Computer Science Unplugged and Related Projects in Math and Computer Science Popularization

Tim Bell[1,⋆], Frances Rosamond[2], and Nancy Casey[3]

[1] Department of Computer Science and Software Engineering
University of Canterbury
Christchurch, NZ
tim.bell@canterbury.ac.nz

[2] School of Engineering and Information Technology
Charles Darwin University
Darwin, Northern Territory 0909 Australia
Frances.Rosamond@CDU.edu.au

[3] Logwood Stone
Moscow, Idaho
Nancy@logwoodstone.com

Abstract. *Mathematics popularization is an important, creative kind of research, entangled with many other research programs of basic interest* — Mike Fellows

This chapter is a history of the Computer Science Unplugged project, and related work on math and computer science popularization that Mike Fellows has been a driving force behind, including *MEGA-Mathematics* and games design. Mike's mission has been to open up the knowns and unknowns of mathematical science to the public. We explore the genesis of *MEGA-Math* and "Unplugged" in the early 1990s, and then the sudden growth of interest in Unplugged after the year 2003, including the contributions from many different cultures and its deployment in a large variety of contexts. Woven through this history is the importance of story: that presenting math and computing topics through story-telling and drama can captivate children and adults alike, and provides a whole new level of engagement with what can be perceived as a dry topic. It is also about not paying attention to boundaries — whether teaching advanced computer science concepts to elementary school children or running a mathematics event in a park.

Dedicated to Mike Fellows
on the occasion of his 60th birthday.

1 Introduction

It is quite uncommon for a world class research scientist to also be heavily involved in K-12 education. It is rarer still for such a scientist to be involved in

⋆ Corresponding author.

H.L. Bodlaender et al. (Eds.): Fellows Festschrift, LNCS 7370, pp. 398–456, 2012.

developing new programs and methodologies for popularizing and teaching basic principles in education.

Mike Fellows and some of his co-workers initiated just such a program beginning in the 1980's. They were deeply concerned with the trends in mathematics and computer science education. The plan was to develop materials based around modern research in computer science and mathematics and have these ideas used to make early education more exciting and engaging.

As we will describe in later sections of this paper, these ideas involved things like NP-completeness, parallel sorting networks, automata, and many other mainstays of modern computing research. The early material evolved from various projects and groups (including "Family math", "Mathmania") culminating in the "MEGA-math" project, which ultimately led to the "Computer Science Unplugged" project that has become widely used internationally.

In this paper, we will describe the projects involved and look at how the material evolved. A subtext of the paper is the difficulty of getting the material accepted, necessitating a long and hard fought campaign for eventual adoption. We also track the chance meetings and collaborations that brought about a rich and diverse range of material and events under the "CS Unplugged" umbrella.

Acceptance of Mike's efforts in mathematical outreach had a bit of a slow start, somewhat similar to the slow acceptance by theory researchers of parameterized complexity. Mike has told about publishers in the 1990's who rejected Computer Science Unplugged saying, "It is not a math book, and since it is 'unplugged,' we cannot publish it as a computer science book either. But, my wife loves it and so does her friend who is a teacher, so would you please send us another copy." It was quite a different scene at the 2007 ACM Special Interest Group in Computer Science Education (SIGCSE) Conference. Carnegie Mellon Computer Science Department Chair Jeannette Wing had just finished her insightful description of "computational thinking" when Lenore Blum promptly announced,"We are fortunate to have someone here who has written materials that exemplify computational thinking. Would Michael Fellows please stand up." The SIGCSE workshop featuring Unplugged overflowed the venue, and had to be repeated, with standing-room only.

The prehistory of Unplugged began with "Family Math" in the seventies, which was part of the inspiration for the *MEGA-Math* program that started to take shape in the late eighties. This happened in the United States, at a time when many parents, often educated professionals, organized "free schools," hiring teachers and volunteering at the schools. Mike attributes his early popularizing efforts to volunteering in the elementary classrooms of his children Hannah and Max at Apple Blossom Family School in Moscow, Idaho. Mike recalls hurrying from his job at the university to the primary school. He had just been teaching a topic on sorting in a graduate class, and decided to teach the same topic to the children. It was a huge success, and the beginning of many of the activities that now are mainstays of *MEGA-Math* and Computer Science Unplugged.

As Rod says in his chapter, Mike's homes were always full of books from all kinds of areas of human endeavor, and papers from many areas of science. Furthermore, Mike loves to talk with people from all backgrounds, about almost any subject. Rudolf Fleischer calls his thinking "top down," in the sense that he can see quickly right to the heart of an issue — and recall all the details, no matter how many years have passed. These aptitudes coupled with vast imagination and an indignation that children were being given short-shrift by the school curriculum, resulted in four Cowboy Melodramas — satires about mathematics education, that were presented at the 1998 Fringe Theatre in Victoria. Each play dramatizes the proof of a mathematical theorem, and Mike considered the plays an experiment in presenting technical information to the public. He called them "content-driven" theatre. These are discussed in more detail in the chapter on "Passion Plays," but they are closely related to the Unplugged project because they make strong use of imaginative stories to illustrate a deep point; and they directly address the issue that young students should be exposed to the exciting parts of our discipline.

As computer games became increasingly popular, Mike thought about how they could be used to convey mathematics to children, and he developed a systematic method of creating computer games harnessing the intractable computational problems in the compendium of Garey and Johnson [1].

These various experiences came together to produce Computer Science Unplugged, a collection of stories, games, puzzles, and tricks, presented as activities, shows and videos, which have led to the *Unplugged* approach to pedagogy that has become a meme in the world of computer science education.

This history of Unplugged is timely because the year 2012 marks the 20th anniversary of the publication of the book *This is MEGA-Mathematics!*, which was the seed that led to the collaboration that became known as "Computer Science Unplugged." The Unplugged project began out of an interest in providing engaging and accessible ways of introducing children to big ideas from mathematics and computer science, and has grown from a few chance collaborations into an approach to outreach and teaching with direct contributions from dozens of academics. It has been translated into about 16 languages, used in classrooms in many countries, and found its way into creative endeavors tangential to mathematics and computer science.

In the spirit of the style of teaching described in this chapter, we begin in Section 2 by diving headfirst into describing the sorting network as an example of the type of activity that was used as a tool for engaging young children with advanced ideas from math and computer science. The remainder of the chapter is organized somewhat chronologically. Section 3 reviews some of the activism that Mike engaged in to change attitudes amongst educators, one product of which was the *MEGA-Math* workbook, which is described in Section 4. Section 5 describes how this led into Computer Science Unplugged, and Section 6 explains how it suddenly gained momentum around 2003 to 2006. The general principles that emerged through this work are captured in Section 7, and evaluations of Unplugged are reviewed in Section 8. In parallel to the work on *MEGA-Math* and Unplugged, Mike was working on computer games and the mathematical "passion plays". Section 9 reflects on Mike's insights into computer games; the separate chapter on passion plays describes the Cowboy Melodramas of Mathematics.

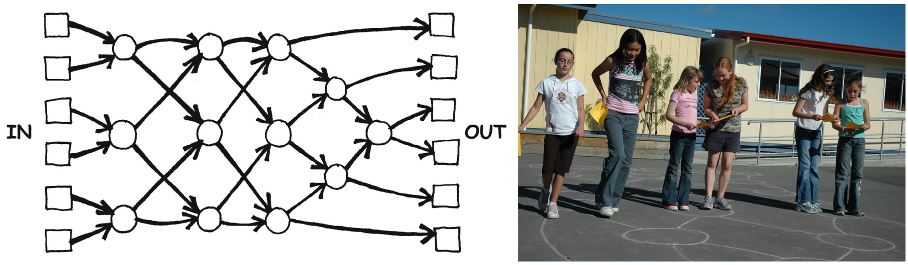
The information in this chapter has been gathered by personal recollection of many of the people involved, and a survey of the large number of writings that these projects generated. By chance, two natural disasters also provided source material for us: Mike and Frances' papers arrived in Darwin from Newcastle, delayed by the 2010–2011 Queensland floods, just in time to use in writing this chapter, and Tim Bell's office had to be completely emptied after the Christchurch earthquake of February 2011, bringing to the surface some early documents relating to Unplugged. Writing this chapter involved something of an archaeological dig through the resulting material, unearthing all sorts of relics from the last 20 years!

We know that the ideas have had lasting influence. It is moving to Mike, to receive on a fairly regular basis, an email from an unknown person saying something like, "Dear Dr. Fellows, I have found your article about Unplugged or *MEGA-Math* or . . . , and I just want you to know how much it means to me . . . ." In fact, Elena Prieto, who subsequently became Mike's Ph.D. student, knocked on his University of Victoria (UVic) office door to say, "I just want to shake the hand of one of the authors of Computer Science Unplugged." Elena had been teaching for an NGO as a mathematics lecturer at the National University of El Salvador, and relied on Unplugged when the power went out, which was not infrequent. This chapter reveals many more unexpected applications and situations where Mike's vision has changed the way math and computing is taught!

2 The Sorting Network

The quintessential "Unplugged" activity that has been an instant hit with all ages for the last two decades is the "Sorting Network", where a layout like the one in Figure 1(a) is drawn on the pavement in chalk (Figure 1(b)) or on an indoor surface with painter's tape. Six students holding numbers start in the six boxes on the left, and move to the right following their respective arrow until they meet another student at a circle (node). At the circle, two students compare numbers, and the student with the smaller one follows the arrow to their left, while the student with the larger number follows the arrow to their right. Each student arrives in a new circle where they again compare numbers with the student they meet there. This structure is called a *parallel* sorting network because there are three comparisons happening at the same time.

Students and teachers alike are generally surprised when they come out the end of the network with the numbers they are holding in ascending order, and suddenly everyone is plunged into the kind of observation, questioning, critical thinking and reflection that is at the core of mathematics and computer science. Does it work backwards? Can you sort in descending order? Can you use it to



(a) (b)

Fig. 1. (a) A 6-input parallel sorting network (b) Chalked in a school playground

sort 12 numbers? Or 7? Can you give it a set of numbers that will make it fail? Can you find a shorter network that still sorts the numbers? How many permutations would you have to test to check every possible input? Some students might immediately insist on trying it again. Others might try drawing their own networks, or begin inventing/drawing something that only they can understand. Some students simply listen and watch. While the class as a whole mimics a mathematical community whose members are grappling with different aspects of an intriguing problem, it's likely that neither the students nor teachers will have a sense that they are "doing" math or computer science, because school math tends to be directed towards finding right answers to known problems, and computer science is understood to be some kind of drudgery one does in front of a computer, like writing programs or fixing the system.

Mike tells a story of the first time he made a sorting network with children. He showed the children the topic he had considered that day with his university students. The parallel sorting network is a well-understood area of algorithms, but is seldom taught before senior levels of university. Yet students as young as 5 years old can fairly easily understand how to use one, and more significantly, because of the experience they can begin to understand the sort of ideas that computer scientists work with. By "failing" to conceptualize a child's mind as miniature and mildly incompetent, activities like the sorting network invert the notion of age-level hierarchies for mathematical topics, and instead give children of any age and development a chance to engage with an idea in computer science with whatever intellectual horsepower they have.

Since Mike's first experiment with it in the late 1980s, the sorting network activity has been used in many classes—spray painted on grass, chalked on pavement, taped on carpet, glued onto portable tarpaulins, paved in a garden, drawn as miniaturized Japanese board-game versions for schools where space is limited, and crafted in a virtual world for use by students with mobility impairments. It has been done with up to 50 people at once, by Girl Scouts, by senior citizens, by music students, and by guests at birthday parties and a wedding. A number of videos of groups doing it can be found on YouTube. Figure 2 shows some of these variations around the world, and in a virtual world. Figure 2(d) shows the difficulty of using it with students in wheelchairs, motivating the virtual version in Figure 2(e); Figure 2(f) shows a student who can't walk, yet is "running" around a virtual sorting network. Figure 2(g) shows the idea being implemented in a popular introductory programming environment — in this case it has come full circle, and school children are actually able to implement a kind of sorting network in a program (as long as no-one tells them that it is supposed to be difficult—to them it is just a simulation of something they have done physically). Recently the sorting network has been used regularly to teach music theory, comparing things like note pitches (Figure 2(i)) and note lengths [2]. In Lisa Whittle's classroom, the sorting network was kept on the classroom floor for use in many subjects: ordering distances from planets to the sun (science), molecular weights or densities (chemistry), fractions (math), notes and scales (music), eras or events (history), or priorities (social studies).

The parallel sorting network teaches much more than logic or algorithms. For example, students often try to get to the end as quickly as possible, leaving behind another student who is waiting on the outcome of a comparison. At this point they realize that their haste has caused the whole team to fail, and this is a salutary lesson for those who might be interested in computers but not so good at team work. Eventually it is understood that nobody wins alone; all win together as the sorting resolves the different values into a clear order. The sorting network is a model of cooperative learning, more of a dance or a series of conversations than a race. It is useful to ask people to greet their partner when they arrive at a node, which has led to pleasant surprises as children in some countries salute or charmingly bow in greeting. Another topic of discussion is what sorts of activities can/cannot be done in parallel—digging a hole? digging a trench? getting parcels from Darwin to Christchurch?

The nice thing about this demonstration, and many of the others that have become part of the Unplugged canon, is that children don't want to stop "playing." Tim recalls being asked by a girl for a copy of the network so she could use it at her birthday party, and Frances reports having a class that refused to stop, as they went on and on sorting everything they could, including replacing library books on the shelves [3].

3 Early Activism on Computer Science and Math Education

The sorting network is one of dozens of engaging, thought-provoking activities that could be developed for young students, yet the education establishment found little use for them beyond "enrichment," or novelties offered as a break from rote learning of the calcified topics one is sure to find on standardized tests. Mike expressed his sense of injustice to children at this state of affairs in his dissident 1991 paper about the way math and computing were approached in schools: "Computer SCIENCE and Mathematics in the Elementary Schools" [4]. This paper is essentially a manifesto for the work that continues to this day, and makes the following key points:

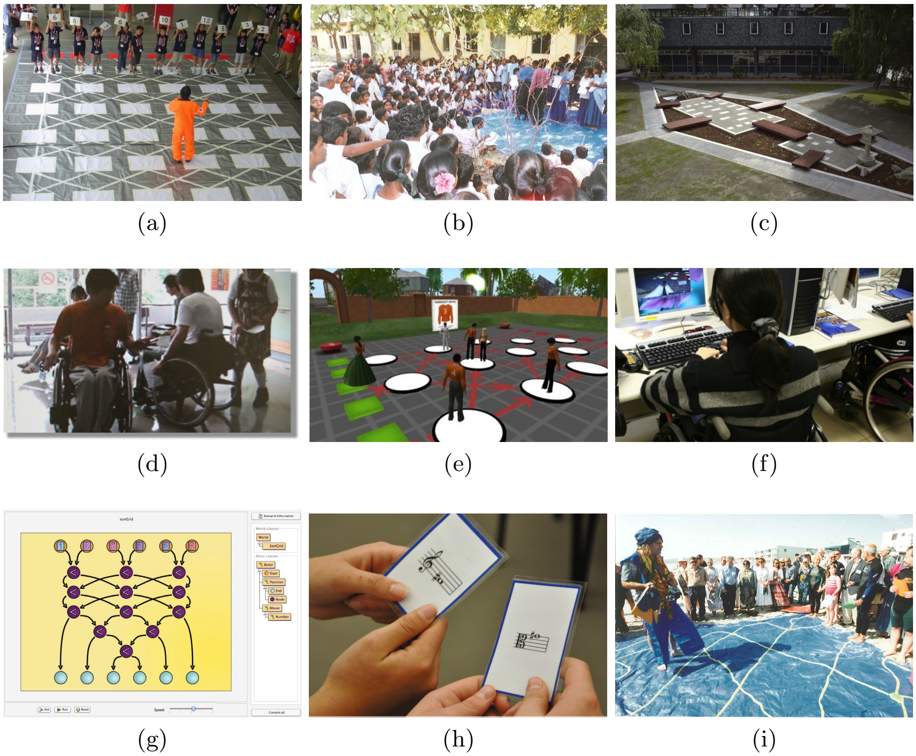


Fig. 2. The ubiquitous sorting network (a) a 12-way network at a kids' event in Tokyo (b) in India (c) on an "island" of the "seven bridges" garden at the University of Canterbury (d) students in wheelchairs in Japan (e) in Second Life (f) using a Second Life sorting network (g) an exercise in Greenfoot (h) in a music theory class, and (i) at Mike and Fran's wedding!

- Elementary school students deserve to experience profound and imaginative mathematical ideas. Such ideas shouldn't be reserved for graduate students.
- Open unsolved problems are the creative drivers for mathematical activity, but children are "taught" a version of mathematics based almost entirely on correct answers.
- Mathematics itself is an "interdisciplinary powerhouse." The pursuit of mathematical ideas will open doorways and raise interesting questions in the sciences and humanities.
- Mathematics popularization is a research area of basic interest. Exciting mathematical ideas will not find their way to children and their teachers without an effort on the part of mathematicians to communicate about them in accessible ways.

Mike was undaunted by the education establishment's lukewarm reception to his manifesto and remained bent on drumming up enthusiasm for the work rather than getting bogged down in the politics of curriculum development.

For example, as chair of STOC in Victoria, he created an "Ad Hoc Committee for SIGACTion on Elementary and Secondary Mathematics and Computer Science Education Reform" to coordinate the potential contributions of SIGACT to mathematics and computer science education reform (posted to *theorynet*, March 17, 1992). Members of the committee included: Mike Fellows, STOC 92 Chair; Maria Klawe, Chair, CS Dept UBC; Joe Rosenstein, DIMACS Education Coordinator; Jeff Vitter, Vice Chair SIGACT; Donna Baglio, ACM Headquarters; Avi Wigderson, STOC 92 Program Chair; Vance Faber, Los Alamos; Bonnie Yantis, Los Alamos; Eric Manning, Dean of Engineering, UVic; and Neal Koblitz, Math Dept, Univ Washington. The committee set up a specific project to compile a compendium of algorithmic topics and possible presentation strategies and supporting discussions for the use of interested educators. Rather than issuing a simple bureaucratic plea for material, Mike convinced the UVic Dean of Engineering to contribute $250 to purchase a raffle prize so attendees at the STOC 93 banquet could earn a raffle ticket by contributing a topic or presentation idea.

