Use of Logical Puzzles to Promote Techeracy for Non-Science/Engineering Students

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***Abstract*—Literacy and numeracy, introduced long ago to define the skill sets of a competent workforce, are no longer adequate for the 21st century. We need what is described by "techeracy," which is loosely equivalent to "grasp of technology." Just as numeracy is fundamentally different from literacy, there are key differences between the scopes and requirements of techeracy and numeracy. Achieving techeracy requires a further shift away from story-telling and word problems, used to instill literacy and numeracy, toward logical reasoning, as reflected in the activity of solving puzzles. I draw upon my experience with teaching a freshman seminar to non-science/engineering majors to convey how a diverse group of learners can be brought to understand the underpinnings of complex technical concepts. Once the basics are imparted in this manner, learners become empowered to pursue additional science and technology topics through suitably designed self-contained study modules.**

Keywords—Technical literacy, Engineering literacy, Freshman seminar, Puzzle-based learning

I. Introduction

Literacy, as a desirable attribute of a competent workforce, has a long history [1]. As far back as the Middle Ages, one can find references to the importance of literacy, the skills of reading and writing. Advances in science and technology and the shift from agricultural and manufacturing jobs to service-oriented careers led, over time, to the need for literacy at higher levels. Literacy is instilled and improved by telling stories that use more and more advanced vocabulary and grammar. Improving literacy (recently expanded to include the appreciation of traditional and digital media) has long been a stated goal of planners in many societies (e.g., [4]).

The need for numeracy, that is, arithmetic skills, again expanded to include problem solving and reasoning, was added in modern times. Numeracy, sometimes referred to as "quantitative literacy" [12], came about when data and calculations began to pervade jobs and other societal functions. Quantitative and numerical reasoning skills seemed to blossom in early 19th-century America, alongside vast transformations in the economy [2]. The key tool in teaching and advancing numeracy is dealing with real-life problems, be they book-keeping and accounting tasks, analyzing geometric shapes and relationships, or deriving answers from (partially) supplied information.

The importance of literacy and numeracy has caused their incorporation into educational plans (e.g., [4]). There is often a tendency to expand the definition of literacy to include numeracy, viewing what is known as "quantitative literacy" as an extension of "prose literacy" and "document literacy" [1], so that a single word is used to refer to both sets of skills. Hence, when reading or hearing about literacy, one must make sure to understand the context and intended meaning.

The rarely used "techeracy", also known as "technical literacy" [5], represents a further shift of focus, which is needed to update the minimal skill-set of our workforce in the 21st century. Technological literacy and engineering literacy have been used, but these terms are poorly defined and not compelling enough. The word "techerate," the counterpart to "literate" and "numerate," has also seen only limited use.

The need for techeracy has actually been recognized and discussed for decades, since before World War II, or by some accounts, since the 18th-century Industrial Revolution. However, techeracy has assumed urgency in the age of digital computing, quantitative finance, smart everything, and artificial intelligence. Just as numeracy is fundamentally different from literacy, there are key differences between the scopes of techeracy and numeracy.

I use "techeracy/techerate" to continue the pattern set by "literacy/literate" and "numeracy/numerate." These words, though not new, have seen very limited usage. A Google search reveals only a couple of relevant hits, including a Web page whose only significant content is about James Bond films [13].

I maintain that teaching techeracy requires a further shift away from story-telling and word problems toward logical reasoning, as reflected in the activity of solving puzzles. In this paper, I will draw upon my experience with the freshman seminar "INT 94TN: Puzzling Problems in Science and Technology" to convey how a diverse group of learners can be brought to understand the underpinnings of complex science and technology concepts. Once the basics are imparted in this manner, learners become empowered to pursue additional science and technology topics through suitably designed self-contained study modules based on the same puzzle-based strategy.

