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Share Globally, Adapt Locally: Software Assistance to Locate and Tailor Curriculum Posted to the Internet

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Abstract

Many teachers yearn to break through the confines of traditional textbook-centered teaching to present activities that encourage students to explore and construct their own knowledge. But this *requires developing innovative materials and curriculum* tailored to local students. Teachers have neither the time nor the information to do much of this from scratch.

The Internet provides a medium for sharing innovative educational resources globally. School districts and teacher organizations have already begun to post curriculum ideas on Internet servers. However, just storing unrelated educational materials on the Internet does not by itself solve the problem. It is too hard to find the right resources to meet specific needs. Teachers need productivity software for *locating* sites of materials across the network, *searching* the individual curriculum sources, *adapting* retrieved materials to their classrooms, *organizing* these resources in coherent lesson plans, and *sharing* their experiences across the Internet.

We have designed and prototyped a Teacher's Curriculum Assistant (TCA) that provides *software support for teachers to make effective use of educational resources posted to the Internet*. TCA maintains information for finding educational resources distributed on the Internet. It provides query and browsing mechanisms for exploring what is available. Tools are included for tailoring retrieved resources, creating supplementary materials, and designing innovative curriculum. TCA encourages teachers to annotate and upload successfully used curriculum to Internet servers to share their ideas with other teachers. In this paper we motivate the need for such computer support and discuss what we have learned from designing TCA.

Introduction

The Internet has the potential to transform educational curriculum development beyond the horizons of our foresight. The process has begun, as educators across the country start to post their favorite curriculum ideas for others to share. Already, this first tentative step has revealed the difficulties inherent in using such potentially enormous, loosely structured sources of information. Teachers wandering around the Internet looking for ideas to use in their classrooms confront a set of problems that will not go away by itself as the Internet becomes a more popular medium for sharing curriculum—on the contrary:

1. Teachers have to *locate* sites of curriculum ideas scattered across the network; there is currently no system for announcing the locations of these sites.
2. They have to *search* through the offerings at each site for useful items. While some sites provide search mechanisms for their databases, each has different interfaces, tools, and indexing schemes that must be learned before the curricula can be accessed.
3. They have to *adapt* items they find to the needs of their particular classroom: local standards, the current curriculum, their own teaching preferences, and the needs or learning styles of their various students.
4. They have to *organize* the new ideas in coherent curricula that build toward long-term pedagogical goals.
5. They have to *share* their experiences using the curriculum or their own new ideas with others who use the resources.

In many fields, professionals have turned to *productivity software* to help them manage such tasks involving complex sources of information. We believe that teachers should be given similar computer-based tools to meet the problems listed above. If this software is designed to empower teachers—perhaps in conjunction with their students—in open-ended ways, opportunities will materialize that we cannot now imagine.

In this article, we consider how the sharing of curriculum ideas over the Internet can be made more effective in transforming education. We motivate specific issues in the design of productivity software for curriculum development by classroom teachers, and introduce the Teacher's Curriculum Assistant (TCA) we are building for this purpose. First, we discuss the nature of constructivist curriculum, contrasting it with traditional approaches based on behaviorist theory. Then we present an example of a problem-solving environment for high school mathematics students. The example illustrates why teachers need help to construct this kind of student-centered curriculum. We provide a scenario of a teacher developing curriculum using productivity software like TCA, and conclude by discussing some issues we feel will be important in *maximizing the effectiveness of the Internet* as a medium for the dissemination of innovative curriculum for educational reform.

The problem of curriculum in educational reform

The distribution of curriculum over the Internet and the use of productivity software for searching and adapting posted ideas could benefit any pedagogical approach. However, it is particularly crucial for advancing *reform* in education.

The barriers to educational reform are legion, as many people since John Dewey have found. Teachers, administrators, parents, and students must all be convinced that traditional schooling is not the most effective way to provide an adequate foundation for life in the future. They must be trained in the new sensitivities required. Once everyone agrees and is ready to implement the new approach there is still a problem: what activities and materials should be presented on a day to day basis? This concrete question is the one that Internet sharing can best address. We generalize the term *curriculum* to cover this question.

