Computational Thinking for the Rest of Us: A Liberal Arts Approach to Engaging Middle and High School Teachers with Computer Science Students

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Abstract: Recruiting talented college students remains a significant problem because of difficulties relating and connecting their knowledge with wider audiences. We implemented over the past two years Google Computer Science for High School (CS4HS) workshops with computer science students, faculty, and middle and high school teachers. Computer science students developed hands-on programming lessons using Scratch Programming and App Inventor, presented these lessons during most of the sessions, and participated in a panel discussion about computer science at the middle and high school levels. We evaluated the effectiveness of our workshops through teacher and student surveys. In the short term, students highly valued the opportunity to enrich their education and found our efforts to be socially meaningful. In the long term, our goal is to create a feedback loop where students train teachers in computational thinking, thereby helping them in turn mentor future computer science students.

Introduction

According to the U.S. Bureau of Labor Statistics, "among all occupations in all fields of science and engineering, computer science occupations are projected to account for nearly 60% of all job growth between now and 2018" (Lacey & Wright, 2009). However, the 2010 Computing Research Association (CRA) Taulbee Survey of Ph.D. granting universities states that the percentage of Black and Hispanic computer science Bachelors degree recipients is 3-fold less than their representation in the U.S. population. Women of all ethnic groups are very significantly underrepresented at only 11% (Zweben & Bizot, Betsy, 2012).

While causes for these disparities are debated Beyer, Rynes, Perrault, Hay, & Haller, 2003; Katz, Allbritton, Aronis, Wilson, & Soffa, 2006), one may be a lack of mentors and role models to encourage these students early in their learning. Since Wing's seminal papers on computational thinking (Wing, 2006, 2008), many approaches have applied that framework to new studies and workshops. The most obvious opportunities are in math and science courses, but Lu and Fletcher argue that scholars in the social sciences and humanities are discovering that computing processes can advance their disciplines too (Lu & Fletcher, 2009). Settle et al. suggest that modifying the K-12 curriculum to include a stronger emphasis on computational thinking will make a bigger impact on computational competency (Settle et al., 2012).

A program that has seen large success in introducing computer science concepts to precollege level teachers is the Google CS4HS program (http://cs4hs.com) that began at Carnegie Mellon University in 2006. The program now includes workshops in the US/Canada, Europe, Asia, Africa, and Australia. Previous workshops have predominantly focused on middle and high school mathematics, science, and technology teachers (Ahamed et al., 2010), and recently started working on a more broad-disciplined approach (Perković, Settle, Hwang, & Jones, 2010; Settle et al., 2012).

Historically, large research-focused state universities that are well-known for science and mathematics education provide most of the STEM graduates. However, we argue that the potential for growth in smaller liberal arts universities may be largely underestimated, and they could in fact contribute to the greatest increase in STEM graduates by attracting students across disciplines using computer science as a bridge. Our approach appeals to the liberal arts ideals of service and educating the whole person. At most universities, such as ours, there are generally few opportunities for STEM students to present their domain knowledge to the general public, and these valuable experiences are not part of a standard STEM curriculum.

In response to these pressing issues, we set out to start annual summer workshops to assist middle and high school teachers incorporate computational thinking in their curriculum. In addition, since on average 84% of public school teachers are female (Feistritzer, 2005), we sought to recruit teachers as role models for encouraging underrepresented minorities early on in their education. By involving computer science students as mentors during the workshops, we seek to create a *feedback loop* where students train teachers and teachers mentor future computer science students.

Background and Context

University and Computer Science Department Profile

Wake Forest University is a liberal arts university with a predominantly undergraduate population of about 4,800 students. Similar to other small, liberal arts schools, our student/faculty ratio of 12:1 encourages one-on-one interactions and student-professor intellectual collaborations. The faculty are called to a "teacher-scholar ideal" dedicated to excellence in both teaching and research. The students do not select a major until their sophomore year in order to receive exposure to a wide range of academic subjects in the humanities and sciences. Historically, Wake Forest University's liberal arts tradition has attracted students more inclined towards the humanities and service and less towards STEM subjects.

