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Impact of Effective Pedagogy on Information Technology Students with Weak Academic Backgrounds*

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In India today, many students in STEM disciplines at technical institutions below the top rank are seriously lacking in prerequisite knowledge and skills and motivation to learn. This paper reports on the implementation of a learner-centered teaching approach in an information technology program in such an academic setting. Learning objectives covering the full spectrum of Bloom's Taxonomy of Educational Objectives were used to guide the preparation of lessons, assignments, and examinations, and active and inquiry-based learning were used for lectures and assignments. Compared with previous students who had been taught traditionally, the students taught in this manner showed dramatically improved performances in analytical problem solving and critical and creative thinking, and they reported a greater interest in the subject and a greater level of enthusiasm about the lectures. Although there is still considerable room for improvement, the results indicate a great potential for proven learner-centered pedagogies to improve the chances of success for STEM students who are at high risk of failure in developing countries.

Keywords: information technology education; active learning; learning objectives; inquiry-based learning

1. INTRODUCTION

IN THE LAST TWO DECADES, India has gone through a technological revolution, rapidly assuming a position of world leadership in information technology and creating a large and rapidly growing demand for engineers. The capacity of the Indian engineering education system was initially far below what was needed to meet that demand, and in the years since 1980 the number of public and private institutions granting engineering degrees underwent a dramatic rise. In 2008, there were more than 1500 technical institutions in India (20% public and 80% private) that admitted close to 600 000 students, a five-fold increase in admissions over a six-year period. However, only 24 of those institutions were top-rated (IITs and NITs) and they only admitted about 25 000 students. While the total number of students currently in institutions below the top rank would go a long way toward meeting the demand for engineering graduates, a significant percentage of them have weak academic backgrounds and either drop out or graduate with skill levels that are too low to meet the current criteria for employment.

As is true almost everywhere in the world, college instructors in India are not given any training in pedagogy before they begin their teaching careers. As a consequence, they fall back on the only instructional model they know, which is the one used by their college teachers, who had also never been taught to teach. In India, this model is non-interactive lecturing in classes, perhaps some problem-solving in tutorials, and no feedback on progress in learning except for a final examination in which a mark of 50% or even less (35% or 40% is common) is considered acceptable. As anyone familiar with modern cognitive science or pedagogical research knows, that model is supremely ill-suited to promote learning; however, it was created at a time when only the very best and brightest of the nation's youth went to college. When the only applicants to college come from elite primary and secondary institutions and fewer than 1% of them are admitted, it almost doesn't matter how they are taught: they are smart enough to learn with good teaching, poor teaching, or completely on their own if necessary. On the other hand, when many students have weak pre-college backgrounds and are also deficient in the language of instruction (in India, English), how they are taught can make a great difference in whether or not they graduate and are considered employable.

I teach in a Master of Computer Application (MCA) program at the GLS Institute of Computer Technology, located in Ahmedabad, Gujarat, India. The general problems described above completely characterize this program. Five years ago, only about 500 out of 10 000 applicants were admitted for the program; today the program admits nearly 2000 out of 3000 applicants. Most students enroll with either BCA (Bachelor of

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Computer Application), B.Com. (Bachelor of Commerce), or B.Sc. (Bachelor of Science) degrees. Except for the small number in the third category, most of those admitted have poor backgrounds in mathematics and seriously inadequate English writing and speaking skills. Their approach to learning relies heavily on rote memorization; any instruction that calls for conceptual understanding or analytical thinking and problem solving is a major challenge for them. In the years prior to 2008, the passing rate on my tests was typically 40 to 50%, and I had to teach at a very low level to get the rate even that high.

In May 2008 I participated in a teaching workshop presented under the auspices of the Indo–US Collaboration for Engineering Education (IUCEE). The workshop effectively transformed the way I teach. Although the intellectual level of my courses is much higher than it used to be, my pass rate is now 70 to 80%. In this paper I will briefly review the history of IUCEE, outline the principal features of the new instructional approach I adopted and the methods that I used to assess its effect on my students' learning, summarize the assessment data, and discuss the implications of the results for the education of engineering students in developing countries. My goal is to offer a case study demonstrating that properly implemented instructional methods can enable students in developing countries to learn effectively, regardless of the deficiencies in background and motivation they may bring to class with them.