Consider curriculum for mathematics. Here, the reform approach is to emphasize the qualitative understanding of mathematical ways of thinking, rather than to stress rote memorization of quantitative facts or "number skills". *Behaviorist* learning theory supported the view that one method of training could work for all students; reformers face a much more complex challenge. There is a growing concensus among educational theorists that different students in different situations construct their understandings in different ways [1]. This approach is often called *constructivism* or constructionism [2]. It implies that teachers must creatively structure the learning environments of their students to provide opportunities for discovery and must guide the individual learners to reach insights in their own ways.

Behaviorism and constructivism differ primarily in their views of how students build up their knowledge. Traditional, rationalist education assumed that there was a logical sequence of facts and standard skills that had to be learned successively. The problem was simply to transfer bits of information to students in a logical order, with little concern for how students acquire knowledge. Early attempts at designing educational software took this approach to its extreme, breaking down curriculum into isolated atomic propositions and feeding these predigested facts to the students. This approach to education was suited to the industrial age, in which workers on assembly lines performed well-defined, sequential tasks.

According to constructivism, learners *interpret* problems in their environments using *conceptual frameworks* that they developed in the past [3]. In challenging cases, problems can require changes in the frameworks. Such conceptual change is the essence of learning: one's understanding evolves in order to comprehend one's environment [4]. To teach a student a mathematical method or a scientific theory is not to place a set of propositional facts into her mind, but to give her a new tool that she can make her own and use in her own ways in comprehending her world.

Constructivism does not entail the rejection of curriculum. Rather, it requires a more complex and flexible curriculum. Traditionally, curriculum consisted of a textual theoretical lesson, a set of drills for students to practice, and a test to evaluate if the students could perform the desired behaviors. In contrast, *a constructivist curriculum* might target certain cognitive skills, provide a setting of resources and activities to serve as a catalyst for the development of these skills, and then offer opportunities for students to articulate their evolving understandings [5]. The cognitive skills in math might include qualitative reasoning about graphs, number lines, algorithms, or proofs, for example.

We believe that the movement from viewing curriculum as fact-centered to viewing it as cognitive-tool-centered is appropriate for the post-modern (post-industrial, post-rationalist, post-behaviorist) period. Cognitive tools include, importantly, *alternative knowledge representations* [6]. As researchers in artificial intelligence, we know that knowledge representations are key to characterizing or modelling cognition. We have also found that professionals working in typical contemporary occupations focus much of their effort on developing and using alternative knowledge representations that are adapted to their tasks [7]. Curricula to prepare people for the next generation of jobs would do well to familiarize students with the creation and use of alternative conceptual representations.

A diverse learning ecology

We are interested in helping teachers to create learning environments that stimulate the construction and evolution of understanding through student exploration using multiple conceptual representations. *A stimulating learning environment is one with a rich ecology, in which many elements interact in subtle ways.* In this section we present an illustration of a rich ecology for learning mathematical thinking that includes: inductive reasoning, recursive computation, spreadsheet representation, graphing, linear equations, and programming languages.

A typical curriculum suggestion that might be posted on an educational resources listing on the Internet is the *problem of regions of a circle*: Given **n** points on the circumference of a circle, what is the maximum number of regions you can divide the circle into by drawing straight lines connecting the points? (See Figure 1.) For instance, connecting two points divides the circle into two regions; connecting three points with three lines creates four regions. This is a potentially fascinating problem because its subtleties can be explored at length using just algebra and several varieties of clear thinking.

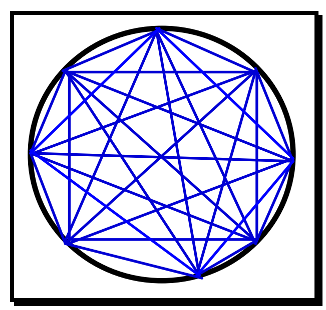

Figure 1. Regions of a circle; ***n*** *= 8..*

The problem with this curriculum offering as an Internet posting is that it has not been placed in a rich setting. To be useful, a fuller curriculum providing a set of conceptual tools is needed. For instance, a discussion of inductive reasoning brings out some of the character of this particular problem. If one counts the number of regions, **R(n),** for **n** = 1 to 6, one obtains the doubling series: 1, 2, 4, 8, 16, 31. Almost! One expects the last of these numbers to be 32, but that last region is nowhere to be found. For larger

n, the series diverges completely from the powers of 2. Why? Here *inductive reasoning* can come to the rescue of the hasty inductive assumption—if, that is, the problem is accompanied by a discussion of inductive reasoning.