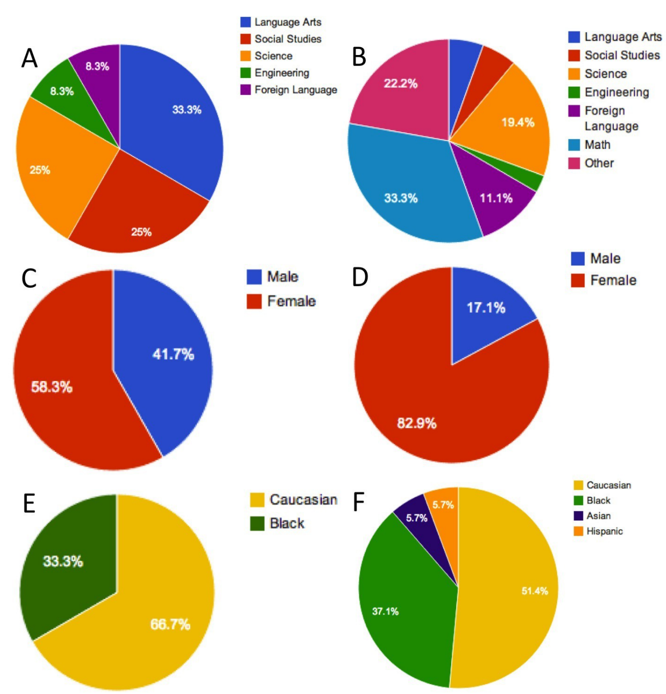

Figure 1: Demographics of the computer science students who helped organize and presented in our workshop during the first year (left column) and the second year (right column). Their rank (A,B), genders (C,D), and ethnicities (E,F) are shown.

Our computer science department consists of 12 research professors and 1 instructor, with about 60 undergraduate and 10-15 graduate students. The student demographics are similar to most other computer science departments in that a large majority are Caucasian or Asian males with 18% female and 3% Black or Hispanic students. Interdisciplinary research projects currently funded by external agencies are in the areas of network and computer security, digital media, advanced imaging, and computational biophysics and biology. Three faculty have joint appointment in two departments, and they have a track record of recruiting students for interdisciplinary research from several other departments including physics, chemistry, biology, mathematics, and economics to name a few.

Student Volunteer Profile

To assist in the development of our workshops, we enlisted 7 high school, undergraduate, and graduate student volunteers in the first year and 10 in the second year. Four students from the first year volunteered again for the second year, and the rest of the students could not volunteer again because they had graduated or otherwise moved on. Each of the students had at least some experience in computer programming, but they also included research students who were authors in peer-reviewed publications. None of the students had previous experience with outreach programs to teach computer science to a general audience.

In both years, at least half of the participants were undergraduate students, and the gender balance was about equal. In the first year, there was only one underrepresented ethnic group (Hispanic) among the student volunteers, and in the second year, there was one Hispanic and one Black student (Figure 1).

Year 1: Pilot Workshop for Middle School Teachers

In the first year, to gauge interest in a teaching workshop on computational thinking, we contacted and visited Hanes Magnet School, a middle school in North Carolina about four miles from Wake Forest University's main campus. Hanes Magnet School serves grades 6-8 in an economically and culturally diverse population. It has a magnet program with enrollment that ranges from the academically highly gifted to ethnically diverse students who live in very economically disadvantaged situations (29%). Currently, the student population is 47% female, 21% Black, and 11% Hispanic students. Computer science is not taught at the school, and students can only take AP Computer Science at the high school level in one location in the entire county. We presented our goals and objectives during a Hanes Magnet School faculty meeting and received commitments from 10 teachers on the same day.

A total of 12 teachers participated in our inaugural workshop (Figure 2A,C,E), and they included 7 women and 4 African-Americans, which are underrepresented groups in computer science. To encourage maximal participation, we opened up the workshop to any interested teachers. Interestingly, teachers from Language Arts (4), Social Studies (3), and Spanish (1) signed up, and the teachers of non-STEM subjects accounted for 2/3 of all teacher participants. The broad distribution of teaching backgrounds required us to develop a workshop that was widely accessible across disciplines.

Year 2: Expanded Workshop for Middle and High School Teachers

The following year, we expanded our program to include middle and high school teachers across Forsyth County, where Wake Forest University is located. We again targeted teachers in economically and cultural diverse populations and contacted teachers through a county-wide email. Restrictions were not placed on enrollment and the email targeted teachers interested in incorporating STEM concepts into their curriculum.