2. IUCEE AND THE EFFECTIVE TEACHING WORKSHOP

The Indo–US Collaboration for Engineering Education [1] was started in 2007 with technical assistance provided by the American Society for Engineering Education (ASEE) and the International Federation of Engineering Education (IFEES) and financial and logistical support provided by the Infosys Technologies Corporation. The IUCEE vision is to improve the quality and global relevance of engineering education in India and in the United States by fostering collaboration in teaching and research between the two countries. Under the leadership of Dr. Krishna Vedula of the University of Massachusetts at Lowell, a Faculty Leadership Institute was developed jointly by US and Indian academic leaders and took place in May and June 2008 at the Infosys Technologies Global Education Center in Mysore, India. The Institute consisted of 23 one-week 'Train-the-Trainer' workshops on effective pedagogy and teaching specific courses in information technology. Most participants enrolled in one of each type of workshop.

I was fortunate to be chosen as a participant in the 2008 IUCEE Faculty Leadership Institute, as part of which I attended a two-day workshop on effective teaching given by Drs. Richard Felder of North Carolina State University and Rebecca Brent of Education Designs, Inc., an educational consulting firm in the United States. The workshop covered a variety of topics, including: the importance of teaching in a manner that addresses different student learning styles; writing learning objectives and using them to guide course planning, instruction, and assessment; effective lecturing techniques; and active, cooperative, and inquiry-based learning strategies. Much of the workshop content can be found in papers on Dr. Felder's website Resources in Science and Engineering Education [2].

Prior to attending the workshop I had been frustrated by my inability to increase the level of understanding attained by most of my students. The workshop helped me to identify mistakes that I had been making in my classes for many years, such as not explicitly defining my learning objectives until I made up the tests, which often led to my teaching and assigning homework covering one set of skills and testing on different skills. My students were forced to guess what they needed to be able to succeed in my courses and I expected them to acquire complex knowledge and skills without my providing the required practice and feedback. I also learned that they could learn much more if I engaged them actively in class (active learning) instead of just lecturing at them nonstop, and if I taught course material in the context of real-world questions and problems (inquiry-based learning) instead of just asking them to trust that the material would eventually prove useful to them.

Immediately after completing the workshop, I set out to try some of the strategies it advocated, with considerable success. Most of my students are now actively engaged throughout the class, and low attentiveness and vacant faces during lectures are things of the past, even when I am covering the most difficult aspects of the subject being taught. While the outcomes of my attempts are still preliminary, they convince me that effective pedagogy can go a long way toward addressing the problems of student background and skill deficiencies that India and other developing countries currently face.

3. INSTRUCTIONAL APPROACH

I taught two courses in the 2008–2009 academic year: Network Technology I (NT1), which was taught in a traditional manner to 47 students in the fall, and Network Technology II (NT2), taught to the same group of students in the spring using an approach based on methods presented in the IUCEE workshop. NT1 deals with the fundamentals of networking, and includes physical layers, data links, network and transport layers and application layers, mechanisms for error handling, and issues related to network protocols, encryption and several other topics. NT2 deals with TCP/IP protocol stacks, Internet functions, applications like DNS, FTP, and SMTP, and security issues. There were two midterm tests in each course, with the students being allowed to retain the best of the two course marks up to a maximum of 15 points, and a centrally composed and administered final examination worth 75 points. The students were surveyed twice before the second midterm exam in the second course, once to assess their attitude toward the new instructional approach and once to determine their opinions of the primary causes of any increases or decreases in their performance from the first to the second course.

