Chapter 14

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# Technology Education for High-Ability Students

## Developing High-Ability Technologically Talented Teens

Best practices in education technology commonly view software and hardware as a means to improve learning and student engagement (Chen, 2010; Fadel, 2010). But there remains an aspect of technology in education that is largely unexplored and underutilized. What if students see technology itself as an opportunity for improvement? Rather than use what is given them, what if they design new technology?

## Beyond Using Technology to Creating Technology

Technologically adept teens not only consume technology voraciously; they create it. Gifted and talented students are attracted to technology for its capacity to transform learners from "receptacles of knowledge to active producers who direct their own learning" (Siegle, n.d.). Beyond the capacity to produce or innovate *with* technology is the opportunity to conceive and produce innovative technologies, a distinct type of tech giftedness (Siegle, n.d.) and the focus of the present chapter.

Technologically skilled teens have been doing this for some time, typically unassisted. It's not hard to locate the connections between Facebook, Google, and YouTube and their gifted creators. Mark Zuckerberg, Sergey Brin, and Steve Chen each participated in gifted programs as youth (Landau, 2010). Literature in this field comes mainly from the popular press; primary sources pertaining to elementary and secondary education are difficult to locate. At the present time, technology creation—to say nothing about its association with giftedness—remains the least documented member of the STEM family. There is a need to focus on current practices and resources that have effectively helped talented teens produce innovative technologies.

## Technology Innovation

Innovation, on the other hand, has been extensively researched. *The Innovator's Dilemma* (Christiansen, 2000), a leading text in this field, helps companies know when to abandon traditional business practices. Innovation applies to practically any human endeavor, including education (Chen, 2010). Innovation in education centers around abandoning traditional pedagogical practices in which students are held back by their dependency on being taught (Martinez & Stager, 2013). Consequently, new roles for teachers are envisioned.

For Marshall (2009), this "new breed" of STEM educators is future oriented and applications focused, adept at navigating, integrating, and synthesizing a broad spectrum of STEM disciplines, seeding and cross-pollinating ideas developed by scientists, researchers, engineers, inventors, designers, technology creators, social entrepreneurs, and policy strategists. This, along with constructivist practices that encourage students to take the lead, is an innovation vision for education. Marshall (2006) described a future learning landscape that looks little like schools today: an experimental laboratory, an interactive hands-on museum, an entrepreneurial think tank, and a reflective retreat center. Physical spaces that first appeared as business solutions to encourage innovation—design studios and incubators—indicate that the time is now for designing the next generation of schooling and learning.

Educational innovation takes two forms: sustaining and disruptive (Christiansen, 2010). Sustaining innovations improve existing practices (e.g., whiteboards replacing chalkboards). The latter is messier and may be harder to read, but in the end, whiteboard use is predominantly a tool for teaching. A disruptive technology, on the other hand, changes the ecosystem and roles. Putting a laptop in each student's hands transfers the locus of learning. Teaching and textbooks are no longer sole sources of information. This doesn't mean that technology alone is responsible for educational innovation. One-to-one programs may be poorly implemented; as Alan November (2013) cautioned: "Unless we break out of this limited vision that one-to-one computing is about the device, we are doomed to waste our resources" (p. 1).

The standard application of innovative education technologies, whether sustaining or disruptive, can easily become tool-centric. A balanced approach distinguishes between learners using tools and learners making new tools, which is an example of the disruptive application of innovative education technologies.

## Learning Opportunities: Curricular, Extracurricular, and Self-Initiated

To understand how self-taught, nascent professionals produce innovative technologies, this chapter documents a number of cases in which schools and adolescents have created opportunities to develop technology and are classified as *curricular*, *extracurricular*, and *self-initiated*. Curricular opportunities include academic courses; afterschool programs, clubs, contests, and camps are extracurricular. Internships may be either, even self-initiated. Arguably the most frequent opportunities are self-initiated; however, schools that recognize the need to encourage innovation and production are adding entrepreneurial methodologies to traditional course and program offerings (Bozzo, 2012).

Creating technology is an inherently entrepreneurial endeavor involving both creative risk and making interpersonal connections. Drawing from the French word *entrepren(dre)*, the "task undertaken" is the creative venture or risk in which adolescents produce new technology; thus, technology entrepreneurship involves more than the creation of new hardware or software for its own sake. Additionally, successful technologies provide solutions and support not only for their creators, but also for others. Although a fraction of the hardware and software created by talented adolescents may be intended for or destined to become a business, it is educationally viable to view the making of a new technology as entrepreneurial. Technology development follows essentially the same path whether or not a product is developed as a business. Sparking interest in entrepreneurship, *The Lean Startup* (Ries, 2011) described this creative process as iterative and interconnected, building, measuring, and learning, and without it, there would be no Facebook, Google, or YouTube.

This model of entrepreneurial development is both methodological and pedagogical because opportunities to create pass through stages that are a variation of the scientific method (see Table 14.1). Prior to the building stage, the innovator takes note of a problem that needs to be solved, which Kao (2007) described as "seeing problems as opportunities" and which Ries (2011) referred to as the "pain point." This is also the point at which the scientific method begins. Prior to building, technology entrepreneurs approximate the first three steps in the scientific model by observing people and practices in order to identify a problem or opportunity, proposing a probable solution, and creating a minimal viable product or service instead of a scientific experiment. Rather than a formal statement of the problem, the innovator thinks of a possible solution. It may be that others have already thought of a similar idea, so the innovator researches the competition and explores the uniqueness and feasibility of the idea. Next, the problem-solving idea is taken through a variety of "making" activities, such as sketching, designing, drafting, writing, coding, composing, and constructing.