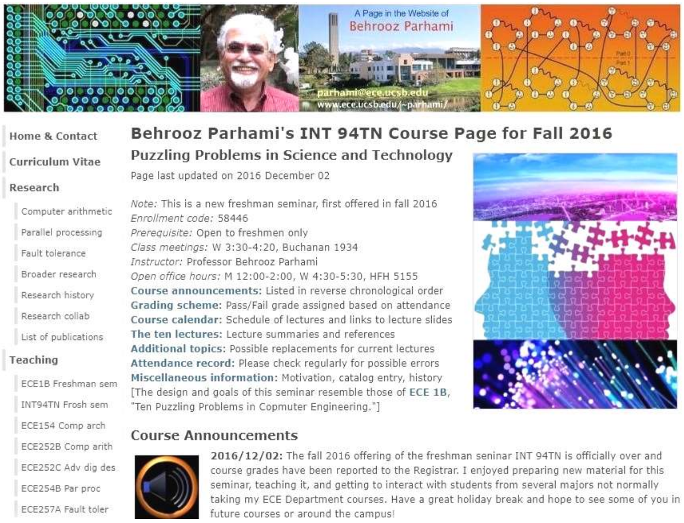

Fig. 1. Beginning of the Web page for INT 94TN's first offering (fall 2016).

II. UCSB's Techeracy Freshman Seminar

Beginning with 2007, my puzzle-based freshman seminar for computer engineering (CE) students has been offered every spring quarter at UCSB [8]. The course came about as a result of a serious retention problem that saw only one-third of our entering CE pre-majors emerge as CE graduates five years later. In rough terms, one-third left the university or dropped out and one-third transferred to and graduated from other majors. We conducted a study that determined the lack of student motivation to result in part from absence of meaningful CE courses during the first two years of their study.

We wanted to create some computer engineering experience during the first two years, but given that courses taken in those two years were primarily on math, basic-science, and general-education topics, plus some programming, bringing forward the more advanced courses was impractical. I had been using puzzle-based analogies in my own teaching to impart complex topics to students and saw an opportunity to do the same for our freshmen. I noted, for example, that word-search puzzle, perhaps the easiest puzzles to solve, can be used to introduce the topic of string-matching. Similarly, Sudoku, with its rules and restrictions, can model task-scheduling problems. It wasn't long before I identified a dozen or so advanced computer engineering topics that could be linked to popular puzzles.

In its 12 annual offerings, "ECE 1: Ten Puzzling Problems in Computer Engineering" (renamed ECE 1B, when another survey-type freshman seminar, ECE 1A, was introduced to cover CE topics and career opportunities for graduates) has been well-received. The course is required for CE students, but we often receive petitions from students in other majors who would like to take the course. The success of ECE 1B prompted me to experiment with the same puzzle-based approach in a techeracy (technology appreciation) course at the campus level, within the framework of UCSB's Discovery Seminars.

In the first offering of the 1-unit freshman seminar "INT 94TN: Puzzling Problems in Science and Technology" during fall 2016 (Fig. 1), carefully-selected puzzles were used to begin a class session, which then led in the following session, to science and technology problems whose methods of solution coincide with those used for solving the puzzles [9]. Whereas in ECE 1B, I introduced puzzles at the beginning of a class hour and proceeded to cover advanced technology topics later in the same class session [10], for INT 94TN, I decided to slow down the pace, using two lectures per topic, one to introduce puzzles and their solution methods and the next to relate the puzzles to advanced science and technology topics. So, only five topics could be covered in 10 lecture hours. These topics were made different from those used in ECE 1B, both to match them better to the needs and backgrounds of target students and to expand the list of candidate topics for future use in both courses.

The 5 topics, each covered in two lectures of INT 94 TN, are discussed in the following sections of the paper.

III. Predicting the Future

Forecasting technological, economic (e.g., stock prices), or climate trends is of great interest in our modern society. Pertinent puzzles for introducing these notions consist of numerical series for which you must supply the next term.

Consider the sequence of numbers 2, 4, 8, 16, __, in which guessing the blank entry following 16 is required. Students quickly realize that the four given numbers are consecutive powers of 2 (or that each is double the previous one) and thus readily guess the missing entry to be 32. This seems to be a perfectly reasonable guess, until they are told that, whereas identifying the nth term as 2^n isn't wrong, there is really no one right answer. One can also say that the nth term is $f(n) = n^3/3 - n^2 + 8n/3$. The difference in the next term according to the two trends is not large (32 versus 30; see Fig. 2), so that if this were an economic or technological prediction, either estimate might do. However, for future terms the difference becomes significant: one series has exponential growth, while the other has polynomial growth. For example, $f(30) = 8180$, whereas $2^{30} = 1{,}073{,}741{,}824$.

