Laptop Computers *in an Integrated First-Year Curriculum*

At Rose-Hulman Institute of Technology, a curriculum that blends science, engineering, and mathematics builds on computing power through student-owned laptops.

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A curriculum that integrates calculus, computer science, physics, engineering design, chemistry, engineering statics, and engineering graphics into a year-long sequence of three 12-credit courses was introduced at Rose-Hulman Institute of Technology during the 1990–1991 school term. The Integrated First-Year Curriculum in Science, Engineering, and Mathematics (IFYCSEM), taught by an interdisciplinary team of eight faculty members [2–4], was designed from the outset with extensive availability and use of computers as a cornerstone [3].

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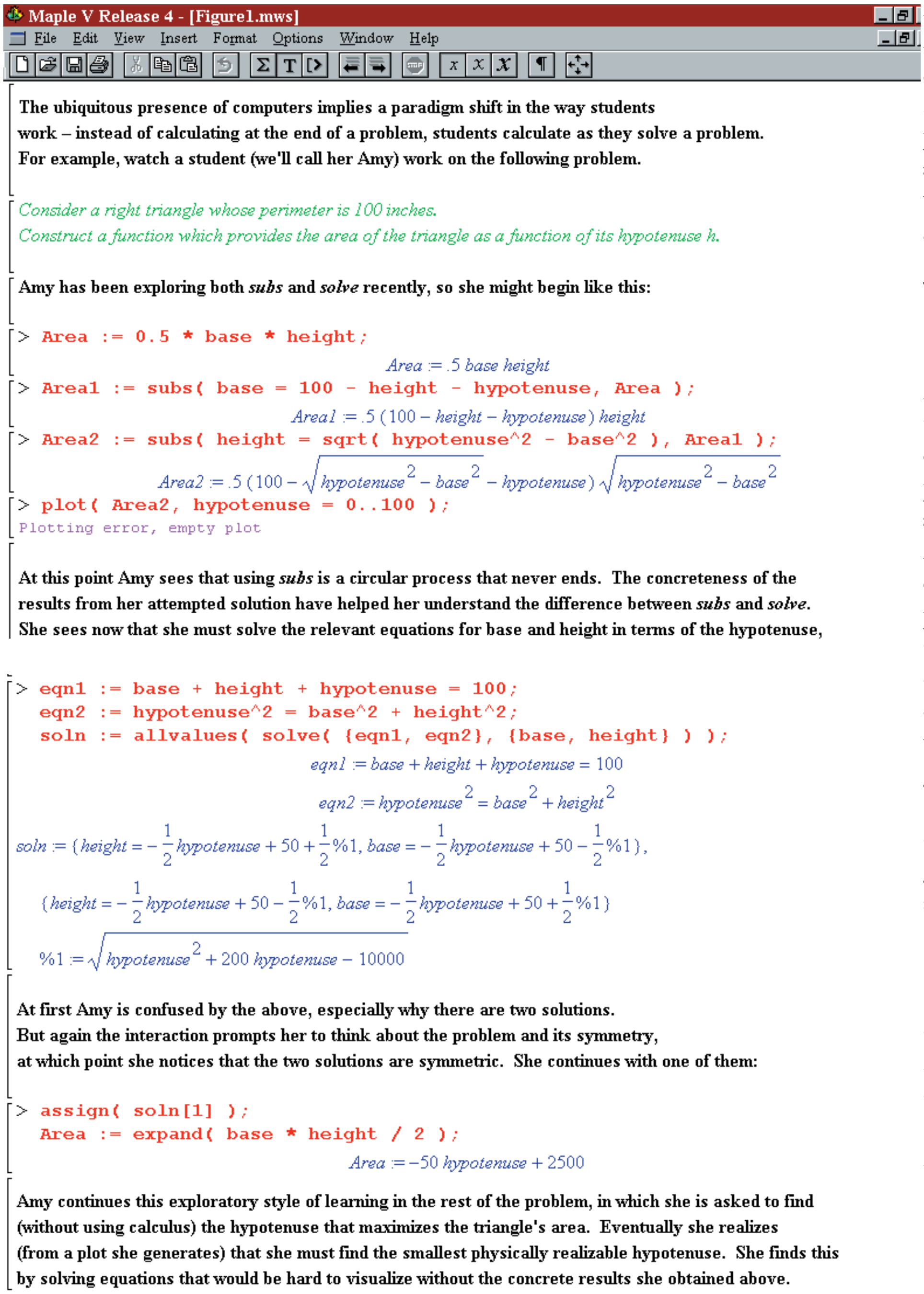
During the period of 1990–95, students in IFYCSEM shared the Institute's primary academic computing resource: six networked classrooms, each equipped with 30 NeXT workstations, together with about 15 NeXT workstations in a computer lab. Since all calculus and differential equations courses at Rose-Hulman were taught in those classrooms, over 700 students were competing for computer time.

