a plant or animal role, passing a ball of yarn between the students. When one part of the ecosystem disappeared—acted out by a student sitting down—some students would feel a tug on the yarn. This concrete, tactile experience provided a forum through which teachers explicitly discussed with students different types of causal relationships and how these relationships played out in the model. The researchers found that the combination of modeling and explicit instruction successfully increased students' understanding of complex causality and was a useful way of teaching to counteract misconceptions.[66]

Correcting Misconceptions about Complex Causality

People tend to have rather deep-seated misunderstandings of complex causality. They struggle less with linear cause and effect relationships, in which one thing simply causes another. But the world is complex and linear relationships cannot explain complex phenomena, such as scientific systems or historical events. To understand the types of causality with which students struggle consider the example of ecosystems. In *domino causality*, a cause has an effect, which causes another effect and so forth. For example, pollution causes acid rain, which kills off fish, which depletes bears' food source, which might limit the bear population, who limit other animal populations, etc. In the *re-entrant causality feedback loop*, causes become effects and effects become causes. When plants die they decompose and enrich the soil in which they will grow again. In *two-way causality*, owls eat mice, which provide the owls with needed energy and also manage the mouse population so there is enough food for the mice that avoid being eaten by the owls. Because the world really works through endless series of complex causal relationships, learners must understand and be able to apply their understanding of complex causal relationships (examples from Grotzer & Basca, 2003).

7. Teamwork is an Outcome and Promotes Learning

The ability to collaborate with others is an important 21st century skill. The science of learning tells us that it is not only a desirable outcome it is also an important condition for optimal learning. Students learn better with peers.[67] As Perkins points out with his baseball analogy, people do not learn to play baseball by themselves—"only Superman could do it and it wouldn't be much fun!" They should learn to play baseball from and with their peers and coach.[68]

In typical transmission-model classrooms, students do not learn from and with their peers. The teacher and textbook transmit information, and the student engages in a one-to-one interchange with the teacher. Through this type of interaction, students lose the opportunity to learn from each other and to develop the skill of working with others. Further, as we have discussed throughout the paper, working in pairs or groups is an ideal way for students to develop their metacognition and communication skills, to replace their misunderstandings with understandings and to practice low- and high-road transfer. The transmission model, therefore, robs students not only of the opportunity to develop the skills of listening to and learning from others and sharing their thoughts, opinions, and knowledge constructively, it also detracts from opportunities to develop other 21st century skills.

There are many ways in which teachers can design instruction to promote learning with others. Students can discuss concepts in pairs or groups and share what they understand with the rest of the class.[69] They can develop arguments and debate them. They can role-play. They can divide up materials about a given topic and then teach others about their piece. Together, students and the teacher can use a studio format in which several students work through a given issue, talking through their thinking process while the others comment. Because the studio approach is so dominant in Asian countries, teachers express concern about class sizes getting too small to find enough different solutions to a problem to have an effective lesson.[70] Another way to promote learning with others is to have older students tutor younger students, which provides the younger students with individualized attention and the older students with the motivation to deepen their understanding of the topic they are tutoring in, as well as develop non-cognitive characteristics like responsibility and empathy.[71] There are many ways in which teachers can design instruction so that students learn from and with others, developing both their ability to work in teams and their other 21st century skills.[72]

8. Exploit Technology to Support Learning

Technology offers the potential to provide students with new ways to develop their problem solving, critical thinking, and communication skills, transfer them to different contexts, reflect on their thinking and that of their peers, practice addressing their misunderstandings, and collaborate with peers—all on topics relevant to their lives and using engaging tools. The *River City Multi-User Virtual Environment* (MUVE) project is an example of a technology-based educational tool that seeks to accomplish each of these objectives. While the program "has the look and feel of a video game," it is based on U.S. national biology and ecology standards.[73] Participating students enter a 19th-century virtual environment, in which they learn to behave as health scientists to help explain why people are getting sick. They collaboratively identify problems with their online peers, form and test hypotheses, and draw conclusions about underlying causes.[74]

There are also many other examples of web-based forums through which students and their peers from around the world can interact, share, debate, and learn from each other. For example, through the *Deliberating in Democracy* program, students from Colombia, Ecuador, Mexico, Peru, and the United States share their perspectives with international peers on various topics that range from corruption and judicial independence to the environment to public health and then vote on different policy decisions.[75]

The Internet itself also provides a forum for students' development of 21st century skills and knowledge. The nature of the Internet's countless sources, many of which provide inconsistent information and contribute substantive source bias, provide students with the opportunity to learn to assess sources for their reliability and validity. It gives them an opportunity to practice filtering out information from unreliable sources and synthesizing information from legitimate ones.[76] Once they know where to look for legitimate information, students can use the Internet as a reference source in countless ways.