The teaching strategies adopted in the second course have been described and validated extensively in the education literature, and so there is no need to go into much detail about them here. However, relatively little evidence has been offered of their effectiveness for students in developing countries with weak academic backgrounds, and it is the presentation of such evidence that constitutes the primary objective of this study. The paragraphs that follow briefly summarize the defining features of the strategies and refer readers to sources of more information about them.

3.1 Learning objectives and study guides

A learning objective (or instructional objective) is a statement of something students should be able to do (e.g., list, explain, calculate, derive, model, solve, critique, design . . .) after receiving instruction [3, 4, 5]. Objectives should refer to actions that are directly observable, so that instructors can determine whether or not students have acquired the desired knowledge and skills. Words like 'know,' 'learn,' 'understand,' and 'appreciate' may be worthwhile goals, but they are unacceptable terms for learning objectives because they are not directly observable: students must do something observable for instructors to be able to determine how much they know, understand, etc. Objectives should also be specific enough for students to judge whether or not they are capable of performing whatever action the objective specifies.

In the second course, learning objectives were written and used to design all lesson plans, homework assignments, and midterm exams, and shared with the students in the form of study guides for the exams ('In order to do well on the next examination, you should be able to . . .'). An illustrative study guide is shown in the Appendix. The study guides included all the kinds of questions the instructor contemplated putting on assignments and exams. The lessons provided instruction and practice in all of the knowledge and skills specified in the objectives; the assignments provided additional practice in the skills; and the tests were completely consistent with the lessons and assignments.

Sharing objectives in the form of study guides had a dramatic effect on the students' performance. For one thing, it eliminated most of the guesswork associated with the traditional way of teaching. ('Here are the text chapters I have covered. Guess which content in them I think is important enough to test you on.') The objectives told the students everything the instructor considered important and eliminated the usual barrage of inquiries about what would be on the test. It is not that the study guides made things easier for the students: on the contrary, the objectives involved more high-level thinking than had ever been required of the students in their previous courses, and in effect opened the door to examination questions at a level of difficulty that most instructors would shy away from. The key was that once the students clearly understood what was expected of them, the likelihood that those capable of meeting the expectations would actually do so increased significantly.

3.2 Active learning

Active learning commonly refers to instruction that engages students in brief course-related activities in class other than watching, listening, and note-taking [6]. The activities may involve answering questions, explaining concepts or observations, solving problems or parts of problems, writing or interpreting computer code, predicting outcomes of experiments, giving additional examples of something that has been explained, identifying similarities or differences among two or more items, speculating on solutions to open-ended problems, comparing different solutions to the same problem, designing or outlining issues related to changed circumstances, extending a solution to a different context or requirement, or doing anything else that students might be called upon to do in assignments and exams. The practice and immediate feedback that students receive in these activities facilitate acquisition of the skills required to complete the course requirements successfully. Many research studies have demonstrated that active learning promotes a variety of learning outcomes more effectively than does traditional lecture-based instruction [7].

The second course in the study made extensive use of active learning. Periodically during each lecture, the instructor would ask a question or pose a problem and give students a short period of time (from 15 seconds to about two minutes) to work in small groups to formulate answers. After stopping the activity, the instructor would usually call on individuals for responses rather than simply asking for volunteers and hearing only from the same small number of students. Occasionally a think–pair-share activity would be carried out in which the students first work individually, then get into pairs to reconcile their responses.

The students engaged in a wide variety of active learning exercises, including some that called for analytical thinking, critical thinking, and creativity, the top three levels of Bloom's Taxonomy of Educational Objectives [8]. For example, following presentation of a networking scenario, the students might be asked to compare the Go Back N protocol with the Selective Repeat protocol, choose which protocol they think is the best for that scenario, and justify their choice (a critical thinking question). Most of them choose Selective Repeat. Specific cases are then presented (such as a mobile phone talking to a desktop computer or a machine talking with a satellite) where the usual implementation of selective repeat would not be effective, and the students would then go back into their groups and try to determine what a protocol should do to cover those cases. In that particular discussion the students went on to think of a protocol for solving real system communication problems, and their answers led to excellent discussions of how Ethernet and TCP work and how these protocols are continuously being improved.