Since 1995–96, all entering students have pur-


Maple V Release 4 - [Figure1.mws]

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The ubiquitous presence of computers implies a paradigm shift in the way students work – instead of calculating at the end of a problem, students calculate as they solve a problem. For example, watch a student (we'll call her Amy) work on the following problem.

Consider a right triangle whose perimeter is 100 inches.
Construct a function which provides the area of the triangle as a function of its hypotenuse h.

Amy has been exploring both *subs* and *solve* recently, so she might begin like this:

```
> Area := 0.5 * base * height;
```

$$Area := .5\ base\ height$$

```
> Area1 := subs( base = 100 - height - hypotenuse, Area );
```

$$Area1 := .5\,(100 - height - hypotenuse)\ height$$

```
> Area2 := subs( height = sqrt( hypotenuse^2 - base^2 ), Area1 );
```

$$Area2 := .5\,(100 - \sqrt{hypotenuse^2 - base^2} - hypotenuse)\sqrt{hypotenuse^2 - base^2}$$

```
> plot( Area2, hypotenuse = 0..100 );
Plotting error, empty plot
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At this point Amy sees that using *subs* is a circular process that never ends. The concreteness of the results from her attempted solution have helped her understand the difference between *subs* and *solve*. She sees now that she must solve the relevant equations for base and height in terms of the hypotenuse,

```
> eqn1 := base + height + hypotenuse = 100;
  eqn2 := hypotenuse^2 = base^2 + height^2;
  soln := allvalues( solve( {eqn1, eqn2}, {base, height} ) );
```

$$eqn1 := base + height + hypotenuse = 100$$

$$eqn2 := hypotenuse^2 = base^2 + height^2$$

$$soln := \{height = -\frac{1}{2}hypotenuse + 50 + \frac{1}{2}\%1,\ base = -\frac{1}{2}hypotenuse + 50 - \frac{1}{2}\%1\},$$

$$\{height = -\frac{1}{2}hypotenuse + 50 - \frac{1}{2}\%1,\ base = -\frac{1}{2}hypotenuse + 50 + \frac{1}{2}\%1\}$$

$$\%1 := \sqrt{hypotenuse^2 + 200\ hypotenuse - 10000}$$

At first Amy is confused by the above, especially why there are two solutions. But again the interaction prompts her to think about the problem and its symmetry, at which point she notices that the two solutions are symmetric. She continues with one of them:

