Contexts in Computer Science Education

Mark Guzdial
Professor
Georgia Institute of Technology (Georgia Tech)
Beyond teaching computing to more, teaching computing to everyone.

Computing for All at Georgia Tech

- 1999-2003: One course for all
- 2003-2008: Contextualized Computing Education
  - Margolis and Fisher’s “Alternative Paths”

Evaluation Results: Different contexts, at different schools

- Media Computation, Engineering, Robotics, Games
- Beyond CS1: Media Computation CS2, Gameboy for Computing Organization
## 1

**Scientists and Decision Making**

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Sir Charles Percy Snow</th>
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<tbody>
<tr>
<td>Author</td>
<td>London, England</td>
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<thead>
<tr>
<th>Discussants</th>
<th>Elting E. Morison</th>
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<tr>
<td>Professor of Industrial History</td>
<td>Massachusetts Institute of Technology</td>
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<table>
<thead>
<tr>
<th>Norbert Wiener</th>
<th>Institute Professor, Emeritus</th>
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<tr>
<td>Massachusetts Institute of Technology</td>
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<tr>
<th>Moderator</th>
<th>Howard W. Johnson</th>
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<tr>
<td>Dean and Professor of Industrial Management</td>
<td>Massachusetts Institute of Technology</td>
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## 5

**The Computer in the University**

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Alan J. Perlis</th>
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<tbody>
<tr>
<td>Director of the Computation Center</td>
<td>Carnegie Institute of Technology</td>
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<tr>
<th>Discussants</th>
<th>Peter Elias</th>
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<tr>
<td>Head, Department of Electrical Engineering</td>
<td>Professor of Electrical Engineering</td>
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<tr>
<td>Massachusetts Institute of Technology</td>
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<tr>
<th>J. C. R. Licklider</th>
<th>Vice President</th>
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<td>Bolt Beranek &amp; Newman Inc.</td>
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<tr>
<th>Moderator</th>
<th>Donald G. Marquis</th>
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<tr>
<td>Professor of Industrial Management</td>
<td>Massachusetts Institute of Technology</td>
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Alan Perlis argued that computer science should be part of a liberal education.

- Explicitly, he argued that all students should learn to program.

Why?
- Because Computer Science is the study of process.
- Automated execution of process changes everything
  - Including how we think about things
The Economist (Sept., 2007) spoke to the algorithms that control us, yet we don’t understand.

Credit Ratings, Adjustable Rate Mortgages, Search Rankings
Alan Kay (2004 ACM Turing Awardee) sees the Computer as humanity’s first *metamedium*

- A medium that can represent all other media.
- Programming as an important new medium

The computer-as-Dynabook is for creative metamedia exploration and reading
Fall 1999: Georgia Tech

Fall 1999:
All students at Georgia Tech must take a course in computer science.
- Considered part of General Education, like mathematics, social science, humanities…

Why did Georgia Tech make that decision?
- Computing was a College.
- Solved a problem for Engineering
- Making a competitive distinction for Liberal Arts
Computing is already cross-campus
- Bio2010 (NRC) calls for programming for mathematical and computational models.
- Physics teaches VPython for labs where they solve three-body problems.

Computer science provides the tools and metaphors for understanding our world
- Jeanette Wing’s “Computational Thinking”

Scientists and engineers use computing to model, simulate, and understand
- Why shouldn’t students?
SS: You close your book saying, "I am thrilled to be alive at a time when humanity is pushing against the limits of understanding." How do you think that's happening in your field of evolutionary biology?

DAWKINS: Well, it's the most exciting time to be a biologist... Since Watson and Crick in 1953, biology has become a sort of branch of computer science. I mean, genes are just long computer tapes, and they use a code which is just another kind of computer code. It's quaternary rather than binary, but it's read in a sequential way just like a computer tape. It's transcribed. It's copied and pasted. All the familiar metaphors from computer science fit.
Key Point: Only one course met the requirement: CS1321 *Introduction to Computing*

- Shackelford’s pseudocode approach in 1999
- Later Scheme: *How to Design Programs* (MIT Press)

Why only one?

