A Computer Science Curriculum for Waldorf Schools

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In today's world, children encounter an unimaginable wealth of technological opportunity. While there are ample opportunities to passively consume the products of technology, as educators we want our students to stand in the world as active creators, able to direct technology rather than being ruled by it and to use technology's power to create changes that matter in the world.

The following is an attempt to describe an age-appropriate sequence of activities, skills, and knowledge that the authors have been exploring with grade school students in Waldorf settings. We begin by describing the principal themes that we believe are appropriate and important to cover in the upper elementary school. We then present feasible topics organized by grade. The curriculum we are advocating is intended to deconstruct what appears as magical technology into its constituent parts and to help children achieve the freedom and power to use these creatively to construct new things. Our goal in this article is to outline best practices for introducing technological concepts to and cultivating abilities in upper elementary school students, grounded in our experiences over the last five years.

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Major Topic Areas

Upper grade school students are very interested in learning about the technological phenomena of our age: music players, computers, the internet, etc. As these technologies are being adopted at home, at school, and in society generally, it is critical to demystify computers. However, much of modern technology is too abstract to be fully understood in the experiential form that supports creative inquiry and production in the upper grades elementary school years. Students should leave elementary school with a solid understanding of technology, including the languages used to communicate through technology, the importance of precision, and the long life of information posted online. Students should develop an understanding of the limitations and unforgiving nature of technology as well as its power for good. We focus on four main topic areas:

Communication: The wish to communicate is one of the most basic drives that define humanity, and many of our inventions and technologies have been concerned with communication, from the earliest spoken and written language through the printing press, telephone, internet, email, texting, and social networks. Students benefit from learning about the relationship of technology to communication, as well as the limitations inherent in this relationship. This requires exploring the acts of representing and conveying information, the potential for and correction of errors, the issues of privacy and encryption, and so on.

It is extremely important for upper elementary school students today to become more conscious of their communication and its consequences, both in person and on social media. Schools—including, in our own experience, Waldorf schools—are confronted with problematic online behavior, such as the viewing of pornography, the posting of ill-advised emails or social media as early as fifth grade, and excessive game-playing and binge watching as early as seventh grade. Preparing students for technologically mediated communication has become a task of our times. The permanency of content and lack of privacy, the social consequences of online behavior, and the appropriateness (and hurtfulness) of personal communications should continue to be addressed. The existence of incorrect, inappropriate, and potentially even illegal online information should be faced—students will most likely be encountering it at home and sharing it with one another.[1]

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Physical sciences: Electromagnetic circuitry underpins much of today's technology. The physical underpinnings of the interface between technological devices and the world (namely, the flow of input, or sensing, and output, or actuation) are at the focus of study as the curriculum moves into explaining how technology works. This begins by exploring the simplest possible signals (such as a switch or an LED light). Depending on the time available, lessons can broaden the scope to include more complex inputs (such as keyboard, mouse, microphone, or camera) and outputs (such as mechanical actuation). Students at this age are excited to learn how the devices so pervasive in modern life actually function. By moving these devices from the realm of semi-magical influences to the realm of practical understanding, we help to shift the balance of power from device to student.

Logic: During their upper elementary school years, students awaken to their powers of logical thinking. It is important to teach students how to think through questions logically and to articulate the steps of a process carefully. This is the essence of programming, employing a logical procedure to empower students to create something useful, new, fun and relevant. After learning to make visual depictions of the flow of decision-making, students can begin to translate these flow charts into the language of computers. Conversely, learning to analyze a problem and find a structured solution path can also provide insights into broader areas of problem-solving.

Crafts: The ability to find practical solutions to real-world problems can be extended by acquiring technical facility with new tools. In the context of technology, computational crafting opens students to the possibility that technology can be part of something beautiful, functional, and material, and that automation can support the creation of beauty and artifacts of practical use in the world. Solving such "functional design problems helps learners develop intricate inquiry skills that include an iterative feedback loop of observation, hypothesis generation, hypothesis testing, and evaluation of solutions."[2]

Practical Skills

By the end of elementary school, students should have learned to type and to make use of vetted online databases for reports.

Research skills: In the upper elementary school, it is important to introduce research skills in a supervised fashion. The challenge here is to first build an understanding of reliable sources, authorship, and fair use in printed works, and then to expand this understanding to online materials, particularly the ability to recognize reliable information online.

Typing: By gaining skill in touch typing before using a keyboard on a regular basis, good habits will be established. Given the prevalence of keyboard use today, many grades schools will need to include typing at some point in the curriculum.