Consider the general case of **n** points. Assume that you know the answer for **n-1** points and think about how many new regions are created by adding the **n**-th point and connecting it to each of the **n-1** old points. There is a definite pattern at work here. It may take a couple days of careful thought to work it out. It would also help if the *sigma notation* for sums of indexed terms is explained as a tool for working on the problem. Perhaps a group effort will be needed to check each step and avoid mistakes.

At this point, a teacher might introduce the notion of *recursion* and relate it to induction. If the students can *program in Logo or Pascal* (programming languages that can represent recursive processes), they could put the general formula into a simple but powerful program that could generate results for hundreds of values of **n** very quickly without the tedious and error-prone process of counting regions in drawings. It would be nice to formalize the derivation of this result with a *deductive proof*, if the method of formulating proofs has been explained.

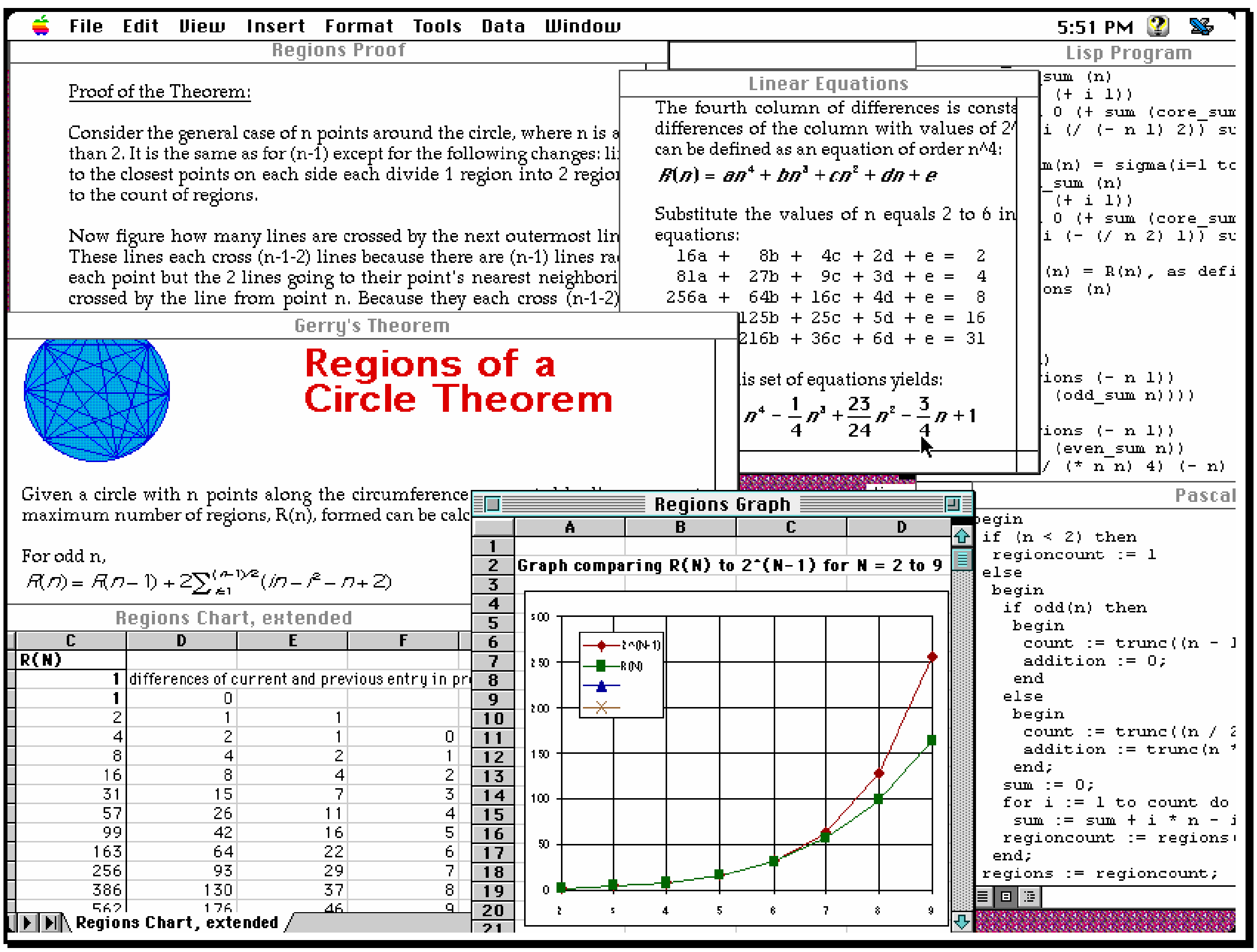

Figure 2. A number of multimedia resources related to the "regions of a circle" problem. These include textual documents, drawings, equations, spreadsheets, graphs, and computer program source code.

Now that students are confident that they have the correct values for many **n**, they can enter these values in a *spreadsheet* to explore them. The first representation they might want to see is a *graph* of **R(n)** *vs*. **n**. On the spreadsheet they could make a column that displays the difference between each **R(n)** and its corresponding **R(n-1)**. Copying this column several times, they would find that the fourth column of differences is constant. This result means that **R(n)** follows a fourth order equation, that can be found by solving *simultaneous linear equations*.

The point of this example is that sharing the isolated statement of the problem is not enough. The rich learning experience involves being introduced to alternative representations of the problem: induction, recursion, spreadsheet differences, graphs, computer languages, simultaneous equations, etc. There is not one correct method for tackling a problem like this; a mathematically literate person needs to be able to view the problem's many facets through several conceptual frameworks.

Curriculum in the new paradigm typically consists of stimulating problems immersed in environments with richly interacting ecologies, including: cognitive skills, knowledge representations, computational tools, related problems, and reference materials. Perhaps a creative teacher with unlimited preparation time could put these materials together. However, the reality is that teachers deserve all the support they can get if they are to prepare and present the complex learning ecologies that constructivist reforms call for. Computer support for curriculum development should make the kinds of resources shown in Figure 2 readily available.

From database to design environment