For a lean start-up, the process is deliberately rapid and is intended to yield a result that can be evaluated, improved, or even discarded before committing additional resources. The next step, measurement, plays a crucial role in the development cycle. Measurement involves obtaining feedback from users, such as determining the new technology's efficacy, so that it has utility and is user focused.

Learning is the final step of the cycle and involves analyzing the outcomes of measurement so that the features best serve the technology consumer. Technology entrepreneurs learn from their successes and failures and many "pivot"—a start-up term for changing direction and even the purpose of the technology—in response to consumers and other technologies. The nature of this learning spans the scope of Bloom's (1956) taxonomy within the context of authentic learning. The ubiquitous process of creating and generating technology immerses talented, entrepreneurial adolescents in a continuous cycle of learning, building, and analyzing—they need not start a business to create technology, but they must realize that if their work is to have lasting impact, it needs consumer appeal.

## Talent and Technology

The general and specific abilities of an above-average population of young adults (Renzulli, 1990) serve to characterize technologically talented adoles-

**Table 14.1**
Comparison of the Scientific Method and Lean Start-Up Method

| Scientific Method | Lean Start-Up Method |
|---|---|
| Observation | Observe people, practices |
| State the Problem | Identify a problem (pain point or opportunity) |
| Hypothesis | Propose a hypothetical solution |
| Experimentation | Build minimal viable product |
| Gather Data | Gather feedback and other measurements |
| Conclusion | Analyze results, learn |
| Verification | Continue to iterate (refine hypothetical solution or pivot new hypothetical solution) |

cents. In addition to abstract thinking, applying verbal and numerical reasoning to varied problems, and memorizing and retrieving information accurately and with ease, they possess the "capacity for acquiring and making appropriate use of advanced amounts of formal knowledge, tacit knowledge, technique, logistics, and strategy in the pursuit of particular problems or the manifestation of specialized areas of performance" (Renzulli, 1990, p. 9). Moreover, they are capable of differentiating between relevant and irrelevant information associated with tasks they are performing.

Regarding their task engagement and creativity, technologically talented adolescents have high levels of commitment, persistence, curiosity, passion, openness to experience, fluency, flexibility, originality of thought, and drive as seen in their ability to engage with challenging problems for extended periods of time—not because *they have to*, but because *they want to*. Self-confidence and a strong belief in one's ability are not necessarily apparent in technologically creative adolescents; however, they tend to seek encouragement and affirmation from adults or peers and show little hesitation in diving into challenging projects!

Let's use the case study in Table 14.2 as an example. The website http://www.tl;drlegal.com has undergone several revisions (one was built on Python and Django; the current version uses Node.js and Mongo DB), but the difficulty never deterred Kevin, even when he didn't know the programming languages. As a sixth grader, one of his first self-selected projects was to build an MMO (massively multiplayer online) game that involved simultaneous players and moving parts. Kevin said, "This kind of game is notoriously hard to build; I chose it as one of my premier projects." This project was on a much bigger scale than anything he had done previously, and much of the material was unfamiliar. Undaunted, he turned to the Internet and sought advice from experts in game development forums who then became his online mentors. The ability to find just-in-time help characterizes not only Kevin but also other young technology developers who start a project

**Table 14.2**
Case Study 1: Kevin, A Serial Innovator

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| Kevin, 19, is currently developing http://www.tl;drLegal.com, a website that condenses hard-to-read legalese into language that nonexperts can understand. He started this project 2 years ago after wrestling with the meaning of open source software licenses. To a developer, software licenses matter. It could be a costly mistake not to read the fine print before creating something new based on the work of others. First he developed a prototype using php and mysql, which he had taught himself. After its launch, the site attracted significant interest from the developer community and Kevin realized he had created a new technology that had value to others. |

and ask questions when they hit a brick wall. This is self-initiated learning, and it has to be resourceful. In the field of cutting-edge technology, development occurs at such a rapid pace that it is impossible for a textbook to keep pace.

In addition to possessing those exceptional abilities as described above, Kevin exemplifies an innovator as described by Kao (2007). Innovators:

- are capable of linking learning and purpose (e.g., Kao discusses this in terms of something teachers need to do for students; however, Kevin accomplished this independently);
- see problems as opportunities (e.g., Kevin recognized the limitations of his current technology skills and would use this as a new opportunity to code in a different programming language);
- sense emergent opportunities (e.g., Kevin recognized that the solution he sought was unique); and
- follow their instincts.

Knowing he would need assistance, Kevin held more than 300 coffee meetings with entrepreneurs and investors during one summer, making his an easy transition from Chicago to Silicon Valley, where he became a Thiel Fellow.