```
> assign( soln[1] );
  Area := expand( base * height / 2 );
```

$$Area := -50\ hypotenuse + 2500$$

Amy continues this exploratory style of learning in the rest of the problem, in which she is asked to find (without using calculus) the hypotenuse that maximizes the triangle's area. Eventually she realizes (from a plot she generates) that she must find the smallest physically realizable hypotenuse. She finds this by solving equations that would be hard to visualize without the concrete results she obtained above.

Figure 1. An exploratory style of learning. Black text is our commentary. Green text is the problem statement. Red text is the student's work, with Maple's responses in blue.

chased laptop computers equipped with a software suite including a word processor, spreadsheet, computer algebra system, programming language, and several additional tools. The ubiquitous presence of computers, in the classroom and in the dormitory, has changed the way computers are viewed and used. Instead of making occasional excursions into a laboratory with computers, students are in the computer laboratory *all the time.* In IFYCSEM, computers strengthen existing connections between disciplines, forge new links, and change the way in which students learn to solve problems.

Why Computer Use is Different in IFYCSEM

In a mathematics course, the computer tool of choice is generally a computer algebra system such as Maple or Mathematica. In a computer science class, students learn to program in Pascal or C++. Laboratory courses often require that students become familiar with a spreadsheet program. AutoCad or Cad-Key might be the tool of choice for engineering graphics. Just as the artificial boundaries between disciplines are broken down, distinctions between the different tools are blurred in IFYCSEM. A student is encouraged to use the computer as a Swiss army knife in which each tool is a blade.

This is practical because the interdisciplinary team can determine that while Excel, for example, may not be of sufficient value for mathematics, physics, or chemistry alone, its value across the curriculum justifies its use. In an integrated curriculum, no single discipline bears the burden of introducing the tools. Further, each instructor on the team knows (and influences) what tools are introduced when and, hence, can plan accordingly. In addition, the standardization of hardware helps promote this integrated view of the computer (see article by Brown et al. in this issue).

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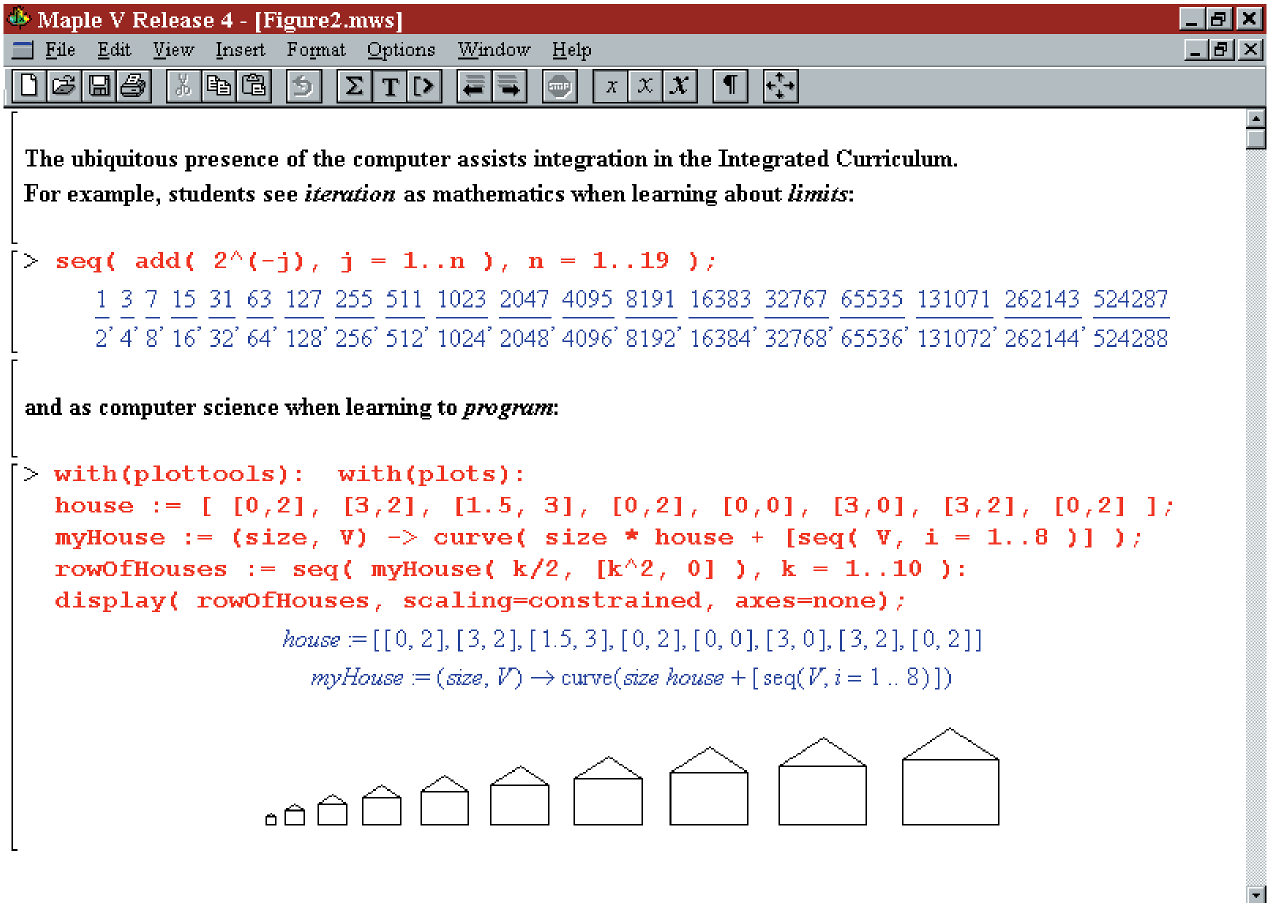

Figure 2. The extensive use of computers facilitates integration across disciplines. The black text is our commentary, while red text is the student's work, with Maple's responses in blue.

calculating at the end of a problem, students calculate as they solve a problem. For example, students see this problem early in the fall term: *Consider a right triangle whose perimeter is 100 inches. Construct a function which provides the area of the triangle as a function of its hypotenuse* h. Initially, students believe they have insufficient information to solve the problem. As they work, however, students formulate and evaluate intermediate expressions, which then guide their problem-solving process (see Figure 1). When these intermediate expressions yield nonsense, students are prompted to rethink the problem.

The extensive use of the computer also facilitates integration of separate disciplines. For example, when Maple [1] is used as a tool for mathematics, concepts from computer science arise quickly and naturally:

- It is convenient to give names to Maple expressions (as in *Expression1* $:= x + 3*y$), so that the expressions can be reused easily. This is the computer science concept of a variable and can be explained nicely against the (different) concept of an indeterminate (as in the traditional x and y of mathematics).
- It is easy in Maple to calculate π to N decimal places for any given value of N. Students discover that the calculation is almost instantaneous for $N \leq 10{,}000$, but is considerably longer for larger values of N. This naturally leads to a discussion of run-time analysis and alternative implementations. (Our version of Maple calculates π by a lookup table for $N \leq 10{,}000$ and uses Chudnovsky's formula thereafter.[1])

