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Urban Middle School Students, Twenty-First Century Skills, and STEM-ICT Careers: Selected Findings from a Front-End Analysis

Jonathan Cohen
Georgia State University

Maggie Renken
Georgia State University

Brendan Calandra
Georgia State University

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Abstract

As part of the design and development of an informal learning environment meant to increase urban middle school students' interest in technology-focused STEM careers, and to support their twenty-first century skill development, researchers developed and administered the ICT/Twenty-First Century Skills Questionnaire. Both STEM-ICT professionals and middle school students completed the survey. STEM-ICT professionals indicated that problem solving, critical thinking and communication were the most valued and the most frequently used skills in their environments. Students underestimated the

amount of critical thinking and systematic design, and overestimated the amount of coding and digital research that occurs in STEM-ICT workplaces. Among skills highly valued among ICT professionals, students reported significantly lower ability levels in problem solving, critical thinking, communication, use of technical systems and information literacy. The researchers discuss implications of this research on future curriculum and program design.

Keywords

Twenty-first century skills
Coding
Critical thinking
Digital research
ICT literacy
Information literacy
Middle school
Problem solving
Systematic design
Urban students

Increasingly, researchers, educators, governmental and non-governmental organizations are considering the role of twenty-first century skills in K-12 education (Adamson and Darling-Hammond 2015; Silva 2009). This recognition is derived in part from economic reports which link the development of these skills to the development of the modern workforce. For example, the World Economic Forum's New Vision for Education: Unlocking the Potential of Technology (2015) states:

> To thrive in today's innovation-driven economy, workers need a different mix of skills than in the past. In addition to foundational skills like literacy and numeracy, they need competencies like collaboration, creativity and problem-solving, and character qualities like persistence, curiosity and initiative. (p. 2)

There are a number of researchers and organizations who have delineated the component skills that make up a twenty-first century skill set (e.g., Griffin and Care 2015; OECD 2013; Partnership for 21st Century Learning 2015; World Economic

Forum 2015). Voogt and Roblin (2010, 2012) analyzed 32 such reports, and they found that there is general convergence on a core of these skills, including collaboration, communication, ICT literacy, social/cultural skills (including citizenship), creativity, critical thinking, and problem solving.

While some of these twenty-first century skills are unique to the current historical moment (for example, digital citizenship is a concept with which previous generations would never have had to grapple), others, such as creativity or collaboration are as old as humanity itself. Dede (2010) addresses this apparent contradiction by dividing twenty-first century skills into perennial skills and contextual skills. Perennial skills, he argues, are legacy skills, such as creativity and collaboration, which are not only particularly important in today's knowledge economy, but also becoming more complex. He uses the example of digitally mediated interactions between collaborators, who have to work productively even though they may be separated by great distances and may never have met face-toface. These perennial skills contrast with contextual skills, such as digital citizenship or information technology literacy, which are uniquely modern.

As the focus paid to twenty-first century skills is a reaction to the knowledge and information economies, and as digital technologies are the foundations of these economies, so does it follow that twenty-first century skills tend to be inextricably linked with digital technologies (e.g., Partnership for 21st Century Learning 2015; World Economic Forum 2015). Consequently, educational programs that aim to support development of students' twenty-first century skills should also take into account the role technology plays in such skill development.

The authors' interest in this phenomenon stems in part from their collaborative work on the Acquainting Metro Atlanta Youth with STEM (AMAYS) project, which includes the design, development, implementation and evaluation of an informal learning environment meant to increase urban middle school students' interest in technology-focused STEM careers, and to support their development of twenty-first century skills. This project goal is consistent with a broad-based, national agenda to increase diversity in STEM (President's Council of Advisors on Science and Technology 2010), and derives from a persistent gap between underrepresented groups and the typically male, white or ethnically Asian, and socioeconomically advantaged students who provide much of the input to the STEM pipeline (Anderson and Kim 2006; Blustein et al. 2013; Hernandez et al. 2013; Wang 2013).

One step the authors took in order to inform the AMAYS design process was to address the following questions:

1) What specific twenty-first century skills are valued by professionals, and used in technology-focused STEM workplaces?

