Cliff Zintgraff
Sang C. Suh
Bruce Kellison
Paul E. Resta *Editors*

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Editors
Cliff Zintgraff
The University of Texas at Austin
IC2 Institute
Austin, TX, USA

Bruce Kellison
The University of Texas at Austin
IC2 Institute
Austin, TX, USA

Sang C. Suh
Texas A&M University-Commerce
Commerce, TX, USA

Paul E. Resta
The University of Texas at Austin
College of Education
Austin, TX, USA

ISBN 978-3-030-39850-7 ISBN 978-3-030-39851-4 (eBook)
https://doi.org/10.1007/978-3-030-39851-4

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

In memory of George Kozmetsky and in honor of David Gibson, for their lifetimes of research into the technopolis and the potential for technology-based economic development and for educating the next generations.

Foreword

Education is key to the economic vitality of cities! And it is important to every stakeholder in cities around the world. Education is important to parents and family members of school-age children and to those who teach them. Education is important to college students and their professors and to the leaders of those institutions. Education is important to local employers, to staff of nonprofits who improve quality of life, and to policymakers who make cities worthy of their citizens. Through education, students prepare for the jobs of tomorrow. As educated students become young citizens, they will better understand the challenges faced by their communities, make better decisions about their leaders, and be ready to contribute to the cities they call home.

I've had the privilege to see the importance of education up close in my work at the Annenberg Public Policy Center, as Chairman of Sister Cities International, and as Mayor of San Antonio. San Antonio provides a great example. With a population of 1.5 million people, San Antonio is the second largest city in Texas and the seventh largest in the United States. Between now and 2040, we will add another 1.1 million people to the 1.5 million already living inside our city limits. Another million or more will live in our metropolitan area. This growth is wonderful for our economy. It is less wonderful for the traffic on our roads. It is a challenge to the sustainability and resiliency of our water, land, and other natural resources and to our ability to provide government services to citizens.

San Antonio also exemplifies the importance of education because of culture and demographics. It may be 2019, but San Antonio is already the America of 2050. The city was founded by Spanish missionaries, first populated by Canary Islanders, grown through European immigration and through immigration from Mexico and Latin America. Today, our city's population is over 60% Hispanic. We have a rich Tejano culture, and we are home to the Alamo and all San Antonio Missions, collectively a UNESCO World Heritage site. We are a welcoming city that represents the best of the melting pot that is America.

In the midst of this growth and culture is the industry of San Antonio. We are known for tourism and as Military City USA. We are also known for our industry clusters in health, biomedical research, manufacturing, aerospace, and financial services. We are home to the second highest number of certified information security professionals in the United States, improving the safety of our military, government, and the private sector.

In light of this background, how is our city preparing today's students—*all* of our students—for tomorrow's careers? Of particular importance is STEM education, the integration of science, technology, engineering, and mathematics to prepare citizens for the challenges of the twenty-first century. Also important is STEAM education. STEAM integrates the arts and injects a special degree of creativity. STEM and STEAM create a nexus between scientists, engineers, and the creative people of our communities. STEM and STEAM experiences help students connect their studies to the real world.

In San Antonio, we are aggressively moving on the STEM and STEAM fronts, at all education levels and very much in K–12 (grades kindergarten through 12). In 2010, the city adopted *SA2020*, a comprehensive framework for development of the city. In 2014, leaders of the SA2020 effort founded the San Antonio STEM Council as a gathering place for STEM educators. The council is now the Alamo STEM Ecosystem and a member of STEM Learning Ecosystems, one of over 80 communities in the United States organizing to drive STEM education and prepare citizens for careers.

Before that, in 2008, our robust cybersecurity industry cluster founded San Antonio's version of CyberPatriot, a national cyber defense competition. The strength of the local cluster helps area schools field 300+ teams a year, the highest per capita participation in the nation. San Antonio's flagship university, The University of Texas at San Antonio, leads technical development for the competition. I have the honor of awarding the yearly CyberPatriot Mayor's Cup. CyberPatriot is helping drive a virtuous development cycle, preparing students for cybersecurity education in college. Those students enter local jobs with employers who in turn support K–12 through CyberPatriot. The CyberPatriot program is the subject of this book's San Antonio chapter.

Meanwhile, from 2015 to 2016, I served as Tri-chair of SA Tomorrow, an initiative building San Antonio's long-term development plan. In 2018, with area nonprofit partners, my office started *SA Smart*, a middle and high school research competition focused on the challenges identified in SA Tomorrow. The 2018 topic was transportation, and the 2019 topic was sustainability. It was my honor to award the 2018 and 2019 SA Smart Mayor's Cup to K–12 teams who developed and researched ideas for improving quality of life in San Antonio. It's important to note that these students did more than develop great ideas. They spent months talking about their ideas with their teachers, friends, and families and became ambassadors for important conversations we need to have in our community.

San Antonio provides just one example of how unique circumstances in cities and city-sized regions are great platforms for STEM and STEAM education. On such platforms, partnerships can be built between K–12 schools, local industries, local college programs, city government leaders, and city's nonprofit organizations. These partnerships are key to unlocking the virtuous development cycle illustrated in the volume's first chapter.

In the current volume, *STEM in the Technopolis*, many other examples are shared from cities and regions around the world. The volume also highlights education philosophies and methods, economic development principles, national policies, and equity principles that connect the challenges of cities to great STEM and STEAM experiences for students. In San Antonio, we will be taking these ideas to the next level! We challenge you to do the same.