Indeed, sometimes the material is integrated so smoothly that students don't notice the integration. For example, somewhere in the introduction of Maple for the purpose of doing mathematics, computer programming concepts appear: lists and iteration. These concepts sometimes look like mathematics and sometimes looks more like com-

[1] Bruce Char, personal communication.

puter science, as shown in Figure 2.

The extended examples that follow illustrate the impact of the laptop computer in several aspects of IFYCSEM.

Mathematics/Physics Laboratory: Programming in Maple

In parallel with the mathematics and computer science instruction, traditional physics topics are introduced, such as the motion of a particle in the presence of gravity.

Later in the first term, this physics concept, already closely linked to mathematics, is integrated with computer science in the form of a programming laboratory[2] in which the motion of a particle is simulated, incorporating air resistance. Students know the physics of falling bodies without air resistance and can describe this motion mathematically. They incorporate air resistance by assuming constant acceleration over a very short time interval and using the mathematics they already know. Then they write a program, applying ideas like functions, parameters, loops, assignment, and local variables, to simulate projectile motion, using the equations they developed. Thus the laboratory integrates physics, mathematics, and computer science and enables students to understand the impact of a phenomenon—air resistance—whose discussion usually must be delayed until students have taken a course in differential equations. All this is made practical by the fact that students have used a common set of computer tools throughout an integrated course in science, engineering, and mathematics.

Mathematics/Physics Laboratory Using Excel and Maple

By the winter term, students have developed the concept of conservation of energy and they know how to solve separable differential equations. In class, Torricelli's Law for the velocity of water draining from a tank (under ideal conditions, $v = \sqrt{2gh}$ where v is the discharge velocity, g is the gravitational constant, and h is the height of the water above the discharge orifice) is derived from conservation-of-energy principles. The class is then asked to speculate what discharge velocity might be achieved under real (less than ideal) conditions. Typically, students propose two or more models: that discharge velocity will be proportional to that predicted by Torricelli's Law and that the discharge velocity will be modified by some function of the height of the water in the tank. A laboratory setup is described in which the height of water in the tank can be measured and recorded electronically, and the students participate in the development of the experiment they will conduct to determine which, if any, of the models they have proposed is valid.

A small tank is filled with water, and the discharge orifice is equipped with one of several different nozzles, all having the same cross-sectional area, but inducing different amounts of friction and turbulence. The height of the water in the tank is measured electronically using a pressure sensor. Therefore, students first need to construct a function that relates the height of the water to the voltage output of the sensor. Students drain the water from the tank, stopping the flow periodically and recording the height of the water and the voltage output of the sensor. Then they use Excel to fit a function to the data, so that they can relate the voltage output to the height of the water in the tank. Then they refill the tank and drain it while the computer records the voltage output from the pressure sensor every two seconds. Students finish the lab by using Excel to fit a polynomial curve to their height-vs-time data.

Meanwhile, the students set up and solve the differential equation

$$\frac{dt}{dt} = \frac{a}{A}\, v(t) = \frac{a}{A}\, k\sqrt{2gh(t)},$$

where a is the cross-sectional area of the discharge orifice, A is the cross-sectional area of the tank, and k is the postulated constant or function of proportionality. This differential equation can be solved (by hand or by using Maple, depending on the function k). The solution to the differential equation is not a polynomial, but by using the laboratory data, the students are able to determine the function k and plot the resulting curve $h(t)$ against the data.