The following year, Mike gave a public lecture organized by UVic professor Bill Wadge entitled "Mathematics Education: The Paranoid Theory." It grew out of numerous rebuffs from academics in mathematics education that implied that he was out of touch with what children needed to learn in school mathematics. The abstract for that lecture reads: "Mathematics, the main engine of modern science, and the widely despised arbiter of social opportunity, functions in many ways like the medieval Church. The talk will focus on the culture of mathematics, the hidden agendas served by mathematics education, and on various associated amusing stories that serve to illuminate the issues, or perhaps only explain the speaker's evident paranoia. More of a performance than a lecture—whatever happens is at least the work of a mathematician."

The abstract is accompanied by a Calvin and Hobbs cartoon:

Calvin: You know, I don't think math is a science. I think it's a religion.
Hobbs: A religion?
Calvin: Yeah. All these equations are like miracles. You take two numbers and when you add them, they magically become one new number! No one can say *how* it happens. You either believe it or you don't. This whole book is full of things that have to be accepted on faith. It's a religion.
Hobbs: And in the public schools no less. Call a lawyer.
Calvin: As a math atheist, I should be excused from this.

The paranoid theory proposed that mathematics (taught as only arithmetic) was used by society as an arbiter of social opportunity, and was really about power, authority and control. He wrote about the Paranoid Theory in "Computer SCIENCE in the Elementary School" [4].

Mike says that he is not sure how much he actually believed in his theory. Almost everyone he has told it to endorses it to some extent, sometimes enthusiastically (the public lecture drew an overflowing audience), yet there is an incredible resilience to the shopkeeper way of teaching. Perhaps this is because most people have never seen anything else.

The Inaugural Lecture by University of Sydney anthropologist Linda Connor in October 2011 gave us an anthropological perspective on the Paranoid Theory. The core mythology being promulgated in the 18th century had to do with profit and consumerism, and therefore numbers and operations on numbers were of foremost importance. Mike suggested considering the modern "number" to be "networks of relationships," as in gene regularity networks. One can speculate on what society would be like if children's math began with networks, continued with patterns, dynamics, processing, and strings of symbols over a two letter alphabet, and eventually came to counting. We plan to explore these possibilities with First Peoples (Indigenous Aboriginal), for whom networks of familial relationships form a precise, intricate and primal construct, at a future workshop.

Mike made enormous efforts to engage people with this view of math teaching, sharing his ideas with any students, teachers, academics or administrators who would listen. He has sought funding and moral support, and worked passionately to help anyone who is interested. Ideas in mathematics and computer science are exciting, and Mike has never been picky about who he shares that excitement with. It might be a researcher of his caliber, or it might be a 5-year-old. Rod Downey recalls feeling pretty bruised by trying to push for improvements in math education, and advised Mike that it was really not worth it as it sucked all the energy out of you. Mike's boundless energy was such that he persisted despite setbacks, and it's a testimony to his persistence that 20 years later some of his work has found a foothold in formal curricula around the world.

We now look at the history of Computer Science Unplugged and associated projects, how it began with the *MEGA-Math* project and steadily grew—because exciting ideas won't be squelched.

4 *This Is MEGA-Mathematics!* —The *MEGA-Math* Project

The impact of Computer Science Unplugged is extraordinary, winning awards worldwide, being translated into many languages, and having its own YouTube channel with sound tracks and subtitles in multiple languages. This section describes the roots of Unplugged, which are found in the *MEGA-Math* project, starting with Mike's classroom visits to his children's elementary school in Moscow, Idaho.

The United States in the 1980s considered itself a "Nation at Risk" due to dismal results from international assessments of mathematics education, and to immense differences in achievement traced to race, ethnicity, poverty, and gender, and to huge gaps between low- and high- achievers. One response was to set national standards for school mathematics, an unprecedented venture for the United States, and which resulted in classrooms largely being turned into test-preparation centers. Innovations tended towards (often artificial) "uses" of mathematics. The result was a collective popular conception that mathematics is incomprehensible, accessible only to a gifted elite, yet very important.

An early approach to putting excitement into math was "Family Math," which came out of the "Math for Girls" program (created by Diane Resek, Nancy Kreinberg and Rita Liff Levinson) and the "Equals Teacher Training" program, in which engaging, hands-on math activities were developed at the Lawrence Hall of Science (LHS) in Berkeley in the early 1970s. These activities were also a key element of the "Expanding Your Horizons" conferences created in those early days by the Math/Science Network (co-directed then by Lenore Blum and Nancy Kreinberg) and still going strong today. One of the developers of Family Math was Virginia Thompson, and Mike had heard her speak at a meeting in Los Angeles and was influenced by her[1].

In this context, the chance collaboration that resulted in the *MEGA-Math* project began when Mike and Nancy Casey met in 1989 while Mike was at the University of Idaho. Their children were the same ages — 5 and 6. Mike had already developed a few games and puzzles to expose his children and their schoolmates to current research ideas. As a K-12 Language Arts teacher, Nancy was interested in the way children learned reading and writing skills inside a language-rich environment which situates those skills in a context that includes storytelling, fact-collecting, art, music and movement. Although she knew many teachers confident in their ability to organize a classroom in a way that brought children's active language-learning faculties to bear on the expansion of an array of communication skills that included reading and writing, there didn't seem to be any teachers with a similar creative vision for mathematics learning. She wanted to know what belonged in that vacuum [5]. At the same time, Mike saw a disconnect between what he did as a research scientist, and what his children did most school days in the name of math.

Mike and Nancy began exploring the possibility of teaching mathematics using the "Whole Language" (also known as "Natural Learning") philosophy. Children were given large blocks of time to explore, discuss, and write their ideas in notebooks. They began to explore the possibilities of teaching modern mathematical ideas through communication about games and puzzles, having students express their mathematical thoughts in language, a curricular area where teachers felt most secure.

Second grade teacher Prudy Heimsch joined the experiment. According to Mike, every parent in Moscow wanted Prudy to be their child's teacher. She had the patience to allow the excitement of learning (which may look like chaos) to follow its natural course (rather than provide overly strong guidance for students), and this has become a hallmark of the *MEGA-Math* and Unplugged projects.

[1] Intriguingly, this inspiration ended up coming full circle, as Lenore ended up engaging with CS Unplugged some two decades later after it had traveled from the US to New Zealand and back again!

Prudy's class explored a DOMINATING SET problem[2], described as "Where should we place a minimum number of fire stations, so that every house is located either on the same vertex as a station, or within one block of a station?", given a map such as the one in Figure 3. Nancy has described the ensuing frenetic and alternately careful, quiet struggles of the children to invent vocabulary with which to explain their thinking about this problem to each other, and write about it [6].

The students were shocked to find out that a teacher wasn't going to give them a correct answer if they waited long enough, and were empowered as they discovered that they didn't need a teacher as they could evaluate one another's fire station maps. This was an inversion of the traditional mathematics lesson where students are handed a series of problems to practice on after being led through a series of strategies for solving them. Also in these sessions, it became apparent that neither Nancy nor the classroom teacher grasped the full richness of the children's problems-solving engagement until afterward when they sat down together to discuss what occurred and plan for the next day. Building these debriefing sessions into the activities was essential to establishing why and how such unbridled classroom enthusiasm was purposeful mathematical activity.

Allowing the students to explore problems in their own way is something that doesn't always come naturally to teachers and visiting university faculty [7]. Yet it is remarkably effective. The students end up taking ownership of the problem without realizing how "hard" it is, and they build confidence that they can cope with novel mathematical situations.

In the workbook that grew out of these experiences, the introduction assures the reader that "Good mathematics ultimately comes from and returns to good stories" [8]. For example, in "Gertrude, Superperson and the Monster Recover from a Disaster," the stage is set for a discussion that may well end up with the the 4-color map theorem, although the phrase "map coloring" never appears in the story, which begins:

> HORRORS! The Land of Many Ponds has been clearcut! Where there were once tall, tall trees and flyways, there is nothing but stumps and empty space.
>
> Gertrude, Superperson and the Monster meet in one of the ponds to talk over what they should do.
>
> Gertrude swam round and round in furious circles. "Oh we are doomed, just doomed!" she wailed. "As soon as it rains, WHOOSH! the soil will begin washing away... The (pond) water will get silty and soon the ponds will dry up. Oh it's awful! We are doomed!"

[2] A slight variation of the story uses the VERTEX COVER problem, where every *edge* in the graph is incident on a vertex in the solution set; in contrast, the DOMINATING SET problem requires that every *vertex* in the graph is adjacent to a vertex in the solution set. The difference in the story is whether the houses are on the roads or on the intersections. Later versions of the story included choosing the placement of ice cream stands and the location of wells.

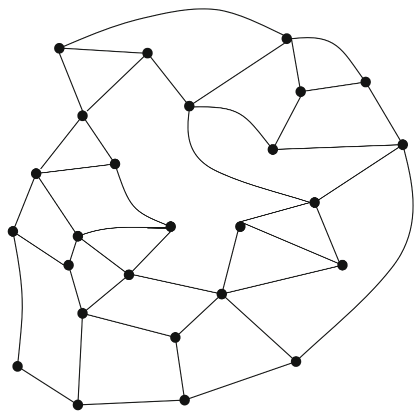


Fig. 3. A graph used as a map of the town that needs the location of fire stations to be decided

The characters set off to make plantings to prevent erosion and decide to plant colored flowers in a way that makes the old boundaries still clear. In the process they are likely to encounter ideas relating to the four-color theorem, the exponential complexity of exhaustive searches, and special cases of maps that require fewer than four colours.

Examining a dots and lines network of relationships requires a "spatial" reasoning that seems quite different from that used in calculating addition or subtraction, with the result that some students who always were the "best" in math no longer knew what to do, while those who normally did not do well became leaders. Mike has described one little boy who had a reputation as the class trouble-maker. He became so excited working on the network that he exclaimed, "This is math? This is MEGA-mathematics!!" and thus was named the project. They also found that *teachers'* confidence levels with mathematics skyrocketed when they were encouraged to consider how their students expressed and developed their mathematical thoughts in language, the area of the curriculum where they were often most secure.

In his 1991 paper, *Computer SCIENCE and Mathematics in the Elementary Schools* (the most definitive description of the vision and innovation of the project), Mike urged that children be respected as genuine (child-sized) researchers (the paper was published in 1991 on the *MEGA-Math* site, and later appeared as [4]). Mike states: "In the same way that children's art is interesting as art and children's writing is interesting as writing, mathematics with children can be interesting as mathematics." Research problems sometimes "turned up" during classroom visits. For example, Jan Kratochvil visited for several months from Prague, and he and Mike noticed that if two children take turns coloring in the regions of a map, the Four Color Theorem assures that four colors are enough, provided you are coloring perfectly and strategically. But how many colors will it take if one player is a child who plays legally but not strategically?

Or, if they are trying to "force" the map to require more than four colors? (An upper bound was established by Kierstead and Trotter in 1992; they show that 33 colours suffice for a planar graph, and they establish 8 as a lower bound [9].) Children are always challenging the rules of the game, and they don't know which questions they shouldn't ask.

In the 1991 paper, Mike describes (retrospectively, he says) the goals of his classroom visits:

– To show that mathematics is fun and full of stories, activity, invention and play.
– To show that mathematics, like dinosaurs and outer space, is a live science with visible frontiers of knowledge.
– To present the essential unity of mathematics and computer science and display the intellectual core of the latter.

These early experiences led to a lively discussion of how math should really be taught in schools. In that discussion, juxtaposed to these experiences of very young students having an exciting time exploring graph theory we have school curricula that teach the ingredients of math — operators, fractions, probability and so on. Yet if these ideas are the entire curriculum, students are merely learning ancient techniques from what appears to them to be a dead discipline [5].

4.1 The *MEGA-Math* Book

The ideas that led to the *MEGA-Math* project were gradually collected, and built up a grass-roots level of interest. In 1993, under the leadership of Vance Faber and Bonnie Yantis of the Computer Applications and Research Group at Los Alamos National Laboratory, Mike became principal investigator on a grant entitled *Research On Mega-Math: Discrete Mathematics And Computer Science for Children*, which resulted in the publication of the activities in a 134-page, *This is MEGA-Mathematics!* workbook by Casey and Fellows [8].

The *MEGA-Math* workbook covers six topics: map coloring, knot theory, graph theory, finite state machines, algorithms, and infinity. The introduction states: "We hope that these materials will provide opportunities for children and their teachers to experience mathematics in ways it is experienced by mathematicians and scientists. Mathematics is lively and exciting; it is a field more akin to art and poetry than many people think." Written at a level an enterprising student could grasp, it contains descriptions, explanations, games, stories, pictures, problems and questions for discussion. It assumes that teachers are not familiar with the topics. Detailed information describes how the activities can be used to meet the curriculum goals outlined in the *Standards* of the National Council of Teachers of Mathematics (NCTM) (standards.nctm.org). In their article, *Implementing the Standards: Let's Focus on the First Four* [10], Mike and Nancy have argued that in order to properly address the NCTM elementary school standards — reasoning, problem-solving, communications, and connections — *new content* must be introduced into the K–4 curriculum. The authors show by example how the goals of the standards can be achieved using material from computer science and discrete mathematics, and they describe their approach to teaching mathematics as parallel to the “Whole Language” approach to teaching reading.

After the publication of *This is MEGA-Mathematics!*, a larger following developed. In 1994, with continued funding from Los Alamos, the materials were expanded and put up on the then-new World Wide Web [11]. *MEGA-Math* material was soon used for summer camps, and in 1994, a presentation of these materials won first prize for “New presentation ideas” in a Canadian summer camp national organization. Activities from *MEGA-Math* were adapted by other organizations, including DIMACS (Rutgers University, NJ), Family Math (Lawrence Hall of Science) and the Math Department, University of Illinois at Chicago. It ultimately had some influence on curriculum design, especially in British Columbia, Montana, California and New Jersey.

By the time *MEGA-Math* was taking off, Mike had moved from the Laboratory of Applied Logic in the Department of Computer Science at the University of Idaho to the Department of Computer Science at the University of Victoria, British Columbia. Mike continued to develop games and activities, trying them out in elementary schools in Victoria while Nancy collaborated with several teachers in Moscow, Idaho doing week-long sessions (including teacher-debriefing) like those which had worked so well with the Minimum Dominating Set problem. By 1995, over 1200 copies of the free workbook had been distributed to more than 400 individuals, including bulk orders to organizations such as DIMACS and Family Math program at Lawrence Hall of Science. It was used in departments pursuing mathematics education reform, demonstrated in many classrooms, and parts had been translated into Spanish [11].

MEGA-Math took a radical approach to engaging very young students (including pre-schoolers) with what is conventionally regarded as post-high school topics, such as graph theory and finite state machines. New pedagogical notions were introduced such as linking the concepts with playful stories about monsters, animals and bakers, and representing a math problem physically, with giant ropes for knot theory or large tarpaulins with networks constructed on them made of colored tape. Significantly, it established that there is value in the head-first, constructivist approach, where students are given a hard problem (such as finding a dominating set), and are left to explore it in their own way. The innovative *MEGA-Math* approach set the scene for expressing computer science so that elementary school students could engage with the deep concepts that get computer scientists excited. Furthermore, due to Mike’s infectious enthusiasm for the possibilities expressed in *MEGA-Math* and eventually Computer Science Unplugged, many in the parameterized complexity community have joined in presenting innovative activities in their children’s classrooms and other public venues, opening up public understanding and participation in mathematical science.

MEGA-Math continues to have a life of its own — in 2011 the web site was getting fairly constant traffic at around 4,000 hits a month, and the ideas are referenced in popular lists of math and computing activities. But one of its biggest impacts is that it laid the groundwork for the soon-to-be-created Computer Science Unplugged project.

5 Computer Science Unplugged—Genesis

The Computer Science Unplugged project began through a chance online meeting of Mike Fellows and Tim Bell in March 1992 via an Internet newsgroup. From about 1989 Tim had developed computer science material for a "Science Extravaganza" in Christchurch, NZ [12]. The extravaganza was a temporary science exhibition set up annually in the late 1980s, reminiscent of the San Francisco Exploratorium, and in 1991 evolved into a permanent science center called "Science Alive!" At the time computer exhibits in science centers didn't demonstrate "real" computer science, and Tim was interested in preparing engaging material that communicated the great ideas of computer science, and not just programming or using a computer. Amongst other things he had developed a demonstration of tractability where you have to watch a program count down while it solves the Travelling Salesperson Problem [13] — which can be dressed up as the "birthday party problem," dropping n kids home after a birthday party. At the exhibit the child chooses n, and the program animates an evaluation of all $(n-1)!/2$ possible paths, one per second. For a few cities, this is very fast, but for $n = 27$, the system brings up a timer that counts down from 6,394,144,170,576,570,000 years, one second at a time. The ensuing humor emphasizes the futility of exponential time algorithms, and provide opportunities for follow-up questions (e.g. what if the computer was a million million times faster? Then it would only need 6,394,144 years!)

During 1992 Mike and Tim exchanged ideas for communicating computer science to young children. In August 1992 Tim was asked to give a talk to his son Michael's class at Shirley Primary School, Christchurch (just two months after Michael started school). It was part of a series of talks by parents about their jobs, and followed on from other parents such as policeman who brought a police car for the kids to see and a nurse with real bandages for the kids to try. Faced with the challenge of trying to communicate how one could make a living working with algorithms, and inspired by discussions with Mike, Tim decided not to bring a computer at all — after all, how convincing would it be to show 5-year-olds a computer running a slow and then a fast algorithm? This led to the development of material such as the cards for teaching binary numbers, and the parity card trick. The session turned out to be a resounding success, and armed with these ideas and others gleaned from Mike, by October 1992 Tim was making regular visits to Shirley Primary school, and had engaged illustrators (initially Gail Williams and Malcolm Robinson) to design handouts that would appeal to the students. Two senior computer science students (Gwenda Benseman and Richard Lynders) also helped with the visits.