Serial entrepreneurship is an additional behavioral characteristic found in gifted innovators, which is the ease of transitioning from project to project and upon completion, providing a point of exit or identifying project failure (Bonnstetter, Bonnstetter, & Preston, 2010). Failure is not a deterrent, but provides an opportunity to learn and move on. In the span of 2 years at the Illinois Mathematics and Science Academy, Kevin developed two different technology projects: a working game development platform for hobbyist gamers and a customizable, digital storefront for web businesses. He pursued neither one after graduation but immediately set to work on http://www.tl;drLegal.com. A study of serial entrepreneurs by Bonstetter, Bonnstetter, and Preston (2010) found that 67% of those surveyed dreamed, like Kevin, about starting their own business before age 18.

Today's technologically talented adolescents are also characterized by the generation into which they were born. As members of Generation Z, born between 1994 and 2012, they are considered more entrepreneurial than their predecessors, Generation Y (Schawbel, 2014). A recent Gallup poll identified strong entrepreneurial interests: 45% of students in grades 5–12 said they planned to start their own business, and 42% said they would invent something that changes the world (Calderon, 2011). Compared to Generation Y, the advantages of Generation Z include greater availability of online resources to teach themselves; access to mentors at a younger age; entrepreneurial programs offered by colleges, businesses, and organizations (such as the Network for Teaching Entrepreneurship [NFTE] and the Thiel Fellowship); and parents who expect their children to acquire professional experience during high school.

## Technology and Educational Standards

Despite an array of educational standards, when it comes to students creating technology, only the Next Generation Science Standards (Achieve, Inc., 2014) for engineering design align with relevant competencies in learner-centered terms. The International Society for Technology in Education (ISTE) Standards for Students (formerly the NETS) were written to help evaluate " . . . the skills and knowledge students need to learn effectively and live productively in an increasingly global and digital world" (ISTE, 2014, para. 1). In terms of creativity and innovation, ISTE emphasizes the *use* of technology. Twenty-first-century skills (Partnership for 21st Century Skills, 2009) weave entrepreneurial literacy into a discussion of core subjects; however, information as to how that translates into practice is vague. In terms of creativity and innovation, technology receives no mention. One area where 21st-century skills do intersect with an entrepreneurial model is in conceptualizing learning as a cyclical process of small successes and frequent mistakes.

The NGSS approach to engineering (see Table 14.3) starts with the observation step of the scientific method as students gather and analyze data. This starting place is more familiar territory to a scientist or engineer than a youthful entrepreneur, whose creative practice may be to build first and ask questions later (Clear, 2014). For this reason, students may be more attracted to the lean startup process of rapid prototyping followed by obtaining feedback from potential consumers. As Kevin discovered, his idea solved a problem that could be quantified and qualified. By spending very little time gathering data, it was possible to obtain a proof of concept in a market where speed is survival. Had Kevin analyzed, qualified, and quantified his potential product first, it is doubtful it would ever have been built.

**Table 14.3**
Next Generation Science Standards for Engineering Design—High School

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| ▪ ETS1-1: Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants. |
| ▪ ETS1-2: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. |
| ▪ ETS1-3: Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. |
| ▪ ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem. |

Table 14.4 is a second case study. Like Kevin, Dane did not conduct a thorough inquiry before making the puzzle, nor did he consider the extent to which others might be interested in it. Furthermore, this was not a major global problem; however, it led him far beyond what most students in an engineering class ever achieve: technology with his name on it sold in stores. Finally, it was not part of any coursework, although with sufficient time and guidance, it is conceivable he could have gotten it to market a year or two earlier while still enrolled in high school.

This approach is contrary to NGSS in that rigorous inquiry *up front* is missing and the product doesn't necessarily solve a problem (it does have to satisfy a need). Jumping into process without inquiry can result in solutions with little lasting value; therefore, it makes "educational" sense first to study a problem in depth. The "inquiry-light" alternative—a fast fail—gives the developer a reality check before proceeding far into the process (Ries, 2011).

Once the product reaches step three, evaluation (measurement in the lean start-up model), the developer or inventor has evidence that due diligence (i.e., research) is now needed. What tips the scale as to the preferred approach is the speed at which technology needs to be created and the mindset of the creator (e.g., scientist versus tech geek). For coursework, either approach could be used without forsaking inquiry, but building first is more attractive to gifted students who want to direct their own learning.

The evaluation step specifies criteria including cost, safety, reliability, aesthetics, as well as possible social, cultural, and environmental impacts—each worthy of evaluation. The developer of a product intended for market has to consider these things and more: competition, intellectual property protection, and possibly personnel and human resources. A technology product designed for a class only has to simulate these things. However, simulating the process is a

**Table 14.4**
Case Study 2: Dane, Building for Fun

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| While attending Illinois Institute of Technology (IIT), Dane created a twisting logic puzzle called the X-Cube (Christianson, 2014). The idea began as something he "just wanted to do," unrelated to any coursework. |
| Back in middle school a friend showed him how to build puzzles. This was the start of Dane's interest in starting a puzzle business. He had an opportunity to build a prototype using a 3D printer as a student at the Illinois Mathematics and Science Academy (IMSA), but he lacked time. A student in IMSA's Robotics Club introduced him to computer-aided design (CAD), and Dane taught himself how to use it. When he got to IIT, he decided to build it "just for fun" using the Idea Shop. |
| Based on the enthusiastic response to an online video he posted of the puzzle, it turned out to be a popular idea. Dane eventually raised more than $50,000 on Kickstarter, a crowd-sourced funding site. Prior to that, he knew very little about raising money, mass-producing a product, getting it into stores, or putting it in people's hands. He spent a year figuring out those details, starting by emailing the director of the entrepreneurship center at IIT. |

poor substitute for the real thing and may produce technology that is abandoned after a course ends. Unfortunately, that situation is typical of a traditional coursework model: a narrow focus on a product that does not follow to its natural conclusion—production.