Sometimes students are asked to look at a figure or diagram in a book and speculate on its purpose and importance and then, after some discussion, they read the explanation from the book. Sometimes they speculate on the differences between two items with similar purposes (such as fiber optic and UTP cables), and then they look at the differences noted in the text. This method accustoms the students to actually using their texts as sources of information. Also, when their speculations are proven right, they feel pleased with themselves.

I never had discussions like these in my pre-active learning classes, and my attempts to present high-level considerations in my lectures fell on deaf ears, except for a few genuinely interested students. Now students frequently ask and answer high-level questions in class. They may struggle with these questions but only briefly, and afterwards they are much more likely to understand the answers when they are presented. Also, the students are much less afraid that their answers may be wrong, as they have become aware that most real questions have more than one answer and the best answer in one context could be inappropriate in another. When homework assignments contain similar questions, many of the students do very well with them and take pride in completing them.

Since active learning was introduced, the amount of interaction occurring in class has been phenomenal. Interestingly, some of the students who are normally quite shy and never used to open their mouths in the class now answer enthusiastically when called on and even volunteer answers themselves. In the feedback form collected in the middle of the course, the students almost unanimously indicate a strongly positive attitude toward active learning, with some noting that now they not only enjoy the lectures more but they learn more than they ever did before.

3.3 Inquiry-based learning

In the networking course, the students learn the processes required to communicate from one machine to another, and the roles of the various devices and the layers of protocols involved in the communications. The normal instructional format—and the format used in the first course—is deductive, starting with basic definitions and operating principles, developing and implementing procedures, and finally describing problems that may occur and solutions for them. In the second course, an inquiry-based approach was followed. For each topic such as file transfer protocol (FTP), remote login (Telnet), web access (browsing), VOIP (Internet telephony), etc. a problem is first presented, with student teams being challenged to figure out what might be causing it and how they might approach solving it. The course material is then presented in the context of the problem, so that the students are taught on a need-to-know basis. This approach has frequently been shown to lead to greater learning relative to the less motivational deductive approach [7]. The trouble-shooting approach also helps the students to understand that one technique for error handling (a CRC or cyclic redundancy check, for example) may work very well for solving one type of problem but not others. At the end of each topic the introductory challenge is reintroduced and the students outline its solution; this makes clear to them how much they have learned.

3.4 Start-of-class reviews and minute papers

Each class session begins with a review of the previous class, usually as an active learning exercise. The students work in groups of two or three with one recorder in each group to summarize the points they remember from the last class. They are allowed to look at the text and their class notes and the recorders are instructed to write down important points. The students report that they find this technique quite useful in establishing a link between the current session and the previous one and helping them better understand the current lecture material by placing it in the context of the previous lecture.

Periodically the students also complete the familiar classroom assessment technique known as the minute paper [9]. At the end of a class session they anonymously write brief answers to two questions: (1) What are the main points of today's class? (2) What are the muddiest (most confusing) points? The instructor collects their papers as they leave the room and reviews their responses, looking for common patterns. As part of the start-of-class review in the next class, the confusing points that showed up most often in their responses are clarified.

4. ASSESSMENT

4.1 Performance on examinations

Fifty-three students took both the first test of Course NT1 (traditional teaching) and the first test

Table 1. Midterm examination marks in two courses

Marks	NT1	NT2*
0–3	15	1
4–6	9	7
7–9	8	8
9–12	8	13
12–15	5	16
Average	4.2	8.8

*Course taught with new instructional approach.

of Course NT2 (learner-centered teaching). The marks on both tests are summarized in Table 1. The average mark in the first course was 4.2 (28% of the maximum mark of 15), and that on the second test was 8.8 (59% of 15), an increase of more than a factor of two. (In the culture of Indian engineering education, 40% is the pass mark and 60% is very good.) The marks of 37 students increased from NT1 to NT2 by a total of 292 points and those of 16 students decreased by only 47 points. Fifteen students in NT1 scored 3 points or lower, indicating an almost total lack of understanding of the material, and only one did so in NT2; conversely, 16 students in NT2 and only five in NT1 scored in the top point range of 12–15. Since the tests in the two courses were different, the impact of the new teaching methods on learning cannot be conclusively determined from these results; however, since the second test contained more high-level questions than the first one, a positive impact can be inferred with a high level of certainty.