With best regards,

Ron Nirenberg
Mayor, City of San Antonio, TX, USA

Preface

If you are looking for a book that crosses disciplines, you have come to the right place. *STEM in the Technopolis* grew from ideas that view wholes as greater than the sum of parts. This is how a global innovation program developer, a computer scientist, an economic development researcher, and a professor of education became coeditors of one volume. We are privileged to share with you the individual stories of this volume, and the story as a whole. Our story is about great STEM education experiences for students that spring from the challenges of cities and regions. We share examples from around the world, common themes, and ways to elicit the same kinds of results we see in the cases from our volume.

Two large themes first drew us together. The first is STEM education. Whether we are building global programs and software, driving economic development, or training the next generation of teachers, the topics of science, technology, engineering, and mathematics are prominent. It is especially important to understand how the topics are co-taught—or, to use the fancy words, how they are taught in an integrated and transdisciplinary manner.

To teach them together, we need context, and few people were better at context than Dr. George Kozmetsky. It is through his influence on Austin, Texas, USA, at The University of Texas at Austin, and through his global network that we, editors, found common ground. His receipt of the US Presidential Medal of Freedom for Technology is one validation of his ideas. He believed strongly in the power of collaboration. He founded the Society for Design and Process Science (SDPS) and the IC^2 Institute at UT Austin. These two organizations have led development of the volume, and his DNA is seen throughout our work.

Dr. Kozmetsky would honor our desire to critique that work, build on it, and think of ways to take it to new places and make it bigger and better. In that spirit, we think the *technopolis model* first defined by Kozmetsky and his colleagues needs to grow. For example, imagine that 15 years ago an education advocate (like one of us) walked into a large company and said "You need to educate middle school students so they will come to work for you!" That really happened, and the large company employees considered the idea to be crazy. The exact response referred to the long wait for a return on investment. That company was focused solely on students in college.

The emergence of STEM education has radically changed that perception. STEM is a platform everyone can see themselves in. STEM is a powerful way for diverse stakeholders to think about the root causes for why many students come to the workplace unprepared. There is a big difference between technical knowledge and project know-how. The context of real-world problems motivates teachers and students, provides content, and makes the effort to learn more worthwhile and relevant.

And what better problems are there than the problems of cities and regions? We all know what they are: transportation, water, energy, pollution, health, economic security, physical security, cybersecurity, equity, quality of life for all people on the planet, etc. Every stakeholder group in a technopolis cares about the solutions to these problems.

Our volume illustrates how the challenges of cities and regions form rich context for STEM education, cutting across many disciplines. In this one volume, you will read about STEM, STEAM (STEM+Arts), regional economic development, industry clusters, network building, education philosophy, education theory, educational methods and practice, the structure of schools, the nature of twenty-first-century learning, digital equity, rural development, health, ICT, energy, cybersecurity, the Fourth Industrial Revolution, manufacturing, agriculture, cloud software development, technology commercialization, and innovation—and, in one case, how a city's world-class crisis became their inspiration for great STEM education.

Building effective collaborations among different kinds of people is hard work. It is also one of the most rewarding tasks in life, both professionally and personally. We hope you value the ideas of this volume, but more than anything, we hope the volume inspires you to connect with others as we have during its development. We hope you connect in your communities and that, along the way, you create great educational experiences for students.

Austin, TX, USA Cliff Zintgraff
Commerce, TX, USA Sang C. Suh
Austin, TX, USA Bruce Kellison
Austin, TX, USA Paul E. Resta

Acknowledgments

We gratefully acknowledge the invitation of Dr. Murat Tanik of the Society for Design and Process Science (SDPS) to contribute to the scholarship on STEM education and economic development in cities and regions and to SDPS for advancing development of the book at their 2017 Annual Conference.

We also thank the IC^2 Institute at The University of Texas at Austin (UT Austin) for generous funding to bring together the contributors to this volume for a public conference and discussion on STEM education and economic development policy. In particular, Institute Director Dr. Art Markman and Deputy Executive Director Dr. Gregory Pogue supported the project from its inception and encouraged us to keep the initiative's focus squarely on the characteristics of successful technopolis policy. We thank UT Austin PhD student Songhee Han for her dedication and skillful organization of the conference and for her intellectual contributions based on her experience as an educator. We regularly counted on the superpower administrative skills of Diane Skubal and Inez Traylor to track and complete the myriad tasks that made the conference and this volume possible.

Finally, we recognize the tens of millions of committed STEM educators, leaders, mentors, and volunteers around the world who work every day to transform lives and regions. Some of their stories illuminate this volume but most do their work without the credit they deserve. We honor their commitment to educate students and improve quality of life for their fellow citizens.