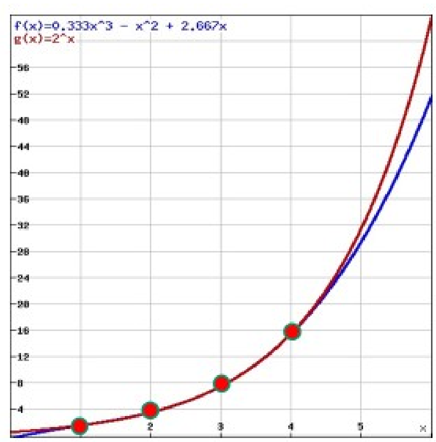

Fig. 2. Extrapolation of the series 2, 4, 8, 16 to find the next two terms.

IV. Recommender Systems

My second example is that of recommender systems, now in widespread use for predicting book purchases (Amazon), movie rentals (Netflix), and many other contexts. Take the case of Netflix, which, based on movies you have watched, rated, saved for future viewing, or discussed, picks candidate films for your attention. How is this done? The pertinent puzzles consist of series of numbers, symbols, shapes, or images in which you are asked to pick the next term or to detect similarities/differences in a list or series.

Puzzle 1, depicted in Fig. 3, asks what shape should appear in the box at the end of the figure. Another puzzle asks us to identify which term in the digit-sequence (0; 3; 6; 7; 8; 9) isn't like the others? In example Puzzle 3, we must detect a common feature among these words, besides all having at least two repeating letters: assess; banana; dresser; grammar; potato; revive; uneven. Answers appear in the appendix at the end of the paper.

The solution method entails establishing a feature space and then determining how various features remain the same or change from term to term. Now, substitute films, books, songs, or products for numbers and other elements used in the puzzles and you have the beginnings of a recommender system that magically predicts your likes and dislikes.

Connecting the unfamiliar notion of a recommender system to a familiar puzzle-like activity is a key to understanding and remembering how recommendations are derived from a wealth of available information.

V. Three-Dimensional Models from 2D Images

My third example relates to deducing the shape of 3D objects from their 2D projections, or, conversely, using 2D images to represent 3D objects. This kind of deduction is of utmost importance in image processing/understanding and in AI systems that rely on visual cues to make decisions about various tasks such as robot motion-planning.

It is now quite common for architects and structural engineers to create 3D models of their designs before actually building them, so as to get a feel for how the finished product will look when it is placed in the planned environment. Similarly, archaeologists are interested in creating 3D models of ancient sites, both to preserve the structural information in case of destruction and to help with understanding of the design and functional elements. Building 3D models of human organs and entire bodies are among the tools used in modern medicine to study ailments and to prepare for treatments and procedures.

For much of human history, objects have been built from the requisite raw material through subtractive methods. A large piece of metal, e.g., is obtained and various parts of it removed using lathe and drill machines to create a desired shape in one piece. Combining different pieces via welding or attachment, or using molds, allows the construction of more complicated parts. The technology of 3D printing, aka additive manufacturing, is revolutionizing what we can build inexpensively, even at low production volumes, and has found applications in many domains.

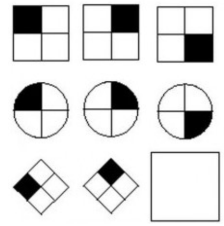

Fig. 3. What geometric shape should go in the blank square?

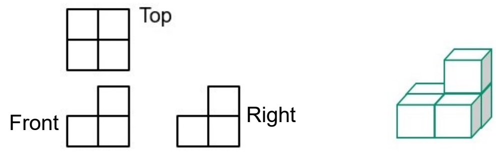

Fig. 4. The projections on the left depict the block arrangement on the right.

VI. Computational Geometry

My fourth example relates to the digitized representations of continuous images (Fig. 5). For example, modern computer display screens are essentially large matrices of dots or pixels onto which texts and images are mapped for viewing. Similarly, modern computer printers use dot-matrix technology for its versatility and flexibility. A straight line drawn on a display unit or on printer paper is essentially a digital approximation of the continuous line we see and study in geometry, hence the name "digital geometry" or "computational geometry," the latter encompassing procedures for deriving and representing geometric shapes as collections of dots on a regular grid. Images we see on digital TV sets and on huge stadium displays are formed by dots having one of several colors in order to create the illusion of continuous colored images.

Computational geometry is used extensively in a variety of domains, from circuit design and layout, through computer-aided design, to robot navigation. Digital or algorithmic art is a byproduct of the notions above.