- It’s all the same computer science.
- Resource issues
- “Service Ghetto”
- Sealed the deal: The offer to help them do their own
<table>
<thead>
<tr>
<th>Subject</th>
<th>Success Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>46.7%</td>
</tr>
<tr>
<td>Biology</td>
<td>64.4%</td>
</tr>
<tr>
<td>Economics</td>
<td>53.5%</td>
</tr>
<tr>
<td>History</td>
<td>46.5%</td>
</tr>
<tr>
<td>Management</td>
<td>48.5%</td>
</tr>
<tr>
<td>Public Policy</td>
<td>47.9%</td>
</tr>
</tbody>
</table>
What’s going on?

- Research results: Computing is “tedious, boring, irrelevant”

Since Spring 2003, Georgia Tech teaches three introductory CS courses.
- Based on Margolis and Fisher’s “alternative paths”

Each course introduces computing using a context (examples, homework assignments, lecture discussion) relevant to majors.
- Make computing relevant by teaching it in terms of what computers are good for (from the students’ perspective).
Contexts, Results, and Themes

Media Computation
Computing for Engineers (MATLAB)
Robotics for CS1
  - Institute for Personal Robotics in Education

Gaming
Beyond CS1
  - Impact on CS2
  - Gameboy programming for Computer Organization
Presenting CS topics with media projects and examples:

- Iteration as creating negative and grayscale images
- Indexing in a range as removing redeye
- Algorithms for blending both images and sounds
- Linked lists as song fragments woven to make music
- Information encodings as sound visualizations
def clearRed(picture):
    for pixel in getPixels(picture):
        setRed(pixel, 0)

def greyscale(picture):
    for p in getPixels(picture):
        redness=getRed(p)
        greenness=getGreen(p)
        blueness=getBlue(p)
        luminance=(redness+blueness+greenness)/3
        setColor(p, makeColor(luminance, luminance, luminance))

def negative(picture):
    for px in getPixels(picture):
        red=getRed(px)
        green=getGreen(px)
        blue=getBlue(px)
        negColor=makeColor(255-red, 255-green, 255-blue)
        setColor(px, negColor)
open-ended, contextualized homework

Sound collage

Music
Change in Success rates in CS1 “Media Computation” from Spring 2003 to Fall 2005

<table>
<thead>
<tr>
<th>Subject</th>
<th>Spring 2003</th>
<th>Fall 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>46.7%</td>
<td>85.7%</td>
</tr>
<tr>
<td>Biology</td>
<td>64.4%</td>
<td>90.4%</td>
</tr>
<tr>
<td>Economics</td>
<td>54.5%</td>
<td>92.0%</td>
</tr>
<tr>
<td>History</td>
<td>46.5%</td>
<td>67.6%</td>
</tr>
<tr>
<td>Management</td>
<td>48.5%</td>
<td>87.8%</td>
</tr>
<tr>
<td>Public Policy</td>
<td>47.9%</td>
<td>85.4%</td>
</tr>
</tbody>
</table>
Int'l Affairs student (female): “I just wish I had more time to play around with the IDE and make neat effects. But JES [IDE for class] will be on my computer forever, so… that’s the nice thing about this class is that you could go as deep into the homework as you wanted. So, I’d turn it in and then me and my roommate would do more after to see what we could do with it.”

Results from a survey a year later.

- 19% of respondents have programmed since class ended
- “Did the class change how you interact with computers?”
- 80% say “Yes”
- “Definitely makes me think of what is going on behind the scenes of some programs like Photoshop and Illustrator.”
Results at Gainesville College

<table>
<thead>
<tr>
<th>ともにメディアコンピュータ科学</th>
<th>ゲオリアテク</th>
<th>ゲインズビル</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>気</td>
<td>職業</td>
</tr>
<tr>
<td>はっきりと同意</td>
<td>12.5%</td>
<td>6.8%</td>
</tr>
<tr>
<td>共感</td>
<td>47.3%</td>
<td>38.7%</td>
</tr>
<tr>
<td>中立</td>
<td>23.9%</td>
<td>31.5%</td>
</tr>
<tr>
<td>反対</td>
<td>13.1%</td>
<td>16.2%</td>
</tr>
<tr>
<td>はっきりと反対</td>
<td>3.2%</td>
<td>6.8%</td>
</tr>
</tbody>
</table>