2) What are urban middle school students' perceptions of whether these skills are used in the workplace, and of their own abilities in relation to these twenty-first century skills?

3) How do students' perceptions of these skills and their own abilities compare with the skills that are used and valued in technology-focused STEM workplaces?

The purpose of this article is to add to the literature on twenty-first century skills in K-12 education by providing some insight into how these skills are perceived in the workplace and by a group of traditionally underrepresented youth, and by presenting some rationale for design choices within our project and for others working in similar contexts. We describe briefly the instrumentation, methods for data collection and analysis, and results of an investigation guided by the questions listed above.

Methods

In order to measure a group of urban middle school students' perceptions of whether twenty-first century skills are used in the workplace, and of their own abilities in relation to these skills, the authors developed the ICT/Twenty-First Century Skills Questionnaire (ICT/21Q). The questionnaire was initially based on skills that had been identified in the literature as requisite of successful twenty-first century ICT workers. The development of this instrument proceeded in two steps: (1) a literature review to explore the various constructs associated with the domain of twenty-first century skills, and (2) construct validation via a group of ICT professionals.

First, the authors identified four major reports related to preparing students for STEM/ICT careers: New Vision for Education: Unlocking the Potential of Technology (World Economic Forum 2015), ISTE Student Standards (International Society for Technology in Education 2007), P21 Framework Definitions (Partnership for 21st Century Learning 2015), and Proficiency in Key Information Processing Skills among Working-Age Adults (OECD 2013). From these reports, the authors synthesized the various component skills, identifying 12 that were consistent across all reports: problem solving, critical thinking, communication, collaboration using technology, creativity, technology systems understanding, technology

applications understanding, information literacy, media literacy, coding, digital research and systematic design. The authors then developed two different questionnaires based on these 12 skills to administer to practicing ICT professionals. In the first section of the questionnaire, professionals indicated the extent to which they value each of the 12 component skills in themselves and their colleagues. In the second section, professionals indicated whether they or their coworkers used each of the component skills. Please contact the authors for copies of the questionnaire.

ICT professionals were invited to participate via their membership in a statewide technology association, which at the time had 475 active members. Of the 20 who responded, 75% reported working in management or senior management positions with job descriptions which included managing a STEM workforce development non-profit, implementing enterprise-wide corporate training, and strategic planning. Others reported working as outside consultants in technologyfocused industries. Sixty percent of participants were male. None of the participants identified as Hispanic/Latino, 65% identified as White/Caucasian, 25% as Black/African American and 5% as Asian. One participant did not indicate race.

Next, the authors administered the ICT/21Q to the students. The questionnaire began by providing definitions of each skill at a 6th grade (or lower) reading level, and asking students whether they believed ICT professionals used each of the 12 skills. Students were then asked to assess their own ability on each of the skills on a four-point Likert-style scale, with choices ranging from “I don’t do this at all” to “I’m very good at this.” “I don’t understand what this is” was also included an option.

A total of 183 students were recruited through an afterschool program at ten school sites to complete the ICT/21Q. Nine of the 10 schools were designated as Title I schools. Participants’ ages ranged from 11 to 15 (M (age) = 12, SD = 1). Selfreports of race indicated 82.4% of the sample was African American, 5.5% was Hispanic, 4.9% was Native American, 1.1% was White, and 6.0% reported other or preferred not to answer. Gender was unevenly distributed. Forty percent of the sample was male, 58% was female, and 2% preferred not to answer.

Results

Research Question 1

In order to answer research question 1: What specific (twenty-first century) skills are valued by, and used in technology-focused STEM workplaces? AMAYS researchers asked a group of STEM-ICT professionals which twenty-first century skills they

valued most, and which were most often used in their STEM-ICT workplaces. None of the ICT professionals answered, “I don’t understand what this is” for any of the dimensions.