The final examination marks in the two courses did not show a similar improvement. The average mark was 36% in both NT1 and NT2, with 29 students earning higher marks and 24 earning lower marks in NT2. The relative lack of improvement in the final exam may be attributable in part to the fact that the externally written final exam covers only low-level material requiring primarily rote memorization to master, and the learner-centered teaching strategies used in NT2 are generally no more effective than traditional teaching at promoting mastery of such material. If the instruction in the course had included more drill in the factual material stressed on the final exam and the final examination had included questions that required analytical, critical and creative thinking, it is likely that an improvement in performance from NT1 to NT2 comparable to that observed on the midterm exams would have resulted. (This conjecture is of course purely speculative at this point, but the author plans to test it in future course offerings.)

4.2 Survey responses

The first survey asked the students anonymously to rate the effect of several teaching methods on their learning and confidence levels. The responses, which are summarized in Table 2, make it clear that the students felt positively about virtually every aspect of the unfamiliar teaching approach adopted in NT2. To varying extents, they felt that active learning, learning objectives and study guides, minute papers, and reviews of prior material improved their learning, increased their ability to pay attention and participate actively in class, and made the classes more enjoyable.

The second survey asked the students to reflect on reasons for changes in their exam marks from NT1 to NT2. Thirty-eight students submitted responses, of whom 30 improved their marks from NT1 to NT2 (Group A), 7 had lower marks (Group B), and one student had equal marks in the two courses. The results are summarized in Table 3. Even though they were asked to identify only the most important reason for their increased or

Table 2. Survey of attitudes to teaching methods

Question	1	2	3	4	5	Av.
I pay more attention to lectures (in Course NT2)[a]	0	0	1	21	26	4.52
I enjoy lectures more[a]	0	0	3	30	15	4.25
My understanding has improved[a]	0	1	8	25	14	4.08
I retain knowledge longer by reviewing the previous class session first[c]	1	0	14	32		3.66
I feel more comfortable about participating in class[a]	3	2	6	14	16	3.93
I feel more comfortable about asking questions in class[a]	1	5	10	14	15	3.83
I feel more comfortable about answering questions in class[a]	0	6	9	12	14	3.82
Minute papers are useful[a]	3	4	12	18	11	3.63
Group activities in class are useful[a]	0	0	6	7	35	4.60
The exam study guide is useful[a]	0	1	15	13	19	4.04
Learning objectives help make the instructor's expectations clear[a]	0	4	18	16	9	3.64
I find questions related to knowledge . . .[b]	0	5	15	19	5	3.55
I find questions related to application . . .[b]	1	8	12	20	2	3.33
I find questions related to evaluation . . .[b]	0	9	13	21	0	3.28
Working in a groups improved my communication skills[a]	1	3	11	16	15	3.90
Working in groups improved my teamwork skills[a]	0	4	7	12	13	3.94
My instructor's teaching has improved (since NT1)[a]	0	1	5	28	13	4.13
My learning has improved[a]	0	0	7	29	12	4.10
Overall, the new methods used in NT2 helped my learning[a]	0	1	0	16	30	4.60

[a] 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree
[b] 1 = intimidating, 2 = interesting, 3 = important, 4 = extremely important
[c] 1 = does not promote learning, 2 = is enjoyable, 3 = promotes learning, 4 = promotes learning and retention

Table 3. Survey of instructional method rankings and attributions of causes for increased or decreased test marks