Computing at Home and at School

By seventh or eighth grade, computers are occasionally used for homework in some schools, and students in group projects may coordinate the use of computers/social media. It is therefore important to formulate clear rules and foster informed choices about the appropriateness of device use at school and at home for school work.

Students and teachers can together reflect on how easily devices affect the quality of time spent on a task and how easily the use of these devices can become addictive. It can be helpful to view a movie treating themes such as screen hygiene and risks, bullying, inappropriate content (such as pornography), and online safety, then follow up the screening with discussions of these themes.[3] These topics can also be addressed when studying health and physiology: There is, after all, a physiological component to addiction and a neurological basis for mental distraction.

Teachers and parents may also want to explore these issues together. Older parents who did not grow up with these technologies, may not have the same degree of personal experience as do teachers, who have watched the use of technology accelerate over years and across several generations of children by now. Given the speed at which technology changes, the experiences parents had a generation ago will not be the same as those of their children today.

A Suggested Lesson Plan

It can be challenging to find appropriate ways and times in school to introduce technological concepts. We offer here one set of suggestions based on our experience, our recognition of what children are exposed to today, our understanding of child development, as well as published research on children and technological readiness.[4] Whether a Waldorf school has a high school or not may also influence when some of these concepts are introduced; for example, schools that end in eighth grade may find themselves introducing certain topics earlier, so that their students are prepared for the expectations of the high schools they will attend. We look forward to further refining and expanding this curriculum.

FIFTH GRADE

At this age, students are not yet ready for an advanced exploration of technological themes, but they are certainly encountering computers in various forms (and at the very least seeing adults use them). Thus, it is important to begin the process of demystifying the world of computing.

The ideas below can all be addressed in one to three lessons. If only one can be addressed, we would suggest the communication topics.

Logic: The notion of an algorithm can be previewed by having students write out a sequence of practical instructions, e.g., cooking recipes.

Craft: The usual fifth grade handwork project, knitting a sock, directly connects measurement with creativity in a very concrete way. If students measure the foot of the person for whom the sock is intended, knit a swatch, and then use this to calculate the number of stitches per row required, they experience the practical use of logical reasoning and the relation between specification (and specification errors) and outcomes that will ultimately reside at the core of understanding technology.

Communication: At this age, students enjoy making "secret languages." In this context, the number systems of e.g., Babylonia, Egypt, and China can be introduced as the "secret number systems" of these cultures, while binary numbers can be introduced as the "secret language" of computers. Listening to a fax machine is one way to make this experience concrete.

Alternating between these different ways of representing numbers helps students understand the challenges faced by any communication between cultures, including the challenges encountered by a person instructing a computer to act. This also raises the potential for misunderstanding (error) when encoding and decoding. A concrete example of encoding is the way checksums of ISBN numbers on books are calculated and used to prevent errors.

Due to the likely use of smart phones, digital readers, and other internet-enabled devices by students of this age, now is also the time to begin raising awareness among parents and students about some of the risks and serious potential problems that students may face when going online.

SIXTH GRADE

Sixth graders are ready for a higher level of abstraction and are better able to generalize relationships. Concepts relating to engineering and logic can reflect this readiness and prepare the groundwork for computational concepts in later years.

As with fifth grade, each of the topics below fits into one to three lessons and is ideally presented in connection with the existing curriculum. Among the topics below, logic and communication should get priority.

Physical sciences: The science and technology of ancient cultures are simple enough that sixth graders can readily understand them. Key examples: Heron's primitive steam engine, Archimedes' host of intriguing machines for defensive warfare and efficient spiral water pump, and Roman central heating, road construction, and water-transport technology (gravity-fed piping, aqueducts).

The physical science curriculum of this grade provides an essential basis for work in later grades with electrical circuits and computing. In the geology block, students should experience magnetic rocks (magnetite) and explore basic phenomena of magnetism. Students can experience how to induce static electricity using amber, as discovered by Thales (*elektron* is Greek for "amber"), and other materials. The study of warmth can include a demonstration of bimetallic strips curling in response to temperature variation and their use in thermostats.[5]

Communication: The phenomenology of perception, a central theme of the year, includes the way we synthesize successive images into a smooth flow (for a project, see "Craft" below). It is a small leap from perception to representation. Curating a grades school bulletin board provides an opportunity to explore communication in practice and to begin reflecting on what should and can be shared publicly, and how to use different media to do so.

