



Lessons from the Emporium, 1: Goals and Economics

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The Math Emporiumⁱ at Virginia Tech was one of the first large math computer learning facilities, and to the best of our knowledge is still the largest by a factor of at least two. It serves over 6,000 students per semester with 550 computers and a yearly help staff budget over half a million dollars. Getting it organized and working effectively has certainly been a learning experience. This article is the first of three describing some of what we have learned, with emphasis on things we did not fully appreciate going into the project.

Obvious topics such as course design and testing are not discussed until the third article because we discovered---the hard way---that there are other factors that can lead to failure no matter how good the course designs.

Introduction: In the summer of 1997 the department launched the Math Emporium by leasing a vacant department store and installing the first 250 of an eventual 550 computers. This was a seizing of opportunity, a leap of faith rather than the result of careful planning. The consequences of failure were too severe for it to be considered an experiment, but there was no experience with a program of this scope, and goals and operational plans were hazy. In some ways this was just as well: our preconceptions were so far off the mark that explicitly-set goals and careful planning would have only made the learning process more difficult. The objective of this series is to share the fruits of the process. In this installment we discuss what we have learned are realistic and appropriate goals, and sometimes more to the point what to avoid, in a computer learning environment. Ways to go about achieving the goals will be discussed in later installments.

Not online: This facility was not intended as a base of operations for online courses. In the beginning going online seemed a natural and profitable next step, but as we have gotten more experience this seems increasingly problematic. Our computer-based courses

are available online. However success in our student population is strongly dependent on human help available on site. We have experimented with online help, but found it to be less effective and significantly more expensive. At present an affordable online version would have to be tolerant of significantly higher dropout and failure rates, or target a different group of students. We believe these problems can be overcome, but at present online and on-site computer based courses are significantly different in problems and goals and we advise a focus on one or the other.

Economics: We, like most academics, dislike thinking in economic terms. However economics is a “killer”: being over-budget in faculty time or other resources will, in the long run, lead to failure no matter how good other indicators may look. Wealthy institutions or big grants may mask economic problems for a while, and there should be an economic grace period during startup, but grace periods end and a program must be prepared to stand on its own.

Economics enter goal formulation in two ways. First, economic measures should appear explicitly among the evaluation criteria. It may turn out, particularly during startup, that there are economic savings but educational outcomes are mixed. This should be counted as a success if the savings allow enrichment of the rest of the departmental program, or if (as in our case) they help avert disaster when budgets are cut. Secondly, economics must be carefully considered when setting other goals. It is tempting, for instance, to set educational goals that are unrealistic with available resources.

“Economics” here is used as a shorthand for the relationship between costs and output. “Costs” are in dollars, and “output” is in student credit hours, with no reference to quality. It is not our idea to use these measures: they reflect realities of our funding sources. Both the state legislature and tuition-paying parents feel strongly that they are already paying enough for quality education. Recent history shows resources are more likely to be reduced than increased. A realistic formulation is that (internal) resources are linked only to student-hour output, and the faculty task is to maximize quality within this constraint.

External costs: In our institution resources are roughly of two types. “Internal” resources are provided to the department, mostly for salaries but with some flexibility in allocation. These are the resources that should be considered fixed or linked to student-hour “productivity” and carefully included in planning. “External” resources are outside the departmental budget and usually unavailable for operations. External resources are usually insensitive to operational issues and should not be included in operational planning.

For example most universities expect to make large expenditures for computer labs and supporting infrastructure, and have no illusions that this can be taken from academic budgets. Physical space, startup costs, infrastructure, and some maintenance therefore come from other budgets and are “external” to the department. Help staff and software maintenance are usually internal costs.

It can be very important to separate external and internal costs. For instance in the Emporium the building, 550 student machines, dedicated servers, and a systems manager for the servers are included in external support. Personnel needed to keep the student machines up and running are provided by the department so are an internal cost. We use slightly more expensive machines with a stable and maintenance-friendly (non-Windows) operating system. Cheaper machines would have slightly reduced external costs but significantly increased internal costs since more department-supported personnel would have been required to maintain them.

External budgets may be more flexible than internal ones. Administrators who cannot increase academic budgets may be able to increase startup funding if there is a sensible argument that this will contribute to the success of the program. In the example just above, more-expensive machines would contribute to success by freeing departmental resources for use on student help. Note however that arguments are more likely to be seen as “sensible” if the benefits can be described in economic terms and economic measures are included in the criteria for success.