It turned out that being able to teach binary numbers using 5 cards drew a lot of interest. Teachers and parents who observed it over the years often commented that they felt empowered because they understood this mysterious idea of binary numbers, bits and bytes, which previously seemed to be a secret language of the in-crowd. It has been popular as a demonstration to senior citizens for the same reason, once again giving life to Mike's approach of not paying attention to boundaries and allowing anyone with curiosity to explore ideas from math and computer science.

As the collaboration with Mike developed, Tim organised a one-month visit to Victoria BC in March 1993, funded by a University of Canterbury Erskine fellowship. *This is MEGA-Mathematics!* had been published by that time, Mike had been working on "Kid Krypto" [14], and he had considerable experience in schools using these ideas to communicate with elementary aged students.

During that time Tim gained experience observing events that Mike ran. Mike's somewhat organic approach provided a whole new perspective on communicating with students. Often ideas for presenting concepts would be developed the night before, or in the car on the way to a school, or even in the classroom as the students explored the concepts. Tim remembers driving up Vancouver Island to Hans Helgeson school one morning, leaving town somewhat less than 45 minutes before the class started (the drive was about 45 minutes). As Tim was busy calculating the expected time of arrival, Mike spotted a gas station with a store, pulled in, and like a child in a candy store went around collecting items like cans of spray paint, string, and coloured tape. They arrived at the class a few minutes after the appointed time, but oblivious to any concern from teachers, and with no lesson plan at all, Mike launched into a session with the students and soon had them eating out of his hand as he spun stories about pirates or lost animals, whose fictional problems could be solved using only a finite state automaton or sorting network. Grass was spray painted, tangles of string and tape emerged, and suddenly it became obvious that students were gaining a deep understanding of advanced ideas from computer science and math.

Of course, at such sessions some teachers were probably unsuccessfully trying to work out which curriculum boxes they could tick after the session — it couldn't be math because there was no arithmetic, and it couldn't be computing because there were no keyboards! Even the students may not be aware — on a different occasion a student commented "I'm glad you're here today, otherwise we'd have to do math"! On that occasion, instead of "math" the student ended up doing things like combinatorial problems and modulo 2 check sums.

An important observation about this "organic" approach to teaching is that although it appeared to be chaotic as students threw themselves at problems with some taking obviously sub-optimal approaches or exploring beyond the boundaries given, Mike's infectious enthusiasm and gripping story telling had them engaged and fully aware of the context he had given them. Later it became clear that this student-driven exploration was an approximation to constructivism, a well-known teaching philosophy that came to be a valuable approach to successful outreach programs. Instead of telling students some information and leaving them to digest it or be impressed that the speaker knows a lot, the students explore the problem for themselves, finding good or bad solutions, and enjoying the journey rather than worrying about the destination (which after all is only a meaningless solution to an artificial problem).

Tim's 1993 visit to Victoria resulted in the drafting of what became the Computer Science Unplugged "original" edition, although because of various delays and distractions, it was a couple of years before the book became available.

5.1 Mathmania

Also in 1993, at Victoria BC, Mike began the "Mathmania Society"[3]. One of the Mathmania group's first events was a "Mathmania in the Park" day, which was on Saturday 13 March 1993, during Tim's visit to Victoria. Figure 4 shows the poster advertising the event, and Figure 5 shows snapshots of the event, with families doing serious math as part of a picnic in a park. The event included a "finite state treasure hunt", which was a pre-cursor of the Treasure Island game: kids would go to a "station" in the treasure hunt (an adult with a sticky label) and ask to take the "A-train" or "B-train", which would result in them being directed to run to another station. The knots made out of inch-thick rope provided a tactile experience for even the youngest attendees to explore the basic elements of knot theory!

The mission statement of the Mathmania Newsletter states that it is "introducing mathematics as it is done by professionals." The first newsletter (dated 05/94, presumably May 1994) says "We hope we have given a hint of how this can be done in a way that is engaging, accessible, and that does not require the teacher to invest a great deal of time or funds. Hopefully, the activities allow for the playful, open-ended, provoking and enjoyable style of mathematics enjoyed by mathematics researchers everywhere."

The newsletter quotes some key principles from a paper written by Mike:

- There is an essential unity of mathematics and computer science.
- The competencies required for the increasingly computerized world are essentially mathematical. It is a serious (and common) mistake to make a fetish of the machines.
- The intellectual core of computer science can be presented to children even in situations where there are no computers (for example, in countries or school systems that cannot afford them), laying a foundation for later computer science education. Many of the core ideas of computer science are best introduced without machines.
- Computer science represents a tremendous flowering of mathematics. It is particularly good news for children because it is a treasury of accessible, colourful and active mathematics.

[3] Not to be confused with a group with the similar name of "MathmaniaCS" in Urbana-Champaign, Illinois, who do excellent related work combining the *MEGA-Math* and Unplugged material as well as other original material.

Fig. 4. Poster advertising the “Mathmania in the park” event in 1993

(a) (b) (c)

Fig. 5. Mathmania in the park (a) A “station” in a Finite State Machine giving directions (b) a sorting network spray painted on the grass (c) knot theory for the whole family

- Most children in grades 1–4 are never exposed to mathematics. Arithmetic is not mathematics!
- Most children in these grades are never exposed to computer science, despite all the PCs in the classroom. Programming is not computer science!

Later the Mathmania organization became more formal, and in 1995-1997, while at UVic, Mike secured funding to found the "Mathmania Society for Public Education and Appreciation of Mathematical Sciences," incorporated under the Society Act by the Victoria, BC Registrar of Companies. Mike was a Director of the Society (along with Nancy Casey, Day Kirby, Gerald McLean, Kathy Beveridge and David Vogt). A joint project of Mathmania and the Canadian Mathematics Society was to create a website of kid-sized open mathematics problems with prizes under a project called "Erdös for Kids."

5.2 The "Original" Unplugged Book

In parallel to the development of the Mathmania society, the book by Mike and Tim about doing computer science without computers was drafted. General principles and an outline were drafted during Tim's 1993 visit, and it was developed over the next couple of years. Until 1995 its working title was "Junior Algorithmics", basing the title on that of Harel's 1987 book "Algorithmics: the spirit of computing" [15], which was a popular account of computer science written for an adult audience. The full working title was: "Junior Algorithmics: Computer Science for kids (and grown-ups who don't mind having fun)". However, early on it became apparent that the word "Algorithmics" was daunting or confusing for many people.

The name "Computer Science Unplugged" was coined around 1996. The term "Unplugged" came from a style of music that had become well-known around that era. During the 1980s it had become popular for artists to perform versions of their music "acoustically," especially using acoustic guitars instead of electric guitars with effects. The term "unplugged" for such music seems to have been used first for the "MTV Unplugged" series that started in November 1989. The Unplugged format became particularly popular with a 1991 Paul McCartney recording, and then Eric Clapton's 1992 "Unplugged" album, which received many awards. Thus at the time the Computer Science Unplugged material was being developed, the term "Unplugged" had just become well established as being associated with avoiding having music cluttered by technology, returning to the essence of the music. This resonated strongly with the work that Mike and Tim were doing, trying to avoid the distraction of the technology so that students could appreciate what is really happening.

The term "Unplugged" has come to have strong recognition in the computer science education fraternity and is often used without definition to describe some aspect of a teaching or outreach program. It is often associated with kinesthetic activities, although when used properly it also has much visual and oral learning. At least one independently written book, "Algorithms Unplugged", has picked up the term and the spirit of the approach [16].

Unfortunately the word has posed considerable problems for translators, since the translation in other languages generally has pejorative meanings that imply that it is describing something that has no power, is not working, or is broken. Taking the lead from the music industry, most translations either keep the English term "Unplugged", or replace it with a more inspiring description of the material. For example, the Korean subtitle means "Learning Computer Science with Games".

The idea of rejecting the use of computers has created some soul-searching moments for the authors, particularly when it became clear that the material needed to be made available online, and then supporting material such as videos and online games started to appear. More recently "Unplugged" has even been implemented in virtual worlds! However, an analogous situation occurs with unplugged music—every "Unplugged" recording uses electronic devices, often including guitar pickups and even electric organs. In fact, the cover of the best-selling Unplugged album by Eric Clapton clearly shows a microphone that is plugged in! Unplugged is really an attitude rather than a technique. The pragmatics of making the material widely accessible mean that we don't eschew computers per se, but we do avoid the situation where the physical device becomes the object of attention and displaces the great ideas that will engage students' minds. Of course, right from the start computers were used to design and communicate the Unplugged ideas, although it was tempting to make it a hand-written book.

An ongoing debate about the title has also been the use of the term "Computer Science"; this term is very well established and is reflected in the names of many university departments that teach the subject, but it can create confusion for those not familiar with the field (for example, is it about using computers for science?) There are competing terms such as the European "Informatik," and the general term "computing", but since the main international professional organization, the ACM, uses the term "computer science," that phrase was chosen. The abbreviation "CS" is almost more effective because it removes emphasis on the two words that cause the confusion, and the project is now often referred to as "CS Unplugged." Another minor distraction with the term "unplugged" when associated with computers is that it is also used to refer to wireless devices—for example, computingunplugged.org is a magazine about mobile gadgets. The use of the term "computer science" (rather than "computing" or "computers") generally avoids this confusion, or at least, it gives an opportunity to point out that computer science has a very particular meaning.

Progress on the CS Unplugged book was slow for the first couple of years as during this period the project was still a side interest for both Mike and Tim—Mike's early work in parameterized complexity was keeping him busy, and Tim had become involved as an expert witness for several major compression court cases (in fact, he was first approached to help Microsoft while in Victoria on the March 1993 visit). Requests and encouragement from colleagues to see the material completed gave a sense of urgency, and in 1995 Ian Witten was invited to become involved to help massage the collection of disparate ideas into a coherent collection that would be useful for people involved in outreach. Ian also proposed and added the sections on Artificial Intelligence and Human-Computer Interaction, since these were areas he had an interest in.

The coverage of topics wasn't entirely haphazard. There was an effort early on to systematically list computer science topics so that fairly broad coverage would be possible. Every one of the five dozen chapter titles in Dewdney's book "The Turing Omnibus" [17] was considered for a possible Unplugged topic, and the ACM curriculum was checked to see if the coverage was representative. There were some topics that weren't covered initially because of the criterion that the activities had to be engaging for children, and it wasn't always possible to come up with a relevant one. Also, given the authors' interest, there is some bias towards algorithms, compression and tractability!

The activity on text compression was invented by Michael Bell around 1994. He was writing up a diary and had decided that instead of writing out every word, he would just put arrows pointing back to where he had already used the word before to save writing. Tim observed this, and was about to reprimand his 6-year-old son for being lazy when he realized that it was a form of Ziv-Lempel coding. To add irony, at that time Tim was testifying in a US$339 million court case that a patent for a similar form of Ziv-Lempel coding should be regarded as invalid!

While the book was being written, the material was tested extensively in schools, mainly those where Mike and Tim's children attended (Shirley Primary School in Christchurch, and South Park School in Victoria BC); and also schools close to the respective universities (Ilam School in Christchurch, and Hobbes Elementary School in Victoria, BC). Often apparently interesting ideas didn't work as well as expected, and vice versa. An important principle was not to publish something that hadn't been successful, and the activities contain advice on things that can go wrong and ways to avoid (or embrace!) such problems. Sometimes suggestions for improvements came directly from teachers and children, such as using a balance scale for sorting. The trials were also run by university students who did them as course projects or just out of interest; those who helped included Gwenda Benseman, Richard Lynders, Sumant Murugesh and Matt Powell.

A rough version was complete by 1996, and parts of it were distributed informally (including 100 copies in the Coquitlam BC school district) while a suitable place to publish it was found. The authors were aware that teachers were more likely to take a book seriously if it was published by a well-known educational publisher rather than distributed as photocopied notes or on disk. Colleagues had expressed great enthusiasm about the 1996 drafts, and so it came as quite a surprise when it was rejected when sent to a publisher. In fact, between 1996 and 1997 it ended up being submitted to 27 publishers, and not one accepted it. The general response from the publishers was very positive about the book contents, but they couldn't pigeon-hole it in their range of offerings! One publisher wrote that they "will not pursue the idea of publishing the book" yet described it as "your wonderful volume..." and said it "would be a real pity not to have this book released." The difficulty was that it was breaking new ground. A children's publisher said it "may be too academic for children", while an academic publisher referred us to a children's publisher! An education department of a publisher referred it to their computing department, but then the computing department said that they couldn't publish a book if it wasn't about how to do things on a computer!

While these frustrating conversations continued, the authors completed the book, and when it became clear that no-one would publish it, the authors decided to sell it as "shareware" online, from about March 1998. Samples were available online at www.unplugged.canterbury.ac.nz, and interested people could email or fax in a US$15 credit card order to get an electronic copy (download or CD-ROM). For US$75 they could get an "institutional license" to make multiple copies in a school or university. Some dozens of copies were sold this way, and many more were given away. There were probably many bootleg copies around too, which the authors were relaxed about since it created an even wider distribution (there was no copy protection on the PDF files distributed), and the only goal of sales was to fund further work on the project.

Free copies were distributed any time funding could be found to make a print run. For example, in October 1998 Tim received a contract through the Royal Society of NZ Science and Technology Promotion Fund, and ran teacher training days in April/May 1999 in Canterbury, Waikato and Auckland, in which teachers got to participate in the activities, and were then given a copy of the book to take away.

Around this time much of the material had also appeared in a slightly different form through the "MathmaniaCS" project at the University of Illinois at Urbana-Champaign (the name "MathmaniaCS" was defined as "persons exhibiting an excessive passion for MATHematics and Computer Science"). The project was run by Lenny Pitt, Cinda Heeren, and Tom Magliery; they had written a manual for teachers, as well as providing on-line instructions and a lending library of materials for running Unplugged sessions. They ran various outreach events, including family math nights, camps and classroom visits. Their material is available through www.mathmaniacs.org.

By 1999 the book authored by Mike, Tim and Ian settled into a final version called "Computer Science Unplugged... offline activities and games for all ages", which contains 20 activities. This one is usually referred to as the "original book" [18]. It had been intended to be useful for teachers (the preface says that it is "principally for teachers who would like to give their classes something a bit different from the standard fare, teachers at the elementary, junior high, and high school levels") but it became apparent that it was too advanced for teachers with a weaker background in math and computer science, even though they found the topics interesting. Teachers who had seen the activities demonstrated readily adopted them, but in the end the book had been written by three academics and didn't suit the audience, given that almost no school teachers would have a formal background in computer science, and few would even have taken advanced study in math!

5.3 The "Teachers' Edition" of Unplugged

As it became apparent that a more teacher-friendly version was needed, the authors decided that this would be best achieved by having some teachers re-write the material. In 1999 Tim obtained funding for this from the local Brian Mason Foundation, and hired two teachers, Robyn Adams and Jane McKenzie, over their summer break (December 1999 to January 2000) to do this. Neither had a strong computer science background, but both were experienced teachers with a strong interest in science, and thus were able to write something that would appeal to other teachers who hadn't done computer science before. They were co-teaching a class at a local primary (elementary) school, and Jane had been using Unplugged material for some time; she had also been a writing tutor in the Canterbury computer science department.

In addition to improving the writing, Matt Powell was engaged to add a lot more cartoon images to make the material more attractive for students. Matt was a computer science student and so was able to create relevant cartoons that embodied a deeper understanding of computer science. The cartoon characters and logos that he created for this remain the main visual "branding" of the Unplugged project.

Because the time for writing the teachers' book was limited to just the summer, only the first 12 of the 20 "original" activities were completed. It turned out that this was more than enough to satisfy demand; we suspect that most people only use a few activities from Unplugged, and it is more important to have a few approachable ones, with more available in the original form for those who are keen.

The teachers' edition was released in 2000, again as "shareware". Minor changes were made over the following years, and the main version referenced is from 2002 [19]. It has a different subtitle that distinguishes it from the "original" version: "Computer Science Unplugged: An enrichment and extension programme for primary-aged children". The use of New Zealand terminology ("programme" and "primary") is an acknowledgement that the "translation" was funded by a New Zealand organization even though the largest audience was US-based. The funding also meant that copies were free to Canterbury/Westland teachers, and discounted copies were distributed in New Zealand; at the time the NZ dollar was quite weak, so the shareware fee was fairly nominal for people overseas, and the book had a wide distribution. The on-demand printing service lulu.com was also used to distribute the book, and a large number of copies were sold (mainly in the US) through this service.

The funding for the teachers' edition was focussed on the Canterbury and Westland regions of New Zealand. As part of the followup to re-writing the book, Tim ran workshops around Canterbury and Westland in 2002. Westland is is one of the most isolated parts of New Zealand, and visits from computer scientists were no doubt rare. In late 2002 Tim fulfilled the funding obligations by doing a tour of schools in Westland, in the towns of Greymouth, Hari Hari and Hokitika. One particularly memorable class was a "technology" class where

Tim found himself speaking to a group of 15 year old girls who were studying a particular form of technology — food technology. They had no interest in computers or math, which became obvious very quickly. Fortunately the versatility of Unplugged kicked in — several of the activities involve food (including paying in candies to make comparisons when searching, the divide and conquer cake, and transmitting a chocolate bar securely using an encryption protocol). These generated some interest, but what suddenly got them all engaged was when Tim mentioned that the "From:" field in an email isn't guaranteed to be accurate, and that emails in plain text can be intercepted and read. Suddenly they were very interested in cryptography—apparently they wanted to be sure that their communications were private and authenticated!

The focus on Unplugged in New Zealand increased because Mike lived in Wellington, NZ, from 1999 to 2001, so by chance all three main authors were living in New Zealand, albeit in three different cities. To add to the confusion, the university that Mike moved to in NZ was Victoria University of Wellington (VUW), not to be confused with Victoria BC! During the time in Wellington Mike taught a summer class in introductory computing with Frances Rosamond, and the Unplugged activities featured heavily in the class. They weren't just used on campus; the class (mainly adult students) was sometimes run downtown in outdoor locations. The sorting network activity was done outdoors in a weekend next to New Zealand's national museum, Te Papa.

5.4 The Unplugged Shows

A new format of Unplugged began in 1998. Tim had the opportunity to present Unplugged at the Edinburgh International Science festival in April 1998. The presentation was mainly based on the Unplugged activities, and was originally intended as a classroom style presentation. However, after seeing other shows at the festival, Tim quickly adapted some of the activities to a more theatrical version: the small desktop binary cards became large A4 cards with one held by each child, coloring in small pixels with a pencil became a can of black spray paint putting inch-high pixels on the wall, and the ubiquitous sorting network was laid out as large as possible on the floor using colorful tape.