Since online activity is likely to be increasing among the students at this age, this is the time to begin talking about issues such as the spread and permanency of online content and the ease with which online communications may offend. (see endnote 1: *The Cybercivics Curriculum*)

Craft: It can be valuable if the craft curriculum takes up the central study of this year's physics block: investigations into perception. This can happen either in craft lessons or in the form of a science fair. Animations can be created using flipbooks, by making a stroboscopic disk/zoetrope, or stop-motion photography using movable figures out of clay or Legos in front of drawn or painted backgrounds. Students are delighted to discover that the same principles employed in these activities are used in film and video.

The creation and assembly of a physical object also allows students to learn about design, the importance of precision, working in teams, breaking something up into steps, and the importance of checking and rechecking measurements.[6]

Logic: Sixth graders, like the Romans, are very interested in efficiency! Determining how to approach tasks efficiently can be both fun and practical. Examples include the most efficient way to find an entry in an alphabetized reference work (which can lead to the idea of a binary search) or to sort a group of items (for example people by height or first name).[7] In math instruction, formulas can be presented as ways of making efficient calculations.

SEVENTH GRADE

Seventh graders today are beginning to have an awareness of the social influences of computation, just as their social lives are changing dramatically. In addition, it is likely that they have already or will soon begin to make regular use of online communication. Finally, seventh graders are ready for task-based, step-by-step logical and causal thinking.

The seventh grade curriculum is more expansive in its scope than the lessons of the earlier grades. Though some of the themes can be treated as add-ons to existing topics, a semester-long class on technology is ideal at this stage. We suggest priority be given to working with circuits (the underlying basis of computers), either Scratch programming or a Rube Goldberg machine (both of which offer the experience of translating an algorithm or process into a realized project), and treating the social consequences of online communication.

Physical sciences: In the mechanics main lesson, students should not only learn how simple machines revolutionized medieval technology, but also how the water wheel and windmill offered vastly greater power to drive these technologies. An upper elementary school science fair gives space for autonomous exploration within a structured curriculum, providing a healthy acknowledgment of students' increasing capacities for thoughtful experimentation. The electricity and magnetism curriculum should lead to simple, parallel, and serial circuits using switches and bulbs or LEDs. This can be expanded, if time is available, to include mechanical actuation, e.g., of motors. The concepts of input from the world (sensing) and output to the world (actuation) follow naturally.

Logic: After drawing constructions (e.g., using the Golden Section and Fibonacci sequences), students can attempt to precisely describe the process they employed. This gives an experiential basis to what will later become algorithms using repetition (loops) and decision-making (conditionals).[8]

There are ways of programming computers that do not require technical expertise and are thus accessible to this age group. It is possible to introduce at this age a block-based graphical language such as Scratch (see the eighth grade curriculum below for a fuller explanation of this system).

One way to explore the difficulties and potential of designing a simple user interface is to ask students to design an interactive electronic invitation to the school's May Fair. Students learn how to transform a design concept into something they can express in Scratch. They then test it with their peers and observe the inevitable gulf between their concept and what they can express in the program itself and the experience of someone using the program. After this feedback is incorporated into an improved design in an iterative process, the invitation can be shared with the school community. With such a project, students learn much about the inherent difficulties of making something real with technology and the necessity of being aware of the end-user experience.

Craft: Sewn circuit crafts provide an opportunity to begin experimenting with representing, capturing, and displaying information; possible projects include creating a bookmark that also functions as a book light, a bike glove that can signal a turn, or a sparkling bracelet.[9] Rube Goldberg machines[10] that incorporate simple machines or circuits provide an exciting way for students to apply these concepts.

Communication: During the Wish, Wonder, and Surprise block, students can be asked: Which gives us more new information—something surprising or something unsurprising? The potential for error (and error correction) during communication is also relevant, as is the wish for privacy and therefore encryption. These ideas set the stage for regarding computers as creative tools shaped by people, demystifying technology, and illustrating the large gap between human methods of communication and what computers can understand.

At this age, when the peer group begins to take paramount importance in a child's life, it is time to discuss how to communicate in a socially appropriate manner, including a description of the bully-victim-bystander triad, and how communication via social media can magnify many social problems. This tender subject needs to be addressed at two levels: first, to raise awareness of each individual's role in social interactions; second, to raise awareness of how much more serious, more permanent, and more widely disseminated hurtful comments can be when made over social media. As students spend increasing time online, the topic of balancing screen time and non-screen time becomes relevant.