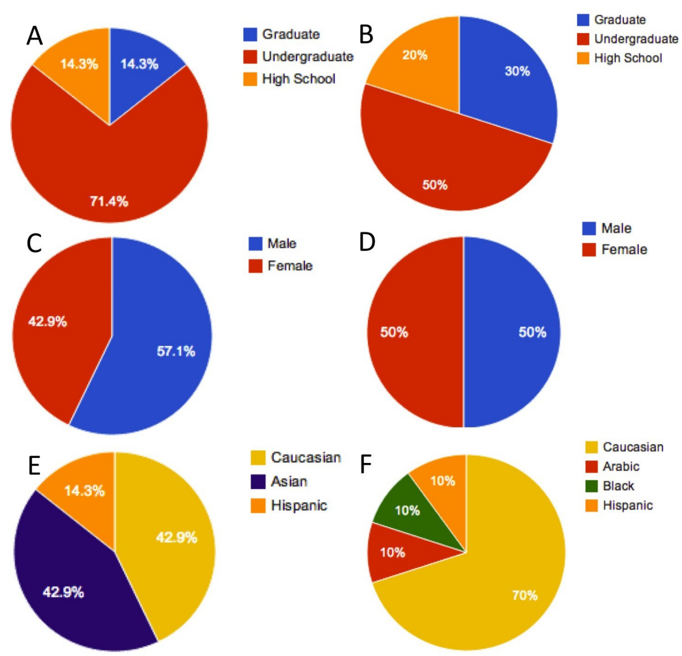

Figure 2: Demographics of the middle and high school teachers who participated in our workshop during the first year (left column) and the second year (right column). Their subjects taught (A,B), genders (C,D), and ethnicities (E,F) are shown.

In all, there were 35 teachers who participated in the second workshop (Figure 2B,D,F), including 5 teachers from our first workshop. A large majority (82.9%) of the participants were women, and 37.1% were Black. About 57% percent of teachers taught in STEM courses, but we also found significant representation in other disciplines such as social studies, language arts, foreign language, and others that are not typically associated with STEM subjects. Although there was a significantly higher representation of teachers from STEM subjects, computational thinking was clearly appealing to teachers across many subjects. The broad distribution of subjects again required a workshop that was catered to the needs of many different disciplines.

Results

Workshop Overview

The workshops were held over the course of two days in both years. A modest stipend and meals were provided for the teachers. The main theme of both workshops was computational thinking as a skill benefitting everyone across disciplines. The goals of the workshop as presented to the teachers were 1) to improve the societal perception of research and job opportunities in computer science, 2) to prepare teachers to become effective role models for computational thinking, and 3) to help integrate computational thinking into their curricula.

With these goals in mind, we developed brief presentations highlighting key concepts of computational thinking (abstraction, automation, and analysis) (Wing, 2008) as applied in topics including error detection, data representation, binary search, and the knapsack problem. The bulk of the workshop involved hands-on activities using Scratch (http://scratch.mit.edu) and App Inventor (http://appinventor.mit.edu) that enabled teachers to develop interactive lessons in their own fields relating to some aspect of computational thinking. Our student volunteers worked in groups three weeks prior to the start of each workshop to develop these presentations and hands-on activities. During the workshops, students also gave the presentations, led the hands-on activities, and actively assisted teachers with developing their interactive lessons.

	Year 1			Year 2		
Statements	Before	After	Change	Before	After	Change
Computer science jobs are mainly programming positions.	2.50	1.67	-0.83	2.35	1.80	-0.55
Computer science is mainly focused on problem solving.	3.92	4.56	+0.64	4.15	4.24	+0.09
Computer Science requires a strong foundation in math.	4.17	2.67	-1.50	3.56	2.86	-0.70
Sending email and browsing the internet are fundamental computer science skills.	3.33	3.00	-0.33	3.09	2.35	-0.74
Computer Science jobs are often solitary and involve very little social interactions.	2.75	1.44	-1.31	2.03	1.24	-0.79
Computer Science graduates typically do not advance to higher management positions.	2.08	1.56	-1.24	1.50	1.43	-0.07
Men outnumber women in the computer science field.	4.67	4.22	-0.45	4.26	4.43	+0.17
Computer science is not as important to society and business as other disciplines.	1.50	1.22	-0.28	1.59	1.19	-0.40

Table 1: Pre- and Post-Workshop surveys given to the teachers at the very beginning and end of the workshop in each of the two years.