The goal was to develop something that was a cross between a pantomime, magic show, and science demonstration, with plenty of audience participation (inspired by Mike's chaotic classes where learning and fun were apparent in abundance). It was also intended to provide a computer science equivalent to the science center demonstrations where a chemist would hammer in a nail with a frozen banana, or explode a can containing custard powder dust (of course, one wonders how much chemistry children learn from these demonstrations).

Observing other popular science shows at Edinburgh made it clear that advertising was important; the most popular events had an attention grabbing photo, used humor, and usually mentioned food; the educational value was assumed! This led to the following advertisement for the shows:

> This wacky show takes kids (and the young at heart) through some of the great ideas in computer science, using low-tech games, magic tricks and stories. Come and see the giant fax machine, find out how to feed a crowd and always have food left over, and learn new ways to keep information secret.

Building on the experience at Edinburgh, the show was revised to make it as engaging as possible for a large audience, and was presented in the middle of 1998 at the Christchurch "Kidsfest" mid-winter festival for 5 to 12 year old children, and the Dunedin (NZ) International Science Festival. Matt Powell, who had theatre/comedy experience, assisted with the shows, acting as an uninformed assistant who assumed that a computer science show would need to be all about computers. The story line was Tim demonstrating to him, with the help of the audience, that you can explore great ideas in computer science without any computers at all[4]. Extra ideas were added including the "binary birthday cake" (celebrating an audience member's birthday with candles coding their age in binary), and ideas from Mike's work with Neal Koblitz and others on cryptography [20]. Figure 6(a) shows the inevitable sorting network race in a show from 1998.

The Kidsfest shows went remarkably well, and were sold out year after year as new generations of young children came through; it was also performed at the 1999 Australian Science Festival in Canberra. A survey of the show indicated that it had a very positive impact on the audience [21]. Informally, the most gratifying feedback was from parents and grandparents who had brought the children along; they repeatedly reported how empowered they felt because they left with a deep understanding of some key ideas from computing.

The show accidentally found a mascot for Unplugged. "Arnold the Wonder Parrot", a puppet that squawked when squeezed, was introduced by Matt Powell in the 1998 Kidsfest show, originally as a pun on "Parity Error." In the surveys about the shows Arnold regularly featured as one of the most popular elements, and so he remained a part of the show. He eventually became the Unplugged mascot, appearing around the world in cameo photos at events. In Figure 6(b) he appears with Jason Alexander, a postgraduate student who ran later Kidsfest shows, and in Figure 6(c) he appears in a photo advertising a 2008 video of the show run by Matt Powell and Javier Jarquin.

Ideas from the shows and Unplugged in general were provided as background to Christopher Bishop (Chief Research Scientist at Microsoft Research Cambridge) as he prepared the televised 2008 Royal Institution Christmas lecture. This was the first "Faraday lecture" in 183 years on computer science.

By the year 2002, 10 years after the Unplugged collaboration began, the main ideas had been published, a show had been developed, and it seemed that this "hobby" could be put aside. Indeed, at that time computer science departments were at what turned out to be the peak of an incredible growth in enrollment,

[4] Almost exactly ten years later Matt played the role of the informed demonstrator in a video of the show that went viral on YouTube (`www.youtube.com/watch?v=VpDDPWVn5-Q`).

(a) (b) (c)

Fig. 6. Computer Science Unplugged: The Show (a) Matt Powell timing a sorting network race at one of the first CS Unplugged shows, 1998 (b) Jason Alexander with Arnold the Wonder Parrot (c) Matt Powell and Javier Jarqin with Arnold, in a publicity shot for the 2008 version of the show

and given dire shortages of teaching staff, it was hard to motivate faculty to spend time using material like CS Unplugged to drum up more business when those staff were needed to teach the overwhelming number of students that had arrived.

However, in 2003 that was about to change.

6 Computer Science Unplugged—Maturity

Two important changes in 2003 triggered a significant increase in interest in the "CS Unplugged" material. First, it was becoming clear that the overwhelming interest in studying computer science at universities around the turn of the century was dropping off sharply[5]; second, and more significantly for Unplugged, the ACM released a proposed K-12 computer science curriculum [22] that gave 15 examples of ways to teach computer science in schools; five of those examples were direct references to CS Unplugged activities, and another two were from *MEGA-math*. This combination of events triggered increased interest in CS Unplugged from around the world over the next few years. As well as requests for copies of the books and permission to use material, there was a sudden interest in producing translations of the book.

By 2006 the first translation of the teachers' edition had been produced in Korean [23] by the Computer Education department of Korea University. Because South Korea already had a strong culture of teaching computer science in schools, the book became well-known around the country, and later when Tim visited the university they ran all-day Unplugged events, with a keynote presentation from Tim followed by reports from various educators about how they were using Unplugged.

Meanwhile CS Unplugged was alive and well in Scandinavia. While working with Jan Arne Telle on Parameterized Complexity, Mike had visited Bengt Aspvall's group at the University of Bergen, Norway, around 1997, which was the

[5] This has been tracked by the CRA "Taulbee survey" `www.cra.org/resources/taulbee`

starting point for Unplugged work in Scandinavia. Bengt has since been giving workshops in Sweden and Norway, and produced a Swedish translation. In 2005 Bengt had just finished six years as pro-vice-chancellor at Blekinge Institute of Technology, Sweden, and was able to visit Christchurch for a couple of weeks, where he and Tim collaborated on developing more Unplugged material. One particularly notable outcome is that they realized that teachers were more likely to use Unplugged if they had seen activities in action, and that it would be good to make some videos to demonstrate this. Because it was December and schools were having a quiet period towards the end of the year, they were able to arrange filming the very next day. The video production was done by Michael Bell, and three videos were completed within a matter of days. YouTube had just been created, so the timing was just right to make distribution easy.

From August to October 2006 Tim was on leave after a long stint as HOD, and visited around 18 institutions in the US, China, Sweden and Canada. Although much of the trip was intended to gather information for a course he was planning on computers and music, it became clear that the universities were much more interested in hearing about Unplugged, and the effect of the trip was to stir up even more interest in the project. During the two months he gave about 16 workshops, shows and seminars specifically on the Unplugged project with audiences from elementary school pupils and teachers to university academics and Google engineers. By visiting schools and enrichment programs where the Unplugged material was being used, and through discussions with computer science lecturers, school teachers and education officials, he was able to come away with valuable feedback and ideas that stimulated a new phase of the Unplugged project.

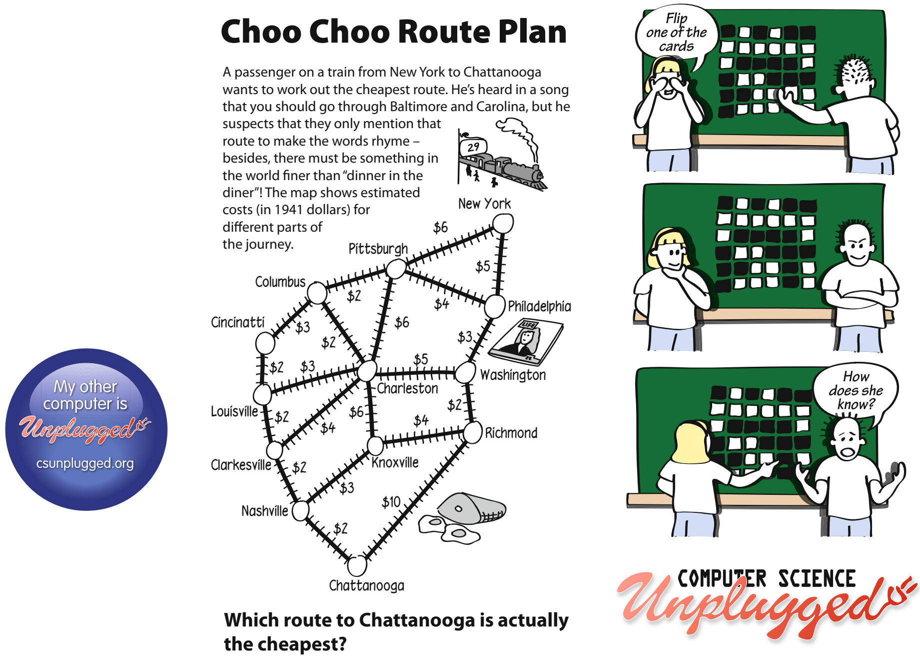
Another place that Unplugged had gained visibility was through the "Computer Science for High Schools" (CS4HS) program (see www.cs4hs.com). This event for high school teachers started as a pilot for 48 teachers in 2006 at Carnegie Mellon University (CMU), where high school teachers were funded to spend a full weekend on campus to learn about computer science and computational thinking, and get ideas that they could take back to their schools [24]. The event was sponsored by Google, and one of the invited speakers at the pilot event was Craig Nevill-Manning from Google New York. Craig was an ex-student of both Tim Bell and Ian Witten, and so when asked to speak to high school teachers he chose to use some material from CS Unplugged. A survey of teachers at the event reported that the Unplugged workshop was the second most popular out of 11 workshops offered [24], which no doubt was a contributing factor to it being adopted as a regular part of the CS4HS event. Tom Cortina reports that in subsequent workshops Unplugged continued to come in as a highly rated and relevant activity for the teachers — they liked it because they could use it immediately in the classroom. Tom Cortina and Lenore Blum ended up running workshops elsewhere on Unplugged, further spreading interest (for example, Tom ran workshops for several years at NECC). In 2007 the CS4HS program was run at two additional US universities [25], and by 2011 had expanded to about 60 sites in the US and overseas; universities can apply to Google for funding to run such programs, and they are given a list of suggested workshops topics, including Unplugged. In 2011 for the first time the University of Canterbury in New Zealand was given a grant to run one locally, so the Unplugged material has come full circle!

6.1 Sponsorship and the New Web Site

Because of the CS4HS connection, the Unplugged project itself managed to get sponsorship from Google at the beginning of 2007. The funding was used to greatly improve the web presence, with its own domain (csunplugged.org, and also redirection from csunplugged.com and computingunplugged.org), new graphics and web design, publicity, more videos, and workshops for educators. Because of the funding there was no longer any need to charge for the books, so the PDF files of the books were made available online for free download under a Creative Commons Attribution-NonCommercial-NoDerivatives license (the NoDerivatives clause was needed because of the existence of commercially published translations.) Initially web hosting was provided by Carnegie Mellon University, as it was better to have a server in the United States rather than New Zealand. More recently this has been moved to a general hosting service.

One of the challenges was to publicize the new website; we were aware that having exciting material wasn't enough on its own to motivate a busy teacher or academic to use it. A key target for publicity was the SIGCSE and ITiCSE conferences, where hundreds of passionate computer science educators meet regularly. Figure 7 shows some of the material that was used for publicity at SIGCSE and ITiCSE conferences around 2007–2010. These were giveaways for which the main purpose was to have delegates take away the URL for the new Unplugged site (csunplugged.org). The buttons proved very popular (hundreds were printed and few were left). The "Choo Choo Route Plan" was one of two puzzles that were given to the audience while they were waiting for the keynote session. The main point was to illustrate that Unplugged puzzles could be adapted to a theme—in this case the conference was in Chattanooga, and the puzzle was a shortest-path problem based on elements of the song "Chattanooga Choo Choo." The postcard (Figure 7(c)) is still used as a give-away at workshops and events so that visitors have something worth keeping that has the URL on the back. The designs for this publicity material were done by Isaac Freeman.

Traffic to the new website (csunplugged.org) has been steady, with peaks now and then as it gets attention on the Internet (for example, in 2008 someone posted Unplugged on reddit.com, and the site had over 50,000 visits within about 24 hours). In 2011 the traffic on the sited averaged about 780 page views per day from about 202 unique visitors. About 38% of the visits are from the USA, with about 6% each from India and the UK, and about 4% each from Brazil, Germany, Canada, New Zealand, Italy and Japan. People from 140 different countries accessed the site during the year. The most frequently accessed pages are the activities for binary numbers, image representation, sorting algorithms and searching algorithms, although because the whole book can be downloaded, this doesn't necessarily represent which activities are used the most.



(a) (b) (c)

Fig. 7. Publicity material used for CS Unplugged (a) buttons given away at SIGCSE 2008 (b) the Chattanooga Challenge from SIGCSE 2009 (c) the front of a postcard explaining the parity trick

Experience has shown that the best way to get people switched on to Unplugged is through doing it, not reading about it. For this reason many workshops have been run over the years by the authors, as well as colleagues in many countries, in places as diverse as Bergen, Wuhan, Seoul, Tokyo, Münster, Stockholm, Washington DC, Tacoma, Vancouver, Pittsburgh, Oregon, remote villages in India, Vietnam, Australia, and of course Christchurch, Hamilton and Victoria BC. Mike is especially proud that many in the parameterized community have joined in his enthusiasm by presenting workshops on Unplugged with him in their children's classrooms, and by finding other innovative ways to open up public understanding and participation in the mathematical sciences. Since the year 2007 workshops on Unplugged have been run annually at SIGCSE, with various people helping to run the workshops and other Unplugged events at SIGCSE including Mike, Frances, Tim, Bengt Aspvall, Peter Henderson, Lynn Lambert, Daniela Marghitu, Ben Tsutom Wada and Tom Cortina. At a "Birds of a feather" session at SIGCSE in 2008 we were pleasantly surprised to hear how widely Unplugged was being used, including for a one-week visit to an orphanage in Haiti and on trips by float plane to First Nations communities.

We have already mentioned the 2007 SIGCSE workshop which was so popular it had to be repeated. Another memorable workshop was one that was part of the 2008 New Zealand Computer Science Research Students' (NZCSRS) conference in Christchurch. The postgraduate students participated in the workshop at the end of a conference. It began with a demonstration with some local school classes coming in to the university and participating in an Unplugged show. One of the "aha!" moments was when an HCI topic came up—the postgrads were at the back of the lecture theatre, and Tim asked for a show of hands of those who were researching the topic, which greatly impressed the school children (they probably imagined researchers as stuffy old professors rather than young PhD students). The PhD students themselves were impressed that 12-year-old kids could understand the essence of the topic that had been consuming them 24 hours a day for several years! That evening the postgrads had dinner at a science center (Science Alive!, where Tim first started doing computer science outreach), and they were encouraged to "play" on the equipment. Inspired by this, the next morning they got into teams to develop new activities. Several clever ideas came up (including "Harold the Robot"), and at this point we realized the importance of giving people a lot of time in workshops to develop ideas.

Another memorable workshop was held in Seoul, Korea, run by the "PINY" group, which is a mixture of artistic and scientific thinkers. The workshop began with a visit to a stationery store, where all sorts of papers, card, tubes, balls, wires and other props were purchased. The remainder of the day was spent in the inspiring surrounds of a traditional Korean house, trying to make activities using the materials purchased (Figure 8). Tim would suggest a topic (such as Euler paths), and they would try to make as many activities as possible relating to that from the props available. Photos and information about this event and related ones are on the web at blog.piny.cc/8.

Fig. 8. A PINY CS Unplugged workshop in Seoul, South Korea

6.2 Professional Videos for CS Unplugged

The funding from Google meant that the project team was able to be a lot more creative with video production. The original three videos were done on a zero budget, and although they had proved very popular—for example, the binary number video has had over 17,000 views on YouTube—the production quality was low and a lot was learned about making them suitable for an international YouTube audience. Even with funding from Google, the budgets for the videos were nowhere near what video companies would normally expect for short movies, but fortunately two Christchurch video companies (Shuriken and Orange Studio) were found who were prepared to work on the projects. Between them they produced about three videos per year, mainly using students from Chisnallwood Intermediate School in Christchurch to demonstrate the activities. Some images from the videos are shown in Figure 9. Many of the videos have had translated commentaries or subtitles added, and more recently full high quality versions of the videos have been made available for download from vimeo.com/user6351443. They have also been distributed with the Chinese version of the book. Table 1 gives a full list of the currently available CS Unplugged videos on the Unplugged channel on YouTube (www.youtube.com/csunplugged).