Group A. Students with increased marks	
What is the most important reason for your improved marks?	
Having to think about the inquiry questions	13
The small-group discussions in class	12
My improved attendance and enjoyment of lectures	6
Having study guides for exams	4
My own efforts—nothing to do with teaching methods	0
Group B. Students with decreased marks	
What is the most important reason for your lower marks?	
My lack of ability	3
My failure to attend and participate in the lectures	3
The difficulty of the subject	3
My failure to participate in active discussions	0
My complacency and failure to keep up with the work	0
The lack of helpfulness of the study guides	0
The difficulty of the inquiry questions	0

decreased marks, a few students checked off more than one, which is why the total number of attributions in each group is greater than the number of students in the group. Of the students in Group A, the great majority attributed their improvement to the reflection or discussion that took place in response to the inquiry-based questions and/or the active learning exercises, and all gave credit to one aspect or another of the new instructional approach. Of the far smaller number whose marks decreased, none placed any blame on the new teaching methods. All students, whether their marks increased or decreased, agreed that the new teaching techniques should be deployed by other instructors.

One initially surprising result was the relatively low number of students who attributed their improved marks to having detailed study guides for their examinations. This outcome probably reflects the fact that their guides were 3–4 pages long and so filled with small details that the students tended not to use them. In subsequent course offerings the guides have been 1–1½ pages long, and the students are far more enthusiastic about them than the survey respondents were.

5. CONCLUSIONS AND RECOMMENDATIONS

A cohort of students at a small private university in India was taught two information technology courses. The first course was taught using a traditional teacher-centered lecture-based approach, and the second made use of a number of learner-centered methods, including using learning objectives to guide the design of lessons, assignments, and examinations; sharing the objectives with the students in the form of study guides for the exams; active learning; inquiry-based instruction; pre-lecture summaries of previous lectures; and minute papers. Most students in the second course earned substantially higher marks on a midterm examination. Those who did so credited one or more of the new teaching methods with their improvement, and none of the few whose marks decreased attributed the decrease to the teaching methods. The final examination marks did not improve in the second course, which may reflect the fact that the exam tested only low-level factual information while the new teaching methods led primarily to improvements in conceptual understanding and higher-level problem solving. The students almost unanimously agreed that the methods led to greater attentiveness and enjoyment in lectures, higher comfort levels regarding asking and answering questions in class, improved communication and teamwork skills, and overall greater learning.

A common contemporary academic belief is that students have been getting worse every year and this generation (the 'millennials') are generally impossible to motivate and teach, and we have no choice but to accept this state of affairs. However, as Felder and Brent [3] put it, 'While grumbling about the students may have some therapeutic benefit, it doesn't solve anything. For better or worse, these students are the ones we have to work with—we can't write off an entire generation and hope for better things from the next one.' If conventional teaching methods don't work, we have to develop better ones.

My experience in this study convinces me that properly implemented proven teaching methods can help our students, regardless of the background and motivation deficiencies they may bring to our classes. I offer the following recommendations to my colleagues who face students with such deficiencies.

- *Believe that methods exist that will enable your students to learn.* The methods are not exceptionally hard to implement and they do not require expensive technology. There are many available choices, and one can choose whichever ones suit his/her teaching philosophy and classroom environment. The only requirements are to initially have patience to implement learner-centered teaching methods with students unaccustomed to them, and to keep getting feedback on what is working and make changes as necessary.
- *Be aware that not all students learn the way that you do* [10]. Students have a variety of different learning styles and respond to different instructional environments. Most professors teach in a manner that is well suited to intuitive, verbal, reflective, and sequential learners, while most engineering students are sensing and visual learners, and many are active and global. You can help your sensing learners by balancing theory with concrete facts and data and providing ample practice in solution procedures and algorithms; show extensive illustrations and figures to illustrate points in your lectures for the visual learners ; use active learning in class to give the

active learners opportunities to practice and discuss lecture material and the reflective learners opportunities to reflect on the material; provide broad contexts for every topic you teach to help the global learners, and be methodical about presenting clear sequences of steps for the sequential learners.