Dimension	Min	Max	Median	Mean	SD
Coding	1	4	3	2.8	.95
Media literacy	1	4	3	3.05	.95
Systematic design	2	4	3	3.25	.79
Digital research	2	4	4	3.45	.76
Creativity	2	4	4	3.45	.69
Collaboration using technology	3	4	4	3.55	.51
Information literacy	1	4	4	3.55	.83
Understand technology apps	3	4	4	3.55	.51
Understand technology systems	3	4	4	3.70	.47
Communication	3	4	4	3.90	.31
Critical thinking	3	4	4	3.95	.22
Problem solving	4	4	4	4	0

Value The median response was 4 (strongly value) for all of the dimensions except coding, systematic design, and media literacy, whose median responses were 3 (value) on a 1–4 scale. (See Table 1 for descriptive statistics.).

Table 1

ICT/21Q professionals questionnaire descriptive statistics for value ratings on each dimension

Of the 12 component skills, problem solving, critical thinking, and communication were strongly valued, almost universally, Across the three dimensions, each respondent strongly valued problem solving, one respondent indicated “somewhat value” for critical thinking and two respondents indicated “somewhat value” for communication. Coding, media literacy and systematic design were the least strongly valued by the sample, though the mean rating for each of these dimensions falls at or above the “values somewhat” rating.

Respondents were given the opportunity to write in any other skills they valued. The only skills included more than once in this item were variants on skills that were redundant to those the questionnaire had already asked about, namely collaboration,

independent/critical thinking and communication. Many of the other responses to this item were character traits, such as humility and compassion, or skills researchers deemed not to be twenty-first century skills, such as grammatically correct writing and time management.

Use The survey then asked the ICT professionals to identify which of the 12 component skills they use or observe others using in their workplaces. As a followup, for each skill used or observed, respondents were asked how frequently they used/observed the skills, with "rarely" scored as 1 and "every day" scored as 4. The use ratings correspond with the value ratings. Each (100%) of the ICT professionals reported either using or seeing their colleagues using problem solving, critical thinking, and communication, with frequency ratings at 3.9, 3.8 and 3.9 respectively. The dimensions scoring lowest on the use ratings were coding, media literacy, and systematic design, with only 50%, 61% and 67% of the respondents respectively reporting that either they or their colleagues use those skills in their work.

Research Questions 2 and 3

Encouraged by these results, we gauged student perceptions of the selected skills by developing and distributing the ICT/21Q student questionnaire. This was in part in order to answer the questions: What are middle school students' perceptions regarding specific twenty-first century skills in the workplace and their abilities in relation to these skills? and How do students' perceptions of these skills and their own abilities compare with the skills that are used and valued in technologyfocused STEM workplaces?

Students were asked to rate their own ability with each of the 12 component dimensions of a twenty-first century skill set using a Likert-style scale, with 1 denoting "I don't do this at all", 2 denoting "I'm not good at this", 3 denoting "I'm pretty good at this" and 4 denoting "I'm very good at this". Students also could indicate "I don't understand what this is" for any of the dimensions. (See Table 2 for descriptive statistics.).

	N	Mean	SD	Doesn't understand	% Doesn't understand
Coding	183	2.55	1.1	25	13.7
Systematic design	183	2.9	1.06	18	9.8
Critical thinking	183	2.96	0.96	10	5.5

Information literacy	91*	3.02	0.99	6	6.6
Digital research	183	3.11	0.98	11	6
Use of technology apps	183	3.14	0.9	9	4.9
Media literacy	91*	3.18	0.91	4	4.4
Problem solving	183	3.19	0.79	9	4.9
Collaboration using technology	183	3.23	0.9	12	6.6
Use of technology systems	183	3.26	0.83	10	5.5
Communication	183	3.31	0.83	7	3.8
Creativity	183	3.6	0.73	7	3.8

*Because we had concerns that information literacy and media literacy may be difficult skills for students to conceptualize, we developed and implemented 2 forms of the ICT/21Q: a simple form and an expanded form. The simple version defined and asked about information literacy and media literacy holistically, whereas the expanded version broke information literacy into 3 dimensions (i.e., find information online, evaluate information, and attribute others' work) and media literacy into 2 dimensions (i.e., make media and media awareness). Having the two forms allowed us to assess students' understanding of the holistic dimensions. Subsequent analysis indicated that the measure is acceptable for use in its simple 12-item, rather than expanded, form. Responses from those who completed the simple form are reported here