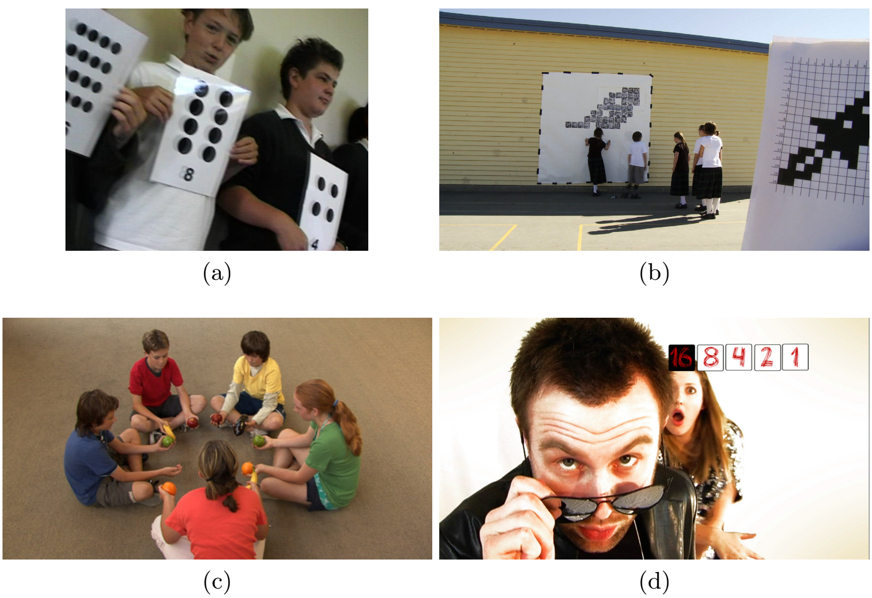


Fig. 9. Samples from Unplugged videos (a) the first video on binary numbers (b) transmitting an image and decoding it on the side of a school building (c) the "Orange Game" with a variety of fruit (d) "Reaching Out", with hidden messages coded in binary in the music

Table 1. CS Unplugged videos

Video title	Production team	Comments
Count the dots (Binary numbers)	Tim Bell, Michael Bell, Bengt Aspvall	Commentary in English, Chinese, French, Korean, Swedish
Beat the clock (Sorting networks)	Tim Bell, Michael Bell, Bengt Aspvall	Commentary in English, Chinese, French, Korean, Swedish
Card flip magic (Error detection and correction)	Tim Bell, Michael Bell, Bengt Aspvall	Parity trick, commentary in English, Chinese, French, Korean, Swedish
Computer Science Unplugged — The Show	Orange Studio; Tim Bell, Michael Bell	The one-hour show presented by Matt Powell and Javier Jarquin in 2008, with a commentary by Tim. Polish subtitles available. Also presented on YouTube broken into shorter parts.
Treasure Hunt	Shuriken; Tim Bell, Richard Bell	Finite State Automata, commentary in English, Chinese, French, German, Japanese, Korean, Swedish [26]
Orange Game	Shuriken; Tim Bell, Richard Bell	Routing and deadlock, commentary in English, Chinese, French, German, Japanese, Korean, Swedish [27]
Image Compression (Making Contact)	Shuriken; Tim Bell, Richard Bell	Run length coding activity, commentary in Chinese, French, Swedish [28]
Sorting algorithms	Shuriken; Tim Bell, Richard Bell	Selection sort and quicksort, commentary in Chinese, French, Swedish; Polish subtitles [29]
Computer Science Buskers?	Orange Studio; Tim Bell, Michael Bell, Kristen Finnerty	Parity error correction codes, subtitles in Chinese, French [30]
Santa's dirty socks (divide and conquer)	Orange Studio; Tim Bell, Michael Bell, Victor Chicha, illustrations by Tim Powell	Story book reading, has an accompanying book that can be downloaded; Polish subtitles [31]
Reaching Out (Binary Codes)	Orange Studio; Tim Bell, Michael Bell	Modem activity with text coded as notes in a song [32]

From 2009 to 2011 the SIGCSE conference accepted videos as submissions, and so the Unplugged videos during that period were submitted and ended up being played at the conference. Because the conference encouraged creativity in the videos, they gradually moved from being a simple commentary on a standard activity to some quite creative takes on communicating the ideas. They include the parity trick being done by a street magician, an animated divide-and-conquer story called "Santa's dirty socks" (written with Victor Chicha, a visiting intern), the run-length coded image painted on the side of a school building (Figure 9(b)), and an MTV style video where the tune of the song encodes hidden messages in binary using high and low notes (Figure 9(d)).

Some of the videos were tailored to the theme of the SIGCSE conferences; the 2011 conference theme was “Reaching out”, which was also the title of the song that coded the binary messages; and the 2010 theme was “Making contact”, for which the video discussed coding pictures as numbers based on an idea in Carl Sagan’s book “Contact” [33].

Two of the videos (the “Reaching out” song and “Santa’s dirty socks”) have led to two new activities on csunplugged.org to support them. The song is supported by an activity that explains how binary can be transmitted using sound (as on modems), and has a warm-up exercise with a recording of a jazz singer singing short coded messages. The singer had first performed the songs as part of an impromptu exercise at a music education conference; the theme of the music conference was “Modulations,” so a modem exercise seemed appropriate! The “socks” video is about divide and conquer, which now has its own activity, including a picture book of the story that is provided as a PDF file.

Most of the videos are short demonstrations, but the 2008 video of the Unplugged show was intended to help future presenters, with a live recording of the one-hour event, interspersed with a commentary that explained the purpose of the show (and the Unplugged philosophy in general), and hints on presenting it. On 9 January 2011 the YouTube video about the show was picked up on the Reddit recommendation site, and in 24 hours about 20,000 people watched the video, making it the largest audience for an Unplugged event yet! To date the show video has had over 47,000 views, and has drawn a lot of positive comments.

6.3 Translations to Other Languages and Cultures

The English-language Unplugged material has been used internationally since it was first written. The first enquiry about a translation came from Korea University, which had been actively involved in seeking ways to teach “real” computer science in the South Korean school curriculum, as reflected in the title of a 2006 paper they had published called “Informatics Education — The Bridge between Using and Understanding Computers” [34]. The translation was headed by Prof Won Gyu Lee, and the liaison with the Unplugged team was done by Sook Kyoung Choi, one of his postgraduate students who was researching how to adapt such activities to the Korean education system [35].

The Korea University initiative resulted in the first translated version, published in 2006 [23]. Because it was done through a publisher, it also became the first commercially published version of the Unplugged material. Susumu Kanemune, who was a Japanese colleague of Prof Lee, took an interest in the book, and by 2007 had published the Japanese version, with an appendix by Yasushi Kuno providing additional ideas and discussion. Many other translations followed, some prepared for formal publication, but most done by volunteers who were enthusiastic about the material and wanted to make it available to colleagues in their native language; these translations are available through the CS Unplugged web site. Table 2 lists the translations that have been made.

In addition, translations in Bahasa Indonesia, Bengali, Dutch, Hungarian, Maori, Tamil and Welsh have been proposed or started, although because such projects are done by volunteers, often it can take some time until they are completed! A translation into Uzbek was also started at one stage, but unfortunately the NGO doing the translation was asked to leave the country, and the project was cancelled.

Using Unplugged material in other cultures brought both challenges and fresh ideas. Mike had already observed that the “stories” might not make sense in other cultures — for example minimizing the number of ice-cream stands didn’t make sense in Peru if there was high unemployment [37]. When the Unplugged activities were used in Asia some of the examples dependent on language needed to be revised; for example, the 5-bit binary number code for the alphabet doesn’t work so easily for some languages, and some cultural assumptions needed to be adapted [38]. Interestingly, one of the first exercises in the teachers’ edition of the book involves Christmas trees, and Tim checked with each translator whether they felt this symbol from a Christian tradition would be a sensitive example in their country. Most translators (including those from Asia and the Middle East) felt that Christmas trees were generally acceptable and even enjoyed in their country, and intriguingly the only pushback came from a country with an English heritage... the USA!

As mentioned earlier, the title in translations usually keeps the word “Unplugged” in English to avoid pejorative meanings in the local language. Choosing a suitable subtitle has needed local input. Usually it contains the word “games” as this would be considered an attractive feature, but in Asian countries, we were advised to avoid the word because parents concerned about their children getting a serious education might shun a book that purported to be fun! Of course, the books still contain games, and fun is an important part of learning, so it’s almost as if the fun had to be smuggled in to the students between covers that parents would approve of.

Most cultural problems were easily overcome once recognized, and in general translations and internationalization also brought cultural richness and fresh ways to present the activities [38]. For example, Chinese colleagues suggested strings of lanterns for binary numbers, and Japanese colleagues introduced us to double-sided magnetic sheets for doing the parity trick on a whiteboard.

An example of a culturally adapted Unplugged activity is shown in Figure 10, where the binary number activity involving Christmas trees has been used for a “Fujitsu Kids Event”; as well as translating the instructions, the Christmas trees are now lanterns on a string, the alphabet has been changed to hiragana, and the cartoon characters are Manga style, which is appealing for Japanese students. The code table used is limited to 32 characters, which are sufficient for the particular message being coded, but a 6-bit code would be needed to code all hiragana characters to allow any message to be represented.

The Chinese edition, published by HUST press in 2010 [39], was a heavily re-written version aimed at students rather than teachers.

Table 2. Translations of CS Unplugged

Language	Translator(s)	Status
Arabic	Mohammed Obaid	All activities translated, seeking publisher, two activities available on csunplugged.org
Chinese (Simplified)	Muzhou Xiong, Zhensong Liao, Su Yu, Wang Shenglan, Han Ying Chun, Xie Xia, Dong Rongsheng	Student edition with 15 topics available for purchase from HUST press www.hustp.com, original edition translated, most videos translated, csunplugged.org site translated
Chinese (Traditional)	Long-Yuan Ya	Several activities translated
French	Francois Rechenmann, Paul Gibson, Anne Berry, Isabelle Souveton, Victor Chicha	Teachers' edition available with preface by Roberto di Cosmo through Interstices site interstices.info, and csunplugged.org, most videos translated
German	Maexl Stege, Katrina Kranzdorf	Five activities available on csunplugged.org, two activities used for www.informatikjahr.de
Greek	Constantine Mousafiris, Theophanis Hatz	Teachers' edition available through activities at csunplugged.org
Hebrew	Benny Chor, Simon Schocken	Being published as a blog at csu-il.blogspot.com
Italian	Giovanni Michele Bianco, Renzo Davoli	Teachers' edition available on csunplugged.org
Japanese	Susumu Kanemune, Yasushi Kuno	Teachers' edition available for purchase from Etext publishers, www.etext.jp/unplugged.html [36]
Korean	Won Gyu Lee, Sook Kyoung Choi, Hyeoncheol Kim	Teachers' edition available for purchase from www.yes24.com [23]; most videos translated
Polish	Pawel Perekietka, Lukasz Nitschke	Teachers' edition available through activities at csunplugged.org, subtitles available for Unplugged show and some other videos
Portugese (Brazil)	Luciano Porto Barreto	Teachers' edition available through activities at csunplugged.org
Russian	Irina Derevianko	Teachers' edition available on csunplugged.org
Spanish	Alfonso Rodríguez, Lorena Mendoza, Clara Eugenia Garza	Teachers' edition available from csunplugged.org
Swedish	Stefan Hellberg, Bengt Aspvall	Teachers' edition available from www.ide.bth.se/˜bia/unplugged/UnpluggedTeachersSwedish.doc, web site at www.bth.se/csunplugged, most videos translated
Turkish	Sertan Girgin	Seven activities available through csunplugged.org

6.4 Adaptations and Variations of Activities

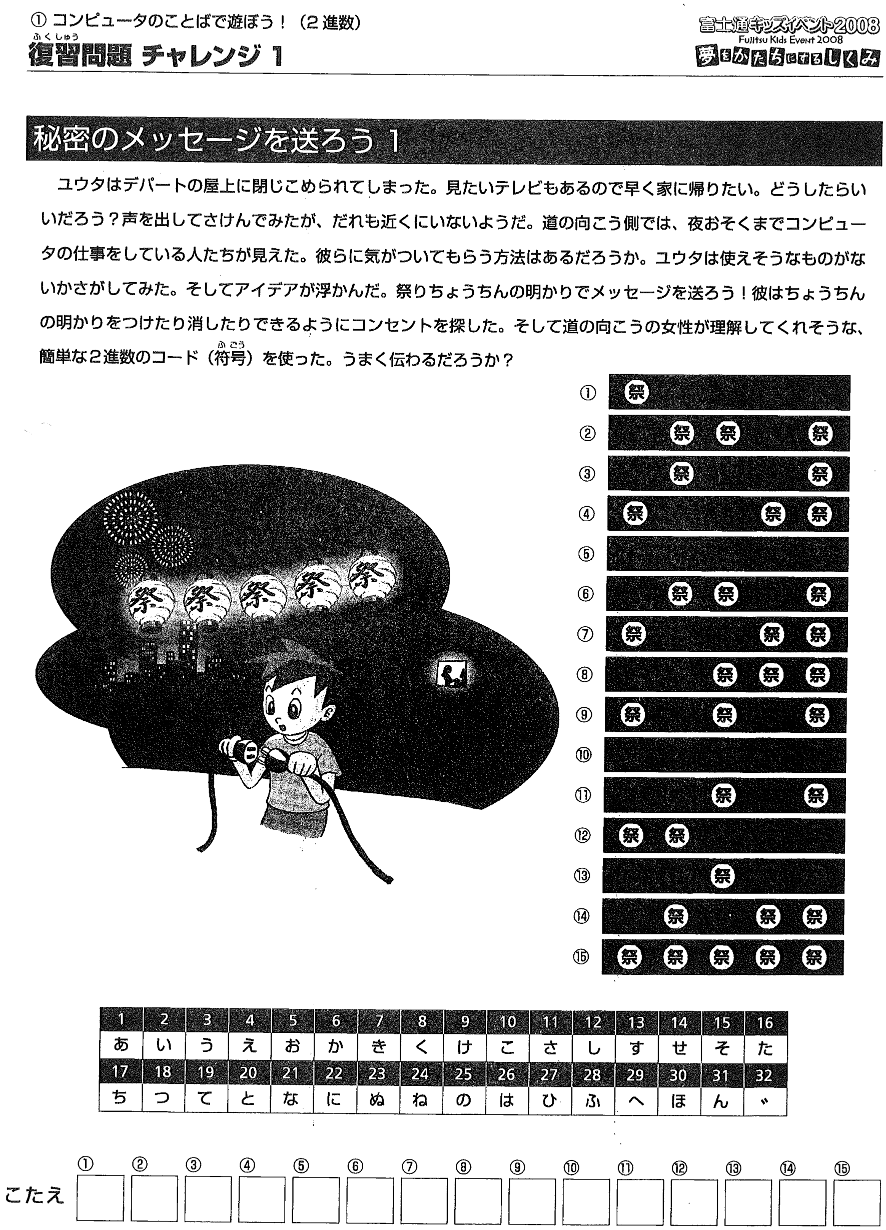
In the early days of Unplugged we had expected that the number of activities would continue to grow. Although new ideas did come up, the real growth has been in variations of activities and taking them into different contexts.

For example, Figure 11 shows some of the examples that followed from the binary number card activity, which was the first activity in the two main Unplugged books. Over the years several follow-up strands of thought developed. The first is a discussion of how birthday cakes actually use base one (unary), and that a binary system for candles would be more efficient and safer (Figure 11(a) and (b)). This can lead on to discussions relating to the logarithmic/exponential relationships that permeate computer science and both excite and frustrate algorithm designers. Dividing the cake itself can illustrate the power of binary divide and conquer approaches: give half the cake to the first person, half of the remainder to the next, and so on. People down the line soon realize how efficient logarithmic complexity is, even though the word "logarithm" isn't mentioned! Another practical application of binary numbers for children is coding names and words into jewelry using binary (Figure 11(c)).

A variation of the orange game that was created in two places independently was the idea of using different colored fruit instead of labeling the oranges, and having students wearing t-shirts corresponding the fruit. This was proposed by both Richard Bell (making a video of the activity) and Gottfried Vossen (running a "children's university" in Germany).

These kinds of variations have gradually arisen as the Unplugged material was used over the years and others contribute ideas.

Another significant change has been the adaptation of Unplugged for different contexts. In some places it has been used with little adaptation, such as having activities catalogued in the CSTA repository of teaching materials. Other times some local expertise has been added to improve the suitability of the activities. For example, the CS4FN (Computer Science for Fun, cs4fn.org) has a book of magic tricks, and the parity trick appears in their book in a more flamboyant version: the demonstrator is blindfolded right from the start, so they never get to see the original cards that the volunteer puts down, making the trick even more impressive. The National Center for Women and Information Technology (NCWIT) promotes "promising practices" to people wishing to communicate ideas from IT to attract and retain female students, and one of their promising practice handouts features the sorting network activity, and promotes Unplugged in general. They also have a "programs-in-a-box" series, and 7 of the Unplugged activities have been adapted and turned into NCWIT's "Computer Science in a box: Unplug your curriculum" (www.ncwit.org/unplugged). These activities are very similar to the teachers' edition, but are mapped better to the US curriculum. In 2006 some of the Unplugged activities were translated into German and packaged with other material for their "Informatikjar" (Computer Science Year). Andrea Arpaci-Dusseau has been working on a parent-child version of


① コンピュータのことばで遊ぼう！（2進数）

富士通キッズイベント2008
Fujitsu Kids Event 2008
夢をかたちにするしくみ

復習問題 チャレンジ 1

秘密のメッセージを送ろう 1

ユウタはデパートの屋上に閉じこめられてしまった。見たいテレビもあるので早く家に帰りたい。どうしたらいいだろう？声を出してさけんでみたが、だれも近くにいないようだ。道の向こう側では、夜おそくまでコンピュータの仕事をしている人たちが見えた。彼らに気がついてもらう方法はあるだろうか。ユウタは使えそうなものがないかさがしてみた。そしてアイデアが浮かんだ。祭りちょうちんの明かりでメッセージを送ろう！彼はちょうちんの明かりをつけたり消したりできるようにコンセントを探した。そして道の向こうの女性が理解してくれそうな、簡単な2進数のコード（符号）を使った。うまく伝わるだろうか？

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
あ	い	う	え	お	か	き	く	け	こ	さ	し	す	せ	そ	た
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ち	つ	て	と	な	に	ぬ	ね	の	は	ひ	ふ	へ	ほ	ん	゛

こたえ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩ ⑪ ⑫ ⑬ ⑭ ⑮

Fig. 10. A page from activities for the Fujitsu Kids Event, 2008

Unplugged, intended as a workbook for a non-specialist parent to work through with their child. This requires more hints for the parent, and also requires some of the group games to provide versions that can be played by two people (for example, turning the sorting network into a board game).

(a) (b) (c)

Fig. 11. Binary numbers in everyday life for kids: (a) the dangers of using unary (base 1) instead of binary (b) the binary birthday cake (c) a bracelet coding a name using beads

Unplugged activities have found their way into formal curricula. The "Computing Science Inside" program hosted at the University of Glasgow provides activities that are ready for classroom teachers to use, and is particularly aimed at the Scottish curriculum; it contains several Unplugged activities that have been repurposed for this use. The resources include Powerpoint slides and handouts (see csi.dcs.gla.ac.uk). The "Exploring Computer Science" (ECS) program in Los Angeles (www.exploringcs.org) is a successful initiative that uses several Unplugged activities as part of its curriculum [40,41]. Another initiative that is likely to draw heavily on Unplugged activities is Peter Denning's "Computer Science Field Guide" (www.csfieldguide.org), which is planned to be a merit badge system where participants can earn "badges" for achieving competency in a selection of areas, and at different levels [42].

Around 2006 the idea of Computational Thinking (CT) became prominent in discussions about computer science education, championed by Jeanette Wing [43]. It turns out that CS Unplugged is a good example of an approach that emphasizes CT, and was already in widespread use when CT became a hot topic. Unplugged has been explored in a 2010 workshop on Computational Thinking [44].