## Technology Development in School

Out-of-school support made available to technologically talented adolescents is unprecedented (Richtel, 2014), but in-school programs for secondary students are uncommon and exist in isolation. Program leaders are simply unaware of similar programs and when a new initiative is announced, it is considered groundbreaking and rare (Barrington220, 2014). Colleges and universities, on the other hand, have increased the number of entrepreneurship courses by a factor of 20 since the 1980s (Kauffman Foundation, 2013). The "booming interest in start ups" has been significant enough to prompt top-ranked business schools like Babson College, Stanford University, and the University of California, San Francisco, to license entrepreneurship courses to other colleges (DiMeglio, 2013, para. 1).

Extracurricular programs are increasing in high schools and include credit courses and noncredit programs in entrepreneurship, computer science, and engineering. Many programs are vocational or designed for middle-skilled learners and/or students at risk. For example, Entrepreneur High School in Charlotte, NC; Austin Business and Entrepreneurship High School in Chicago, IL; and

Leadership and Entrepreneurship High School in Portland, OR, offer coursework and entrepreneurial opportunities that support secondary students in launching new businesses, not necessarily creating new technologies.

Curriculum and instruction at specialized STEM schools include project-based learning and technological innovation in addition to traditional gifted education. What average students do in entrepreneurship schools bears a strong resemblance to pedagogy found at institutions serving gifted populations. Although the Illinois Mathematics and Science Academy does not have a credit course in entrepreneurship, the North Carolina School of Science and Mathematics does. However, both schools use similar approaches that are changing the face of teaching and learning by incorporating entrepreneurial ventures into their curricular offerings. A comparison is made among programs offered at Barrington High School in Barrington, IL (BHS); Illinois Mathematics and Science Academy in Aurora, IL (IMSA); and North Carolina School of Science and Mathematics in Durham, NC (NCSSM). Entrepreneurial experiences at each of these schools include:

- coursework in entrepreneurship adapted from practices of successful start-ups;
- students learning independently of teachers;
- participation by successful entrepreneurs, which may include mentoring;
- seed funding or other resources to support student projects; and
- students launching their own entrepreneurial ventures while still matriculated in high school.

## School Case Study 1: Barrington High School

Barrington High School (BHS) offers an elective course, "Business Incubator Start Up 1," that breaks through the business-simulation barrier and is an academic, graded, project-based coursework paradigm. Designed for learners with a wide range of skills and not limited to STEM, it is included here because the methodology is decidedly entrepreneurial. This new course was developed to revitalize traditional business courses that were focused on studying business cases from textbooks. The two-semester course is designed for juniors; sophomores are admitted as space allows. The course features the lean start-up model, beginning with ideation followed by iterative phases of building, measurement, and learning and includes six units: twenty-six distinct modules covering 172 instructional days. Common Core State Standards were mapped to learning activities, particularly ELA standards (Achieve, Inc., 2013).

The course involves coaches and mentors from the community, a dedicated incubator space, experiential learning, team collaboration, authentic assessment, and a conditional guarantee of project funding. The curriculum was designed by the teacher, coaches (subject matter experts), and mentors (team guides), and was vetted with the assistance of faculty at the University of Miami in Oxford, OH. To start the year, students generate ideas for businesses and then are aligned into teams of no more than five members who have similar ideas. In its inaugural year, 31 teams emerged from five course sections with a total enrollment of 124 students. Each team has a mentor experienced in business/entrepreneurship. The course meets in a dedicated space that resembles workspaces at Google or Facebook: tables conducive for small-group work, state-of-the-art technology, a separate conference area, walls that function as writing surfaces, large screen monitors, and a virtual portal for replaying session content. According to students, this space feels more like going to work than school (Barrington220, 2014). Teams huddle around tables where they each have a MacBook Air and can display their work on workstation monitors, or in soft seating areas where they meet with mentors, write on walls, or use the conference room for private meetings, sales calls, or web conferences. Another area, the "Igniter Bar," provides space for ideation.

The learning in Business Incubator Start Up 1 is deliberately experiential. After teams are formed, students develop and test their business assumptions using the Business Model Canvas (Business Model Foundry, 2014). Besides *Running Lean* (Maurya, 2012), *The Lean Start Up* (Ries, 2011), and *Business Model Generation* (Osterwalder & Pigneur, 2010), there is no textbook. The first semester ends with each team presenting its Minimal Viable Product (MVP). Seed funding may be provided to build products. Teams engage in competitive analysis, purchase supplies, and determine an effective way to demonstrate the value of their idea to potential users. The second semester ends with a pitch of the product, which serves as the assessment of students' work. A board of directors, comprised of local business leaders, selects teams to participate in a competitive investment pitch round where at least one team receives funding to launch its business. The school plans to offer space and mentoring support during the following summer and during students' senior year for teams that are funded.