Table 2

ICT/21Q student questionnaire descriptive statistics for ability ratings on each dimension

Because the ICT/21Q was derived from the questionnaire delivered to ICT professionals, we were able to compare students' responses on the items to the answers provided on both the use and value items by the ICT professionals. On the use items, students answered how often they thought professionals use a given skill, while professionals answered how often they (or their colleagues) use a given skill. These use items' responses were dichotomous and dummy coded as 1 = on, 0 = off. We assessed differences in what skills students expect professionals to use and what professionals report using with Chi-square tests of 2 (use) × 2 (population) contingency tables for the 12 skill dimensions. A Chi-square test is appropriate for determining group differences when outcome data is categorical. Analysis revealed that students' expectations of use were statistically significantly different than professionals' reporting of use on 4 skill dimensions: critical thinking, coding, digital research, and systematic design (see Fig. 1). Specifically, students

overestimate the use of coding and digital research in IT professions and underestimate the use of critical thinking and systematic design.

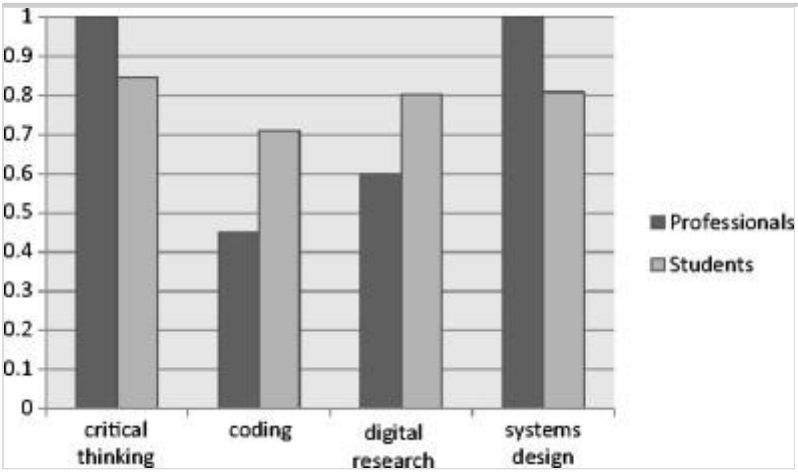


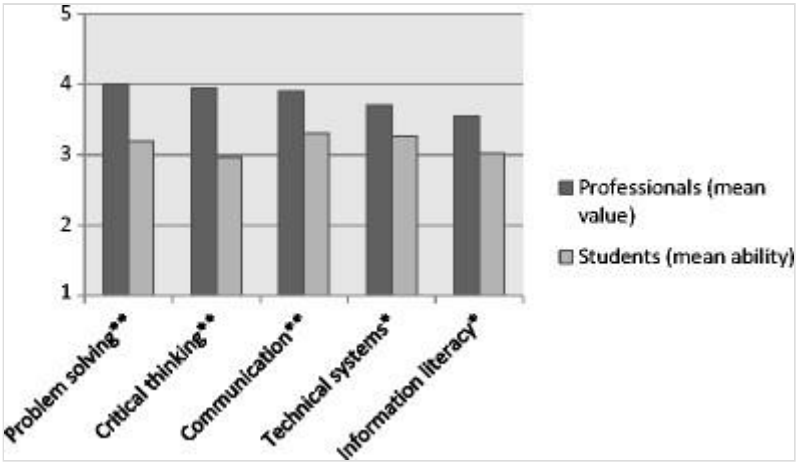
Fig. 1

Proportion of professionals versus proportion of students who reported use or expected use of the four skills on which professionals and students differed at a statistically significant level

We also were interested in how the students' perceptions of the importance of the various skills measured compared with the ICT professionals' valuation of those skills. Students' perceptions and ICT professionals' valuations were not normally distributed. Because the assumption of normality required by a traditional t-test of independent samples was not met, we used a Mann-Whitney U-test of independent samples with unique variances (Ruxton 2006; Zimmerman 1987). Analysis revealed that how strongly professionals value a skill differed from how strongly students rate their ability with regard to that skill on five dimensions: problem solving, critical thinking, communication, technical systems and information literacy. On highly valued skills among ICT professionals, including problem solving, critical thinking, communication, use of technical systems and information literacy, students rate significantly lower ability levels (Fig. 2).