A more significant adaptation that is now underway is to make the material more suitable for direct use in the classroom. The teachers' edition was written as extension exercises, but for everyday use teachers need background reading for the students (currently the books are written for the teacher, not the students), and assessment material (the nice thing about outreach is that you don't usually have a test at the end!) A version intended for students has been written for the Chinese market [39], but is yet to be adapted for English speaking countries. This version has a teacher guide, and the main text is addressed to the student, being careful to cover basic information that would be expected in the classroom (such as defining kilobytes and megabytes) as well as the more open-ended material like the muddy city puzzle. As the Unplugged material gets wider adoption and is used in the formal school setting, it is becoming apparent that the original open-endedness and sense of adventure will take some creativity to retain, as schools around the world feel an obligation to standardize and assess, and there is no guarantee that the teacher will have the passion or experience of math that someone running an outreach program would.

Although the Unplugged philosophy generally eschews using digital devices, there has been value gained by integrating it in some situations. For example, Daniela Marghitu has had students design and program robots to carry out Unplugged activities, so they need to understand the activity first, and then program the robot to simulate the actions of a child who would have been doing the activity, which requires an even higher order understanding of the concept. These activities have been done as part of "Robo camp", a robotics program for advanced students ages ten to eighteen [45]. Moti Ben-Ari has also demonstrated how Unplugged activities can be followed up with Scratch programming exercises by implementing many of the activities in Scratch (available from code.google.com/p/scratch-unplugged), and Ward *et al.* also give hints for using Unplugged with Scratch [46].

In 2008 the "New Media Consortium" (NMC) awarded a prize of US$5000 to the Unplugged project to develop activities in the Second Life virtual world. A sorting network was implemented (it can be seen in Figure 2(e)) and was used for a period by students, including some with disabilities who couldn't walk in the real world. Although this might appear to be cheaper and simpler than a physical sorting network, the ongoing cost of virtual land to put the sorting network on, and a lack of ongoing funding and support, prevented it becoming a public facility. Work is still continuing on the possibility of virtual worlds for implementing and evaluating Unplugged activities, although it has moved to private areas that can be hosted within a school, which avoids the many issues that surround school children using a public virtual space [47].

Yet another adaptation of the material is for a programming competition environment [48]. By using Unplugged stories as scenarios to be solved in a competition the programmers end up having to grapple with deep issues from computer science, but also there is the potential to use the physical activities as a break from working intensely at the keyboard, where the break itself provides the next programming challenge!

At the University of Canterbury some of the Unplugged activities have been landscaped into a "Bridges of Friendship Math/Computer Science garden", which includes the seven bridges problem (Eulerian path), an 8-queens puzzle, and of course, a 6-way sorting network (shown in Figure 2(c)). Running around the seven bridges trying to find an Eulerian path provides a valuable break from lecture theatre activities for school visits, and even regular student classes.

A new development with Unplugged has resulted from abstracting the principles of this approach to teaching computer science, and thinking about how it could be applied to other subjects. If the meaning of "Unplugged" is to remove traditional gateways to the subject, and enable young children to grapple with advanced ideas before learning the "basics," what would the equivalent be in a different subject, such as music? The first task is to identify the gateways — perhaps having to learn a musical instrument, or read music notation, before one is allowed to become a performer or composer? Such ideas are being explored in workshops, including the transdisciplinary environment of the SDPS conference [2], and a workshop under development called "It is Really About Thinking." This kind of approach can be found in the book "Statistics Without Math" [49], which provides a gentle explanation of statistics based on diagrams, which in turn might provide motivation for a student to tackle the mathematics behind the concepts. It will be valuable to explore these principles in other disciplines; who knows how many educational opportunities could be opened up this way!

7 CS Unplugged—Emerging Principles

With 20 years' experience, much has been learned about delivering computer science using the Unplugged approach, although Mike's original writings about computer science and math education still emerge as the key principles that have stood the test of time.

There were several motivators for Unplugged, which was initially mainly done as a labour of love. The philosophy that drove the project was largely captured in Mike's paper "Computer SCIENCE and Mathematics in the Elementary Schools" [4], which made the radical proposition that elementary school students could enjoy learning about algorithms, and that computer science was a "treasury of accessible, colorful and active mathematics". The paper points out that grade 1–4 students mainly get to do arithmetic, and arithmetic is not mathematics. It then demonstrates how such students could easily work with concepts from graph theory, sorting networks (of course), and knot theory. The paper discusses why such inspiring math might not be welcomed in the education system, and also demonstrates some examples of young children contributing to or inspiring serious avenues of research in math and computer science, including an example of a paper that was published as a result of a classroom visit. There are many inspiring quotes and analogies that challenge traditional thinking about math and computers in schools, and it is just as relevant now as it was 20 years ago. It should be compulsory reading for everyone involved in computer science and math education.

Another motivation of Unplugged and related projects has always been to make the ideas from computer science available to those who can't afford a computer, or might not even have a reliable power supply to run one. Mike was active in working with teachers and students in such situations, particularly through the Kovalevskaia Fund, which Neal Koblitz discusses elsewhere in this book.

Both motivations speak of wanting children to be empowered to understand and reason about the world they find themselves in, and not be mere users of technologies that are imposed on them or are inaccessible to them. It has been said that "Only two industries refer to their customers as 'users': computer design and drug dealing.[6]" The *MEGA-Math* and Unplugged initiatives can largely be seen as a desire to rescue children from becoming only users, that is, becoming addicted to whatever technologies are inflicted on them, rather than being given the wherewithal to create systems that work for them; to choose between what is good and what is harmful; and to discern what will improve their quality of life, and what will improve someone else's quality of life at their expense.

Neal Koblitz shares these sentiments in his article "The case against computers" [50], in which he quotes Mike as saying "Most schools would probably be better off if they threw their computers into the dumpster" (a phrase which many people would have heard Mike say!) Neal also mentions Mike's use of the term "Cargo Cult" to refer to the "fetishization of computers by the media and educational establishment."

Mike wrote and spoke frequently about these issues. It was worded particularly eloquently in an article with Ian Parberry in 1993: "SIGACT trying to get children excited about CS" [51], which said:

> We need to do away with the myth that computer science is about computers. Computer science is no more about computers than astronomy is about telescopes, biology is about microscopes or chemistry is about beakers and test tubes. Science is not about tools, it is about how we use them and what we find out when we do.

The analogy between computers and telescopes is a particularly powerful one that has served well to make the point quickly to laypeople about the difference between computer *science* and simply learning to use computers. As an interesting side note, it appears that the telescope analogy originated with Mike (for example, he used it in a 1991 online pre-publication of his "manifesto" document [4]), but searching the Internet shows people widely attributing it to Dijkstra, without any reference to where Dijkstra first said or wrote it (and it doesn't appear in his collected writings). Mike and Dijkstra had spent time together around the time that Mike was writing this material, so it is quite likely that it was discussed and possibly even originated from those conversations. It would be an interesting research project to settle the history of what has become such a definitive quote. Some initial research is reported via en.wikiquote.org/wiki/Edsger_W._Dijkstra, which concludes that the quote is misattributed to Dijkstra, and is actually from Mike. Establishing this without doubt would provide an extreme example of the spread of misinformation by copy-and-paste reporting on the Internet!

Another quote from Mike that left an impression on Tim during the 1993 visit was "Computer science is the rock and roll of mathematics." This inspires all sorts of imagery — is computer science the part of mathematics that people actually use every day? Is it the part that causes things to happen? Is a computer scientist looked down on by a "pure" mathematician because they make compromises to make things work for everyday people? Like so many of Mike's

[6] This is usually attributed to Edward R. Tufte.

epigrams, it's a concise statement that gives people pause for thought, and enables someone speaking to laypeople to communicate a lot of meaning in a very short time.

As Unplugged became popular, the following features emerged that defined its value as an approach to education and outreach:

- Teaching a student to program takes many hours, if not months. If you only have one hour to spend with students (e.g. an outreach visit), then the Unplugged approach enables the presenter to launch into a range of computer science topics, rather than just scratch the surface of programming. Extending Mike's analogy, if an astronomer had one hour to spend with a class, it wouldn't be inspiring if it was simply some preliminary information about how to set up a telescope.
- Programming is usually put up as a gateway to getting into computer science. Some students may not particularly enjoy programming, but would be prepared to use it if they knew what they could do with it. The way computer science is often taught, students get the impression that it is primarily about programming; Unplugged reverses this view.
- It is often assumed that the first thing you need to do computer science is a computer, but often a large amount of effort can be spent setting up a computer lab, installing appropriate software that will soon need updating, creating accounts for students, and so on, making the computer a distraction that preoccupies both students and administrators. And of course, in some countries there might only be a few computers in the whole school, or maybe none at all. Unplugged activities enable learning about the discipline to occur in the first minute the lesson starts, and only inexpensive equipment is needed — typically paper and pencil, and maybe some string!
- There are many misconceptions about what computer science is, and the way it is often approached in schools can reinforce them. We encounter many students who had assumed that computer science could not possibly be an interesting career for them, yet somehow got into it by accident, and find it thoroughly fulfilling. It would be a tragedy if students decided not to follow a path that they would have loved based on misconceptions; Unplugged provides a means to sweep away many of these preconceptions.
- Information systems have a huge influence on everyday life, whether or not people are interested in computers. People who don't understand even simple computer science concepts have to make important decisions relating to the security of their computers, the way they do financial transactions, or whether a technology is reliable, based mainly on the opinions of others. It would be equivalent to supporting the invasion of a foreign country based on friends' opinions, rather than understanding the culture and politics of that country and making an informed decision.

A key theme in *MEGA-Math* and Unplugged is the sense of story—there are pirates, monsters, ice cream vendors and football teams who are at the centre of some story that invokes a problem that must be solved.

In Mike's "advice to students" at mrfellows.net he write:

> Story is central. Story is a bigger force than science. Everybody lives by stories. They are a primal force. In mathematics, we add formalism. We have equations that lead to solutions but story has its own logic. Find the story in what you are telling and presenting. This will help the listener meet you more than half-way.

Some might think that fictional, even preposterous, stories have no place in teaching science and mathematics. But stories engage children and adults, they provide a compelling description of a situation, they remove boundaries, and they give the message that it's time to start using your imagination. Mike is a consummate story teller, and has been able to use story to great effect, as well as providing stories that others can use, if only they are prepared to suspend reality for the sake of science.

A more prosaic analysis of the Unplugged approach can be found in a paper initiated by some Japanese Unplugged enthusiasts, who analysed Unplugged activities and came up with a *design pattern* for the activities [52]. The paper explores mapping everyday objects (such as cups and stickers) to concepts in computer science (such as variables and states), and gives ideas for creating new activities.

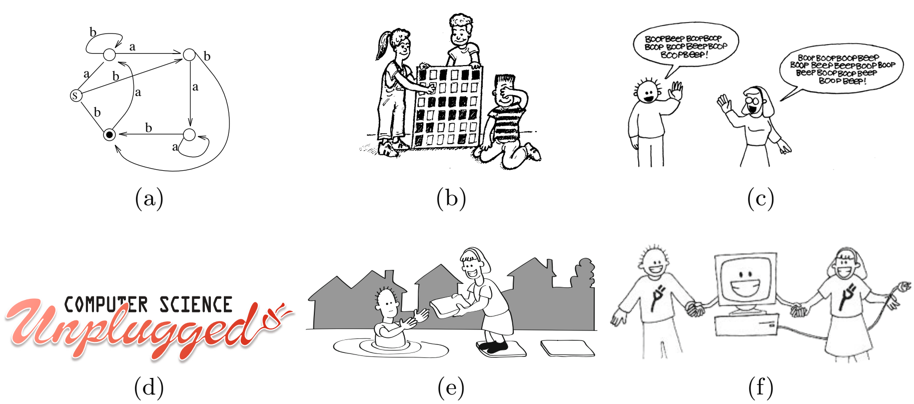


Fig. 12. Illustrations for CS Unplugged (a) early material from *MEGA-Math* (b) from the "original" 1999 book, by Gail Williams (c) from the teachers' edition, by Matt Powell (d) the logo designed by Matt Powell (e) from the web site by Isaac Freeman (f) theme image from recent books and web site

Having good illustrations has been an important aspect of the Unplugged project. The *MEGA-Math* workbook [8] used line drawings of diagrams without any people shown in the images (Figure 12(a)), although the *MEGA-Math* website includes low-resolution images including some characters. Early illustrations for CS Unplugged were done by various computer scientists involved in the project, with some help from Malcolm Robinson (a Christchurch-based graphic artist), but for the book published in 1999 most of the illustrations were done by Gail Williams, who introduced illustrations of children doing the activities (Figure 12(b)). The teachers' edition was illustrated by Matt Powell, a CS graduate who captured ideas from CS in the illustrations, and also created the characters that have become the familiar face of Unplugged (Figure 12(c)). He also designed the logo (originally for the KidsFest show in 1998), which is still used (Figure 12(d)). More recently the illustrations have been taken over by Isaac Freeman, who has continued developing new illustrations in the style established by Matt Powell (Figure 12(e)).

8 Evaluations of CS Unplugged

The ideas in CS Unplugged have clearly had a wide impact around the world, and a search of the computer science education literature reveals that it is cited in dozens of papers. In October 2011 the website was getting nearly 12,000 unique visitors each week, and the various videos on the YouTube channel have had over 80,000 views in the few years they have been available. The widespread adoption of the ideas in many countries is an endorsement of the material, but formal evaluations are important to understand more carefully how well the approach works, and in what contexts it doesn't work. Although many evaluations of Unplugged exist, they either use very small groups, or mix Unplugged with other material, which means that it is difficult to draw general conclusions from them. More often than not, teachers have quickly recognized the effectiveness and value of Unplugged and adopted it, proving its worth in practice for themselves. However, there are many factors that can affect how well it works, including the time of day (children seem to have a better attention span in the morning), the enthusiasm of the presenter and especially their patience to let students explore ideas.

There are two research projects that report on using Unplugged in its raw form with older school students. Taub *et al.* [53] report on a group of thirteen 7th and 8th grade students who did 18 of the 20 activities from the "original" book as a series of after-school meetings. Six of them were then interviewed; the sample is too small to draw firm conclusions, and it's unfortunate that the original edition was used because some of the problems encountered were addressed in the revised teachers' edition, but the paper does make the following useful observations:

- Activities should build on students' prior knowledge (Unplugged was designed for elementary age children who would have a much less sophisticated prior experience of math and computing, and the teacher should adapt activities to suit the students' background),
- There should be an explicit link to central concepts in computer science (some of the activities were intended to be exploratory, to follow the students' interest, but if Unplugged is to be used as a high school text book then more formal links to curriculum would be needed), and
- students should be informed about careers in computer science (this was seen as an important motivator, although is clearly complementary to the material presented in Unplugged).

Another study by Feaster *et al.* [54] describes an outreach to a high school where they ran 10 lessons from Unplugged activities for two groups of 14 and 15 students respectively. The paper reports that those who started with low interest increased their level of interest, but those with a high level didn't; that is, Unplugged seemed more suitable for getting students interested than for those who were already interested. After the sessions the students seemed to have a better idea of what university CS would be (for example, they decreased their belief that web design would be important preparation for studying CS, and saw math as more important for CS). The authors observed that high school students didn't seem as excited about these kinds of activities as more junior students; this reflects our experience, where for senior classes Unplugged is best used as a short demonstration followed by a more technical discussion, whereas younger children are content to spend more time exploring ideas for the sake of it.

A more positive picture emerges when the material is used to add interest to camps and outreach programs. Carmichael [55] reports using Unplugged interspersed with teaching video game programming for a summer camp, and achieving an overall increase in interest in taking CS further as a subject. In this case the Unplugged activities apparently helped students see the connection between theory and practice.

Hart *et al.* used Unplugged to link CS to the math curriculum in a 3-day workshop for math teachers [56]. A survey showed that 100% of teachers agreed or strongly agreed with the statements "Sessions stimulated my interest", "Content is useful to me", and "Program will improve some aspect of my teaching." One teacher commented: "I loved getting a little 'taste' of many different aspects of the CS field. I now have some first-hand information about the CS field to pepper my lessons with throughout the year."

A computer science outreach program for fourth graders based on Unplugged activities reported success in increasing interest in computer science [57]. They noted that it is hard to get public schools schools interested in such events because of the lack of computer science state standard tests. From pre- and post-intervention surveys they reported that "students were more interested in computer science, had significantly higher cognitive competence, and were significantly more confident about math ($p < 0.05$ for all), but not significantly more interested in math."

Groover reports success from activities with girls in a middle schools "conference" which included Unplugged activities [58]; the conclusion says that "post activity discussions showed that the students seemed to understand the connection of each activity to computer science." Interestingly, the "Marching Orders" activity was more popular than the Parity Magic trick; our experience is that the parity trick usually generates a lot of interest, which illustrates how experience can vary a lot in different contexts.

The Parity trick has also been used as part of a successful program based on magic tricks [59]. Feedback from this magic-based program indicated that a significant number of students indicated that they learned something about computer science. Having the presentation as a "show" rather than a "lecture" was seen as positive, and the authors report that it "clearly worked for girls."

One of the main points of Unplugged is to change attitudes, and a research project that measured this was reported by Cottam, Foley and Menzel in 2010 [60]. They organised a roadshow that talked to students about topics like stereotypes and careers in computing, and the main computing activity was the Parity trick. The evaluation was for 613 freshman students (59% female), and the results were generally positive. The question asked of students that relates most to understanding the field was "Computing is mostly about writing programs"; 24% of students agreed before the intervention, and 17% agreed afterwards. In response to the statement "Computing is full of exciting opportunities", 55% of students agreed before the intervention, and 81% agreed afterwards. A larger change was seen for female students: 49% of females agreed before the intervention, and 79% agreed afterwards.

Another report on a workshop for teachers that uses Unplugged as a major component found that the attendees "felt much more comfortable advancing the use of computing and computational thinking in their classes" after the workshop [61]. In a survey 4 to 6 months after the workshop, one of the three most widely adopted materials from the workshop were the Unplugged activities (particularly the binary numbers activity).

A program that combines parents and students in a series of workshops is reported by Hart [62]. The target audience is fourth through sixth grade female students. In the workshops they covered a variety of topics including programming in Alice. Unplugged was used for for an introductory session, during lunches, and with the students while parents had sessions on topics of less interest to the students. It is difficult to draw conclusions about Unplugged from this report because it was an adjunct activity to the main program.