Contents

List of Contributors

Ademar Aguiar University of Porto, Porto, Portugal

Hemanth Bandi McKesson Corporation, Richmond, Virginia, USA

Alejandro Roldán Bernal Ruta N Innovation Agency, Medellín, Antioquia, Colombia

Tricia Berry The University of Texas at Austin, Austin, TX, USA

Richard V. Butler Trinity University, San Antonio, TX, USA

Cheng-Yuan Chen Taiwan First Girls High School, Taipei, Taiwan

Ting-An Chou Taiwan First Girls High School, Taipei, Taiwan

Paulo Estevão Cruvinel Embrapa Instrumentation – Laboratory for Precision Agricultural Inputs Application, São Carlos, SP, Brazil

Silvia Rocha Falvo São Carlos School, São Carlos, SP, Brazil

Cristiane Chaves Gattaz Embrapa Instrumentation – Laboratory for Precision Agricultural Inputs Application, São Carlos, SP, Brazil

Songhee Han The University of Texas at Austin, Austin, TX, USA

Bruce Kellison The University of Texas at Austin, Austin, TX, USA

Donna K. Kidwell Arizona State University, Phoenix, AZ, USA

Jinoh Kim Texas A&M University-Commerce, Commerce, TX, USA

Chung-Hsien Kuo National Taiwan University of Science and Technology, Taipei, Taiwan

Sara Pereira University of Minho, Braga, Portugal

Anthony J. Petrosino Southern Methodist University, Dallas, TX, USA

Gregory P. Pogue The University of Texas at Austin, Austin, TX, USA

Guolong Quan Jiangnan University, Wuxi, China

Paul E. Resta College of Education, The University of Texas at Austin, Austin, TX, USA

Graciela Rojas Movimiento STEM, Mexico City, Mexico

Joe Sánchez CyberTexas Foundation, San Antonio, TX, USA

Laura Segura Movimiento STEM, Mexico City, Mexico

Ravae Villafranca Shaeffer Education Service Center, San Antonio, TX, USA

Maximilian K. Sherard The University of Texas at Austin, Austin, TX, USA

Sang C. Suh Texas A&M University-Commerce, Commerce, TX, USA

U. John Tanik Texas A&M University-Commerce, Commerce, TX, USA

Sneha A. Tharayil The University of Texas at Austin, Austin, TX, USA

Hsiao-Yen Wei Taiwan First Girls High School, Taipei, Taiwan

Chao-Lung Yang National Taiwan University of Science and Technology, Taipei, Taiwan

Yun-Chi Yang Taiwan First Girls High School, Taipei, Taiwan

Cliff Zintgraff The University of Texas at Austin, Austin, TX, USA

Part I
Foundations

Chapter 1
The Virtuous Cycle: Global Cases of K-12 STEM Education in the Technology Policy of Cities

Cliff Zintgraff

Abstract When leaders in cities and local regions talk about technology policy, they usually talk about government, universities and industry and how the three work together. This relationship is important. But what about the hundreds of millions of young students, taught by tens of millions of teachers, supported by hundreds of thousands of volunteers, who deliver STEM education to primary and secondary students around the world? K-12 STEM education should be a full participant in the building of modern knowledge economies. In this chapter, the opening chapter of *STEM in the Technopolis*, readers are encouraged to think hard about how to make K-12 STEM education a full participant in city/regional technology and development policy. Three global cases exhibiting this integration are introduced. Topics covered include the technopolis model, industry clusters, K-12 STEM pedagogy, social and digital equity, building the brand of cities and regions, the eight indicators of a virtuous cycle, and a model for the virtuous cycle that happens when K-12 STEM education is fully integrated into local policy. A brief introduction is provided to the rest of the volume. This chapter and volume are offered as a platform and encouragement to educators, academics, STEM professionals, policymakers, and all stakeholders. The author encourages the building of effective and inspirational STEM education programs, rooted in local priorities, benefiting students, families, and quality-of-life in cities and regions around the globe.

1.1 Introduction

1.1.1 The Argument for K-12 Education in the Technopolis

During the 1980s, Dr. George Kozmetsky and colleagues were completing seminal work on a model for technology-based economic development in regions (Jones 2018). Based on their particular experiences in Austin, Texas, U.S., they would

C. Zintgraff (✉)
The University of Texas at Austin, Austin, TX, USA
e-mail: cliff.zintgraff@utexas.edu

C. Zintgraff et al. (eds.), *STEM in the Technopolis: The Power of STEM Education in Regional Technology Policy*,
https://doi.org/10.1007/978-3-030-39851-4_1

Fig. 1.1 The technopolis wheel (Smilor et al. 1989)

ultimately publish the *technopolis model*, also known as the *technopolis wheel* (Smilor et al. 1989). The model described a highly collaborative framework for technology-based development that involved all sectors of a city or region. Ultimately, Dr. Kozmetsky would be recognized for his contribution with a Medal of Freedom for Technology from U.S. President Bill Clinton. The transformation of the Austin economy stands as proof of the model's efficacy.

Today, one hears more about the Triple Helix (Etzkowitz and Leydesdorff 2000), but the technopolis model remains broader in its approach. The model incorporates federal, state, and local government; large versus emerging companies; and support groups, also known as NGOs or non-profits; and universities. Figure 1.1 is the original illustration of the model from Smilor et al. (1989).

Smilor et al. (1989) planted a seed that helps start discussion of K-12 in the technopolis. A story was relayed of an early Austin success recruiting the Microelectronics and Computer Technology Corporation (MCC) to Austin. The quality of schools contributed to Austin's quality of life, which contributed to Austin's selection as the site for MCC. The link to technopolis development is indirect, but telling for the future. The children of the people moving to Austin would soon be among the schools' students. The parents would soon be influencers of how their children receive an education.