Business Incubator 1 is proving to be a disruptive innovation. Students are creating community interest around their projects, extending their work beyond the classroom, and experiencing alternative learning. Furthermore, the Incubator is creating a need for other types of courses, particularly in coding. Students who develop an app business are motivated to build it. Plans are underway to collaborate with Mobile Makers Academy and to expand the district's computer science program by developing an industry-style boot camp and a full-year course in objective-oriented programming.

## School Case Study 2: North Carolina School of Science and Mathematics

The North Carolina School of Science and Mathematics (NCSSM) is a public, residential, coeducational high school for juniors and seniors with high intellectual ability that offers an elective entitled "Introduction to Entrepreneurship." Enrollment is by permission and the class meets once a week for 100 minutes (NCSSM, 2012), providing students with a broad understanding of entrepreneurship and introducing them to the tools and skills necessary for a successful start-up. Whereas BHS structures the start-up process using student-initiated ideas, the NCSSM course simulates it by having teams of students evaluate a case study. Given a startup example, the task is to determine how much demand exists for that product or service. Successful entrepreneurs are involved in course meetings so students may learn from their successes and failures. A follow-up elective provides an additional opportunity for NCSSM students to move their ideas from brainstorming to the marketplace. "Applications of Entrepreneurship" meets 2 hours weekly for one trimester. Students submit a proposal for a business product or service that is based on a theme announced each year. A committee reviews the applications and selects teams to engage in market analysis, business plan development, and presentation to potential investors. If invited, student teams may pursue their work as a special study option for an additional term. NCSSM alumni established an endowment to fund student research projects and entrepreneurial ventures (Wolf, 2011) with $500 grants awarded biannually to five to ten students for developing their innovative ideas.

The entrepreneurial programs at NCSSM and BHS (a) utilize a project-based approach with student teams, (b) involve mentors in the classroom, (c) encourage students to develop real businesses, and (d) make funding available for deserving ideas. Programmatic differences include enrollment that is open (BHS) versus screened (NCSSM) and length of study for an accelerator program (NCSSM) versus an incubator (BHS). BHS's Incubator course is nearly three times longer than the combined NCSSM courses, with students ending up in similar places—making pitches to investors. The brevity of NCSSM's first course (40 hours) may explain why students simulate an entrepreneurial experience by learning from guests' ventures and working on a business case of the teacher's choosing. The applied entrepreneurship course moves faster, providing just 24 hours of instructional time. Even by entering with a well-defined idea, the speed at which teams work their way to a pitch suggests that NCSSM's model is more an accelerator than an incubator.

Although not new to higher education and business, incubators and accelerators are new to secondary education (see Table 14.5). BHS, as a hybrid incubator, combines elements of both in its program, notably frequent reality checks, sig-

**Table 14.5**
Comparison of Incubator and Accelerator Models

| Incubator | Accelerator |
|---|---|
| Less time pressure, less intensive | Intense, 3-4 month program |
| Small mentor network | Large, mentor-driven business network |
| Open enrollment | Selective enrollment |
| No equity at stake | May have equity at stake (e.g., 6%–8%) |
| No seed funding | Small seed funding |
| Peer support | Peer support |
| Some resources | Ample resources |
| May have reality checks | Weekly reality checks |
| No Demo Day | Demo Day with investors present |

*Note*. Table adapted from "What's the Difference Between an Accelerator and an Incubator?" by B. Halper, 2013, *AlleyWatch*, retrieved from http://www.alleywatch.com/2013/03/whats-the-difference-between-an-accelerator-and-an-incubator/. Copyright 2013 by AlleyWatch. Adapted with permission.

nificant resources, and a "Demo Day" with investors for selected teams. NCSSM approximates the academic accelerator approach in its admissions screening and the pace at which students complete the coursework. An important question arises: What stake does a school hold in the technology that its students produce? Schools that promote entrepreneurship eventually find themselves in this dilemma when students develop a potentially profitable enterprise. With regard to underage developers and inventors, models from business or higher education are too different, complex, and challenging to apply. NCSSM prefers a philanthropic approach by encouraging its alumni to support the institution when they become successful.

## Nonacademic Extracurricular Programs

In addition to academic courses, a variety of afterschool programs, clubs, summer camps, and contests provide gifted adolescents with opportunities to create technology, such as the Robotics Club and TALENT program at the Illinois Mathematics and Science Academy (IMSA). IMSA is a 3-year public, residential high school enrolling academically talented Illinois students. Its student-led FIRST (For Inspiration and Recognition of Science and Technology) robotics team provides IMSA students with intense engineering experiences. For 6 weeks, mentors and coaches assist teams with designing, building, programming, and testing robots for annual competitions. Programming robots provides students with immediate feedback on their codes through an iterative design-testing process that is used to improve robotic performance. Students grapple with mechanical and programming issues, and they learn how to work effectively as a team. To allow students room to work within the iterative build-measure-learn process, it is important for adults to be available for giving advice, but they do not control the process. A technique that has proven successful is for coaches to ask guiding questions that help students think through their work. Students come up with excellent solutions when given the freedom to do so. See Table 14.6 for a sample case study.

