Infusing Critical Thinking Skill Compare and Contrast into Content of Data Structures Course

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Abstract

*This paper describes some of our efforts in infusing the critical thinking skill of comparing and contrasting into a course on data structures. **Comparing and contrasting** is the process of looking at similarities and differences in order to reveal important characteristics of two objects, systems, organizations, events, processes or concepts. In comparing and contrasting two subjects, we*

- *identify relevant factors for comparison,*
- *discuss both similarities and differences between the two subjects with respect to each of these factors,*
- *investigate if there are any patterns in the similarities and differences, and*
- *make a conclusion based on this investigation.*

A skillful use of compare and contrast yields greater and deeper understanding of what is being taught. The conclusion drawn from compare and contrast can also help in designing a better system or process.

Using a set of carefully chosen examples, we demonstrate that critical thinking skills can be naturally introduced in the course content of computer curricula at tertiary level. It is expected that infusion of critical thinking skills into course content and their explicit introduction stimulates students thinking and improves their learning ability.

1. Introduction

Recently there has been an increasing emphasis on life long learning and one is expected to learn new things even long after finishing formal education. The mere transfer of knowledge from teacher to students is considered inadequate. To facilitate learning outside university and after formal education, many good thinking skills such as critical and creative thinking should form part of classroom teaching [2]. The best way to achieve this is to infuse these skills into regular course content [12]. This exercise also gives an opportunity to use active learning techniques in the class room. In this paper, we describe some of our efforts in infusing the critical thinking skill of comparing and contrasting into a course on data structures.

The purpose of specifically teaching critical thinking in computer science or any other discipline is to improve the thinking skills of students and thus better prepare them to succeed in the world. But, one may ask, don't we automatically teach critical thinking when we teach our subjects, especially engineering disciplines which need rational thinking in optimizing the design while balancing many (often conflicting) requirements through judicious trade-offs? The answer to this question is often `no' for the following reasons. All education consists of transmitting to student two different things: (1) the subject matter or discipline content of the course ("what to think"), and (2) the correct way to understand and evaluate this subject matter ("how to think"). We do an excellent job of transmitting the content of our respective academic disciplines, but

we often fail to teach students how to think effectively about the subject matter, that is, how to properly understand and evaluate it. This second ability is termed critical thinking. Due to various constraints (time being the main constraint), majority of us approach content, not as a mode of thinking or as a system of thought, but rather as a sequence of stuff to be routinely covered and committed to memory. When content is approached in this lower order way, there is no basis for intellectual growth as there are no deep structures of knowledge formed and no basis for long term grasp and control. Critical thinking, in contrast, approaches all content explicitly as thinking and weaves new thinking into old. It is thinking about thinking while thinking in order to make thinking better [10].

While there is a significant amount of literature available [3, 4, 9] on infusing critical thinking skills into course content in medicine, nursing, psychology, engineering and pure sciences like physics and chemistry, very little literature is available on such efforts in computer science. It is our endeavor to bring these issues to the notice of the computer science community.

While many university administrations encourage introduction of good thinking skills and other interpersonal skills, the initial reaction of faculty is an apprehension that introduction of these (perceived to be) extra skills eat into their classroom time. On the contrary, our experience shows that explicit introduction of these important skills stimulate the students thinking and enhance their learning skills without eating much of classroom time.

Data structures course is central to most programs in computer science, software engineering, information systems and computer engineering across the world [1, 8]. Many data structures (lists, doubly-linked lists, stacks, queues, deques, binary trees, heaps, hash tables, etc), their implementation and analysis are covered in typical data structures course. Further, most courses on data structures also discuss various graph/tree traversal algorithms. The basic nature of the course content allows for many lively debates and infusion of critical thinking techniques –in particular, compare and contrast– in a natural fashion. In this paper, we share our experiences in infusing this important critical thinking skill into our data structures course.

2. Explicit Introduction of Thinking Skills

Even though we started only recently introducing these thinking skills explicitly, we have always been using them in our teaching. Explicit introduction of thinking skills facilitates

1. students to reflect on what ways of doing specific types of thinking are good for them to practice, and what plans are the best ones for them to adopt in doing these kinds of thinking,
2. practice directed at building the habit of doing specific types of thinking, and
3. familiarity with occasions on which such thinking is appropriate or called for [12].

This helps in building a good repertoire of skills that will be useful in lifelong learning. In fact, the following principles emerged during the thinking skills movement [12] support explicit introduction of thinking skills.