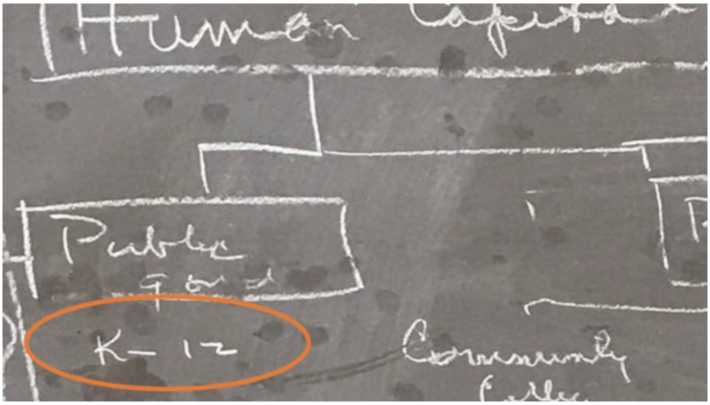

Fig. 1.2 Dr. George Kozmetsky's diagram and K-12

One finds more than a seed in Jones (2018) biography of Dr. Kozmetsky, which includes early stories of Kozmetsky's economic development laboratory, the IC^2 Institute, supporting secondary education until others came to fill the role. IC^2 was involved in high school entrepreneurship training programs, and IC^2 helped create EnterTech, a technology job training program whose target included high schools. Late in his life, Dr. Kozmetsky helped design CBIRD, the Cross Border Institute for Regional Development, built for Texas' Rio Grande Valley and for northern Mexico. The CBIRD program contained extensive designs for high school activities that would support technopolis development goals (Gibson et al. 2003).

At the IC^2 Institute, there is an undeniable indicator of K-12's role. In Dr. David Gibson's former office (of Smilor, Gibson, & Kozmetsky), and Dr. Greg Pogue's current office (co-author of this volume's technopolis chapter), there is a chalkboard with the preserved writing of a Kozmetsky-drawn diagram, an activity he was famous (and sometimes "nicely infamous") for. The legitimate place of K-12 in the technopolis is, in this author's opinion, immortalized in the diagram, as seen in Fig. 1.2.

Is the role of K-12 in the technopolis more widely recognized today? An anecdote from the author's experience can illustrate. In the mid 2000s, there was a meeting at an industry site for discussion of university STEM education, with talent pipelines feeding local industry. The author raised the idea of expanding the program in question into high schools, starting the pipeline earlier, perhaps as early as ninth grade. The idea was not well received. Waiting six years or more for a return on investment was not something industry players in the room could imagine.

This perspective has changed dramatically. With the rise of STEM schools (Scott 2012; Texas Education Agency 2014), there is clear understanding in industry that broad policy intervention needs to happen in middle school (grades 6 through 8) at the latest, before students' perceptions are set, and while a sense of self-efficacy around STEM subjects is easiest to instill. Programs like FIRST Robotics (Melchior et al. 2016) and CyberPatriot (Zintgraff 2016; Sanchez & Zintgraff, this volume) make heavy use of industry support and mentors with programs starting in elementary school.

So when governments think about driving technology-based development, they should think about more than the well-understood and important partnerships between governments, academia and industry that address issues like intellectual property, research funding, and technology transfer (Etzkowitz and Leydesdorff 2000; Smilor et al. 1989). They should also think about the hundreds of millions of students, taught by tens of millions of teachers, supported by hundreds of thousands of volunteers, who deliver STEM education to children around the world.[1]

1.1.2 Principles of K-12 in the Technopolis

K-12 in the technopolis is about more than STEM education in schools, and it is about more than development of a talent pipeline for industry, as important as both are. A rational and intentional integration of K-12 impacts the brand of a city or region; creates mutual benefits with priority industry clusters; creates a virtuous cycle of pedagogical reform; and ultimately a virtuous cycle of economic development. Social concerns and equity are addressed whenever education efforts in the technopolis are expanded to include more students from underrepresented populations.

1.1.2.1 The Central Role of Industry Clusters

Michael Porter (1990) elaborated the role of industry clusters in cities and regions. The basic idea is simple, that a cluster of related businesses result in benefits of networking and economy of scale to all cluster participants. As it relates to K-12 in the technopolis, aligning STEM education with industry clusters can be a powerful strategy. For schools, industry clusters can provide content inspiration, vocal support, volunteers, mentors and funding. For industry, programs aligned with their interests provide rich outlets for philanthropic activity, and they feed the talent pipelines that can fuel a virtuous cycle for the cluster.

In fact, using Porter's (1990) ideas, a case can be made that K-12 is just another industry cluster participant, right next to the more traditional actors. Within industry clusters, there is much transfer of knowledge, explicit and tacit. Porter emphasized this cluster attribute, and Gibson and Conceição (2003) also studied knowledge transfer (KT) at length. One only need look at the knowledge that flows from industry to schools, knowledge about real-world applications, about careers, and about the core STEM content itself, to realize that schools act in many respects like just another member of the cluster. Information flows both directions regarding the

[1] The number of students and teachers is extrapolated from the U.S. National Center for Education Statistics (2017). The number of volunteers is almost met by the number of volunteers worldwide in FIRST robotics (FIRST, 2019), with additional support from Zintgraff (2016). The author expects there are actually many more global STEM volunteers.

twenty-first century skills necessary in the workplace and how they can be taught. When programs are intentionally organized around priority industry clusters in a region, that knowledge transfer is enhanced (see Sanchez & Zintgraff; Gattaz, Falvo, & Cruvinel; and Aguiar & Pereira, this volume).

