

Mathematics Education Is at a Major Turning Point

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Quotes from Two Futurists

- "If you want to teach people a new way of thinking, don't bother trying to teach them. Instead give them a tool, the use of which will lead to new ways of thinking." (Richard Buckminster Fuller)
- "Don't worry about what anybody else is going to do.... The best way to predict the future is to invent it." (Alan Kay)

Math Problem Solving

- “Mathematics consists of content and know-how. What is know-how in mathematics? The ability to solve problems.” (George Polya)
- What if your student says: “I know how to calculate square root. I press my calculator’s square root key.”

Two Fundamental Questions

- If a computer can solve or greatly help in solving a category of math problems for which we have traditionally taught “by hand” methods of solution, what should students be learning about solving such problems?
- If a computerized teaching machine is more successful in a broad range of math teaching/learning situations (compared to a classroom teacher working with 30 students) should we use such teaching machines in these situations?

My Thoughts

- How we answer these two questions will play a major role in determining the future of math education
- I say, “Bring on the computers.”
- There are other things we need to do. In this presentation I use helping students gain in math maturity as an example.

Math Maturity

- I think of math education in terms of students learning **math content** and gaining in **math maturity**.
- **Math maturity** can describe a person's general math-oriented insights, approaches to problem solving, ways of thinking, habits of mind, and ability to transfer math learning to new problem-solving situations.

Indicators of an Increasing Level of Math Maturity

1. Understand the discipline of math as a very important (and enjoyable to many) human endeavor.
2. Learn to make the significant shift from learning math by memorization to learning math through understanding.

Math Maturity (Continued)

3. Recognize a valid mathematical/logical proof or argument, and detect "sloppy" thinking. Provide solid evidence (informal and formal arguments and proofs) of the correctness of one's math problem-solving efforts.
4. Apply (3) in other disciplines.

Math Maturity (Continued)

5. Pose and/or recognize math problem situations and patterns.
6. Transfer one's math knowledge and skills into math-related areas and problems in other disciplines.
7. Understand the capabilities and limitations of tools (including calculators, computers, the Internet, and the Web) to help represent and solve math problems.

Using Two Brains (Human and Computer) to Do Math

- **Human brain** improved through better informal and formal education.
- **Artificially intelligent computer brain** improved through research and development.

The Medium Is the Message

- “The medium is the message.” (Herbert Marshall McLuhan)
- A medium is a change and growth agent.
 - Broadcast media greatly changed our world.
 - Information and Communication Technology has already greatly changed our world, and we are just getting started in this endeavor.

A Takeoff from McLuhan: “The Tool Is the Teacher”

- Instruction on how to use a computerized tool can be built into the tool.
- A general-purpose computerized teaching machine is both a tool and a teacher.

Example: North American Aerospace Defense Command

- NORAD was a computerized early warning system begun in late 1950s.
- It was both a tool and a teacher of those learning to use the tool.
- It is an excellent example of computer simulations used for education.
- Now such simulations are commonplace.

Ender's Game by Orson Scott Card

- 1985 science fiction novel.
- A young boy named Ender was educated to be very good at playing a computerized war game.
- Near the end of the story, we learn that the game is also a tool for fighting a real war. The tool was the teacher.

Buckminster Fuller Quote (Repeated)

- "If you want to teach people a new way of thinking, don't bother trying to teach them. Instead give them a tool, the use of which will lead to new ways of thinking." (Fuller)
- What is new is that we can build intelligence into tools. The “intelligent” tool facilitates and teaches new ways of thinking.

Moursund's Revision of Fuller's Quote

- "If you want to teach people a new way of thinking and problem solving, give them a computerized tool that has the **intelligence** to teach them how to use the tool while they are using the tool." (Moursund)

Current and Future Intelligent Teaching Software

- Highly Interactive Intelligent Computer-assisted Learning (HIICAL) systems.
- Cognitive Tutor (CT) systems.
- Continued research and development is steadily improving HIICAL and CT.
- Sophisticated computer tools (Big Data tools) are a major aid to this research.

Building on the Work of Others

- “God created the natural numbers. All the rest [of mathematics] is the work of man.” (Leopold Kronecker)
- “If I have seen further it is by standing on the shoulders of giants.” (Isaac Newton)

Three Types of Problem-solving Building Blocks

- Mental: Details stored in one's head.
- Printed: Details stored in physical books and journals.
- Computerize: Details stored in a computer that can be used both for retrieval of details and can also carry out the details. Examples: Computer Algebra Systems; Statistics Packages; and Computer Graphic/Animation Systems.