Internal costs: These are costs that must be met from departmental salary and operating budgets. As explained above we have found it important to approach the project as first of all an optimization problem: can a department do a better overall job with fixed internal resources if part of the program is shifted to computers? “Better” here can (and should) include quality measures, but only when the constraint is met. It is counterproductive in the long run to try to use “better” to justify being over-budget.

To illustrate these points we analyze another program in these terms. The NSF “VIGRE” program offers large grants to departments that enrich their programs in various obviously good ways. However the grants do not support the enrichments. The grants fund postdocs and other activities mostly unrelated to “production” of student credit hours. In our terms these are external resources. The enrichments must be supported by internal resources. For instance undergraduate research projects are at least an order of magnitude over our state-determined budget in terms of average faculty time needed to produce a student credit hour. These overruns come out of something else. Possibilities are: faculty research time budgets are used; time spent on un-enriched educational duties is reduced (i.e. other students pay); some of the salary budget is shifted to adjuncts or other lower-cost ways to cover the extra hours; or faculty voluntarily work overtime (i.e. faculty members and families pay). The program may be “enriched” but violating the constant-budget constraint stresses the system. The stress ensures that most of the enrichments will disappear when the funding runs out, or as faculty become unwilling to continue making sacrifices. This approach to inducing long-term changes in instructional practice will fail for simple economic reasons.

Evaporation of VIGRE enrichments is not a disaster, things just return to normal. Failure of a large computer education project is a disaster. Recognizing and working within budgetary constraints is correspondingly more important.

Educational models: We briefly discuss the ways in which we use computers in our learning program. These will be described in more detail in later installments, but the basic models are described here because they are highly constrained by economics. The principle point is that the Emporium has significant costs not encountered in traditional programs but that must come from internal resources. To balance the budget these costs must be compensated for by savings elsewhere.

The first model is the completely computer-based course. The savings here is the time or salary of the classroom teacher. Some of this is redirected into help, and in fact students in our computer-based courses have access to more, and more timely, one-on-one help than students in our traditional classes. We have precalculus, elementary linear algebra, and calculus for the life sciences in this format.

The second model is a traditional lecture course but with all assessment (testing) done by machine. The savings is the time the teacher or assistants would spend preparing tests and grading tests, homework, etc. Success of this model seems to depend on the way testing is done. Our current (somewhat elaborate) methods have had unexpected educational benefits. We have sections of a calculus course in this format and another in development

A common model we do not use is the computer-enhanced traditional classroom. Since this is an add-on with no compensating savings it is always over budget. At one time the department had the goal of computer-enhancing every class, and many classes were run in this mode. However we were unable to sustain the uncompensated extra load, and this is now voluntary and rare.

Another model we have largely abandoned is the out-of-class computer lab, worksheet, or group project. As an add-on this is also unsustainably over budget: support costs of the computer component are usually as high as for a completely computer-based course. We remain enthusiastic about the educational benefits of these activities and hope eventually to incorporate some form of them, but in the short term they are unusable for economic reasons.

Our favorite educational model is a traditional classroom with an experienced professor and 15 or fewer students. We hope to always have some courses in this mode, but it has been over budget for nearly half a century and cannot be offered to the vast majority of our students. Thus in a sense our whole computer initiative is economically motivated. The fundamental goal is to do better than huge sections taught by adjuncts, but within the budget that would force such measures in the first place.

Scale and efficiency: There are costs associated with the Emporium and not any particular course. Examples are: student computer software maintenance personnel; a director of operations; floor helpers to assist students working at the machines; and a floor supervisor. To explain this last, the Emporium is over an acre in size. It turns out that a full-time supervisor is needed to organize and efficiently deploy helpers to areas

where they are needed. No doubt this would be obvious to the manager of a department store, but it was something we had to learn.

Courseware maintenance costs are associated to particular courses. Whether the materials are commercial or developed in-house, they are software and require real-time availability of expertise and maintenance.

The important point here is the way these expenses scale. Facility-related expenses (helpers, etc.) have a significant lower bound, but increase only slowly with the total number of students. Course-related expenses are nearly independent of the number of students in the course. In contrast traditional costs scale essentially linearly with the number of students. If a section has 40 students then 200 students require 5 sections, 1000 students require 25 sections, etc.