The cyber security cluster in San Antonio, Texas, U.S. presents a strong example. San Antonio has a decades-long history as a community with information security assets. As a result, a high number of professionals in San Antonio are available as mentors; in fact, some retired professionals have second careers as STEM educators in schools (Zintgraff 2016). The cluster's local history, the region's self-image regarding that cluster, and the number of professionals in the region all contribute to the possibility of a virtuous cycle developing between the cluster and STEM programs that serve K-12 students.

1.1.2.2 STEM Pedagogy, a Key Enabler

Compare two scenarios. In one, a teacher follows a traditional lecture-based pedagogy. Students receive content (perhaps very good lecture content), they read, and they pass tests with multiple choice and/or open-ended questions. In the second scenario, a significant portion of the student's time (half or more) is spent on research, inquiries or projects designed to teach content and/or require students to demonstrate understanding, and perhaps do so in collaboration with their peers. Which of these pedagogical strategies is the better platform for collaboration with people from outside the school?

The author argues that inquiry-based or related pedagogy is a richer platform for school-to-technopolis collaborations. While either pedagogy allows for guest speakers and information about careers, deeper understanding and real opportunities for interaction and mentorship come when students deeply engage content hands-on and minds-on. Most of the cases in this volume are good examples of intentional pedagogy enabling interactions between schools and technopolis actors. Petrosino (this volume) provides an in-depth exploration of the educational philosophy, theories and models that enable the type of integration this volume advocates.

Is the definition of STEM education also limited in this manner? The power and beauty of the term *STEM* derives, at least in part, from how diverse stakeholders feel a sense of belonging in the domain—they feel they belong to the STEM club. Does a traditional mathematics class qualify as STEM education? Does a traditional science class? What view is adopted for this chapter and volume? When Judith Ramaley re-coined the term *SMET* to *STEM* while at the U.S. National Science Foundation in the early 2000s, she advanced a narrative of science and mathematics as bookends to engineering and technology (Christenson 2011). Stated differently, STEM education requires integration across the subjects.

In this volume, mathematics education is viewed as important, as is science education. However, when taught with a solo design, such classes are called *STEM-related*. STEM classes happen without qualification when substantial integration (far more than a word problem or five-minute discussion at the end of class) is seen across two or more of science, technology, engineering and mathematics. It is this integration that changes the nature of instruction, and this integration that opens the educational experience up for deep collaborations with partners from across a community.

1.1.2.3 Technology within Pedagogy

STEM fundamentally involves technology, but to consider its role, a more nuanced view is needed. In K-12 STEM education, one sees: (1) how technology is studied as a subject; (2) how technology is used to deliver education; (3) the use of real-world concerns to create context; and (4) how learning theories and methods are co-evolving with technology to make this approach workable at scale.

Take, for example, the Medellín, Colombia STEAM-LABS program. The City of Medellín 2021 Science and Technology Plan identified energy, health, and ICT as the city's high-technology clusters of focus (Echeverri 2014). STEAM-LABS adopted these clusters as a framework for identifying interdisciplinary topics for study.

The Medellín teachers developed curricula around authentic, locally important problems in those clusters. Two examples were: (1) ways to deliver minimum water allocations to poor citizens; and (2) using video games to teach citizens about health (Zintgraff et al. 2015). Students studied how technology can solve these societal problems, which included interacting with the relevant technology.

Technology was used to deliver the Medellín curriculum, from basic tools like cloud storage, presentation software, video delivery, and desktop publishing software, to more advanced educational technology, like learning management systems and simulation environments. The students studied technology of different types (e.g., electromechanical flow systems). They used technology in their projects, including many of those same tools, along with software development platforms.

All instruction was developed consistent with the principles of learner-centered design. In the specific case of STEAM-LABS, instruction was developed based on the Buck Institute of Education's project-based learning model. Instructional design emphasized the Buck Institute's 6 As– authenticity, academic rigor, applied learning, active exploration, adult connections, and assessment practices (Markham et al. 2003).

Likewise, San Antonio's cyber competitions delivered problem-based instruction, with online training content and a live monitoring system on PCs assessing student performance. Technology is both subject and mechanism for delivery. The program addresses a critical societal need, cyber security. Sanchez and Zintgraff (this volume) also describe the pedagogy as mentor-based learning, with mentors serving a central role in the program.

Additional developments in educational technology, instructional theory, and instructional design are moving forward in lockstep. Technology and instructional methods are evolving to support personalized instruction at scale (Powell et al. 2015). Students are being assessed formatively, with assessment emerging from authentic coursework (versus through costly and timely–and often despised–standardized tests). Simulations, virtual worlds, and augmented reality are blurring the gap between artificial classroom exercises and authentic experiences (Wu et al. 2013).

The recent two volumes of Reigeluth's *Green Books* on instructional design (Reigeluth and Carr-Chellman 2009; Reigeluth et al. 2016) focused almost exclusively on learner-centered design, from philosophy to practice.

1.1.2.4 The Technopolis, Social Concerns and Digital Equity

Equal availability of physical resources for education and instructional designs/content is a worldwide challenge (Resta and Laferrière 2015). A functioning technopolis presents possible solutions to the local instances of equity challenges. Successful industry clusters are motivated to build their brand in regions. Their members have the capacity to deliver physical resources and human capital support while meeting philanthropic goals. Resta (this volume) notes the need for culturally responsive content. Content built around the local challenges of cities and regions is fundamentally sensitive to local needs.