VII. Maps and Graphs

My fifth and final example relates to maps and graphs, as representations of spatial and other relationships. The use of maps has a long history. Claudius Ptolemy was the first person to use math and geometry to develop a method for mapping the planet. His map was Mediterranean-focused and did not include the Americas, Australia, or south of Africa. Over the centuries, maps have been improved to include both greater information and more accurate representations of our world. There are inherent shortcomings in 2D "flattened" maps of our spherical Earth, but many methods can be used to reduce inaccuracies and inconsistencies arising from the fact that there is no perfect way to represent a spherical surface on a flat 2D surface.

Coloring maps has been a mathematical problem of longstanding interest. It was suspected since the mid-1800s that any map can be colored with 4 distinct colors in such a way that no two adjacent regions have the same color, but it wasn't until 1976 that this fact was proven mathematically.

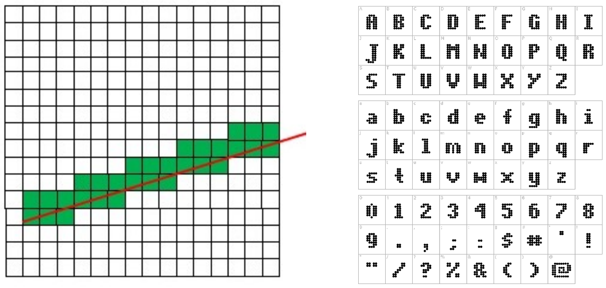

Fig. 5. Digitized line and dot-matrix alphanumeric characters.

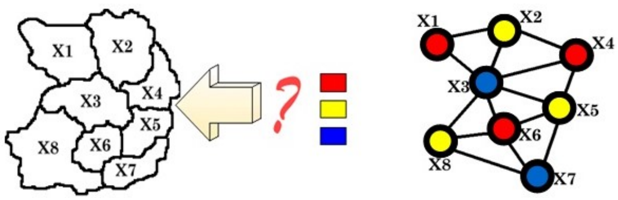

Fig. 6. Map-coloring and its equivalent graph-coloring problem.

For the purpose of coloring it, a map can be represented as a graph, with regions shown as nodes and adjacencies modeled by links connecting regions. So, map-coloring and graph-coloring problems are equivalent, as illustrated by the example in Fig. 6. The lecture concludes by discussing GPS and map tools, such as Google Maps, and their roles in route planning and navigation assistance.

VIII. Conclusion

I have presented arguments for the suitability of puzzle-based teaching/learning to improve techeracy, both for science/engineering students and for those in non-science/technology majors. The short examples provided in the preceding two sections can be pursued in great detail, alongside a wealth of other examples, through the INT 94TN Web site, which includes more detailed descriptions as well as complete lecture slides in both PowerPoint and PDF formats [9].

This type of puzzle-based learning isn't just useful for improving techeracy. There are quite a few reports in the literature describing the use of puzzles as pedagogical tools for teaching in a broad spectrum of fields, including mathematics [11], computing [6], operations research [7], and biology [3], to name a few.

The INT 94TN freshman seminar, described in this paper, is still in its infancy. I will experiment with alternate topics and other teaching methods in future offerings of the seminar, in order to find a near-optimal structure for improving the students' techeracy. In the first two offerings, the second one in progress during fall 2018, there were no homework assignments or exams, with the grade being assigned only based on attendance. Given that the course was part of a set of "Discovery Seminars" offerings taken by highly motivated students, this may have been the best strategy in terms of using class time efficiently. Perhaps the addition of hands-on, self-paced exercises in a discussion or lab session should be considered in future.

I am in the process of compiling the five topics used for INT 94TN, and those of my older seminar (ECE 1B) for computer engineering students, into a book, which would enrich the learning experience by providing additional puzzles, background material, self-paced/independent activities (with links to on-line videos), and example applications. I hope to be able to report on any additional insight or experience in the near future and to complete the aforementioned book within a couple of years.

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Appendix: Answers to the Puzzles

1. Going from left to right in the first two rows, the black section moves by one position in clockwise direction. So, the box at the end should contain a diamond shape in which the single black square is on the right.

2. The digits 0, 3, 6, 8, and 9 are curved, whereas 7 has straight line segment(s).

3. All the given words remain the same if you remove the first letter, attach it to the end, and read backwards.