IMSA's TALENT (Total Applied Learning for Entrepreneurs) program is an elective, extracurricular program that helps students turn ideas into start-up businesses. TALENT consists of multiple offerings, but the mainstay is Monday Night Live sessions that explore lean start-up methodologies. Alumni entrepreneurs and business mentors participate in hands-on workshops, experimenting with ways to help students master concepts and techniques. For example, Joe Abraham (2011), author of *Entrepreneurial DNA*, introduced a session on four roles known as BOSI: Builder, Opportunist, Specialist, and Innovator. TALENT is more of an accelerator than an incubator, but unlike the program at NCSSM, its enrollment is open to other high school students. Similar to the BHS program, IMSA's TALENT program includes a range of student abilities and experiences, and participants are intrinsically motivated and collaborative. Additionally, they work with numerous mentors, apply for seed funding, and pitch to investors. TALENT is multifaceted in its design. In addition to Monday Night Live sessions, students can participate in:

- *Intersession*: an intensive simulation that compresses the first year of a new business into one week;
- *Internships*: TALENT students spend one day a week working with other start-ups, or researching or pursuing their business ideas at 1871, Chicago's incubator for digital start-ups;
- *Power Pitch*: an annual contest where individuals or teams pitch ideas for new STEM businesses to investors for cash prizes;
- *Seed Funding*: an endowment and a memorial fund supporting original projects, including entrepreneurial ventures;
- *Crowd-Sourced Funding*: a design team working on a Kickstarter project;
- *Summer Camp*: an experience that accelerates student products by providing design resources and coaching; for example, an IMSA student and his team transformed WikiRoster (2013) from a prototype to a usable web application, enrolling 85% of the student body in only a few days.

TALENT blurs the lines between students and teachers and school and work, and it provides an opportunity for technologically talented adolescents to under-

**Table 14.6**
Case Study 3: Rachel, Creating Technology Opportunities

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| During her senior year at IMSA, Rachel cofounded IMSA's Robotics Team and served as its leader during the first year, acquiring an industry sponsor and setting the course for the team to be student run. She was highly committed and informed her teachers that her intense involvement during robotics competition season would prevent her from a timely submission of homework assignments. Rachel fell so behind academically that she risked graduating—but, she did. Her determination, passion, and persistence brought about lasting changes at the academy, and her initiative has helped hundreds of IMSA students to experience robotics. Today, Rachel is a software developer at ThoughtWorks. She volunteers as a teacher and is organizing a FIRST LEGO League at Black Girls Code, a company whose vision, according to its website, is "to increase the number of women of color in the digital space by empowering girls of color ages 7 to 17 to become innovators in STEM fields, leaders in their communities, and builders of their own futures through exposure to computer science and technology" (Black Girls Code, 2014, para. 1). |

stand how entrepreneurship is possible for them. Through their participation in TALENT, many students altered plans for college and future careers with new and/or additional focuses on computer science, engineering, and business. The program is integrative, supporting talented adolescents to turn engineering or computer science projects into prospective businesses and conversely, by encouraging students to study computer programming and engineering. See Table 14.7 for a sample case study.

Given how aggressively technologically talented students approach their work, they could figure out how to establish a brand on their own, but TALENT speeds up the process as an extracurricular accelerator. It provides a safety net and a helping hand for students who are capable of creating technology on their own, but need assistance nonetheless to elevate their prototypes to established brands by:

- building their awareness that technology entrepreneurship is a realistic career choice;
- attracting them to resources they could not otherwise access, such as memberships, internships, and production facilities;
- connecting them to business and technology mentors (e.g., venture capitalists, patent attorneys, coding experts);
- arranging interviews with in-demand internships for networking within entrepreneurial and financial circles;
- awarding them seed money (e.g., contest awards); and
- motivating their learning into deeper levels of entrepreneurial and technological education and experiences.

**Table 14.7**
Case Study 4: Summer, Taking Advantage of Opportunities

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|---|
| Summer participated in TALENT every year she was at IMSA. She attended Monday Night Live sessions and went to 1871 to meet with start-ups. She delivered three business pitches as a Power Pitch contestant, but she never won. Before starting her undergraduate studies at Yale, Summer wanted to learn coding. After observing how a classmate used coding during TALENT, and because of her difficulty finding a technical cocreator for her business ideas, Summer was inspired to learn programming. Summer stated, "If you want code, you need to do it yourself." |
| She proposed a one-year internship with IMSA alumnus, Steve Chen, cofounder of YouTube, but prior to moving to Silicon Valley, she visited her local library to learn more about app coding. She also made new contacts with start-ups at 1871 and programmed a simple game in Ruby. |
| Interning at AVOS Systems was a good fit. Summer was free to develop an Android app, except she did not know the language. Like every other gifted student interviewed for this chapter, she turned to Google. What she could not learn from examples and online forums, she supplemented with Android user groups in the Bay Area and developers at AVOS who were working on Android apps. Before her internship ended, Summer had a working version of DropDot, an educational game for preschoolers with a rapidly growing user base. |

# Developing High-Ability, Technologically Talented Adolescents

The case studies in this chapter illustrate instructional models that provide opportunities for gifted and talented youth to accelerate the development of new technologies. Such learning ecosystems include the following key educational program components:

- ideas for projects *must* come from students;
- nonhierarchical structures facilitate learner participation and voice;
- opportunities are created to facilitate meaningful personalized learning;
- setbacks are viewed as learning opportunities, not failures;
- assessment is based on what students create and learn during the process;
- access is available to the Internet and to other technological learning resources;
- courses in computer programming are available; and
- conditions are created for ongoing student collaboration with peers, teachers, mentors, and experts at the local, regional, national, and global levels.