（Tew, Fowler, Guzdial, SIGCSE 2005）
## Results at U. Illinois-Chicago

<table>
<thead>
<tr>
<th>Year</th>
<th>Enrollment</th>
<th>Success Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>61</td>
<td>74.8%</td>
</tr>
<tr>
<td>Spring 2003</td>
<td>38</td>
<td>76.7%</td>
</tr>
<tr>
<td>2003</td>
<td>51</td>
<td>68.6%</td>
</tr>
<tr>
<td>Spring 2004</td>
<td>22</td>
<td>82.9%</td>
</tr>
<tr>
<td>2004</td>
<td>15</td>
<td>93.3%</td>
</tr>
<tr>
<td>Average “Old”</td>
<td>37</td>
<td>75.9%</td>
</tr>
<tr>
<td>New Spring 2005</td>
<td>18</td>
<td>94.4%</td>
</tr>
<tr>
<td>New Fall 2005</td>
<td>29</td>
<td>90.0%</td>
</tr>
<tr>
<td>New Fall 2006</td>
<td>42</td>
<td>76.2%</td>
</tr>
<tr>
<td>New Spring 2007</td>
<td>24</td>
<td>83.3%</td>
</tr>
<tr>
<td>Average “New”</td>
<td>28.3</td>
<td>84.1%</td>
</tr>
</tbody>
</table>

Table 3: Ethnicity of Survey Participants in CS Computation. Data is from 2003 at Gainesville, Georgia Tech, and from Spring 2005 at our school.

<table>
<thead>
<tr>
<th>Ethnicity</th>
<th>Georgia Tech</th>
<th>Gainesville</th>
<th>Our school</th>
</tr>
</thead>
<tbody>
<tr>
<td>African-Am.</td>
<td>6.4%</td>
<td>0</td>
<td>11.1%</td>
</tr>
<tr>
<td>Asian</td>
<td>0</td>
<td>7.0%</td>
<td>27.8%</td>
</tr>
<tr>
<td>Caucasian</td>
<td>80.8%</td>
<td>96.2%</td>
<td>44.4%</td>
</tr>
<tr>
<td>Hispanic</td>
<td>0.3%</td>
<td>0</td>
<td>16.7%</td>
</tr>
<tr>
<td>Other</td>
<td>5.4%</td>
<td>3.8%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Note: Success rate with CS 0.5 before and with approach. Averages weighted by enrollment.
Developed in collaboration with Civil, Mechanical, and Aerospace Engineering.
Uses Engineering problems and MATLAB
Covers traditional CS1 topics

These are the first students to program outside of class.
results: CS1 for Engineering
Trip: How about CS?
Microsoft Research has funded the Institute for Personal Robotics in Education

- Tucker Balch, Deepak Kumar, Doug Blank
- Joint between Bryn Mawr and Georgia Tech
- [http://www.roboteducation.org](http://www.roboteducation.org)

The goal is to develop a CS1 with robotics as the context.

- Includes a camera and media computation functions
Wonderful project by Jay Sumet: Creative and Collaborative – and Distributed/Parallel!

- Robots are characters.
- Multiple characters mean multiple students with multiple robots.
- One robot is camera
  - How do you zoom?
    - Aim and go forward!
- Challenges:
  - How do you know when your actors are in their places?
  - How do you “cue” the others?
- Post-processing media computation for eerie disappearing effects.
Two main trials so-far:

- Spring 2007:
  Attitudes in robot (GT and Bryn Mawr) and in non-robot (GT)
  - Interviews to establish themes
  - Surveys to test themes across whole class

- Fall 2007: More careful testing of learning, same groupings
  - Average success rate: 90.87%
All students enjoyed the robot, were comfortable with it, and found it easy to get working.

Personalizing the robot improved the course, in students’ opinion.

Reported that the class was about *computer science*

Found homework challenging
BMC students did more on homework “because it was cool.”

BMC students were undeclared majors.

Reported being more excited about CS afterward.

GT students were already declared majors.

Less excited about robots overall, but more interested than BMC in more courses in computer science.
Robots vs. Non-Robots

- Equality:Robots = 0.8, Non-Robots = 0.93
- Reading1:Robots = 0.72, Non-Robots = 0.9
- Reading3:Robots = 0.66, Non-Robots = 0.46
- Tracing:Robots = 0.51, Non-Robots = 0.44
- Recursion:Robots = 0.64, Non-Robots = 0.44
Statistically Significant $p \leq 0.015$

Exam Question vs. Percent "Perfect" Answers

- **Equality**
  - Robots: 0.8
  - Non-Robots: 0.93

- **Reading1**
  - Robots: 0.72
  - Non-Robots: 0.9

- **Reading3**
  - Robots: 0.66
  - Non-Robots: 0.46

- **Recursion**
  - Robots: 0.64
  - Non-Robots: 0.44

Ignore the Tracing Question
Due to the laptop requirement, advisors steered students who were declared CS majors into the robots class, and other students into the non-robots class.