Perceptions of Computer Science: Pre- and Post-Workshop Surveys

For both workshops, the teacher participants were surveyed at the beginning and at the end of the workshop. To measure the change of their perceptions of computer science as a result of the workshop, we applied the Likert scale (1=Disagree, 5=Agree) to a set of statements about computer science (Table 1).The greatest differences were seen in the statements regarding the mathematics background requirements (Year 1, Year 2) (-1.50, -0.70), the degree of social interactions of computer scientists (-1.31, -0.79). The smallest differences were seen in statements regarding whether computer science was important in society relative to other disciplines (-0.28, -0.40) and the gender (im)balance of men and women in the computer science field (-0.45, +0.17).

Presentations and Activities

After each activity, the teachers were asked to fill out an online survey using a Likert scale applied to the single statement: "This session was helpful for incorporating computational thinking in my classroom." (Table 2) We also gave the teachers an opportunity to qualify their answer with an open comment. The surveys were administered anonymously through Google Forms on the workshop website and teachers accessed it through laptops provided to them during the workshop. Teachers used these laptops throughout the day for the hands-on activities as well as for filling out surveys periodically. Although survey participation was nearly perfect in the first year, the response percentage in the second year with more participants ranged from about 60-100% per survey with an average of 76%, even with reminders.

	Year 1	Year 2
Topic	Usefulness	
History of Computer Science	4.32	4.21
Computer Science, Unplugged	4.45	4.15
Scratch / App Inventor	4.54	4.45
Research Talks	4.20	4.09
Student Panel Discussion	4.67	4.20

Table 2: Evaluation survey results for each section of our workshop over two years.

In all cases, presentations and activities were found to be helpful for incorporating computational thinking in their own classroom, with every session receiving an average Likert value of above 4.0. The Scratch and App Inventor sessions were the only sessions consistently ranked very high, with a Likert value of about 4.5. Although a significant amount of time was devoted to presentations, in this paper we focus our discussion on the development and impact of the Scratch and App Inventor sessions.

First, the development of hands-on activities was a challenging but rewarding experience for the student volunteers. They prepared Scratch and App Inventor "lesson plans" with very little input from the faculty organizers. They were instructed to discuss and develop a Scratch and an App Inventor program that they thought would be educationally valuable to the teachers. In addition, the lessons had to relate to current middle and high school education standards and be doable in roughly 30-60 minutes by our broad teacher audience. Simplicity and user friendliness of their programs, fundamental concepts in software engineering, were challenging but practical issues they had to grapple with in preparing their lessons.

Second, the finished lessons listed computer science topics and the North Carolina Essential Standards that were addressed, creating a mapping for the teachers between computational thinking topics and educational goals. The lesson plans were structured so that a teacher could start the relevant Scratch or App Inventor activity under our supervision and finish/extend the lesson in their own time. Final completed programs were made available in the website for teachers to get a glimpse of the final product. This approach encouraged teachers to be creative in their own implementations of the lesson plans.

Lesson plans developed by the students and their corresponding Scratch and App Inventor programs are freely available online on the workshop website: http://cs.wfu.edu/ct/index.html. They include story-telling between two interacting characters, a music video, a Spanish vocabulary quiz, a presentation of historical Civil War battles, a FOIL calculator, and an interactive quiz to illustrate the water cycle. All other presentation material are also freely available from the workshop website in editable formats such as Word and PowerPoint.

Post-Workshop Teacher Follow-Up

Although the teacher participants consistently evaluated the workshop presentations and activities as very useful for their classrooms (see Table 2), a post-workshop survey follow-up was necessary to determine accuracy of self-reporting. It is well-known that the teachers' enthusiasm at the immediately conclusion of a workshop is high since they are receiving a stipend to attend a professional development workshop organized by highly motivated professionals (Bort & Brylow, 2013). In addition, to encourage the teachers to follow through with the intentions to include computational thinking in their

Are there any specific needs that you would require to implement a computational thinking lesson?	Percentage
Extra hand in the classroom	45%
Co-teacher	30%
Technical assistance outside of the classroom to prepare lesson	70%

Table 3: Implementation and needs survey given to teachers after three weeks when the school year had started.

curricula, we administered a survey identifying challenges and barriers that would keep them from successfully making this happen. This survey was sent out about three weeks later after the workshop ended.

Initially, over 20 teachers signed up for additional support during the workshop, but only 11 participants submitted requests to receive additional support three weeks after the workshop. Forty-five percent of those respondents teach high school and 54% teach middle school. When asked to describe the type of support that is needed after the workshop, nearly half of the respondents indicated that they needed an "extra hand in the classroom" and 30% wanted someone to co-teach a lesson or activity. Most of the respondents (70%) also requested support outside of the classroom to prepare lessons and/or app for students. For this question, the teacher could select multiple responses.