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The content of the classroom bulletin board might be expanded in seventh grade to include essays and poetry reflecting the internal world of the children or news reports about the school and its community. Students are also ready to understand that language, number, image, and even musical notation are all abstract representations of information, and they are also open to exploring how difficult it is to ensure that interpersonal communications accurately reflect their personal experiences.

Related biographies: Inspiring biographies at this age include those of Leonardo da Vinci, who developed a mechanical lion that walked across a stage, and Blaise Pascal, who developed one of the first calculators to help his aging father, a tax collector, with his accounting. The story of Martin Luther and his use of media provides a relevant illustration of the way information was disseminated in the early modern age.[11] This is also a time to consider how different kinds of communication technologies can help address perceptually grounded disabilities. Case studies, such as the very positive impact of pagers on the deaf community, may be appropriate here.

EIGHTH GRADE

Eighth graders are interested in modern developments, many of which postdate the formation of the Waldorf curriculum. The study of Revolutions should extend beyond the Industrial Revolution to include more recent technical innovations—power sources, computers, robotics, the internet, mobile devices—and their impacts on society, manufacturing, and the environment.

We envision a modern technology curriculum that provides a historical and experiential view of these concepts. Chief areas include: more efficient tools (steel plow, treadle spinning wheel, flying shuttle loom), new power sources (water, wind, steam, electricity, and batteries), and automated control systems (computers, robots, computer-controlled manufacturing technologies such as 3D printers, and laser cutters), new communication technologies (telegraph, telephone, radio, movies, the internet, mobile devices, and social media).

The eighth grade curriculum should bring students up-to-date on technological and social developments. Ideally, an entire main lesson course is devoted to technology. Priorities include binary numbers, practical skills, programming, communication, and the technical and social consequences of the Information Revolution.

Computing: Students at this age are interested in the internal workings of computers. Basic concepts to cover include:

Binary Numbers: Computers work in binary, and the relationship of binary numbers to encoding information provides an understanding of the internal operation of computers.

Physical Components: Computers have hardware for memory, computing, and so on. Students can begin to explore what is happening in a computer by assembling a calculator, PC, or other computational device from components. (There are many kits available.)

Algorithms: Many programs are based on solutions to classic algorithmic problems. Algorithms such as search, sort, path finding, or distributed networking can be understood by acting them out in the classroom.[12]

Input, Output, and Feedback: Positive and negative feedback are fundamental to automation (and are also very prevalent in nature and ecology). Positive feedback loops, which tend to be dangerous, are exemplified by what happens to the noise level at a big party when each person speaks louder, forcing others to also speak louder. The interrelationship of carbon dioxide and global warming is a contemporary example. Negative feedback loops, in contrast, tend to be helpful: They keep our bodies and houses at a stable temperature. James Watts' steam engine governor, which kept the speed of the engine constant, was an ingenious use of negative feedback in the early Industrial Revolution, while electromechanical thermostats (the little round ones that used to be ubiquitous) use mercury switches and bimetallic strips to keep the temperature of a house in a constant range.

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Programming: Students can learn to write their own computer programs. There are three main approaches to introducing programming:

- Plug-and-play graphical programming languages such as Scratch,[13] which invite the student to quickly create an interactive result. If this was already introduced in seventh grade, in eighth grade students could build on this experience by incorporating input from a camera or keyboard and thus explore feedback loops. Students may also design more complex algorithms.
- A simple, easily-learned coding language such as Python, offering the possibility of a programming curriculum that continues into high school. This is the most general-purpose approach, but also requires patience, accuracy in formulating (and typing!) expressions, and teacher experience.
- Microprocessors, such as the Raspberry Pi, that offer a direct experience of computer hardware (buttons and lights; see the craft project described below) on a manageable scale. This gives the students the most direct experience of the steps by which a computer actually operates and of feedback loops employing a wide variety of sensors; it also requires a teacher who has some experience with the Unix operating system and with electrical circuit design. Great teacher resources[14] are readily available.

Combining craft with logic: By combining programming with building, students can give a computer an ability to sense (input) and act (output). Inputs can be expanded to include a keyboard, mouse, microphone, or camera, and output can be expanded to include lights, motors, etc. Possible projects include: translating text to Morse code using sound or blinking lights and creating an adaptive circuit, such as a light that brightens as the surroundings darken, as a book light might. A fan-powered car might combine a 3D-printed fan model, engineering, and circuitry (and would also require feedback loops, if the students wished to program it to go a certain distance when signaled with a button press).