Curriculum planning for learning ecologies is not a simple matter of picking consecutive pages out of a standard textbook or of working out a sequential presentation of material that builds up to fixed learning achievements. Rather, it is a matter of *design*. To support teachers in developing curriculum that achieves this, we must go beyond databases of isolated resources to provide *design environments for curriculum development*.

It may seem to be an overwhelming task to design an effective learning environment for promoting the development of basic cognitive skills. However, dozens of reform curricula have already been created*. The problem now is to disseminate these in ways that allow teachers to adapt them* to their local needs and to reuse them as templates for additional new curricula. It is instructive to look at a recent attempt to make this curriculum available. The "MathFinder CD-ROM: a collection of resources for mathematics reform" excerpts materials from thirty new math curricula [8]. Like the posting of curriculum ideas at several Internet sites, this is an important early step at electronic dissemination.

Unfortunately, MathFinder has a number of serious limitations due to its CD-ROM (read-only) format. It relies on a fixed database of resources that allows resources to be *located* but not expanded or revised. Its indexing is relatively simple—primarily oriented toward illustrating a particular set of math standards—yet its *search mechanism is cumbersome* for many teachers. Since its resources are stored in bitmap images, they *cannot be adapted* in any way by teachers or students. Moreover, MathFinder provides *no facility for organizing resources into curricula*—despite the fact that most of the resources it includes are excerpted from carefully constructed curricula. Because it is sold as a read-only commodity, MathFinder *does not allow teachers to share* their experiences with annotations or to add their own curricular ideas. Thus, of the five issues listed in the Introduction, MathFinder only provides a partial solution to the issues of location and search.

An alternative approach is suggested by our work on *domain-oriented design environments* [9-13]. A software design environment provides a flexible workspace for the construction of artifacts and places useful design tools and materials close at hand. A design environment for curriculum development goes substantially beyond a database of individual resources. We have built a prototype version of a Teacher's Curriculum Assistant (TCA) based on this approach. TCA includes a *catalog* of previously designed curricula that can be reused and modified. It has a *gallery* of educational resources that can be inserted into partial curriculum designs. There is a *workspace*, into which curricula from the catalog can be loaded and resources from the gallery inserted. It is also possible for a teacher to specify criteria for the desired curriculum. The *specifications* are used for searching the case-base of curriculum, adapting the resources, and *critiquing* new designs.