Beyond its pedagogical potential, there are many other ways that technology can affect education. Teachers can use it to develop and share best practices. For example, the Ontario Ministry of Education created the *e-Learning Ontario* website to host instructional and professional development resources in an interactive platform.[77] Similarly, Singapore teachers use the *Networked Learning Communities*[78] and Shanghai, student teachers use *Teaching and Learning e-Portfolios* to develop their pedagogical, content and experience-based understanding.[79] Technology also provides greater opportunities to use student data for formative and summative purposes and to assess students' understanding in ways that harness MUVE environments and artificial intelligence. We discuss the assessment theme below.

There is broad consensus that technology holds great promise for education. It has not yet lived up to this promise, in part because teachers have not had the opportunity to learn to maximize its pedagogical value. Without direction, teachers tend to use it to mimic the transmission model. If students only use technology to listen to lectures, read text, and regurgitate information to their teachers, they encounter all of the pitfalls we have discussed throughout this paper (That said, an electronic version of the transmission model at least minimally allows students to become familiar with computer hardware and software, a skill in itself).

9. Foster Students' Creativity

A common definition of creativity is "the cognitive ability to produce novel and valuable ideas."[80] Creativity is prized in the economic, civic, and global spheres because it sparks innovations that can create jobs, address challenges, and motivate social and individual progress. Like intelligence and learning capacity, creativity is not a fixed characteristic that people either have or do not have. Rather, it is incremental, such that students can learn to be more creative. In contrast to the common misconception that the way to develop creativity is through uncontrolled, let-the-kids-run-wild techniques—or only through the arts—creative development requires structure and intentionality from both teachers and students and can be learned through the disciplines.[81]

Many of the teaching strategies we discuss in this paper are indirectly critical to developing students' creativity. Creativity grows out of intrinsic motivation, which relevance fosters.[82] If students find lessons relevant to their lives, they are more intrinsically motivated to learn and use their newfound knowledge and understanding creatively. Therefore the science-of-learning lesson about the importance of making lessons relevant to students also applies to developing students' creativity. When students frame their ability to learn in a positive light and view failures as learning experiences, they are more open to developing creatively.[83] Therefore the science of learning lesson about developing students' positive (incremental) mental models also applies to developing their creativity. Learning and practicing disciplinary skills like problem posing and solving, transfer, complex communication, and familiarity with a given knowledge base can also develop creativity.[84] For example, when students are asked to pose a scientific problem and design their own experiment to test it, they must use their understanding of the knowledge base and creativity to come up with an interesting problem and successful design. Therefore the science-of-learning lesson about learning through the disciplines is yet another strategy that applies to students' creativity development.

Teachers can also directly enhance students' creativity by encouraging, identifying, and fostering it.[85] Encouragement helps students to develop positive mental models about their ability to develop their creativity. Identifying creativity can help students to recognize their own creative capacities when they might not otherwise. And like metacognition, teaching directly about the creative process and what animates or suppresses it contributes to creative development.

While there are common elements across cultures, there are variations in the spectrum of conceptualizations of the meaning and value of creativity.[86] For example, some cultures tend to view creativity as having societal and moral values, while others perceive creativity as focusing more on the individual. In another conceptual dimension, a survey of more than 400 students from China, Japan and the U.S. found that students from all three countries valued novelty and usefulness in their conception of creativity.[87] Chinese students, however, were more likely to respond positively to novelty than American or Japanese students. For Japanese and American students, perceptions of usefulness had a bigger influence on their conception of good creativity than for their Chinese counterparts. Fostering and teaching creativity should account for these cultural differences.

Science of Learning Lessons as 21st Century Skills

As mentioned in the introduction to the nine science-of-learning lessons, five of the lessons—transfer, metacognition, teamwork, technology, and creativity—help students to learn 21st century skills and are also 21st century skills in themselves. They are not included in all definitions of 21st century skills, though in this paper we attempt to make a strong case for why they should be. We now turn to the question of assessment of 21st century skills.

Assessing 21st century Skills

21st century skills are more challenging to teach and learn and they are also more difficult to assess. Designing tests that measure lower-order thinking skills like memorization is straightforward in comparison to measuring skills like creativity, innovation, leadership, and teamwork. In this section, we first explain the two main purposes of assessment and how they relate to teaching and learning 21st century skills. We then highlight several challenging issues that educators and policy makers must consider as they develop 21st century assessments. Finally, we provide several examples of assessments that measure complex skills and of initiatives that are currently addressing the challenge of assessing 21st century skills. These examples support our conclusion that though the assessment challenge is substantial, it is not insurmountable.