Precision in measurement, an age-appropriate goal, is critical for technology. For example, 3D-printers, which extend the printing press' capacity for replication to three-dimensional objects, depend upon precise measurement. This is still a very experimental technology that can be difficult to maintain, but there are many examples of students making use of them when in-house expertise is available. One of the most compelling applications is the creation of prosthetic hands for children with limb differences. This presents an opportunity to combine craft, mechanics, and physiology, as well as social engagement.[15]

Communication: The printing press could be considered the opening salvo in the Information Revolution. Undertaking interviews and publishing a school newsletter can help students understand print media — journalism, in particular. Many revealing insights can be found by comparing the experiences of writing in a private journal, posting on a public bulletin board, publishing an article (e.g., in a newsletter), and posting on electronic media.

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The social and hygienic issues arising from students' expanding activities online should be addressed this year, as well. In addition, online behavior should be addressed in the school's sexual education curriculum.

The telegraph, radio, television, and internet (including email and social media) are progressive discoveries of how electricity can transmit information and how each has wrought important and transformative (even revolutionary!) effects on society. The history of the internet and email is fascinating: This began through collaborations between scientific and university centers and the need of the US Defense Department for a distributed communication system to be resilient against attacks. It was never expected to expand to its present scale.

Practical skills: Students can begin to search online sources, perhaps within quality databases suitable for the specific subject, and determine their trustworthiness. Public librarians can be an excellent resource for this kind of research. If students are using email, it is critical that they are introduced to concepts such as phishing, scamming, and spam, and that they are taught how to recognize and avoid them.[16]

Biographies: Biographies can illuminate both the technical developments of the computer age and the social issues arising from these developments.

Technical Developments

Pascal's mechanical calculator and Charles Babbage's mechanical computer are early examples of how human thought processes can be "incarnated" into technological devices. Ada Lovelace, who collaborated with Babbage in developing the capacities of the new instrument, introduced the idea of a sequence of procedural steps, or *algorithm,* to accomplish a task.

The development of computation and cryptography during World War II is a fascinating subject. Alan Turing envisioned a general-purpose computing machine, proposed the Turing Test, and worked at the codebreaking center at Bletchley Park in the UK.[17] Admiral Grace Murray Hopper, a leader in the development of early programming languages and related tools, significantly advanced techniques of programming during that same era.[18]

Related Social Issues

There are numerous important social issues connected to the rise of computers. First of all, computers are innately amoral: that is, they are incapable of making moral judgments, which means that the responsibility for their use falls directly upon us, their creators and users. This is true of all science and technology. For example, many jobs, especially those based on repetitive manual tasks, are disappearing. What is the responsibility of a society and its technological innovators to predict and to alleviate the consequences of such changes? Technology can have positive results, as well. Stephen Hawking is a moving example of the way new technologies can enable a person to overcome a physical disability.

New technologies raise new ethical concerns. Examples can be given of unauthorized persons who gained access to information that was intended to be secret. Publication of such information can have significant social consequences. Students learn a great deal from wrestling with the consequential moral questions surrounding the activities of individuals such as Julian Assange and Chelsea Manning, organizations such as WikiLeaks and the NSA, and laws (e.g., the Patriot Act) enacted for the enhancement of homeland security.

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Diversity is another pressing social issue which can be studied with respect to the use and creation of technology. The importance of women's early contributions to computing can be highlighted through the stories of Ada Lovelace, who is celebrated as the first programmer, Admiral Grace Murray Hopper, and the early NASA engineers whose story is told in the film *Hidden Figures* (Dir. Theodore Melfi, 2016).

Activists such as Richard Tapia and Anita Borg have worked to improve the relatively low level of social diversity within the field of computing. Other contributors include Brenda Laurel and her pioneering work in making games girls want to play and Leah Buechley and her innovations in electronic textiles, which she showed are accessible and appealing to women and girls.

Putting Technology Education into Practice

The curriculum laid out above is organized around our students' needs and opportunities. Some parts of this curriculum require technological tools (and someone who can maintain and understand them) as well as guidance and training for teachers.[19]

Many tools and sample curricula are readily available. The Computer Science Unplugged curriculum[20] offers a very accessible set of lesson plans for introducing computational thinking to upper elementary school children without any screen time.[21] The Computer Science Teachers Association has published a series of essays on K-8 learning opportunities[22] and an excellent reading list of relevant research[23] (especially for girls[24]). Specific projects can be found in books such as *Sew Electric* (which has projects such as an LED bookmark book light, a sparkling bracelet, and an interactive stuffed monster) and the *Invent to Learn Guide to 3D Printing in the Classroom.* (Projects include making custom tangrams, a fan- powered car, a two-gear clock, and connectors for the creation of three-dimensional polyhedra.)