TCA allows teachers to download curricular resources from the Internet and to create coherent classroom activities tailored to local circumstances. In particular, TCA addresses the set of problems identified in the Introduction:

1. TCA is built on a database of information about educational resources posted to the Internet, so it provides a mechanism for teachers to *locate* sources of curriculum ideas at scattered Internet sites.
2. The TCA database indexes each resource in a uniform way, allowing teachers to *search* for all items meeting desired conditions.
3. TCA includes tools to help teachers *adapt* items they find to the needs of their classroom.
4. TCA provides a design workspace for *organizing* retrieved ideas into lesson plans that build toward long-term goals.
5. TCA lets teachers conveniently *share* their experiences back through the Internet.

To illustrate how TCA works, each of these points will be discussed in the following sections. These sections present a scenario of a teacher using TCA to locate resources, search through them, adapt selected resources, organize them into curriculum, and share the results with other teachers.

Scenario step 1: locating curriculum

Assume that you are a high school mathematics teacher using TCA. In the coming year you have to introduce some geometric concepts like Pythagoras' Theorem and deductive proofs. More generally, you might like to discuss the ubiquity of patterns and ways to represent them mathematically. The TCA Find menu lets you search for semester themes and their constituent weekly units and lesson plans related to these topics. TCA distinguishes four levels of curriculum available on the Internet:

- A *theme* is a major curriculum, possibly covering a semester or a year of school and optionally integrating several subjects. A theme consists of multiple teaching units.
- A weekly *unit* is part of a theme, typically one week of lessons for a single subject. A unit is described by its constituent daily lesson plans.
- A *plan* is one day's lesson for a class. A lesson plan might include a number of resources, such as a lecture, a reading, an exercise or project, perhaps a quiz, and a homework assignment.
- A *resource* is an element of a lesson plan. It might be a text, available as a word processing document. It could also be a video clip, a spreadsheet worksheet, a graphic design, or a software simulation. Resources are the smallest units of curriculum indexed by TCA.

TCA lets you locate relevant curriculum by analyzing information stored on your computer about items available on the Internet. Along with the TCA software on your computer there is a case-base of summaries (indexes) of curriculum and resources that can be downloaded. These summary records reference curriculum and resources that have been posted to Internet nodes around the world. In addition to containing the Internet address information needed for downloading an item, a record contains a description of the item, so that you can decide whether or not it is of interest.

After you have selected a set of interesting items based on the information in the case-base, TCA downloads the items to your computer. This happens without you having to know where they were located or how to download them. The items are then available for modification, printing, or distribution to your students. If Internet traffic is slow, you may opt to download batches of curriculum and resources over night and then work with them the next day.

Scenario step 2: searching for resources

TCA provides a combination of query and browsing mechanisms to help you select curriculum of interest and to find resources that go with it. You can start by specifying that you want curriculum for tenth grade mathematics. Then you can browse through a list of themes that meet the specification. If the list is too long, narrow down your search criteria.

The *theme* named "A Look at the Greek Mind" is summarized as: "This is an integrated curriculum that explores myth, patterns and abstract reasoning." It emphasizes patterns and is likely to include Pythagoras' theorem. Click on this theme in the list. Your computer now displays summaries of the *units* that make up the curriculum for that theme. This list shows three weekly units. Select the week described as "Abstract thinking: number theory and deductive reasoning."

You now see summaries of that week's five daily *lesson plans*. Look at the geometry example for day 3, "Inductive reasoning example: regions of a circle." Select that one and the screen changes to show the lesson plan in Figure 3. It lists all the *resources* suggested for that period: two lecture topics, a class exercise, three activities for small groups and a homework assignment.