## Ideas for Projects *Must* Come From Students

Talented adolescents' motivation and passion are directly tied to this concept; they cannot be overlooked, as they are central to program success. From a constructivist's perspective, learning proceeds from experience (Martinez & Stager, 2013). From problem-finding and innovation points of view, student experiences should include time for observation and experimentation (Kelley, 2005). As trusted peers and adults provide constructive guidance and affirmation, students begin to trust themselves and move to action. Interaction with experts in the field may also provide the necessary reinforcement.

## Nonhierarchical Structures

To encourage student innovation, classroom teachers need not serve as primary knowledge givers. It cannot be assumed that teachers know or even need to know a great deal about computer science, engineering, entrepreneurship, or new technologies. Therefore, inviting mentors and coaches to interact with students allows the teacher a different role and an opportunity to share insights about how he or she learns. The teacher also has a responsibility and opportunity to observe and, if necessary, train the trainers. Coaches and mentors may try to adopt a teaching/telling role that reinforces student dependency on what is being taught.

## Designing Space for Collaboration

Nonhierarchical structure also applies to physical space. BHS's Incubator offers a vision of what this looks like by not featuring a place of leadership for the teacher, and by grouping students for all-way communication. Freedom of movement is encouraged and state-of-the-art equipment is provided. Form follows function: collaboration here, ideation there, building at the 3D printer, and conferencing in the next room. The space functions more like a workplace than a school, and students respond well to it. As part of a national movement to rethink innovation environments, schools should be mindful of the way they facilitate student capacity to work, following Kao's (2007) thoughtful leadership as reflected in his statement, " . . . the design of place is part of the larger agenda of redesigning the work of innovation" (p. 131).

## Opportunities Are Created and Facilitated for Students to Stretch Their Present Understanding

Opportunities create possibilities that motivate students. The entrepreneurial programs described in this chapter make multiple opportunities available that inspire, challenge, and drive students to deeper learning on their own.

Opportunities may follow one of two paths: one that starts with inquiry and is oriented to scientific exploration (e.g., NGSS engineering standards), or one oriented to building, measurement and learning, and the lean start-up method.

Creating opportunities for learning further redefines the role of a teacher. Now the work becomes recruiting (and sometimes training) mentors and role models, helping secure resources for building hardware and software, introducing students to contests and networking to find internships. Working with gifted students often demands little more than showing them possibilities, getting out of the way, and then looking for opportunities to ask constructive questions and helping students learn to ask more powerful questions. This role or relationship is not limited to class periods, as learning also happens outside class.

Entrepreneurial curriculum and instruction are also described in the Parallel Curriculum Model (Purcell, Burns, & Leppien, 2003) as opportunities to:

- learn core knowledge within a discipline at ascending levels of intellectual demand (enduring facts, concepts, principles, and skills);
- learn about the numerous relations and connections that exist across topics, disciplines, events, time, and cultures;
- transfer and apply knowledge using the tools and methods of the scholar, researcher, and practitioner; and
- develop intrapersonal qualities and affinities within and across disciplines.

Projects intended for market distribution create an authentic context for learning from many disciplines, ranging from what math is needed to what science and physics formulas apply. Personal projects create the need to learn more, which is intrinsically motivating and effective.

## The Learning Environment Is Accepting of Setbacks and Failures

In a rapid prototyping environment, it is virtually impossible to avoid making mistakes, which sets up opportunities for learning. An environment accepting setbacks as a normal part of development helps remove fear from failure. At some point, all start-ups fail; developers tweak the code, builders approach a problem from a different direction, or they move on to the next project. Entrepreneurial learning follows suit when students value failure as much as answering correctly. This invites different models of assessment.

## Basing Assessment on What Students Create and Learn During the Process

In the environment described, grades seem artificial. One option for a credit course, especially when students work in teams, is a pass/fail option. A knowledgeable teacher, mentor, or panel of experts can still evaluate work. For example, a culminating first semester product for BHS students is a Minimal Viable Product (MVP). A rubric could be created to determine its effectiveness: To what extent does the MVP work? How accurately do consumers understand the product? How is it used to measure effectiveness? Because teamwork is often integral or required, a team evaluation is appropriate, and an assessment rubric that takes into consideration elements of design, presentation, and learning should consider the extent to which teams:

- address a global problem, advance the human condition, or whatever opportunity was announced (i.e., problem selection);
- develop the product and address its purpose (i.e., value proposition);
- know their targeted consumers (i.e., customer segments);
- know how to reach their consumers (i.e., channels);
- define actions they must take and who does them (i.e., key activities);
- select materials, protect their ideas, and produce technology (i.e., key resources);
- anticipate costs (i.e., cost structure), and;
- determine what consumers are willing to pay (i.e., revenue streams).