Formative and Summative Assessments

Like teaching for lower-order skills, both formative and summative assessments play useful roles in teaching for 21st century skills. Formative assessments remind students of their learning goals, give them feedback about their progress and misunderstandings as they learn, guide them to shift course as they need and are a critical part of the learning process. In fact, the importance of formative assessment to the learning process could even be a tenth lesson from the science of learning! The *Teaching for Understanding* (TfU) curriculum framework to which we refer earlier in the paper emphasizes the need for ongoing formative assessment from teachers, peers, and students themselves to help learners recognize what they are doing well and where they need to focus more effort. The formative assessment process generally does not involve others beyond teachers and students.

Summative assessments give students the opportunity to demonstrate what they understand at a given point in time. They are useful to certify students' achievements, for example, to assign grades, determine level of preparedness for further study, or award diplomas. They are also useful to measure teachers', schools' and systems' performance for accountability and improvement purposes. The TfU framework recommends that summative assessments take place through an activity referred to as *performances of understanding*. Through the performance of understanding, a student demonstrates that he or she understands a topic and can apply the learning to different situations. There are many ways for students to demonstrate their understanding. They could debate about an issue related to a generative topic from a certain perspective and then from another. They could apply what they learn about literature to their own creative writing. They could use what they learn about the scientific method to develop their own experiment. The list of examples is endless.

The benefit of performance of understanding-type summative assessments is that they provide students and their teachers with an excellent sense of the extent to which students truly understand and can apply what they have learned. However, they pose several challenges, especially in comparison to multiple-choice tests of students' lower-order thinking skills. The first challenge regards who administers the assessment. Teacher-administered summative assessments require high levels of teacher capacity, professionalism, and social trust in teachers. On the other hand, sophisticated summative assessments of 21st century skills that are administered at the district, state, or national level are costly to manage and mark, requiring high levels of expertise, time, financial resources, and inter-rater reliability. [88] The second challenge is that summative assessments often serve several purposes, including certification, accountability, and as a way to determine where to allocate resources. This is a challenge because assessments of performances of understanding—like most summative assessments—are not designed to serve all of these roles. Third, given their purposes, summative assessments and results need to be standardized so that they can serve as a common metric. This standardization of tasks and marking criteria is particularly challenging when the assessed skills are sophisticated.

Examples of 21st century Assessments

Though the task is challenging, there are many examples of tests in current wide scale use that measure students' 21st century skills through disciplinary-based performances of understanding that are standardized with common metrics. In an internationally administered example, the PISA test requires students worldwide to demonstrate their mathematical, language, and science understanding through tasks that require analysis, reasoning, and complex communication skills.[89] The tests are paper- or electronically-administered and include a mix of multiple-choice and open response questions. In an example of a multiple choice mathematics question, the students must interpret a graph of the speed of a racing car along a three- kilometer track as a function of the distance the car has proceeded along the track. The corresponding set of questions asks students to 1) estimate distance from the starting line to the beginning of the longest straight section of the track, 2) note the point at which the slowest speed was recorded and 3) assess the acceleration or deceleration of the car between the 2.6 and 2.8 kilometer marks. In an example of an open-ended mathematics question, students see a map of Antarctica and a scale in kilometers and must estimate Antarctica's area using the map scale, showing how they made the estimate.[90] Both questions require that students draw upon their mathematical skills and knowledge to transfer critical thinking and problem solving skills to a new situation with which they are most likely to be unfamiliar.

Many countries invest in syllabus-based summative assessments that measure the 21st century knowledge, thinking, and communication skills of large student audiences. College entry examinations in many countries including (but not limited to) China, Finland, France, Germany, Japan, and the UK use predominantly open-ended questions to measure students' sophisticated thinking and communication skills.[91] For example, in the UK, students usually take examinations in eight to ten subjects, each of which typically includes two timed written papers that students have about five hours to complete. The French baccalaureate examination is also based on a series of written tests spread out over four days. In Japan, students must take written examinations to enter high school and college. The high school examinations require students to complete examination papers in Japanese, mathematics, social studies, science and a foreign language. Students subsequently must take up to three examinations to enter college, which require students to synthesize knowledge and skills gained through their secondary disciplinary study.[92]

The International Baccalaureate (IB) Diploma Program assessment system is another example of an internally- and externally-administered summative assessment system that measures students' 21st century skills. To allow teachers to address students' local interests while still preparing students for a common assessment, the IB social science examinations require students to answer a few questions in considerable depth, yet give students choice among questions. For example, a recent IB history examination asks students to answer Section A, B, or C. Respectively, the three sections ask students to incorporate provided sources into sophisticated arguments about the Locarno conference, Arab-Israeli relations, and Communism from 1976-1989.[93] This freedom of choice on the examination provides teachers with the flexibility to address a few generative topics in great depth rather than scrambling for superficial coverage of many topics as a way of ensuring that their students will know at least a little bit about many topics the test might address.