Student Discussion Panel

At the end of each workshop, we asked a panel comprised of all student volunteers a series of questions. We saw this as an opportunity to get an inside view of the students' backgrounds and motivations. These questions and answer were given over both years and the answers are summarized here.

Moderator: Why did you choose Computer Science?

Many cited a professor in college or similarity to other interests such as science, mathematics, logic, and problem solving. Experience with a robotics or technology course was also mentioned. They also cited the prevalence of computer in society and employment opportunity.

Moderator: What type of classes or skills might have encouraged you towards computer science?

Most students did not take a formal computer science class before entering college. Only one student volunteer (across the two years) had taken an AP computer science class, and some of the other students took a keyboarding, technology, or robotics elective.

Teacher: Why do you think computer device exposure has not made a significant impact on your career decision?

Three students thought that although computer and technology is widely accessible for usage, the learning environment was not amenable for deeper understanding of computational thinking concepts to create their own programs. They also cited robotics and other technology classes as having been recently introduced to the precollege levels, and not necessarily available to them when they were in middle and high school.

Teacher: What kind of class do you think should be offered in middle and high schools today?

The students generally agreed that giving students the opportunity to develop their own programs through an environment such as Scratch or App Inventor would make a big difference for most students with an inclination to technology. They wished they had taken a robotics, app development, video game development, website development, or other technology design class. They also advocated open-ended assignments that foster creativity. The female students also discussed that social applicability of computer science could be important for drawing other female students into the discipline.

Student Survey

About three weeks after the conclusion of the second workshop, we surveyed the student volunteers to evaluate how participation in the workshop contributed to their knowledge of computer science, problem solving skills, ability to communicate, experience working in teams, and career goals. We also asked the students whether they would recommend the workshop to their peers and whether they found the workshop to be worthwhile. We again applied the Likert scale using an anonymous online survey (Table 4). We were able to receive a response from all of the student participants over the two years except for one from the first year.

Each statement was given a strong agreement by the students, but the lowest values were given to statements regarding to 1) their knowledge of computer science, 2) their problem solving skills, and 3) whether the workshop contributed to their career goals, but they were still ranked highly. In all other statements, the students agreed with a Likert scale for at least 4.5. The students agreed most to statements on whether 1) the workshop positively contributed to their ability to communicate with others, 2) they would recommend the workshop to their peers, and 3) they found the workshop to be worthwhile.

Statements	Responses
Participation in the workshop positively contributed to:	
my knowledge of computer science.	4.17
my problem solving skills.	4.17
my ability to communicate with others.	4.75
my experience working in teams.	4.33
my career goals.	4.33
I would recommend the workshop to my peers.	4.58
Overall, I found the workshop to be worthwhile.	4.92

Table 4: Post-workshop surveys given to the computer science students at the end of the second workshop.

Discussion

To incorporate computational thinking skills into the existing curricula of middle and high school teachers in a broad spectrum of disciplines (Figure 2), we enlisted computer science students volunteers (Figure 1) for annual two-day computational thinking workshops, carried over the last two years. Teachers, whether in STEM areas or not, could be effective role models and mentors for future potential computer science students, particularly those from underrepresented groups in computer science. To train these teachers, the student volunteers were given key roles in developing and presenting Scratch and App Inventor lesson plans throughout most workshop sessions. Students were also key participants in our panel discussion.

Both students and teacher participants found the opportunity given to students to relate and connect their knowledge with a wider audience to be rewarding and enriching. The students gained valuable experience communicating their knowledge to a lay audience as well as from working in teams. Overall, they also found their experience to be valuable and worthy of sharing with their peers (Table 4). Teachers explicitly stated both informally and in surveys how much they enjoyed interacting with the students and learning from them. For some teachers, they enjoyed seeing a student they taught in their own classroom “grow up” to teach them computer science.

We also note that the demographics of the student participants (Figure 1C,D) with respect to gender were very different from that of our computer science department. The female student participants stated that they were drawn to the workshop because of the societal applicability aspects of our program, and their participation in our workshop may be a significant contributor to the successful and effective participation of the teachers. They recommended in a student discussion panel that middle and high schools introduce and promote technological and design courses that encourages creativity, open-ended projects, and societal applications. Despite the relative simplicity and accessibility of Scratch and App Inventor, the most frequently cited need from the teachers after the workshop was technical assistance (Table 3).