A comprehensive study of the Unplugged approach can be found in a thesis by Sarah Carruthers [63]. The thesis reports on a series of lessons with sixth grade students relating to graph theory. A key conclusion is that the students "appear capable of not only learning graph theory, but applying it to solve problems. The use of relational graphs appears to positively impact student performance on at least some types of problem solving activity." In a related paper, Carruthers *et al.* [64] conclude that "Graph theory instruction can support existing mathematics curriculum and provide novel problem solving strategies for students at the grade six level. Student and teacher willingness to participate actively during the graph theory lessons in this study indicates that graph theory may be a suitable computer science topic to integrate in classrooms at this level." This matches with the anecdotal experiences reported early in this chapter—as long as you don't tell students that it is difficult, they are able to work with concepts that are generally regarded as very advanced.

A survey of Unplugged and several other approaches to outreach and teaching that avoid programming was published in 2011 [65]. One issue that was identified was the importance of a suitable motivation for students. For classroom work the extrinsic motivation of grades is usually available, but for other programs motivators include "contest prizes, the challenge of solving a problem, curiosity, humour, and ideally, appealing to the intrinsic interest of the student in this kind of thinking and reasoning." The challenge to any presenter, whether using Unplugged or something else, is to create those motivators so that children want to explore the concepts, rather than complete the work out of necessity.

Based on the evaluations mentioned above, Unplugged has a positive role to play for adding seasoning to classes and outreach programs, and has been well received in workshops for teachers. It works well in combination with other topics, including programming or exploring social issues or careers. Problems have been reported using it directly as a curriculum, which is not surprising since it was developed in the context of outreach and open-ended exploration, rather than a specified set of standards. Its genesis was from an inversion of the normal classroom format of "teach an algorithm and test if the students understand it" approach, and the research reported above seems to confirm that the way in which material is approached in the classroom is as important as what the material is. In terms of the astronomy metaphor, simply taking the Unplugged activities into a classroom and using them to teach a whole course on computer science would be analogous to teaching a course on on astronomy without using a telescope at all. An inspired teacher could pull it off, but in a conventional setting, students are bound to want to look at the night sky for themselves, and for a teacher to insist on not using a telescope could be demotivating, particularly for those who want to be an astronomer one day!

There are two main challenges with introducing Unplugged to a formal curriculum:

– poorly prepared teachers can make the most exciting material become dull because the topics are taught under compulsion, and students who come up with interesting ideas might be squashed either because it doesn't match the curriculum, or because the teacher doesn't have a broad enough background to recognize creative answers. For example, Tim once observed some science demonstrators doing a binary number activity, and an enthusiastic child hypothesized that there might be a card with 256 dots for the 9th bit; the demonstrators essentially told the child that you can only have 8 bits. On another occasion while doing the first step of selection sort with a class using a balance scale, the students had just found the heaviest of 10 weights, and were asked them how many comparisons were made. Normally students work out that it is 9, sometimes incorrectly suggesting 10 as a possibility. On this occasion, one girl said "it's going to be 45". One worries that if they had a teacher not familiar with the problem then their answer would simply be dismissed as being way out of range, instead of recognizing that the student had thought ahead and calculated the number of comparisons for a complete selection sort.

– the school system (administrators, teachers, students and parents!) expect teaching to be followed by assessment. The organic and exploratory nature of Unplugged makes this difficult because one doesn't know what the students are going to learn, and if teachers are required to straight-jacket the material into a strict curriculum, it can squeeze the life out of it. This is not to say that assessment isn't possible, but inspired teaching and creative assessment is required to keep students excited.

9 The Heart of Puzzling: Mathematics and Computer Games

Mike wanted to bring an appreciation for mathematical foundations and frontiers to as many people as possible, and computer games were part of his vision early on. Mike ran his *MEGA-math* theory awareness activities in his classrooms and at Family Night events, and talked about them at the professional meetings he attended, wherever he went. Computer games were galvanizing attention. In 1992, when Mike chaired Local Arrangements for STOC in Victoria and organized an education action committee (see Section 3 on Activism), he met Ernie Brickell, now Chief Security Architect for Intel Corporation. This led to an invitation to speak at Sandia National Labs. Afterwards, Mike visited Vance Faber, Chief Scientist and Director of Research at Los Alamos National Labs. Vance asked Mike what he had been doing in Albuquerque. Mike showed him the manuscript that he and Nancy Casey were writing about teaching mathematics with game style activities, and Vance shouted, "That's great! I've got to show Bonnie Yantis. We've got to turn this into a project." "Research On Mega-Math: Discrete Mathematics And Computer Science for Children" became Vance's favorite project. One of the nine objectives of the project was "The development of connections to the computer games industry."

9.1 A Systematic Mathematical Theory of Game Design

In 1992, Mike offered a course at the University of Victoria (BC) called "Theoretical Computer Science With Applications to Computer Games." By 1993, he had developed a premise that the heart of every good game held both a puzzle and an interactive structure, both inherently mathematical in nature. He proposed that if properly exploited, the addictive fascination of computer game-play would reveal itself to have a fundamental similarity to the mental experiences of mathematical research. The joy of an activity akin to research (carefully constructed gaming) could be a catalyst to popularize mathematics for children.

Mike heard about the Games Development Conference, the largest and primary forum for those involved in the development of interactive games. Insiders gather here to exchange ideas and shape the future of the industry. Mike phoned the organizers and described some of his ideas about math games for children. They said that was very interesting, and they organized Mike to speak in 1994.

This led to consulting with the big game company Broderbund (producer of Myst), and Mike was recruited to a contract with them. That was before they closed their education division.

In his unpublished 1996 article, "Fifteen MEGA-Math Puzzles," Mike described a systematic mathematical theory of game design, and a method of producing an almost endless stream of computer games. His method merged what he termed *vanilla* puzzles (an all-purpose, general ingredient) with game *handles* (that is, a crank, as on an old-fashioned coffee grinder.) The vanilla puzzles came from computational problems such as GRAPH COLORING, DOMINATING SET, INDEPENDENT SET, HAMILTON CIRCUIT, and others from the Garey and Johnson compendium [1]. Each of these vanilla puzzles would form the mathematical backbone of a successful game. Importantly, GRAPH COLORING and all the other computational problems come from significant and interesting applications in the real world. The game's storyline could be built around these relevant applications. The storyline could be another attraction for players to form an interest in mathematical science.

The *game handles* came from the underlying information-action puzzle structure that Mike identified in many popular games. He grouped popular, well-known games into *families* according to their structure, that is, their handles. As an example, there was a *Family of Discrete Repairs Puzzles* (such as "Minesweeper"), and a *Family of On-Line Puzzles* (such as "Tetris"). Mike's insight was that in order to design a collection of computer games (as he described it): "one had only to attach the *game handle* to a *vanilla problem* from the *NP*-catalogue, and turn the crank."

As an illustrating example, consider the popular game of Tetris. From a mathematical point of view, Mike considered the Tetris-handle as an on-line two-dimensional packing problem. Attaching the Tetris-handle to the vanilla problem DOMINATING SET or the vanilla problem GRAPH COLORING would produce the game "Tetris of Dominating Set" or "Tetris of Graph Coloring". The "on-line" meant that as the graph scrolled downward, a player would use a limited but replenished supply of tokens to indicate a dominating set or a proper graph coloring. If an un-dominated vertex, or improperly colored vertex, hit the bottom of the screen, the player loses.

The game story might vary from the unadorned scrolling graph of dots and lines, to a story about the practical importance or history of the underlying computational problem (the vanilla puzzle), or it might simply be a fanciful story where the vertices represent goldfish, which must be properly colored before the water in their tank drains away. Mike's vision of computational puzzling and educational game design is summarized in his 1999 article, "The Heart of Puzzling: Mathematics and Computer Games" [66].

9.2 Designing Games with Jim Andrews

In 1995, Mike met Canadian poet-programmer Jim Andrews at the Mocambo Coffee Shop in Victoria, British Columbia, where Mike was trying his hand at stand-up comedy. Mike says:

> I have ambient literary impulses from time to time. About when I was moving to UVic, I was having a bit of an existential crisis and decided not to do computer science anymore. I was going to do poetry and stand-up comedy. I didn't get very far.

Mike and Jim (who have become a lifelong friends) began designing a game that was part educational and part entertainment, generally termed "edutainment." Their game, "Wordstones," was based on genetics, in which the player creates creatures, machines, and activities (using finite automata) that mimic the behavior of how ribosomes process strands of DNA.

Although Wordstones takes place in an imaginative realm, one of the rewards of the game is that the biological science is eventually revealed to the player. Mike and Jim also designed CoLoRaTiOn, about graph coloring (see vispo.com/software/coloration/CoLoRaTiOn1.0.exe; Jim also designed vispo.com/arteroids).

Jim recalls those times as follows:

> We would get together at my apartment, mainly. This was in 1995 to 1997. If we sat down for a two or three hour session, Mike could come up with at least a half-dozen new ideas. It was a matter, for him, of simply turning his attention to any part of the mathematics of computer science and contemplating the challenges of research, the goals and, often, real-world situations from which the algorithms and problems/theory arose. It was a mark of his work to invariably involve some sort of unsolved problem in the games/puzzles. This is very Mike. It wasn't sufficient to simply create fun puzzles and games. They should also encourage research into productively mysterious, unsolved mathematical problems and issues. The unknown, for Mike, is where the real fun is.
>
> It all needed more work, to be frank. But what fun it was. For me and, I hope, for Mike. I was continually amazed by his dynamic insight and powerful ability to discover games and puzzles in the math of computer science where others saw none. It was a Pythagorean experience for me, as it were. A bit mathematikoi, a little accusmatici, in awe as I was, of his mathematical insight and sweeping vision of the field.
>
> I also saw Mike's genius at work in his creation of materials for kids to explore and play on during evenings where he and his volunteer graduate students and also other math teachers put on entertaining evenings in grade school gymnasiums where kids would play on big tarps illustrated with data structures. How cool is that? The kids loved it. I hope some of them were inspired as I was by this deeply educational involvement very concretely in very abstract work.
>
> Mike Fellows shows the way to the popularization of computer science. And, Lord knows, it needs it. As an artist, I am continually struck by the near complete ignorance in the general culture of all matters pertaining to the theory of computation. And this goes very deeply into the fears people have of the role of machines in our lives. Mike blows all that fear away with his ability to engage curiosity and thought in play. Kids and

adults look at mathematics and computers very differently after one of these evenings. It is presented as something they can think about and deal with in a very playful way. Brilliant. Just brilliant, really.

Mike had a big influence on my vision of many things, such as the role of the theory of computation in digital art and poetics. Many artists think of computers as glorified televisions, or stereos, or typewriters. The radical flexibility of computers is invisible to them, so that they conceive of the vistas of digital art as, fundamentally, more of the same. But computing not only dissolves the borders between media, given that it is all coded in zeroes and ones, but it posits whole new media. Continually. Mike helped me see that the theory of computation is one of the philosophical underpinnings of any interesting philosophy of computer art. He has that sort of effect on people. He teaches very deeply. Not simply at the level of puzzle, but that of enigma and life-long involvement. Thank you, Mike. You are a cosmos and contain multitudes.

9.3 Educational Game Design

Mike and Frances met in September, 1998 (when Mike was presenting mathematical plays at the Victoria Fringe Festival, described in the chapter on Passion Plays). They quickly learned that they worked well together; sometimes Mike calls them the "Mike and Fran Team." They became consultants for a start-up company in Texas that was designing a game to teach basic chemistry. They realized that there are key questions that must be addressed by the chemistry game or any game trying to be both educational and entertaining. Below are a few of the issues in their (unpublished) *Catalogue of Educational Computer Game Design Philosophy.*

1. *Chocolate-Covered Broccoli (CCB)* — sweet coating over bitter substance — is unpalatable to us. To produce a game with curriculum content that is not disguised as unpalatable CCB, a first plan is to analyze the overall structure of the mathematical curriculum, and the architecture of the games approach.
2. *Missed Magic* means throwing out the chocolate just because the recipe also needs a tie-in spice like nutmeg, a format that catalyzes a relationship between the bitter and the sweet elements. The real chocolate is wonder and curiosity. How does the game pay systematic attention to these fundamental resources, including the catalytic format that keeps the wonder going along with the learning? Mike recalled a period when his small child had a chemistry set with galvanizing images that kept her wonder going on a day-to-day basis. "The elements were her personal little friends," Mike said, "the sprites of the world to which she had secret access through her knowledge of Chemistry and atoms."
3. *Ageless Chocolate versus Perishable Broccoli.* Edutainment inherently has conflicting timescales: eternal chocolate versus perishable broccoli. How does one combine an authentic expression of the universal ageless intrinsic appeal of the subject, and the grade-specific curriculum agenda?

Mike and Frances posited that an educational game must possess self-awareness. A game just for entertainment has a simple position: pure fun. A game for education has a simple, authoritarian position: eat this broccoli. It is good for you. In contrast, an edutainment game must express some awareness of its predicament in trying to convey a majestic quest while also being a server of broccoli.

They used the insights they had gained from working on the chemistry game when they moved to New Zealand in 1999. There, they designed a multi-player, auction-type game for children that could be played on a mobile-phone. Mobile phones had become so ubiquitous, even among children, that they believed they now had a global catalyst for introducing mathematics. Mike and Frances were well coached by the Wellington Innovation Council, and eventually presented their business plan to a prominent Sydney venture capitalist. "Mr. B." understood science (he had a Ph.D. in Chemical Engineering) and his heartstrings were sympathetic to their project. He thought he would buy their game for his daughter and that she would like it.

There were two ways that children could interact with the game. They could play by identifying a minimum vertex cover on a graph of dots and lines that was presented on their mobile. The second way children could join the game was to compete in creating graphs (on a given number of vertices) for which it was very hard to find a minimum vertex cover. Mike and Frances would collect and analyze these children-designed graphs, and award prizes for those judged the hardest. In this way, the children would be participating in cutting-edge scientific research. The children would be helping scientists come to understand what makes some graph problems *hard*. As Jim has said above, bringing children along on the grand venture into the unknown is Mike's hallmark. Mike and Frances thought the scientific participation aspect of the game would increase its attractiveness to parents, as well as to the children.

Mike is emphatic that people understand that working with children is not just a good deed.

> Mathematical scientists explaining science to kids is not some sort of noble, but career-nonsensical worthy cause, karma points, like volunteering for an NGO, or Scientists Without Borders. In reality, the effort to explain science to kids is a vital source of new mathematical insights for adults [in this volume, see Koblitz' chapter about Kid Crypto yielding advances in the research area of Grobner Bases cryptosystems — Google on "Poly Cracker cryptosystems".] The effort to communicate math to children is a real win-win.

Major fields do not often undergo major paradigm shifts, yet that is what must happen in education in order that classrooms communicate real mathematics. The issue of assessment and student evaluation has been a major impediment. While at VUW, Mike and Frances proposed a game-like assessment environment. Mike is cautiously confident that assessment along the lines of citation analysis engines (such as Harzing's "Publish or Perish") will speed the (inevitable) mathematical sciences education revolution.

Mike has created or supported many venues for children. The *Erdös for Kids* website, with child-sized open problems and prizes, *MEGA-Math!*, *Unplugged*, Family Nights, computer games, plays — all these and more are manifestations of Mike's quest to bring open, unsolved problems in mathematics to the children — a sense of mathematics as a live, dynamic and wondrous enterprise.

Table 3. Overview of key events in the history of the Computer Science Unplugged project

1989	Mike Fellows and Nancy Casey meet in Idaho and develop activities that become *MEGA-Math*
1989	Tim Bell starts developing computer science exhibits for children for science center displays
1991	Mike writes his "manifesto": Computer SCIENCE and Mathematics in the Elementary Schools [4]
1992	Mike and Nancy publish *This is MEGA-Mathematics!*
1992	Tim develops games and magic trick for classroom use
1993	Tim visits Mike in Victoria, BC for one month, and they plan the book that becomes CS Unplugged
1994	Mike speaks at the Games Development Conference
1995	Ian Witten joins the project to create a broader range of activities and help with writing
1997	Development of Mike's "Cowboy Melodramas"
1998	Unplugged book has been rejected by 27 publishers, so is released as "shareware" on the Internet
2000	Revised version for teachers is released
2003	ACM K-12 curriculum released, recommending several Unplugged activities
2005	First Unplugged video is made when Bengt Aspvall visits Tim in NZ
2006	First translated book (Korean) is released
2006	Google supports the Unplugged project so the entire book can be released at no cost
2010	Chinese version (re-written for students) is released

10 Conclusion

Some of the key dates in the history of CS Unplugged and related work are summarized in Table 3. It is permeated with collaborations that appear to be initiated by chance meetings (e.g. Mike and Nancy met through their children being in the same class, Mike and Tim met through an internet discussion, and Mike and Fran met through the "Passion Plays"), although given Mike's passion for this work, it was inevitable that he would attract collaborators who shared the vision and would work hard to see it bear fruit. These collaborations have each resulted in long-term productive relationships that have had a significant impact on computing education all around the world. CS Unplugged and related projects have engaged students, inspired teachers and empowered presenters to communicate the heart of mathematics and computer science without the distraction of computers. They were driven by the authors' passion for communicating what math and computer science is all about to a public who misunderstood both fields, not by preaching to them about what it is, but by having them *do* math and computer science. They have grown thanks to input from open-minded students and educators who have embraced the ideas, and enthusiastic principals and leaders in education who have supported and promoted it.

Right from the start the broad vision for *MEGA-Math*, Unplugged and related projects has come from Mike, initially through his writings and advocacy in the early 1990s, and his continued creativity and demonstration of the ideas in many countries in the two decades since. A common thread that comes out in Mike's creative problem-solving style in everything he's done, from parameterized complexity to working with kids, is that it isn't about trying to prove his own ability, but the way he has cultivated excitement amongst those around him. He had been captivated by ideas, had come up with wonderfully creative ways to communicate them, and passed his passion on to anyone who would listen, whether colleagues, teachers or young children. It seems that the children were the quickest to embrace the ideas! He just didn't pay any attention to boundaries—for example, working with kids it never occurred to him that there should be any barriers to teaching mathematics as something fun and wonderful. Math as stand-up comedy? Why not! Computer science without computers? Of course! This attitude applies to his research—he seems to break new ground because it doesn't occur to him not to go there. He is just as passionate talking about math and computer science to 6-year-old children or experienced professors.