Meeting the 21st century Assessment Challenge

Assessment is moving in the direction of harnessing technology to address the marking and standardization challenges.[94] MUVE programs like River City use technology to assess students' knowledge and skills in real time as they engage in the learning activity. Artificial intelligence tools are progressing to the point that they can assess students' open-ended answers as well or better than can humans. National governments and technology companies are investing billions of dollars into the development of valid and reliable technology embedded assessments of 21st century skills that do not need human scoring. For example, the National Project Managers in Singapore are building problem solving and information and communications technology (ICT) assessment tasks that will be embedded in ICT environments.[95] In 2010, the U.S. federal Department of Education allocated nearly $400 million to the Partnership for Assessment of Readiness for College and Careers (PARCC) and Smarter Balanced consortiums of twenty-four and twenty-eight states, respectively. Both are working to create assessments that use technology to measure students' 21st century skills and knowledge as they are detailed in the U.S. Common Core State Standards.

Given the intense focus on developing cost-effective, wide scale measures of students' 21st century skills and knowledge, the greatest challenge to transitioning away from the transmission model to the 21st century model may not be assessment. In countries that have yet to or are just starting to implement systematic teacher capacity reforms, the greatest challenge is likely to be that of ramping up curriculum and instruction capacity. Yet countries that have already devoted considerable resources to building teacher capacity might view current deficiencies in primary and secondary 21st century skills assessments as the key barrier.

Building the Capabilities to Teach 21st century Skills

From the local to international levels, progressing from the transmission model to the 21st century model has important implications for the entire educational system. Since education standards and the purposes of education are changing, curriculum frameworks and instructional methods must also change. Those changes in curriculum and instruction have many important human capital implications, including those related to teacher training, professional development, career mobility, and general cultural standing of the teaching profession. In this section, we address these human capital issues.

Researchers and practitioners agree that building an education system that focuses on 21st century skills requires a strong human capital base.[96] After all, teachers cannot teach 21st century skills through the disciplines if they themselves have only mastered basic lower-order thinking skills and do not have a strong disciplinary background! The logic is compelling.

A strong human capital base is essential, but it will take some countries time to increase the capacity of their teaching forces and to build social trust in their competence. To accomplish these ends, in addition to investing in the capacity of teachers who are now starting to enter the teaching profession, countries should also invest in building the capacity of current teachers to teach 21st century skills.

Developing Capacities of 21st century Teachers

Based on a review 2009 review of its teacher preparation system, Singapore confronted the challenge of developing 21st century teachers by establishing the Teacher Education Model for the 21st century (TE^{21}). Based on the TE^{21}, Singapore is implementing critical changes to curriculum, pedagogy, assessment, theory-practice linkages and physical infrastructure. Addressing the concern that teachers themselves need 21st century skills to teach them, the first of two pedagogical shifts is to increase "emphasis on self-directed, inquiry-based, real-world learning." (Lee, 2012)

Effective Professional Development Is Critical

The most critical area to invest in is high-quality professional development. Such training can help teachers to develop their facility with the kinds of instructional techniques we describe in this paper. The challenge is that not enough teachers currently have sufficient experience teaching 21st century skills to have developed the deep expertise needed to train others. As a result, much of the professional development for 21st century teaching has been disappointing. The results have been characterized as ineffective in the U.S. setting.[97]

Effective professional development to train educators to teach 21st century skills should rely heavily on the same processes that we have identified above as helping students learn. Teachers need time to develop, absorb, discuss, and practice new knowledge.[98] Activities need to be sustained and intensive rather than brief and sporadic.[99] Singapore's requirement that every teacher engage in 100 hours of professional development every year is thus consistent with these findings.[100]

Besides time, another key element of effective professional development for 21st century teaching is appropriate materials and activities.[101] Teachers learn most effectively when the training activities involve actual teaching materials,[102] when the activities are school based and integrated into daily teaching work of teachers,[103] and when the pedagogy of professional development is active and requires teachers to learn in ways that reflect how they should teach pupils.[104] Like students, teachers are less likely to change practice as a result of lower-order learning activities that occur via presentation and the memorizing of new knowledge.[105] Professional development is also more effective if teachers from the same school, department, or grade-level participate collectively.[106]