The following table gives data to be interpreted in the light of this discussion. “Costs” are internal costs computed in dollars per student credit hour and then normalized so the traditional situation has cost 100. Traditional classes assume 40 students per section. Costs can be lowered somewhat by using larger sections with cheap (eg. undergraduate) graders. We do not do this so do not have data on cost, but doubt it would be less than some of our lower-cost classroom modes. See the endnotes for additional information.

Traditional, professorial rank	100 ⁱⁱ (200)
Traditional, graduate student	60 ⁱⁱⁱ
Traditional, 30% prof/70% instructor	57
Traditional, instructor	39 ^{iv}
Computer-tested, 30% prof/70% instructor	32 ^v
Computer-based (3,500 students)	18 ^{vi}

Figure 1: Normalized costs per student credit hour

The cost shown for computer-based courses does not include cost of developing or upgrading materials, just as traditional course costs do not include textbooks.

These results show that at large scales great efficiencies are possible with computer-based courses. At smaller scales fixed costs will dominate. For example it would probably be difficult to break even with fewer than 500 students in computer-based mode. This probably means sustainable computer-based education can only be achieved by deliberate institutional initiative. Individual efforts cannot reach break-even levels.

Educational goals: The next step after making sure economic factors are in balance is to consider educational outcomes. We discuss this in detail in a sequel, but mention two observations robust enough to include in formulating goals: there are fewer failures in the new formats, but other outcomes depend strongly on expectations and course materials.

Several factors probably contribute to lower failure rates. First, some weak students benefit from the help available at the Emporium: they can get more personal attention than they would in a traditional course. Second, some courses got easier when they were

converted to computer-based format. Finally in courses that are not easier we see more students drop rather than fail. Presumably it is clear earlier what it would take to do well.

When they cover comparable material, current computer-based courses tend to have fewer top grades than the earlier classroom versions. This may in part be a more accurate reflection of educational outcomes. Grades in computer-based courses are purely performance-based while many classroom teachers weaken the performance-grade link by giving extra credit, dropping the lowest grade, allowing students to negotiate for additional partial credit, etc. However there is no question that some of the difference is due to weak course materials. Our current materials were developed on a shoestring, mostly by translating classroom materials and practices to electronic format. We have learned enough to be able to do much better, but implementation is expensive and progress is slow.

Modes of Failure: A computer-based educational program can be rewarding in many ways, including economically, but it also faces hazards. To summarize the points made above and briefly suggest a few others, these include:

- *Economics:* being persistently over-budget particularly in demands on faculty time, for instance by using expensive course designs or undertaking course development without adequate support; being too small to take advantage of economies of scale.
- *Inappropriate expectations:* being expected to go on-line (off-site) too soon; having the educational outcomes compared to small-section, enriched, or otherwise over-budget courses; putting too much weight on initial student reactions to the system. (Computer-education projects will be evaluated, and in resource-poor or conservative environments evaluations may be hostile. It can be helpful to establish clear and appropriate evaluation criteria at the beginning of the project.)
- *Organizational problems:* being disorganized; having divergent or unclear lines of authority; not having ways to promptly address performance problems. (These projects are much more interdependent than most academic undertakings in that there will be many individuals or groups who could compromise the whole project. It must be managed more like a business than a traditional course.)

Summary: Undergraduate mathematics education in the US is highly budget-constrained. Our experience suggests that small facilities and low-enrollment courses are likely to be unstable for economic reasons; sustainable educational models are tightly constrained; and there are more “modes of failure” than for other academic undertakings. Nonetheless large-enrollment computer-based courses supported by personal help in a dedicated facility can be successful both economically and educationally.

ⁱ See <http://www.emporium.vt.edu> for more information.

ⁱⁱ 100 corresponds to half salary, assigning the other half to research. Using the whole salary gives a normalized cost of 200.

ⁱⁱⁱ Graduate student figures are higher than instructors because they have lower loads and the cost includes tuition.

^{iv} “Instructors” at Virginia Tech generally do not have PhDs, and have twice the teaching load of professorial-rank faculty. They are not “adjuncts” in the usual sense because they are full-time members of the faculty with open-ended appointments. In our department approximately 1/3 of the undergraduate student credit hours are taught by instructors.

^v Teachers have 100 students per section or twice as many sections, but no assessment responsibilities.

^{vi} All materials on computers; tutoring and at-machine personal help is available but there is no classroom teacher.