A special example of equity concerns in education is seen in Roldán's description (this volume) of STEAM education in Medellín, Colombia. Once the most dangerous city in the world, Medellín has become a worldwide model for innovation, and one distinctive of Medellín is the strategy and organization they use to drive STEAM (STEM+Arts) education reform. They drive STEAM education reform, and run STEAM education projects, from the same agency that drives city space planning, transportation equity, large company expansion, university technology transfer, and entrepreneurship. K-12 education is fundamentally integrated in their innovation agency. Medellín's choice to embrace STEAM education, as opposed to simply STEM, is a direct attempt to deliver education in a manner responsive to culture, economic disparity, and specific local challenges.

1.1.2.5 Building the Local Brand

Throughout this volume's case studies, one sees policymakers working to transform their communities through technology-based development. Wherever the tool of government policymaking is used, policymakers need the political support of citizens to fund initiatives, vocally support initiatives, and see policies implemented to completion. Which approach to building support is most effective: a government official's speech, or the advocacy that flows from schoolchildren learning about the challenges of their community? STEM education's first purpose must always be learning. At the same time, students are powerful communicators to their parents, siblings, extended family and friends.

1.1.2.6 In This Chapter

The remainder of this chapter examines the relationship of K-12 STEM education to the long-term development of industry clusters—the same clusters that have led globally to wealth and improved quality of life. The author argues that a city's or region's programs and policies for technology-based development should incorporate support for robust STEM education experiences for students. The policies should address the knowledge and skills needed to succeed in relevant careers, and they should encourage the framing of STEM education experiences within the context of priority local industry clusters and societal challenges. In doing so, regions can drive a virtuous cycle of education, economic development, and quality of life for citizens.

The author argues for the existence of this virtuous cycle by examining three cases from around the globe. The cases are from Colombia, the U.S., and Taiwan. In each case, the author identifies common indicators seen when a virtuous cycle is in operation. The indicators are: industry cluster inspiration, industry cluster support, individual support from professionals, university support, government support, non-profit support, societal concerns driving inspiration, and K-12 education feeding the talent pipeline. Based on the analysis, a virtuous cycle model is presented.

Additional discussion covers what is meant by the term *policy* in the current volume. Some examples of policies are shared that reflect the volume's themes. A closing discussion outlines the content of the remainder of the volume.

There is power in the compatibility between the economic, social and political context provided by regions, on the one hand, and increasingly common methods for teaching and learning that are driving educational reform. Their strategic alignment can benefit all stakeholders in a technopolis.

1.2 The Eight Common Indicators

When virtuous cycles are nascent or in operation, eight indicators are often found. Recognizing these indicators gives all stakeholders the chance to support them, or at the least, to do no harm to them. Readers will note the similarity of the stakeholders described to those found in the technopolis model/wheel. Table 1.1 lists a summary of the indicators, following the narrative description below.

1. Industry Clusters Inspire K-12 Education

K-12 education is not socially isolated from the communities in which it is delivered. Teachers, administrators, parents, siblings, and the students themselves see the activity that happens where they live. Educators who are inclined toward delivering education in context see these examples and find ways to bring them into classrooms. This is especially true if a cluster aligns well with emerging education trends. It may even be the case that in most communities where an industry cluster is strongly present, there is already a related K-12 education program in operation.

2. Industry Clusters Support K-12 STEM Education

Industry players support K-12 STEM educators in many ways. Support is provided through career speaker programs (Young 2007; Laursen et al. 2007), demonstrations of content (Young 2007; Forssen et al. 2011; Bardeen and Cooke 2011), field trips for students and teachers (Goonatilake and Bachnak 2012; Gamse et al. 2014; Bardeen and Cooke 2011), teacher externships (National Science Foundation 2015), and direct funding (e.g., FIRST in Texas 2016b; CyberPatriot 2013a). Seeing students learn through the mechanisms of one's field is inspiring. Industry support

Table 1.1 Indicators of a Virtuous Cycle

Number	Description
1	Industry clusters inspire K-12 STEM education
2	Industry clusters support K-12 STEM education
3	Individual professionals support K-12 STEM education
4	Universities support K-12 STEM education
5	Government entities support K-12 STEM education
6	Non-profits support K-12 STEM education
7	Societal concerns inspire K-12 STEM education
8	STEM education feeds universities and industry

for education also demonstrates corporate social responsibility, and can be an effective marketing and branding strategy for a corporation.

3. Individual Professionals Support K-12 STEM Education

Those industry cluster contributions require the active participation of industry professionals. Through intrinsic motivations, or external ones like self-development or social interaction (Clary and Snyder 1999), professionals get involved as career speakers, field trip hosts, content experts, technical and equipment experts, professional development providers, or as coaches/mentors in project- and competition-based programs (Zintgraff 2016).

4. Universities Support K-12 STEM Education

Not all professionals come from for-profit industry. Volunteers can arrive from universities (Zintgraff 2016)—from university faculty, staff or the student population. Universities are often conducting research as they run programs. University support for STEM programs can help develop the university's reputation locally, providing recruiting benefits.

5. Government Entities Support K-12 Education

Governments are, in the end, responsible for the vast majority of primary and secondary education. Beyond that commitment, government entities with non-education missions often make contributions to education. For example, in the U.S., city governments sometimes provide funding, program and advocacy support to programs, even though separate government entities ("school districts") that are governed by independent boards are responsible for K-12 schools (e.g., CyberPatriot 2013a). Such voluntary behavior suggests the strategic importance governments place on the activities of local schools and their alignment with strategic development priorities.

