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Editor

Computational Thinking in the STEM Disciplines

Foundations and Research Highlights

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Foreword

The future is already here. It's just unevenly distributed — William Gibson

A computer terminal is not some clunky old television with a typewriter in front of it. It is an interface where the mind and body can connect with the universe and move bits of it about — Douglas Adams

In 1943, Thomas Watson, then president of International Business Machines (aka IBM) made one of the most inaccurate predictions ever. Speaking of the future of the computer business he said, "I think there is a world market for maybe five computers." Clearly, he missed the mark by a few billion in sheer numbers. But more importantly he missed the mark in seeing the dramatic shift in human life and culture that would occur. Computers are everywhere today. They drive our work, our society, and our lives in almost every way imaginable. They pervade our reality. So much so that if computers and digital technology suddenly vanished or shut down, global communication, information, and society would come to a grinding halt.

From giant supercomputing machines that can crunch quadrillions of floating-point operations per second (FLOPS), a measure of computer performance to tiny chips that are embedded in everyday objects, we exist in what is often described as the *Internet of things*—or the network of devices that connect our lives, spaces, possessions, communications, and more. More people have access to cell phones today than to safe drinking water (Casey, 2016). Computers have become integral to how we function. Our work lives are often driven by digital communications and tasks. People today buy every good or service imaginable online, from luxury items to basic necessities like food. They meet significant others online or use the Internet to connect with friends and family at near and far distances. Digital technologies are integral to how we work, think, live, and run our world. Though we can speak of the practicalities of such technology, what we are seeing is a fundamental transformation of our engagement with the world as humans.

This global shift was best captured in a talk delivered by the author Douglas Adams at a conference at Magdalene College, Cambridge, in 1998. In a wide-ranging, extempore speech, Adams covered a range of topics, in his inimitably funny yet insightful manner, including the cultural and intellectual history of the human civilization. One of the insights he shared with the audience how human technological history consists of, what he referred to as, *the four ages of sand.* Specifically, Adams seeks to describe how technological change has changed and broadened our understanding of ourselves and the world. Let us quote directly from Adams (1998), as he describes the first two ages, primarily because paraphrasing him risks losing the immediacy and power of his distinctive voice and the precise meaning in his ideas:

> *The first age of sand was the age of the telescope.* From sand we make glass, from glass we make lenses and from lenses we make telescopes. When the great early astronomers, Copernicus, Galileo, and others turned their telescopes on the heavens and discovered that the Universe was an astonishingly different place than we expected and that, far from the world being most of the Universe, with just a few little bright lights going around it, it turned out - and this took a long, long, long time to sink in - that it is just one tiny little speck going round a little nuclear fireball, which is one of millions and millions and millions that make up this particular galaxy and our galaxy is one of millions or billions that make up the Universe and that we are also faced with the possibility that there may be billions of universes, that applied a little bit of a corrective to the perspective that the Universe was ours.
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> *The next age of sand is the microscopic one.* We put glass lenses into microscopes and started to look down at the microscopic view of the Universe. Then we began to understand that when we get down to the sub-atomic level, the solid world we live in also consists, again rather worryingly, of almost nothing and that wherever we do find something it turns out not to be actually something, but only the probability that there may be something there.

The third age of sand, according to Adams, is the discovery that sand can be used to make the silicon chip. The chip led to the digital computer and then suddenly:

> ...what opens up to us is a Universe not of fundamental particles and fundamental forces, but of the things that were missing in that picture that told us how they work; what the silicon chip revealed to us was the process. The silicon chip enables us to do mathematics tremendously fast, to model the very simple processes that are analogous to life in terms of their simplicity; iteration, looping, branching, the feedback loop which lies at the heart of everything you do on a computer.

The fourth and final age of sand according to Adams is that sand can be used to make fiber-optic cables and thus leads to a new communication platform, the Internet. This is a new form of communication (many-to-many), in contrast to previous technologies such as the telephone (which was one-to-one), or radio and TV (which were one-to-many). It is communication between people that forms the fourth age of sand.

The idea here is that each of these ages of sand changes how we, as a species, locate ourselves in relation to the world. The repercussions of the first two ages of sand are felt even today; their contribution to our knowledge of the world and our

place in it is not the stuff of school textbooks. Yet we are actually now living within the next two ages (the third and fourth ages of sand), and this has significant implications for our economy, our lives, and our relationships with each other and our world. The first two ages of sand have power in human knowledge and history but are either felt indirectly or seen as knowledge removed from our everyday lives or experiences. But the third and fourth ages of sand have immediately obvious and tangible affects on our lives and experiences. Without them, our everyday acts of talking or texting with distant friends and family, buying our "stuff" online, sending work emails, or checking the immediate news would be impossible. These ages of sand pervade our experience of the world and each other. In this, they are not only ages of technological development—they become the filter or lens through which we operate and function. They drive our view and experience the world. Thus, they are woven into the fabric of our immediate lives, needs, and beliefs.

Clearly something as world-view changing as the third and fourth ages of sand require new intellectual tools to grasp, understand, control, and experience these devices and technology. It is important to remember that one of the challenges in the world of the third and fourth ages of sand is in their virtual nature. Such technologies are often *black boxes*, in that their inner workings are relatively impenetrable, unless one has explicit technical knowledge to understand them. This requires that we develop intellectual tools or ways of thinking that allow us to understand and engage with such technologies in creative, thoughtful, and appropriate ways. Along with the development of these intellectual tools, we need pedagogical tools to prepare the next generation of learners to work, live, play, engage, and design technologies appropriately, ethically, and thoughtfully. This goes beyond merely learning to program things. This means helping teachers and learners to develop a mind-set, skills, knowledge, and dispositions that allow for creative learning with technologies.

This is where computational thinking comes to the forefront. Broadly, computational thinking is thought processes for structuring and formulating problems that can be effectively carried out by computational devices, or other information processing agents. Given the breadth and depth with which technology touches our world, computational thinking cuts across disciplines and must be of interest not just to computer scientists but to every student and learner. The question of how to bring computational thinking to teachers and learners in creative and interdisciplinary ways is challenging and complex. Given the accelerating rate of technological change, with its dramatic impact on our lives and world, this is also an urgent problem, and one demanding of scholarly attention.

That is what makes this book and the range of ideas in this book so timely and important. The editor of this collection has compiled articles by top thinkers, scholars, and researchers in this emerging, growing field. The work presented in this volume touches on a range of aspects of computational thinking and helps us to better define its range, scope, and potential of learning in this new domain. We believe that this line of work can have significant impact on the future of this area, by providing ideas, guidelines, and solutions for the next generation of learners who will live, learn, and engage with these new ages of sand.

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