Fig. 2

Students' reported mean ability paired with professionals' mean value of five skills for which mean responses were statistically significantly different. *Mann-Whitney U-tests of mean differences indicate the means differed at the p = .05 level. **Mann-



Discussion

Whitney U-tests of mean differences indicate the means differed at the p = .001 level The 20 ICT professional who responded reported that they valued and used twentyfirst century skills that are technology focused, such as the ability to use technology applications and work with technology systems. But, to the same extent, ICT professionals also indicated that non-technology-focused skills, such as problem solving, communication and critical thinking, were equally as valued in their ICT workplaces, and were used as much as the technology-focused skills, something that seems to be in agreement with the literature on 21st skills reported here (Griffin et al. 2012).

It is also notable that, while still reported as somewhat valued and used, coding was the least valued and used of the twenty-first century skills included in the ICT professionals survey. There is an increased focus on coding in education (Google Inc. and Gallup Inc. 2016), and while the authors are in no way trying to argue against this focus, our data also suggest that a small sampling of ICT professionals valued and used a wider range of skills beyond coding where they worked.

Based on this data, one might begin to infer that technological acumen may not be the sole factor contributing to success in these STEM-ICT workplaces (OECD 2013). Although much broader sampling of a much larger group of professionals is definitely in order, it may be incumbent upon educators and curriculum designers to create learning experiences that develop both technology- and non-technologyfocused twenty-first century skills. Problem solving, critical thinking, communication, and information literacy for example, were areas which were highly valued by ICT professionals in this study, and yet they were areas in which the students surveyed in this study reported low levels of ability.

Indeed, when comparing student and professional responses collected in this study, important interpretations may be drawn about these particular students' perceptions of the skills necessary to participate in the ICT workforce. First, when compared to reports from the ICT professionals, these students underestimated the use of critical thinking and systematic design in favor of more technical skills such as coding and digital research. Second, student participants in this study reported low selfperceptions of their problem solving, critical thinking, communication, and information literacy abilities. These skills were all highly valued among management-level ICT professionals surveyed in this study, and are consistently pointed to as necessary elements to addressing the ill-defined challenges facing the modern workforce (Griffin et al. 2012; OECD 2013). Again these findings inform possible points of emphasis in curricula targeting ICT skills that are relevant for workforce development, but also suggest further research might be in order, especially considering the national (if not global) push towards producing a twentyfirst century ICT workforce. This gap also represents an opportunity for curriculum designers to develop activities that can be more targeted towards the types of skills that could provide students with greater opportunities for success in technologyfocused STEM careers.

The sample populations, which were relatively small and limited to a particular geographic region, are a limitation of this study. All of our student participants were members of a single large urban school district, and all of our ICT professional participants were members of a single statewide technology association. Samples from other states with different technology economies could produce different results. Similarly, the majority of our ICT professional sample represented those in management roles. This likely has an impact on the types of skills valued and observed. Future research should include pools of ICT professionals in a variety of positions. Finally, the response rate for ICT professionals in future studies should be higher.

Notwithstanding these limitations, the results reported here provide context for curriculum designers, instructional designers and other stakeholders who shape the focus of STEM-ICT curricula. The authors hope they have also generated questions and presented limitations that can drive further research. Finally, within the professional population we surveyed, there was near consensus on which twentyfirst century skills were most strongly valued. However, the middle school students who were surveyed had misconceptions and misgivings about the same skills. Moreover, for five of these skills (i.e., problem solving, critical thinking, communication, use of technical systems and information literacy) a statistically significant difference existed between the extent to which the professionals valued these skills and the students'

perceptions of their own abilities with these skills. This at the very least should be cause for future work, and as part of a front-end analysis, it has influenced the design of the AMAYS project.

Compliance with Ethical Standards

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Conflict of Interest The authors declare that they have no conflict of interest.

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