6. Non-Profits Support K-12 STEM Education

Non-profits organize programs and volunteers that connect to regional STEM education programs. Three examples that operate at large scale are FIRST robotics, VEX Robotics, and CyberPatriot (FIRST in Texas 2016a; VEX Robotics 2013; CyberPatriot 2013a). The society-driven missions of non-profits often overlap with the topic areas that fuel K-12 STEM education programs; for some non-profits, education in these areas is their primary mission.

7. Societal Concerns Inspire K-12 STEM Education

Simultaneously at work is the influence of societal concerns on actors in the system. Cities and regions face numerous challenges: economic development, equity, transportation, public safety, climate, and many others (NIST 2017; IEEE 2017). K-12 STEM education programs use these challenges to inspire student learning (e.g., Markham et al. 2003). The actors involved in those programs frequently overlap those mentioned above.

8. K-12 STEM Education Feeds Universities and Industry

College students and professionals were once K-12 students. Some followed traditional paths to the workplace. Others benefited from programs tightly tied to local workforce needs. The professional economic development community understands well that the presence of a talent pipeline is key to attracting new businesses to a city or region (Bhatnagar 2008). One must consider the talent pipeline from both individual and group perspectives. These pipelines prepare individual people for work in the field, and they create a group perception in the community that drives interest in programs and careers. Stated another way, the virtuous cycle is practical, but it also psychological. Industry clusters create shared social meaning in the minds of citizens. This socially constructed knowledge (Vygotsky 1978) helps drive the virtuous cycle. Table 1.1 lists the eight indicators of the cycle.

1.3 Cases

Three geographically diverse cases are presented to support the argument made above, and to illustrate the virtuous cycle in action. The first case comes from Medellín, Colombia. Their STEAM-LABS/STEAMaker and Horizon programs are framed by the city's science, technology and innovation plan (Zintgraff et al. 2015; Roldán, this volume). They use the city's development challenges as subject matter for project-based instruction. The second case comes from San Antonio, Texas, U.S., location of a Center of Academic Excellence for CyberPatriot, a cyber defense competition for secondary students (CyberPatriot 2013a). Their effort is supported by an industry cluster that includes the second-highest number of certified information security professionals in the U.S. (Zintgraff 2016). The third case is from Taipei, Taiwan (Yang, Yang, Chou, Wei, Chen, & Kuo, this volume). Framed by Industrial Revolution 4.0, Taiwanese high schools and colleges have embraced robotics and project-based instruction, with support from the local and national government and other actors in their region.

1.3.1 Medellín: STEAM-LABS, STEAMakers and Horizon Programs

1.3.1.1 Overview

In Medellín, Colombia, a series of STEAM (STEM+Arts) education programs have framed educational experiences within the development goals of the city. Two prior programs, STEAM-LABS and STEAMakers, were completed and helped establish a foundation. The Horizons program is ongoing, run by the city's innovation agency and tightly aligned with city goals. All of these programs demonstrate the principles highlighted in the current volume. For more details about the Horizons program, see Roldán in this volume.

STEAM-LABS (Zintgraff et al. 2015) began as a spin-off of a technology commercialization training program in Medellín, Antioquia Department (State), Colombia, delivered by the IC^2 Institute along with the College of Education at The University of Texas at Austin (UT Austin). Framed by the Medellín 2021 science, technology and innovation plan, STEAM-LABS was designed to introduce STEAM-aligned Project-Based Learning (PBL) methods to Medellín educators, with a dissemination plan to grow adoption.

Preliminary planning and vetting of ideas involved meetings with the education ministry; with Proantioquia, the region's premiere industry foundation; with Parque Explora, the local science park and museum; and with other industry representatives and educators. Seven education, government and community leaders visited Austin to see similar programs in action. The STEAM-LABS program trained 23 secondary educators and 8 college educators, organized into 11 teams. The program also conducted activities for school rectors and for industry supporters.

In STEAM-LABS, educator teams developed PBL curricula. The curricula was then delivered to students. Each curriculum unit focused on a problem aligned with one of Medellín 2021's high technology clusters. The UT Austin team delivered two one-week instructional sessions in Medellín, using the same project-based approach being trained; they supported development teams remotely; and they entered each of the 11 schools to visit with teachers, administrators, and/or students receiving instruction. The overall process began with an opening symposium with 130 attendees, mostly educators, but also well represented by university, government, nonprofit and industry leaders.

Figure 1.3 shows a closing activity at the symposium. Consistent with the focus on STEAM, an artist was hired to create a painting reflecting the event. The lady in the painting represents knowledge, and her flowing hair represents the dissemination of knowledge to all citizens of Medellín. The painting was presented to the city's Secretary of Education.

A second symposium was held on program completion, with 100 attendees reviewing progress and making go-forward plans. Going beyond original requirements, the educator participants trained an additional 137 teachers in their own schools, and the program ultimately served 1440 students (Zintgraff et al. 2015).

The STEAMakers program (Parque Exploration 2016) built on the progress of STEAM-LABS. Through a partnership with High Tech High School in San Diego, California, U.S., peer teacher relationships were established. The program added stronger rector training, and introduced maker education methods into instruction. Maker education was seen as adding an important student-as-creator element to PBL, encouraging exploration of solutions to the city's challenges.