This laboratory experience is often the first one in which the students do not know in advance what the results should be and in which their results are supposed to be different from those of their neighbors. This forces the students to rely on their tools for data analysis (Excel) and mathematical analysis (Maple), as well as their common sense.

This laboratory was initially developed by Roger Lautzenheiser at a time when the students were using NeXT workstations. Because of the limited amount of time the students were able to spend actually using the computer to do their data and mathematical analyses, it was not possible to allow the students to consider multiple models. In addition, it was necessary to tell students to use, for

[2] The laboratory was originally developed by Claude Anderson.

example, a linear fit for the voltage-to-water-height conversion. The ubiquitous availability of the computer makes it possible for students to continue their work after the laboratory. In addition, it supports the experiment/refine style of learning in which students consider multiple models and a variety of solution methods. Finally, the students' comfort with the entire suite of computer tools (instead of just "the tool for the subject being taught") facilitates this experiment/refine style of learning.

Curve-Fitting with Excel and Maple

Throughout the year, students use Excel to fit curves to data collected in their chemistry and physics laboratories. In the spring, the students learn multivariate calculus and therefore gain the ability to fit more complex curves than Excel will permit. At that time, we provide the students with weight-versus-age data for a large dog and ask them to fit several curves. In a calculus class, the students would fit all the curves using their computer algebra system, but the IFYCSEM students, with no prompting, immediately begin by using Excel. However, one of the curves, ultimately the best one, is too complex for Excel to handle: $w = k_1 - k_2 \exp(-k_3 t)$, where w is the weight of the dog in pounds and t is the age of the dog in days. Indeed, the resulting system of three equations in three unknowns is sufficiently messy that even Maple has a hard time, so that the students have to invoke a numerical equation-solving routine (*fsolve*) in which they provide Maple with ranges for each of the constants. Determining these ranges requires that the students iteratively refine their estimates, building not only on their understanding of exponential functions but also on their understanding of the algorithm Maple uses to solve systems of equations numerically.

Note how this example shows that the use of computers in IFYCSEM forges new links between mathematics (exponential functions) and computer science (numerical algorithms). As in previous examples, the students' comfort with the entire suite of computer tools facilitates this integration.

Conclusion

The ubiquitous presence of computers in IFYCSEM:

Strengthens existing connections between disciplines as in the laboratory on Torricelli's Law, where the computer tools clarify natural connections between mathematics and physics.

Forges new links between disciplines as in the early use of Maple for mathematics, in which links to computer science arise simply because Maple is a programming language.

Changes the way in which students learn to solve problems (as in all the examples, in which students use their computer to explore the problems, rather than merely solve them).

Some of the ideas in this article translate from IFYCSEM's integrated curriculum to a traditional, course-based curriculum. For example, if all departments devote and coordinate resources to help students learn relevant applications, all departments benefit. If computer scientists assist the introduction of Maple in a mathematics class, or if mathematicians assist a physics or chemistry laboratory involving modeling and curve-fitting, the computer tools they share will facilitate exposition of interdisciplinary connections. And the ubiquitous presence of computers in any curriculum will lead naturally to students' adopting a more exploratory style of problem-solving. C

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