- *Use active learning in every class session* [6, 7]. Active learning is an extremely effective approach to teaching the things that students usually find most difficult. Be aware, however, that some adjustment time for both instructor and students may be required before the benefits start to become apparent. (It took me several weeks before I could easily formulate the right questions or activities to address a particular learning objective.) It is also important to know which topics are most troublesome to students and so can most benefit from activities. Minute papers are a great help in making this determination.
- *Write learning objectives for every course topic and share them with the students as study guides for exams* [3, 5, 8]. The objectives should refer to observable actions and should be extremely specific and the guides should not exceed 1–1½ pages in length. If you want your students to master high-level thinking and problem-solving skills, make sure some of your objectives involve those skills and include corresponding problems on the exams.
- *Visit Richard Felder's web site [2] and look for ideas for teaching and assessment methods you might try*. The best place to start in my opinion is the column 'Random Thoughts.'
- *Don't try to change everything at once (a strong and frequently repeated recommendation in the IUCEE workshop).* Start with one or two new methods that seem promising and easily implementable, and then gradually add others, while dropping any that do not seem to be working after they have been given a fair try. Don't expect to get everything right the first time: there's a learning curve for both students and teachers.
- *Remember that what you teach is not nearly as important as what your students have learned.* I learned this lesson repeatedly in the IUCEE workshop and it has completely changed my view about teaching. I used to think that I was doing my job by lecturing with clever analogies and examples that the students could not find in textbooks, assuming that the students were learning what I was lecturing on. That was a really bad assumption for most of them. The preceding recommendations reflect a change in my focus from teaching to learning. When I made that change, my students' learning improved dramatically.
- *If you have experimented with an unconventional (in engineering education) teaching method on a challenging student population and can demonstrate that it worked well, consider publishing it*. The more success stories disseminated, the more likely the successful methods will be to become part of the academic culture. Our students will then learn more; we will enjoy teaching classes of happier and better motivated students, and most importantly, we will start producing more graduates who can make useful contributions to industry and society.

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APPENDIX. STUDY GUIDE FOR DATA STRUCTURES

To perform well on the examination you should be able to:

1. Describe practical applications of arrays, linked lists, queues, priority queues, inverted tables, hash tables, trees, binary trees, height balanced trees and graphs.
2. Select the best data structure for a specified application and justify your selection.
3. Show how insertions and deletions are done in binary search trees and AVL trees.
4. Describe and illustrate step-by-step processes for data structure operations discussed in class, such as converting from infix to postfix expression, using linked lists for implementing stack or balancing in AVL trees, and using hashing to solve the problem of collision.
5. Show how hashing functions including digit analysis, folding, and mid-square are applied to map data to an array. Select the most appropriate method for a specified application and justify your selection.
6. Differentiate between (a) primitive and non-primitive data structures; (b) axioms and operations; (c) stacks and queues; (d) hashing vs. indexing; (e) normal binary search trees and height balanced trees; (f) binary and sequential search; (g) implementing a data structure using either an array or a linked list; (h) binary trees and binary search trees; (i) binary trees and m-ary trees; (j) trees and graphs.
7. Explain criteria for comparing different algorithms.
8. Implement concepts such as Date as an abstract data type.
9. Generate a formula for accessing an element of a two- or three-dimensional array.
10. List different traversal methods for a given binary tree, find out in-order successor of a node and show need for it.
11. Formulate algorithms for inserting, deleting, and referencing elements of various data structures other than height balanced trees and graphs. Write C or Java code to implement these algorithms.
12. Design algorithms and write code for the following:
    a. Inserting an element in or deleting an element from a sorted array.
    b. Converting an infix notation to a postfix notation using stack.
    c. Using stack to determine if an expression with multiple parentheses is correct.
    d. Implement a priority queue using a combination of arrays and a linked list.
    e. Heap tree generation from an array of values and returning first few maximum values from an array.
    f. Adding two polynomials using a linked list.
    g. Implementing circular queuing using arrays.
    h. Implementing hashing using a chaining method.

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