Computer Programs Are Problem-solving Building Blocks

- Each type of math problem that a student learns to solve can be thought of as a building block. Many of these building blocks are poorly learned and students do not gain long-lasting skill and accuracy in using them.
- Computer programs can be thought of as building blocks that embody some of the intelligence, knowledge, and skills of their programmers.

Story of Eric Chen, a High School Student

- Eric Chen was a 17-year-old high school senior from San Diego, California, when he won Grand Prize in the 2013 Google Science Fair. Quoting Chen:
- “I live in San Diego, where some of the first cases of 2009 H1N1 swine flu took place in the U.S. It was then that I made a realization that flue can kill a lot of people. I thought, ‘Why can’t we use the new computer power at our fingertips to speed up drug discovery and find new flu medicine?’ I came across Dr. Rommie Amaro of the University of California, San Diego, and she was willing to let me work in her computation lab.”

Chen (Continued)

- Chen describes using the computer to screen a half-million chemical compounds, separating out 237 likely candidates, and testing each of them in a “wet” lab. He identified six worthy of animal studies.
- With his good brain, some tutoring from a professor, and the help of computer technology, this high school student was able to do cutting edge research in medicine. What a marvelous learning experience!

Some Capabilities of Future Teaching Machines

1. Future multifunctional teaching machines will handle voice input and output, provide real-time translation of oral and written communications, and be quite portable.
 - When helpful to students, the teaching machine will incorporate wearable technology, and it will include a future version of Google Glass and other data gathering/sensing devices.
 - A teaching machine's responses to its user will be contextual, taking into consideration the user's previous education, knowledge, skills, educational and other goals, current location, time of day, and so on.

Future Teaching Machines (Cont.)

2. The Web was invented in 1989 and is now by far the world's largest library.
 - The *Wikipedia* illustrates how to develop multilingual and multicultural sources of information.
 - Steadily improving connectivity will let every student access a multilingual multicultural comprehensive library that is an integral component of their teaching machine.

Future Teaching Machines (Cont.)

3. The first Massive Open Online Courses ([MOOCs](#)) were developed in 2011.

- By making use of data about the performance of all students enrolled in such a course, educational researchers and course developers are rapidly improving MOOCs.
- Gradually such courses will gain the combined characteristics of today's HICAL systems and Cognitive Tutors, and in many ways will be more successful than the average classroom teacher.
- Computer-delivered and increasingly individualized units of instruction and full courses will be a routine component of teaching and learning both inside and outside of schools throughout the world.

Future Teaching Machines (Cont.)

4. Currently, the frontiers of computer use in the various disciplines focus on a human accurately specifying a problem to be solved or a task to be accomplished.

- Machine learning systems are being developed that deal with imprecise data and problems that are not carefully specified.
- Research and development in IBM's Watson Project, as well as by many other research groups, provide examples of what is being done.
- In complex areas such as medicine, the current goals are to develop computer systems and to educate human users so that they jointly work together, with decisions being made using the combined strengths of computer and human brains.

Future Teaching Machines (Cont.)

5. Use of teaching machines will make education much more individualized and “hands on.” However, individualized does not mean learning in isolation.
 - Students will routinely work in small and large groups, often with a human teacher as facilitator, to solve problems and accomplish tasks that challenge and help advance their current capabilities and interests.
 - We see this grouping process now in social networking, online games, and MOOCs.
 - As in current social networking, academically-oriented groups will routinely represent and incorporate diversity in its many forms.

Final Remarks and Issues

1. Throughout most of human history, education has predominantly been a human endeavor. Teaching machines will change the roles of human teachers in the current “large classroom group” delivery of instruction.
2. I have not attempted to deal with the challenges of restructuring preservice and inservice staff development as we work to implement routine use of teaching machines. Clearly, the roles of teachers will change significantly over time.

Final Remarks (Continued)

3. I have not touched on summative assessment. What will summative assessment of a student look like when the student is educated in a teaching machine environment and is highly dependent on a partnership with the teaching machine?
4. All of us, our educational systems, and our legal system face the major challenge of how far we should trust and act on the judgment and actions (or, proposed actions) of intelligent computer systems. In my opinion, this issue needs to be integrated into the school curriculum.

I foresee a fun and challenging future for math education!

Go to <http://iae-pedia.org/>
for an extensive list of references and
and suggested readings.