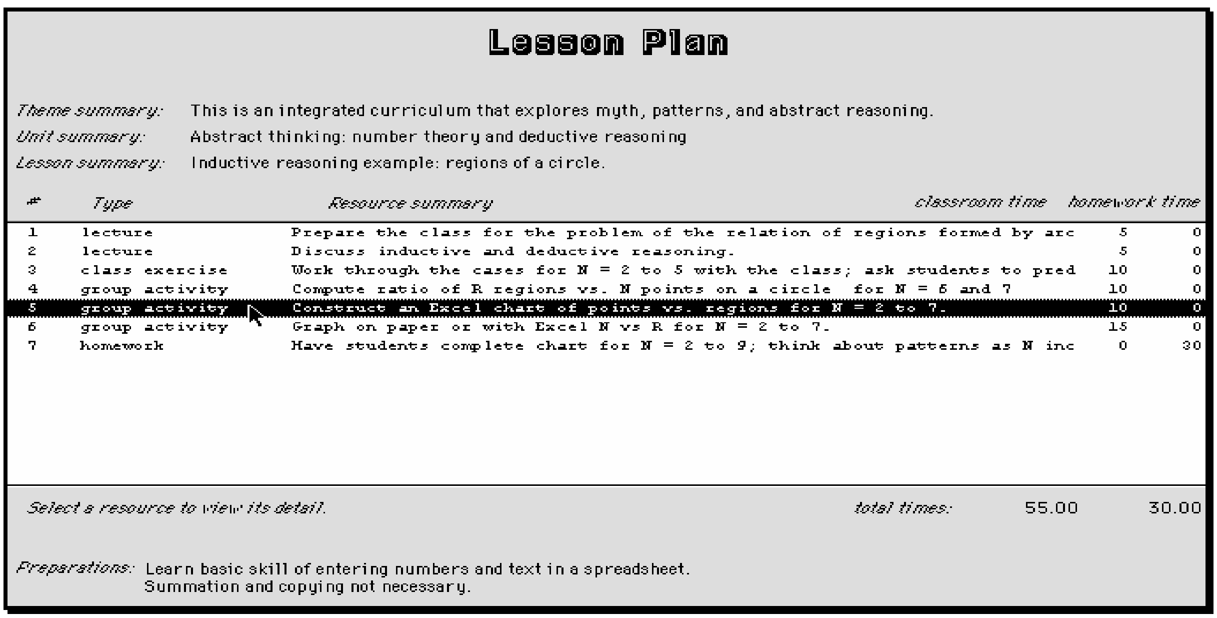

Figure 3. Screen image of the lesson plan workspace. A number of resources (lectures, exercises, group activities, and homework) related to the regions of a circle problem are assembled for a day's class. Note that total class time and homework time are computed and teacher preparations for the resources are listed below the workspace.

Notice resource #5 where students create a spreadsheet chart: "Group activity: Construct an Excel chart of points vs. regions for N= 2 to 7." Select it by clicking the mouse on the summary of that resource. Figure 4 shows the detail for that resource, including its index values.

The description contained in the case-base for each posted resource is organized as a set of 24 indexes and annotations, such as: recommended grade level, content area, pedagogical goal, instructional mode, prerequisites, materials used, required time, and the like. TCA includes search mechanisms that allow you to specify your curriculum needs using combinations of these indexes. Resources are also cross-referenced so that you can retrieve many different resources that are related to a given one. Thus, once you have found the "problem of regions of a circle", you can easily locate discussions of inductive reasoning, formal proofs, recursion, simultaneous linear equations, sample programs in Logo or Pascal, spreadsheet templates for analyzing successive differences, and graphing tools. You can also find week-long units that build on geometric problems like this one, with variations for students with different backgrounds, learning styles, or interests. TCA allows you to search both top-down from themes to resources and bottom-up from resources to curriculum.