Who knows what the future holds for Unplugged; computer science as a subject is starting to appear in schools around the world, and Unplugged may find its way into school text books. If virtual worlds become popular in teaching, Unplugged already has entered that culture. New activities may well appear, although it seems that there is more interest in adaptation of existing activities, including translations, videos, followup ideas, and providing more detailed background information.

Some time around 2010 someone on a newsgroup commented on how quickly computing books go out of date, asking "What 14 year old computing book would you ever want to use?" It was refreshing to realize at the time that the Unplugged book was written about 14 years earlier, and many of the activities were virtually unchanged from the version created in the early 1990s. Even now there's no urgency to update the ideas as they reflect timeless fundamentals of the subject, and are still enjoyed by young and old in many cultures. A recurring theme of Mike's work is a sense of story and drama, and these won't date; in the last 20 years we have seen software companies come and go, and hardware become obsolete many times over, but children—and adults— remain captivated by the stories that bring math and computer science to life.

In the end, this reminds us that computing is about people and not computers. We give the last word to a computing teacher in Japan, who commented on her experience using Unplugged:

"Now the teacher sees the children's faces instead of the back of the computers" (Yayoi Hofuku, teacher at Shouyou High School, Tokyo, Japan).

Acknowledgements. We are grateful to the following people who have contributed their ideas and checked details for this article: Jim Andrews, Bengt Aspvall, Judith Bell, Lenore Blum, Neal Koblitz, Rita Liff Levinson, Geri Lorway, Sumant Murugesh, Heidi Newton, Lenny Pitt, Matt Powell, Ulrike Stege, Geoff and Lisa Whittle, and Ian Witten.

The Unplugged project has benefited from the work of countless people over the years, many of whom are named in this chapter, but others whose great ideas were picked up in passing and the source has been lost. To all those people who embraced the vision we express our gratitude.

The main advisors for the Unplugged project after it received formal funding in 2006 have been Bengt Aspvall, Lenore Blum, Anna Charny, Sam Chung, Tom Cortina, Robb Cutler, Peter J Denning, Rick Dipaolo, Paul Gibson, Pam Hagen, Mindy Hart, Peter Henderson, Susumu Kanemune, Rachel Kestenbaum, Lynn Lambert, Lee Won Gyu, Geri Lorway, Craig Nevill-Manning, Andy and Todd Seymour, Harold Thimbleby, Alfred Thompson, Allen Tucker, David Vogt, Len Wanger, Xia Xie, and Ben Tsutom Wada. Significant support for Unplugged has been provided by Jeff Walz, the University relations contact at Google.

The *MEGA-Math* and Unplugged books acknowledge many teachers and colleagues who supported these projects over the years, but a key role was played by the authors' children, Andrew, Anna, Elizabeth, Hannah, Max, Michael, Nikki and Patrick who "inspired much of this work, and were often the first children to test an activity." They have been involved for around 20 years, and our children have now grown up, but Unplugged and the associated work will no doubt continue to benefit from real research being done by young children all over the world!

References

1. Garey, M.R., Johnson, D.S.: Computers and intractability: a guide to the theory of NP-completeness. W. H. Freeman, San Francisco (1979)
2. Bell, T., Marghitu, D., Bell, J.: Workshop: CS Unplugged — computational thinking without computers. In: Pirkul, H., Spong, M.W., Shah, R., Suh, S. (eds.) Proceedings of SDPS 2011. Society for Design and Process Science, Jeju Island (2011)
3. Rosamond, F.: On-line and off-line computer games and mathematical sciences popularization. In: Rosamond, F., Copes, L. (eds.) Educational Transformations: The Influences of Stephen I. Brown, pp. 407–426. Authorhouse, Bloomington (2006)
4. Fellows, M.: Computer SCIENCE in the elementary schools. In: Fisher, N., Keynes, H., Wagreich, P. (eds.) Proceedings of the Mathematicians and Education Reform Workshop of Issues in Mathematics Education. Conference Board of the Mathematical Sciences, Seattle, vol. 3, pp. 143–163 (1991)
5. Casey, N.: Megamath: Expanding and connecting the mathematics community. In: INET 1995, Internet Society's 1995 International Networking Conference, Honolulu, Hawaii (1995)

6. Casey, N.: Whole language: lessons for math teachers (1990), http://www.ccs3.lanl.gov/mega-math/papers/firest.ps
7. Casey, N.: Three for the money: an hour in the classroom. In: Rosenstein, J.G., Franzblau, D.S., Roberts, F.S. (eds.) Discrete Mathematics in the Schools. DIMACS: Series in Discrete Mathematics and Theoretical Computer Science, A copublication of the AMS, DIMACS, and National Council of Teachers of Mathematics (1997)
8. Casey, N., Fellows, M.R.: This is Mega-Mathematics! Los Alamos National Labs (1992), http://www.ccs3.lanl.gov/mega-math/write.html
9. Kierstead, H.A., Trotter, W.T.: Planar graph coloring with an uncooperative partner. J. Graph Theory 18, 569–584 (1994)
10. Casey, N., Fellows, M.: Implementing the standards: Let's focus on the first four. In: How Can We Have an Impact? DIMACS Series: Discrete Mathematics in the Schools (1997)
11. Fellows, M.: Research on mega-math: Discrete mathematics and computer science for children, final report (1995), http://www.osti.gov/bridge/purl.cover.jsp?purl=/106599-70WLSu/webviewable/
12. Hodder, P.: Science as theatre: a New Zealand history of performances and exhibitions. Journal of Science Communication 10, 1–10 (2011)
13. Bell, T.C.: Computer science for the uninterested: designing displays for a science centre. Computers in New Zealand Schools 4, 40–46 (1992)
14. Fellows, M.R., Koblitz, N.: Kid Krypto. In: Brickell, E.F. (ed.) CRYPTO 1992. LNCS, vol. 740, pp. 371–389. Springer, Heidelberg (1993)
15. Harel, D.: Algorithmics: The Spirit of Computing, 1st edn. Addison-Wesley, Reading (1987)
16. Vöcking, B., Alt, H., Dietzfelbinger, M., Reischuk, R., Scheideler, C., Vollmer, H., Wagner, D. (eds.): Algorithms Unplugged. Springer (2011)
17. Dewdney, A.K.: The Turing omnibus: 61 excursions in computer science. Computer Science Press, Rockville (1989)
18. Bell, T., Witten, I., Fellows, M.: Computer Science Unplugged: Off-line activities and games for all ages (original book) (1999), http://csunplugged.org
19. Bell, T., Witten, I., Fellows, M., McKenzie, J., Adams, R.: Computer Science Unplugged: An enrichment and extension programme for primary-aged children (2002), http://csunplugged.org
20. Bell, T., Thimbleby, H., Fellows, M., Witten, I., Koblitz, N., Powell, M.: Explaining cryptographic systems to the general public. Computers and Education 40, 199–215 (2003)
21. Bell, T.: A low-cost high-impact computer science show for family audiences. In: Australasian Computer Science Conference 2000 (ACSC 2000), Canberra, Australia, January 31- February 3, pp. 10–16 (2000)
22. Tucker, A., Deek, F., Jones, J., McCowan, D., Stephenson, C., Verno, A.: A Model Curriculum for K-12 Computer Science: Final Report of the ACM K-12 Task Force Curriculum Committee. ACM, New York (2003)
23. Bell, T., Witten, I., Fellows, M., Lee, W., McKenzie, J., Adams, R.: Computer Science Unplugged: Off-line activities and games for all ages. Hongreung Science Publishing, Seoul (2006) (in Korean)
24. Blum, L., Cortina, T.J.: CS4HS: an outreach program for high school CS teachers. In: Russell, I., Haller, S.M., Dougherty, J.D., Rodger, S.H. (eds.) Proceedings of the 38th SIGCSE Technical Symposium on Computer Science Education, SIGCSE 2007, Covington, Kentucky, USA, pp. 19–23. ACM (2007)

25. Blum, L., Cortina, T.J., Lazowska, E.D., Wise, J.: The expansion of CS4HS: an outreach program for high school teachers. In: Dougherty, J.D., Rodger, S.H., Fitzgerald, S., Guzdial, M. (eds.) Proceedings of the 39th SIGCSE Technical Symposium on Computer Science Education, SIGCSE 2008, Portland, OR, USA, pp. 377–378. ACM (2008)
26. Bell, T., Bell, R.: The Treasure Hunt. In: Fitzgerald, S., Guzdial, M., Lewandowski, G., Wolfman, S.A. (eds.) Proceedings of the 40th ACM Technical Symposium on Computer Science Education. ACM, New York (2009)
27. Bell, T., Bell, R.: The Orange Game. In: Fitzgerald, S., Guzdial, M., Lewandowski, G., Wolfman, S.A. (eds.) Proceedings of the 40th ACM Technical Symposium on Computer Science Education, SIGCSE 2009. ACM, New York (2009)
28. Bell, T., Bell, R.: Image Compression - Making Contact. In: Lewandowski, G., Wolfman, S.A., Cortina, T., Walker, E. (eds.) SIGCSE, Milwaukee, WI. ACM (2010)
29. Bell, T., Bell, R.: Sorting Algorithms (Unplugged). In: Lewandowski, G., Wolfman, S.A., Cortina, T., Walker, E. (eds.) SIGCSE, Milwaukee, WI. ACM (2010)
30. Bell, T., Bell, M., Finnerty, K.: Computer Science Buskers (Error Correction). In: Lewandowski, G., Wolfman, S.A., Cortina, T., Walker, E. (eds.) SIGCSE, Milwaukee, WI. ACM (2010)
31. Bell, T., Bell, M., Chicha, V.: Santa's dirty socks (divide and conquer). In: Cortina, T.J., Walker, E.L., King, L.S., Musicant, D.R. (eds.) Proceedings of the 42nd ACM Technical Symposium on Computer Science Education, SIGCSE 2011. ACM, New York (2011)
32. Bell, T., Bell, M.: Reaching out (binary codes). In: Proceedings of the 42nd ACM Technical Symposium on Computer Science Education, SIGCSE 2011. ACM, New York (2011)
33. Sagan, C.: Contact. Simon and Schuster, New York (1985)
34. Yoo, S., Yeum, Y., Kim, Y., Cha, S., Kim, J., Jang, H., Choi, S., Lee, H., Kwon, D., Han, H., Shin, E., Song, J., Park, J., Lee, W.: Development of an Integrated Informatics Curriculum for K-12 in Korea. In: Mittermeir, R.T. (ed.) ISSEP 2006. LNCS, vol. 4226, pp. 199–208. Springer, Heidelberg (2006)
35. Choi, S.K., Bell, T., Jun, S.J., Lee, W.G.: Designing offline computer science activities for the Korean elementary school curriculum. In: ITiCSE 2008: Proceedings of the 13th annual conference on Innovation and Technology in Computer Science Education, p. 338. ACM, New York (2008)
36. Bell, T.C., Witten, I.H., Fellows, M.R.F., Kanemune, S., Kuno, Y.: Computer Science Unplugged: Off-line activities and games for all ages, Etext, Tokyo, Japan (2007) (in Japanese)
37. Fellows, M., Hibner, A., Koblitz, N.: Cultural aspects of mathematics education reform. Notices of the American Mathematics Society 41, 5–9 (1994)
38. Bell, T., Wada, B.T., Kanemune, S., Xie, X., Lee, W., SookKyoung, C., Aspvall, B., Wingkvist, A.: Making computer science activities accessible for the languages and cultures of Japan, Korea, China and Sweden. In: Proceedings of the 39th SIGCSE Technical Symposium on Computer Science Education, SIGCSE 2008, Portland, OR, USA (2008)
39. Bell, T., Arpaci-Dusseau, A., Witten, I., Fellows, M.: Computer Science Unplugged: understanding computing through games and puzzles. HUST Press, Wuhan (2010)

40. Goode, J.: Connecting K-16 curriculum and policy: making computer science engaging, accessible, and hospitable for underrepresented students. In: Lewandowski, G., Wolfman, S.A., Cortina, T.J., Walker, E.L. (eds.) Proceedings of the 41st ACM Technical Symposium on Computer Science Education, SIGCSE 2010, Milwaukee, Wisconsin, USA, March 10-13, pp. 22–26. ACM (2010)
41. Goode, J., Margolis, J.: Exploring computer science: A case study of school reform. Trans. Comput. Educ. 11, 12:1–12:16 (2011)
42. Denning, P.J.: Computing is a natural science. Commun. ACM 50, 13–18 (2007)
43. Wing, J.M.: Computational thinking. Commun. ACM 49, 33–35 (2006)
44. National Research Council: Report of a Workshop on the Scope and Nature of Computational Thinking (2010), `http://www.nap.edu/catalog.php?record_id=12840`
45. Marghitu, D., Fuller, M., Brahim, T.B., Banu, E.: Auburn university robotics and computer literacy K-12 engineering camps: A success story. In: Bernal, B. (ed.) ASEE-SE 2009, GA USA, April 5-7. Southern Polytechnic State University, Marietta (2009)
46. Ward, B., Bell, T., Marghitu, D., Lambert, L.: Teaching computer science concepts in Scratch and Alice. The Journal of Computing Sciences in Colleges 26, 173–180 (2010)
47. Thompson, D., Bell, T.: Virtual worlds: Evaluating CS education activities through automated monitoring. In: Pirkul, H., Spong, M.W., Shah, R., Suh, S. (eds.) Society for Design and Process Science, SDPS 2010, Dallas, Texas, pp. 1–7 (2010)
48. Voigt, J., Bell, T., Aspvall, B.: Competition-style programming problems for computer science unplugged activities. In: Verdu, E., Lorenzo, R., Revilla, M., Regueras, L. (eds.) A New Learning Paradigm: Competition Supported by Technology, CEDETEL, Boecillo, Spain, pp. 207–234 (2009)
49. Magnusson, W.E., Mourão, G.: Statistics without Math. Sinauer Associates (2004)
50. Koblitz, N.: The case against computers in K-13 math education (kindergarten through calculus). The Mathematical Intelligencer 18, 9–16 (1996)
51. Fellows, M., Parberry, I.: SIGACT trying to get children excited about CS. Computing Research News 7 (1993)
52. Nishida, T., Kanemune, S., Idosaka, Y., Namiki, M., Bell, T., Kuno, Y.: A CS Unplugged design pattern. In: Proceedings of the 40th SIGCSE Technical Symposium on Computer Science Education, SIGCSE 2009, Chattanooga, TN, USA, pp. 231–235. ACM, New York (2009)
53. Taub, R., Ben-Ari, M., Armoni, M.: The effect of CS unplugged on middle-school students' views of CS. In: Brézillon, P., Russell, I., Labat, J.M. (eds.) Proceedings of the 14th Annual SIGCSE Conference on Innovation and Technology in Computer Science Education, ITiCSE 2009, Paris, France, July 6-9, pp. 99–103. ACM (2009)
54. Feaster, Y., Segars, L., Wahba, S.K., Hallstrom, J.O.: Teaching CS unplugged in the high school (with limited success). In: Rößling, G., Naps, T.L., Spannagel, C. (eds.) Proceedings of the 16th Annual SIGCSE Conference on Innovation and Technology in Computer Science Education, ITiCSE 2011, Darmstadt, Germany, June 27-29, pp. 248–252. ACM (2011)
55. Carmichael, G.: Girls, computer science, and games. SIGCSE Bull 40, 107–110 (2008)
56. Hart, M., Early, J.P., Brylow, D.: A novel approach to K-12 CS education: linking mathematics and computer science. In: Dougherty, J.D., Rodger, S.H., Fitzgerald, S., Guzdial, M. (eds.) Proceedings of the 39th SIGCSE Technical Symposium on Computer Science Education, SIGCSE 2008, Portland, OR, USA, pp. 286–290. ACM (2008)

57. Lambert, L., Guiffre, H.: Computer science outreach in an elementary school. J. Comput. Small Coll. 24, 118–124 (2009)
58. Groover, T.R.: Using games to introduce middle school girls to computer science. J. Comput. Small Coll. 24, 132–138 (2009)
59. Curzon, P., McOwan, P.W.: Engaging with computer science through magic shows. In: Proceedings of the 13th Annual Conference on Innovation and Technology in Computer Science Education, ITiCSE 2008, pp. 179–183. ACM, New York (2008)
60. Cottam, J.A., Foley, S.S., Menzel, S.: Do roadshows work?: examining the effectiveness of just be. In: Lewandowski, G., Wolfman, S.A., Cortina, T.J., Walker, E.L. (eds.) Proceedings of the 41st ACM Technical Symposium on Computer Science Education, SIGCSE 2010, Milwaukee, Wisconsin, USA, March 10-13, pp. 17–21. ACM (2010)
61. Morreale, P., Joiner, D.: Reaching future computer scientists. Commun. ACM 54, 121–124 (2011)
62. Hart, M.L.: Making contact with the forgotten K-12 influence: are you smarter than your 5th grader? In: Proceedings of the 41st ACM Technical Symposium on Computer Science Education, SIGCSE 2010, pp. 254–258. ACM, New York (2010)
63. Carruthers, S.: Grasping graphs. Master of Science thesis, University of Victoria, Victoria, BC (2010), http://hdl.handle.net/1828/3193
64. Carruthers, S., Milford, T., Pelton, T., Stege, U.: Draw a social network. In: Proceedings of the 16th Annual Joint Conference on Innovation and Technology in Computer Science Education, ITiCSE 2011, pp. 178–182. ACM, New York (2011)
65. Bell, T., Curzon, P., Cutts, Q., Dagiene, V., Haberman, B.: Overcoming Obstacles to CS Education by Using Non-programming Outreach Programmes. In: Kalaš, I., Mittermeir, R.T. (eds.) ISSEP 2011. LNCS, vol. 7013, pp. 71–81. Springer, Heidelberg (2011)
66. Fellows, M.: The heart of puzzling: Mathematics and computer games. In: Proceedings of the 1996 Computer Games Developers Conference, pp. 109–120. Miller Freeman (1996)