Popular computational environments include Alice[25] (a virtual world programming environment with low barriers to entry, which can be used to do project-based science and math,[26] narrative design[27] or even social science[28]), Scratch[29] (a graphical programming environment with very low barriers to entry and a large community of learners who share programs), and Lego Mindstorms[30] (a robotic construction + programming kit). Easy environments which provide embedded curricula include Gidgets,[31] a game which teaches programming and debugging. The E-nable community foundation[32] has created a curriculum around the creation of prosthetic hands.[33] The online Python Tutor[34] lets you experiment with and visualize code.

ENDNOTES

1 The *Cybercivics Curriculum* (www.cybercivics.com), designed for sixth to eighth graders, addresses social issues arising from the use of digital media.
2 Kafai, Y., Fields, D. & Searle, K. "Making connections across disciplines in high school e-textile workshops," in L. Buechley, K. Peppler, M. Eisenberg & Y. Kafai (eds.), *Textile messages: Dispatches from the world of e-textiles and education* (Peter Lang 2013), Chapter 6, p. 85.
3 The film *Screenagers* (Dir. Delaney Ruston 2016) is suitable for this purpose.
4 Duncan, C., Bell, T., & Tanimoto, S. "Should your 8-year-old learn coding?" In *Proceedings of the 9th workshop in primary and secondary computing education* (2014), pp. 60-69, dl.acm.org.
5 See Michael Seifert's online physics curriculum at www.waldorfteacherresources.com.
6 One of the authors had students build a 3D printer from a kit and then use it to print parts for a mechanism (see the e-Nable curriculum: http://enablingthefuture.org/e-nabling-education-%E2%80%A2-curriculum-and-resources/). Through this, they learned to see how an object can be visualized in layers and generated through motion in orthogonal (x-y-z) coordinates.
7 The CS Unplugged curriculum (www.csunplugged.org) offers age-appropriate exercises introducing topics such as binary numbers, searching and sorting, path-finding, and distributed networking.
8 In after-school clubs, one of the authors has helped students of this age to create simple programs that control a circuit or produce a 3D model.
9 Sewn-circuit projects can be found in the book and website *Sew electric*, Leah Buechley, Kanjun Qiu, and Sonja de Boer (HLT Press, 2013), www.sewelectric.org, and in many online sources.
10 www.rubegoldberg.com
11 See this NYT article comparing Luther's skill to that of today's Twitter users: www.nytimes.com/2016/10/30/arts/design/long-before-twitter-martin-luther-was-a-media-pioneer.html
12 See The CS Unplugged curriculum: www.csunplugged.org.
13 Scratch.mit.edu
14 www.raspberrypi.org/learning/teachers-guide/
15 The e-nable community has developed an extensive, field-tested curriculum around this opportunity (http://enablingthefuture.org/e-nabling-education-%E2%80%A2-curriculum-and-resources/), and provides much support as well.
16 Anti-Phishing Phil is a game that covers some of these concepts: www.ucl.ac.uk/cert/antiphishing/
17 *The Imitation Game* (Dir. Morten Tyldum, 2014), a movie about Alan Turing adapted from Andrew Hodges' biography *Alan Turing: The enigma*, is appropriate for eighth graders.
18 Useful biographies can be found in Steven Levy's *Hackers: Heroes of the computer revolution* (Garden City, NY: Doubleday, 1984), which also provides a helpful introduction to the history of personal computing, and Howard Rheingold's *Tools for thought* (www.rheingold.com/texts/tft/).
19 Op. cit., Duncan, Bell and Tanimoto.
20 http://csunplugged.org/
21 An example can be seen at https://www.youtube.com/watch?v=WforXEBMm5k
22 https://csta.acm.org/Curriculum/sub/CurrFiles/CS_K-8_Building_a_Foundation.pdf
23 https://csta.acm.org/Curriculum/sub/CurrFiles/K-8CSReadingList_Research.pdf
24 http://www.jstor.org/stable/4137437
25 http://www.alice.org/
26 http://www.cs.duke.edu/csed/rodger/papers/cse12.pdf
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32 http://www.enablecommunityfoundation.org/
33 http://enablingthefuture.org/e-nabling-education-%E2%80%A2-curriculum-and-resources/
34 http://pythontutor.com/visualize.html

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