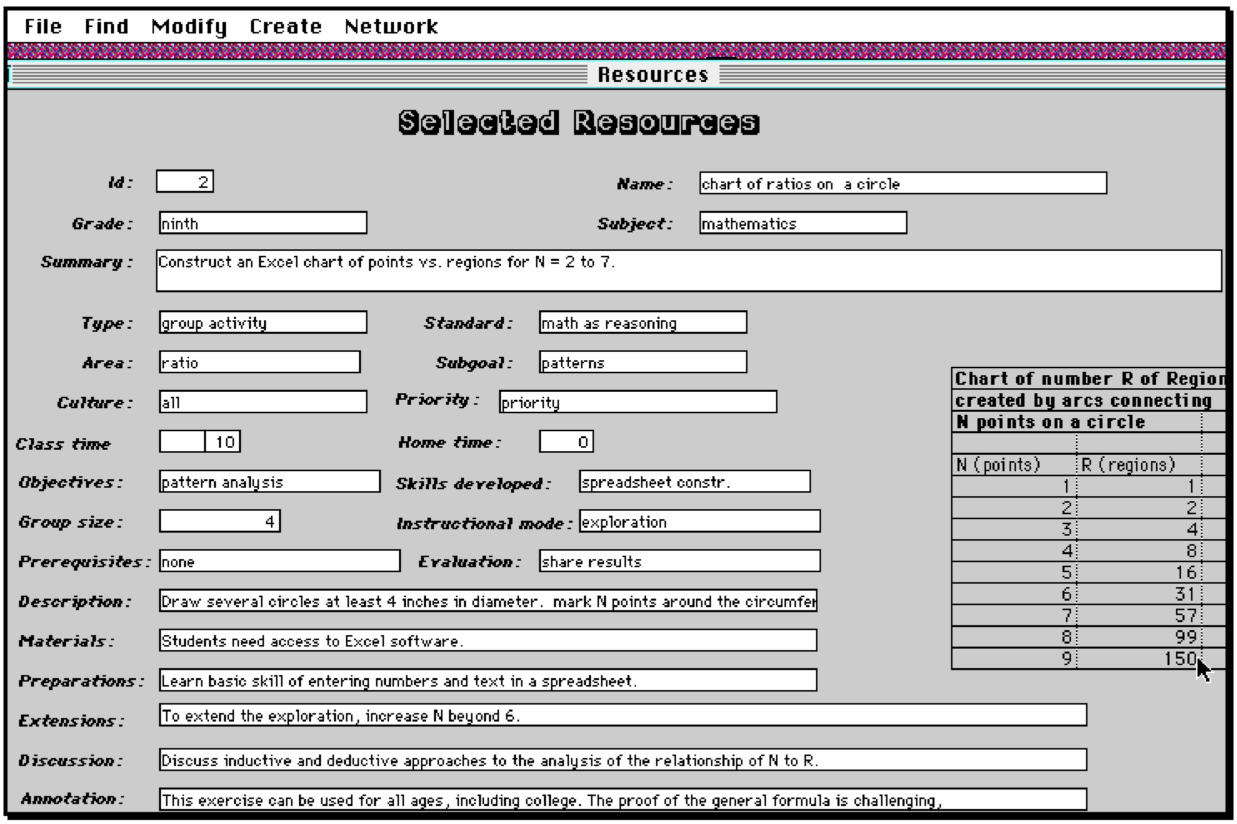

Figure 4. Screen image of a TCA display of the indexing for a resource. The resource is a spreadsheet, which is also shown in the screen.

Scenario step 3: adapting to local needs

Adaptation tools are available in TCA for resources that have been downloaded from the Internet. The TCA system can often *make automated suggestions* for adapting a resource to the specification given in the search process. For instance, if you retrieve a resource that was targeted for 11th grade when you are looking for 10th grade material, then TCA might suggest allowing your students more time to do the tasks or might provide more supporting and explanatory materials for them. In general, you will need to make the adaptations; even where the software comes up with suggestions, you must use your judgment to make the final decision.

While TCA can automate some adaptation, most tailoring of curriculum requires hands-on control by experienced teachers. Sometimes TCA can support your efforts by *displaying useful information*. For instance, if you are adapting resources organized by national standards to local standards you might like your computer to display both sets of standards and to associate each local standard with corresponding national standards. In other situations, perhaps involving students whose first language is not English, TCA might link a resource requiring a high level of language understanding to a supplementary visual presentation.

The adaptation process relies on alternative *versions* of individual resources being posted. TCA helps you adjust to different student groups, teaching methods, and time constraints by retrieving alternative versions of resources that provide different motivations, use different formats, or go into more depth. You can substitute these alternative resources into lesson plans; they can then be modified with multimedia editing software from within TCA.

Included in Figure 4 was a reduced image of the spreadsheet itself. If you click on this image, TCA brings up the commercial software application in which the document was produced. So you can now *edit and modify* the copy of this document which appears on your screen. You need not leave TCA to do this. Then you can print out your revised version for your students or distribute it directly to their computers. In this way, you can use your own ideas or those of your students to modify and enhance curricular units found on the Internet.