All of the programs discussed end with an investor or academic pitch. In the real world, these are not exactly given grades because investors either invest or they don't. Completing all course activities prepares teams for a pitch and giving the pitch could be a measure of academic success. Presenting their work in front of an authentic audience is an effective way to assess what they have accomplished and provide feedback.

## Access to the Internet and Computer Science

As mentioned, the first place tech-savvy adolescents turn for help with coding is Google. Kevin from the case study in Table 14.2, for example, relied on connections he made through Internet forums to build a network of personal mentors. This approach is useful only if the school does not block information. For many schools, this is a challenge. YouTube, frequently blocked by schools, can be a valuable resource for learning code and how to pitch to investors. Open access to information may require changing a policy or lifting a ban on certain channels. Equal and just-in-time access to computing are equally important. In Barrington's lab, for example, every student has immediate access to a laptop and each team has a dedicated viewing and presentation area. No one waits for a turn to use technology.

A well-above-average level of programming aptitude is a likely prerequisite for technology innovation. Gifted students who come up with an idea but lack programming skills can accommodate by acquiring programming knowledge, either through a course or self-teaching, or by teaming up with students who can code. If a school offers programming in languages that help the student build the desired technology, a powerful incentive is created. This is not yet possible for the majority of U.S. high schools because only 10% of them currently offer even one computer science course (Code.org, 2014), let alone one that is useful for web or mobile applications. A school may fill this gap by following Barrington's example, contracting with an outside coding academy to support students intent on building mobile applications.

### Collaboration Among Peers, Teachers, Experts, and Globally Connected Partners

Collaboration is crucial in technology development. Individuals who may appear to be working on their own are often networking with others behind the scenes. When students hit inevitable walls as they build, the teacher plays a critical role connecting them to mentors. Mentor networks cannot be emphasized enough in incubating and accelerating student work. As the examples in the chapter illustrate, mentors are an important part of each entrepreneurial model. Motivated students can tap into networks independently as they reach out for help. However, as an *opportunity facilitator*, an instructor is in a unique position to connect networks so more mentors are available to more students.

As a program matures, alumni become increasingly valuable members of the mentor pool. Kevin, Dane, and Summer have already given back to TALENT by offering insights into the Thiel Fellowship process, use of Kickstarter, and internships. Alumni tend to have a special bond with students that is hard for a teacher to replicate. A mentor community that connects with the school, whether alumni or not, provides other potential benefits, as BHS, NCSSM, and IMSA all attest. Each of those programs is the recipient of generous financial and advisory support, without which innovation spaces and seed funding for student work may not exist.

## Summary

Three instructional models are identified that help adolescents develop new technologies. These may serve as the basis for developing new programs in schools that support student efforts to create technology. The "incubator model" (e.g., Barrington High School) is an academic course for a mixed talent population. Classes meet daily for two semesters in a specially designed innovation space, where students work in teams guided by expert coaches and mentors. The course culminates with an academic pitch, from which teams are selected for a Shark Tank-style investor pitch that is open to the public. At least one student business is funded and mentored the following summer and school year.

The "accelerator model" (e.g., North Carolina School of Science and Mathematics) is an academic course for talented students who are selected on the basis of a business proposal. Classes meet only one day a week for three trimesters: The first section, which spans two trimesters, employs a simulation-based curriculum; students develop their own businesses in the one-trimester course. Mentors provide assistance to students and the course culminates with an investor pitch. Students may receive seed funding from an endowment set up by alumni.

The "nonacademic accelerator model" (e.g., Illinois Mathematics and Science Academy) operates at the edges of schooling and beyond it, where self-initiated technology creation is happening today. Although there are no academic classes, students are able to work on business ideas (most of which are technology based), entering the program through a number of access points: weekly mentor-led or student-led workshops, internships at the 1871 digital incubator in Chicago, summer camps, intersession programs, and an annual Power Pitch competition. Activities in the TALENT program are offered year-round and there is no culminating experience (graduates frequently return to seek guidance for new ventures). Following the investor pitch competition, students are encouraged to work with mentors to pursue their ideas, work as interns, or serve on specialized TALENT-sponsored activity groups (e.g., Kickstarter). Students may work individually or in teams, integrating coursework in computer science and engineering with entrepreneurship opportunities.

Together, these models demonstrate a range of entrepreneurial approaches that support talented students creating new technologies in a paradigm that is constructivist and experiential. Each one is potentially a disruptive educational innovation. These models are also just a starting point. Compared to the volume of information about adolescents' *use* of technology, how educators, mentors, entrepreneurs and investors combine to help talented adolescents create technology is a story still largely untold. The door is open; here is an opportunity for additional study.

## Questions for Discussion

1. What research is needed to document the relative effectiveness of the three models of entrepreneurial learning? What are the merits and limitations of each?
2. What is appropriate for an educational institution regarding an equity share in technology it helped students create and take to market? Whose intellectual property is it if the student created it using school resources?
3. How can computer science, entrepreneurship, and engineering be integrated seamlessly in the high school curriculum?
4. How can a school provide appropriate and safe access to information, and technology—both software and hardware—and open access that promotes and supports students' entrepreneurial and technological learning?
5. How are collaborative, student-led technology projects best assessed?

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