Fig. 1.3 CreAccíon Medellín symposium, December 2013

1.3.1.2 The Eight Indicators

In STEAM-LABS, the indicators described were both (1) partially designed in by the UT Austin team, and therefore self-fulfilling, but also (2) already considered in many respects by Medellín actors. The Medellín 2021 plan was clear about the city's high-technology clusters, and the rationale for using them in pre-college education. STEAM-LABS largely required projects to be aligned to those clusters. STEAM-LABS organized industry supporters, recommended ways to engage those supporters, and organized a training session for them. While outcomes from industry engagement were mixed, some schools had strong outcomes, both through industry provision of resources, and also through the volunteer efforts of professionals. Proantioquia actively supported the program. Empresas Públicas Medellín (EPM), the Medellín-based utility company serving the city and other national clients, continued its long history of education support. University professors were trained and acted as subject-matter experts. The program was funded and managed by the city government's higher education agency and by Parque Explora, which was organized as a non-profit. Sapiencia (the higher education agency) facilitated involvement of university professors, and benefited by positioning themselves as a destination for students interested in the Medellín 2021 clusters. See Table 1.2 for a summary of the eight indicators present in STEAM-LABS.

1.3.2 San Antonio: CyberPatriot

1.3.2.1 Overview

In San Antonio, Texas, U.S., the city's cyber security cluster is the frame for the CyberPatriot program (CyberPatriot 2013a). CyberPatriot is a national competition in which high school teams (grades 9 through 12) and middle school teams (grades 6 through 8) compete in cyber defense challenges. For the city, cyber security is a

Table 1.2 The eight indicators in STEAM-LABS and STEAMakers, Medellín

Element	Description
Industry clusters inspire K-12 STEM education	Clusters were from Medellín 2021 Science, Technology and Innovation Plan
Industry clusters support K-12 STEM education	Industry players provided funding and volunteers to individual schools
Individual professionals support K-12 STEM education	Professionals participated, as individuals, and facilitated by employers
Universities support K-12 STEM education	Support from higher education agency, and participation of teachers from technical universities
Government supports K-12 education	Support and funding from education ministry
Non-profits support K-12 STEM education	Medellín program team was from science museum; event space provided by museum
Societal concerns inspire K-12 STEM education	All projects aligned to industry clusters and strongly exhibited connection to detailed local challenges
STEM education feeds universities and industry	Higher education agency viewed as program to recruit and prepare students

well-established cluster. Several decades ago, the U.S. Air Force's Air Intelligence Agency was formed and located in San Antonio. The mission grew, and a cluster of information security contractors and startup companies developed, with the city eventually claiming the second highest number of certified information security professionals in the U.S. (U.S. Department of Defense Office of Economic Adjustment 2016). More recently the city competed and won placement of the 24th Air Force and 25th Air Force in San Antonio, both focused on cyber operations (24th Air Force 2012, 25th Air Force 2016). Several institutions of higher education in San Antonio are recognized as Centers of Academic Excellence by the U.S. Department of Homeland Security and the U.S. National Security Agency (Greater San Antonio Chamber of Commerce 2012).

The city's program is recognized as a Center of Excellence for CyberPatriot (CyberPatriot 2013b). The program features problem-based learning, extracurricular instruction, classroom instruction in selected schools, teacher professional development, robust mentoring from industry professionals, and a mature training program for a robust corps of volunteer professionals who support the program. According to program staff, 204 student teams competed in CyberPatriot in 2017. With one exception, the city has placed a team in the national finals each year since 2008. In 2011, a San Antonio team won the national finals. The team was from the Information Technology and Security Academy (ITSA), a program formed in 2002 through a partnership of the city government, city-owned utility company, the Alamo Community College District, the University of Texas at San Antonio, and numerous industry partners.

A special feature of the city's program is the Mayor's Cyber Cup. The cup, awarded to the best performing team in the San Antonio metro area, is part of a larger event that includes a job fair, a college fair for cyber security programs, and an awards ceremony. Figure 1.4 demonstrates the participation of secondary education, higher education, government, industry, and community partners in developing

Fig. 1.4 San Antonio Mayor's cyber cup awards ceremony

the program. The participation of the Mayor lends a high profile, and it reflects the city's de facto policy of supporting and developing the cyber security cluster.

1.3.2.2 The Eight Indicators

The start of cyber security secondary education in San Antonio was arguably ITSA. This high school academy was created in direct support of the local cyber security (then called information security) cluster. In organizing, members of the cluster created a support system for delivering education related to cyber security. Between the first and second year (11th and 12th grade years) of the program, all students receive internships, which puts them in direct contact with adult professionals. Later, as CyberPatriot became a prominent program, a corps of professionals, some volunteering on their own, and others organized by industry, served as mentors to teams.

Alamo Colleges, the University of Texas at San Antonio, and other institutions supported these and other programs through funding, in-kind resources, and staff support. The CyberTexas Foundation is a non-profit formed in part to support CyberPatriot. The city government provides funding, and through its actions, promotes the importance of the cluster and its educational programs. All these efforts advance the security of computers, networks, infrastructure and privacy; cyber security is a global top-of-mind concern of society. In San Antonio, almost all students in these programs move on to college education, and some enroll in cyber security programs, graduate, and find employment in the cluster. Although a small number overall, selected students receive part-time or full-time jobs immediately on completion of their high school cyber security programs. These indicators are listed in Table 1.3.