Just as it is important for teachers to adapt curriculum to their needs, it is desirable to have resources that students can tailor. Current software technology makes this possible, as illustrated by a number of simulations in the Exploratorium described in this issue [14].

Scenario step 4: organizing resources into lesson plans

The lesson plan is a popular representation for curriculum. It provides a system for organizing classroom activities. TCA uses the *lesson plan metaphor* as the basis for its design workspace. You can start your planning by looking at downloaded lesson plans and then modifying them to meet your local needs.

The TCA workspace for designing lesson plans was shown in Figure 3. In addition to summaries of each resource, the workspace lists the time required by each resource, both in class and at home. These times are totaled at the bottom of the list. This provides an indication of whether there is too much or too little instructional material to fill the period. You can then decide to add or eliminate resources, or adjust their time allowances. The total homework time can be compared to local requirements concerning homework amounts.

TCA incorporates computational *critics* [11, 12]. Critics are software rules that monitor the curriculum being constructed and verify that specified conditions are maintained. For instance, critics might inform you if the time required for a one-day curriculum exceeds or falls short of the time available.

Scenario step 5: sharing new experiences

Once you have developed curricula and used them successfully in the classroom, you may want to share your creations with other teachers. This way*, the pool of ideas on the Internet will grow and mature*. TCA has facilities for you to annotate individual resources and curricular units at all levels with descriptions of how they worked in your classroom. This is part of the indexing of the resource or unit.

Assume that you downloaded and used the "regions of a circle" resource and modified it based on your classroom experience. Now you want to upload your version back to the Internet. TCA automates that process, posting the new resource to an available server and adding the indexes for it to the server used for distributing new indexes. Because the indexing of your revision would be similar to that of the original version of the resource, other teachers looking at the "regions of a circle" resource would also find your version with your comments. In this way, the Internet pool of resources serves as a medium of communication among teachers about the specific resources. It is in such ways that we hope the use of the Internet for curriculum development will go far beyond today's first steps.

What we have learned

We conceptualize the understanding we have reached through our work on TCA in five principles:

1. Most resources should be *located* at distributed sites across the Internet, but carefully structured summaries (indexes) of them should be maintained on teachers' local computers.
2. The *search* process should be supported through a combination of query and browsing tools that help teachers explore what is available.
3. *Adaptation* of tools and resources to teachers and students is critical for developing and benefiting from constructivist curriculum.
4. Resources must be *organized* into carefully designed curriculum units to provide effective learning environments.
5. The Internet should become a medium for *sharing* curriculum ideas, not just accessing them.

We have designed and prototyped a system to assist teachers in developing curriculum for educational reform. We must now refine all aspects of the system by working further with classroom teachers and curriculum developers. While the approach of TCA appeals to teachers who have participated in its design, its implementation must still be tuned to the realities of the classroom.

The distribution of resources and indexes prototyped in TCA has attractive advantages. Because the actual multimedia resources (text, pictures, video clips, spreadsheet templates, HyperCard stacks, software applications) are distributed across the Internet, there is no limit to the quantity or size of these resources and no need for teachers to have large computers. Resources can be posted on network servers maintained by school districts, regional educational organizations, textbook manufacturers, and other agencies. Then the originating agency can maintain and revise the resources as necessary.

However, the approach we advocate faces a major institutional challenge: the standardization of resource indexing. The difficulty with this approach is the need to index every resource and to distribute these indexes to every computer that runs TCA. This involves (a) implementing a distribution and updating system for the case-base index records and (b) establishing the TCA indexing scheme as a standard.

The distribution and updating of indexes can be handled by tools within TCA and support software for major curriculum contributors. However, the standardization requires coordination among interested parties. Before any teachers can use TCA there must be useful indexed resources available on the network, with comprehensive suggested lesson plans. We hope to initiate cooperation among federally-funded curriculum development efforts, textbook publishers, software publishers, and school districts. If successful, this will establish a critical mass of curriculum on the Internet accessible by TCA. Then the Internet can begin to be an effective medium for the global sharing of locally adaptable curriculum.

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