8% CS/Computation Majors in the Non-Robots class
81% CS/Computation majors in Instructor B's Robots class.
Y's vs. F's, statistically significant
Computer gaming courses in College of Computing are predominantly male.

- Advanced course on game implementation.
- BS in Computational Media degree: 27% female
- ½ the students want to build video games
- All the women are in the other half

Report from Bryn Mawr (Dianna Xu, Doug Blank, Deepak Kumar)

- Introducing gaming into the curriculum has a real danger of discouraging female enrollment
- Significant student frustration over tools and textbook
- Can’t succeed at making the context work without support
What about beyond CS1?

If students get context in CS1, how do they do in a context-free CS2?

Are students as well-prepared in CS2 after a contextualization of CS1?

Is context useful in CS2 and beyond?
The Impact of Contextualized CS1 on CS2

Bryn Mawr College Data for 12 years of CS2

CS2 Data Structures Enrollment
Including last two years (since robots)

CS2 Data Structures Enrollment
Trial at Columbus State University

Fall 2007, 3 sections of CS1 for Majors:
Media Computation Java vs. traditional

From Wayne Summers (Dept Chair):

- We also taught two other CS1 sections without the Media Computation focus (using the Lewis/Loftus book) and are assessing the difference. The Media Computation class had significantly higher completion and pass rate and appears to have a higher student satisfaction rate. We will be able to better compare the two methods after this semester.

Students from both groups are taking the same CS2 class.

Spring 2008: Same CS2 for all 3 sections.

Results:
- No difference on retention rates, midterm exam grades, final exam grades.
Did the Wildebeests charge over the ridge in Disney's "The Lion King"?
Research Question: Is context still useful in a second course?

11% agreed with “Working with media is a waste of time that could be used to learn the material in greater depth.”

“I didn’t take this class to learn how to make pretty pictures.”

A majority of the class (70%) agreed or strongly agreed that working with media makes the class more interesting.

77% of the students agreed or strongly agreed that they were really excited by at least one class project.

66% reported doing extra work on projects to make the outcome look “cool.”

(Yarosh and Guzdial, JERIC, Jan 2008)
Context: Programming a Gameboy

Traditional Computer Organization (Patt and Patel) using an imaginary processor, vs. Computer Organization using a Gameboy

- Not all the same topics (e.g., Gameboy graphics modes)
- Common focus on C programming, bit manipulations, model of the computer (including memory and I/O)

Post-class survey comparison: No significant difference.

- 100% of students in Gameboy class did extra on at least one homework, because it was fun.
- 30% of traditional students *never* put any extra effort in \((p=0.046)\).
Summary:
What do we know about contexts for CS Ed?

Including context has led to evaluation reports of:

- Increased retention (in CS1, across multiple schools, with both majors and non-CS majors, across genders and ethnicities),
- Some evidence of retention into CS2, and
- Student reports of increased time-on-task, even beyond CS1.

Not all contexts work for all students.
- Some students do *just fine* with computing Fibonacci numbers.
What don't we know about context?

What is a context?
What do students perceive as a relevant context?
When do contexts work? For how long? For whom?
Do contexts help with learning?

What are the contexts that help with middle school girls and under-represented minorities?
When the context is fixed (e.g., professional graphics designers), how do you teach within that context?
Computing is important for everyone, we should aim to be able to teach computing to everyone.

Contextualized Computing Education has great promise for achieving the goal of teaching everyone about computing.

The tale isn’t done yet.
With thanks to our funding supporters

National Science Foundation
- Statewide BPC Alliance: Project “Georgia Computes!” [http://www.gacomputes.org]
- CCLI Grant

Microsoft Research

Georgia Tech's College of Computing

Georgia’s Department of Education

GVU Center,

Al West Fund,

President's Undergraduate Research Award,

Toyota Foundation
more on MediaComp approach
including papers, software, and
ides and workshops):

://coweb.cc.gatech.edu/mediaComp-plan

edia Computation Teachers’ Site:
://coweb.cc.gatech.edu/mediaComp-teach