Thus, the type of teacher professional develop that best promotes changes in teacher practices that result in 21st century learning activities are those that mirror the activities for students we've outlined in previous sections: relevance of learning, opportunity to transfer learning to other contexts (including real world contexts), metacognition and reflection on what has been learned, and teamwork or collaborative learning activities. A key challenge is overcoming the traditional learning formats, such as one-time workshops and conferences, serving primarily as "style shows,"[107] that have dominated the profession and have resulted in little change to teaching and learning over time.[108]

> **Wide World: An Example of 21st century Professional Development**
>
> One example of professional development that builds teachers' 21st century skills is the online Project Zero-based Wide World (Wide-scale Interactive Development for Educators) which has worked with 6,000 educators world-wide to develop their understanding of the Teaching for Understanding framework and other teaching and learning concepts we describe in this paper. Wide World instructors train participating teachers to train their school-based peers so that the training eventually becomes self-sustaining.

Schools, as Organizations, Must Support Teachers' Professional Development

Sustaining teacher learning and making sure it is implemented in classrooms is a shared responsibility. While teachers must pursue ongoing professional development, schools also play a key role.[109] Teachers can struggle to implement new teaching strategies in their classrooms when school conditions are unsupportive. Particularly challenging conditions include lack of coordination and leadership, little collegial activity, and no obvious commitment to professional development.[110] Development of teachers' capacity to teach 21st century skills therefore requires attention not only to training, but also to school conditions that support the implementation of what has been learned.

Research on the Learning How to Learn project in England identified four organizational factors that enhance teachers' learning:

- Involvement of teachers in decision making
- Communication of a clear vision for learning
- Support for professional learning
- Networking support. [111]

In an example of a response to the need for supportive school contexts, the Ontario Ministry of Education created *Teaching-Learning Critical Pathway* and *Collaborative Inquiry* processes to foster collaborative planning and ongoing dialogue among teachers, principals and school board leaders.[112]

Schools Must Become Learning Organizations

Closely related to schools' support of teachers' learning through professional development, one of the five overarching lessons from the 2011 International Summit on the Teaching Profession was the need for the development of schools as professional learning organizations. Attracting and retaining effective 21st century teachers requires opportunities for continuous, high quality learning, career advancement and a seat at the table as reforms are discussed and adopted.[113]

Substantial research on the characteristics of learning organizations has identified the following critical processes and practices that promote such conditions for learning:

- Nurturing a learning environment across all levels of the school[114]
- Using self-evaluation as a way of promoting learning[115]
- Examining core and implicit values, assumptions, and beliefs underpinning institutional practices via reflection[116]
- Creating systems of knowledge management that leverage resources, core capabilities, and expertise of staff and pupils[117]

In their book, *The Intelligent School*, authors MacGilchrist et al. summarize the connection between organizational learning and individual learning this way: "A culture of inquiry and reflection pervades the intelligent school, and support for teachers' own learning is fundamental to this culture."[118] The fourth guiding principle of Hong Kong's Teacher Competencies Framework (TCF) reflects the need for this connection, "Schools should be developed as professional learning communities, teachers' professional development should be regarded as an important force in school development."[119]

Also consistent with this idea, the school system in Shanghai implemented professional development in 2008 to support teacher learning of 21st century competencies, placing an emphasis on schools becoming "cultures of thinking for teachers."[120] This culture of thinking is also common in Chinese schools where teachers have time to observe other teachers' classrooms regularly, and borrowing effective lessons is considered a form of creativity.[121]

Schools can play a substantial role in supporting teachers' learning. To do so, they must create continuous learning opportunities, promote inquiry and dialogue, encourage collaboration and team learning, and establish systems to capture and share learning. These activities not only help teachers, they also strengthen schools and mirror the teaching that best fosters student learning of 21st century skills.

Moving School Systems Toward 21st century Education

In this paper, we have explained why 21st century skills are important and summarized what the science of learning tells us about how best to teach and assess those skills, as well as how to ensure that school systems have the human capital to carry out this important mission. While there is some progress toward this goal, the remaining work will be demanding and complicated, and it will require precisely the sorts of skills that we deem critical for the next generation. If we believe that 21st century skills are the key to solving economic, civic, and global challenges and to engaging effectively in those spheres, then we must act upon the belief that using those skills to overhaul our education systems is possible.

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