Conclusions

We have presented the results of two annual Google CS4HS workshops for training middle and high school teachers from multiple disciplines to incorporate computational thinking concepts into their existing curriculum. Student volunteers were active participants with key roles in our workshop, and they developed lesson plans, presented, and participated in a student panel. Our long-term goal is to create a feedback loop in which students act as mentors to train teachers and who in turn serve as role models to future potential students in their own classrooms. Our survey results show high teacher and student enthusiasm during the workshop. This enthusiasm continued for the students but quickly dropped off for most of the teachers after the workshop. Many of the results and strategies we used to incorporate students into our workshop as active participants could be general and replicable in similar liberal arts universities.

Future work

Although we have already started post-workshop follow-up efforts to keep track of the effectiveness of our workshop as described above, we anticipate that there will be significant challenges for effective implementation by teachers in their own classrooms. Unfortunately the current teaching environment does not generally reward innovative teaching approaches. The most effective way to ensure that the teachers continue incorporating the skills they learned from our workshop may be 1) to continue post-workshop interactions to identify and address barriers and challenges they face in their classrooms and 2) to include their administrators and team leaders in future workshops. Several of the teachers commented in their surveys and informally that administrators need to learn about the workshop and may be able to open doors and lower barriers in ways that are inaccessible to the average teacher.

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References

Ahamed, S. I., Brylow, D., Ge, R., Madiraju, P., Merrill, S. J., Struble, C. A., & Early, J. P. (2010). Computational thinking for the sciences: a three day workshop for high school science teachers. In *Proceedings of the 41st ACM technical symposium on Computer science education* (pp. 42–46). New York, NY, USA: ACM. doi:10.1145/1734263.1734277

Beyer, S., Rynes, K., Perrault, J., Hay, K., & Haller, S. (2003). Gender differences in computer science students. In *Proceedings of the 34th SIGCSE technical symposium on Computer science education* (pp. 49–53). New York, NY, USA: ACM. doi:10.1145/611892.611930

Bort, H., & Brylow, D. (2013). CS4Impact: measuring computational thinking concepts present in CS4HS participant lesson plans. In *Proceeding of the 44th ACM technical symposium on Computer science education* (pp. 427–432). New York, NY, USA: ACM. doi:10.1145/2445196.2445323

Feistritzer, C. E. (2005). *Profile of teachers in the US: 2011*. National Center for Education Information.

Katz, S., Allbritton, D., Aronis, J., Wilson, C., & Soffa, M. L. (2006). Gender, achievement, and persistence in an undergraduate computer science program. *SIGMIS Database*, *37*(4), 42–57. doi:10.1145/1185335.1185344

Lacey, T. A., & Wright, B. (2009). Employment outlook: 2008-18, Occupational employment projctions to 2018. *Monthly Labor Review*, 82–133.

Lu, J. J., & Fletcher, G. H. L. (2009). Thinking about computational thinking. In *Proceedings of the 40th ACM technical symposium on Computer science education* (pp. 260–264). New York, NY, USA: ACM. doi:10.1145/1508865.1508959

Perković, L., Settle, A., Hwang, S., & Jones, J. (2010). A framework for computational thinking across the curriculum. In *Proceedings of the fifteenth annual conference on Innovation and technology in computer science education* (pp. 123–127). New York, NY, USA: ACM. doi:10.1145/1822090.1822126

Settle, A., Franke, B., Hansen, R., Spaltro, F., Jurisson, C., Rennert-May, C., & Wildeman, B. (2012). Infusing computational thinking into the middle- and high-school curriculum. In *Proceedings of the 17th ACM annual conference on Innovation and technology in computer science education* (pp. 22–27). New York, NY, USA: ACM. doi:10.1145/2325296.2325306

Wing, J. M. (2006). Computational thinking. *Commun. ACM*, *49*(3), 33–35. doi:10.1145/1118178.1118215

Wing, J. M. (2008). Computational thinking and thinking about computing. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *366*(1881), 3717–3725. doi:10.1098/rsta.2008.0118

Zweben, S., & Bizot, Betsy. (2012). *2010-2011 Taulbee Survey: Continued Increase in Undergraduate CS Degree Production; Slight Rise in Doctoral Production*. Retrieved from http://cra.org/uploads/documents/resources/taulbee/CRA_Taulbee_2011-2012_Results.pdf