- The more explicit the teaching of thinking, the greater impact it will have on students.
- The more classroom instruction incorporates an atmosphere of thoughtfulness, the more open students will be to valuing good thinking.
- The more the teaching of thinking is integrated into content instruction, the more students will think about what they are learning.

It is a well-established fact that thinking skills are most effectively taught when taught directly and deliberately [6] and there is no teaching of thinking skills in isolation from a knowledge base, nor is a knowledge base developed without a dynamic, thinking type of interaction with the content [13].

3. Compare and Contrast

The process of looking at similarities and differences in order to reveal important characteristics of two objects, systems, organizations, events, processes or concepts is called *comparing and contrasting*. A skillful use of it yields greater and deeper understanding of what is being taught. To compare and contrast skillfully it is important not to just list some similarities and differences between them but sort out the important similarities and differences and draw conclusions from them, perhaps after we have thought about any patterns they display. This

yields a deeper understanding of what is compared and contrasted. The conclusion drawn from compare and contrast can also help in designing a better system or process. For example, a software company may compare and contrast its practices with those of a more successful company to get ideas about process improvement and thereby improve its productivity.

Compare and contrast can lead to deeper insights if our attention is focused on a variety of similarities and differences and take time to think about what these similarities and differences show. Based on the breadth of similarities and differences we consider and the objective we are trying to achieve, compare and contrast may be classified into two types, *open compare and contrast* and *focused compare and contrast*. In open compare and contrast, we try to learn about the two compared and contrasted things as much as possible by identifying as many similarities and differences as possible (perhaps through a brainstorming session). This type of compare and contrast is appropriate to use when the two things are very new, such as after introducing two new related algorithms. It helps in deeper understanding. In focused compare and contrast, we have a few specific objectives and try to make a judgment based on the outcome of this process. The specific objectives determine the types of similarities and differences to consider and limit them to a relatively small set. This type of compare and contrast is appropriate to use when we have an evaluation criteria and a specific goal to achieve.

In our data structures course, we cover many data structures (including lists, doubly-linked lists, stacks, queues, deques, binary trees, heaps, hash tables, etc), and different implementations of these data structures. This makes it easy to infuse the critical thinking skill of compare and contrast very naturally in the course content.

4. Model Lesson

It is always a good practice to begin a class by stating objectives of that particular class. This model lesson has two main objectives: (a) to introduce the critical thinking skill of compare-and-contrast and (b) use that skill on stacks and queues, looking at similarities and differences between stacks and queues, thereby facilitate deeper understanding of these two important data structures.

A typical lesson with a critical thinking skill infused in it contains the following four phases.

- **Introduction** of the critical thinking skill to be used and the course content covered in that lesson.
- **Thinking actively**: applying the critical thinking skill on the course content.
- **Thinking about thinking**: reflecting on the process of applying the critical thinking skill.
- **Immediate transfer and reinforcement**: suggesting exercises for internalizing the skill through homework (perhaps an essay writing).

4.1 Introduction phase

Imagine that you went to Australia last month to spend a semester at the University of Queensland, Brisbane in Australia under the student exchange programme in place between KFUPM and UQ. A friend of yours asked you to write a detailed e-mail about your stay and new university. How do you go about this task? Where do you start? (Give a few minutes for students to come up with their answers. A typical response could be: *I start with similarities between UQ and KFUPM; between Brisbane and Dammam. I then write about features where UQ and KFUPM differ; different life styles in Brisbane and Dammam. We may do it best, point by point giving both similarities and differences*).

Imagine that you got 2 job offers (from a company A in Dammam and another company B in Riyadh) in your final semester. How do you go about selecting one of them? (Give a few minutes for students to formulate their answers. A typical response could be: *I will identify factors relevant to the decision I am making (selecting the right job) – location, salary, growth opportunity, job security, etc. I note both similarities and differences between the two jobs with respect to these factors. Make a decision based on the significant differences between the two jobs*).

In the above two examples, we are looking for similarities and differences between two situations to express our opinion clearly and in a structured manner. The first problem is a simple one and how you describe your stay and new university in Australia determines the quality of your letter, while the second problem involves a potentially life defining decision making. In life, we face quite a

few such important decision making situations. The critical thinking skill called compare and contrast is useful in those situations.

The process of looking at similarities and differences in order to reveal important characteristics of two objects, systems, organizations, events, processes, tools, techniques, algorithms, models or theories (we use "subject" to refer to any of these) is called *comparing and contrasting*. Comparing and contrasting involves analyzing features that match and features that do not match and drawing out the implications of this analysis. Compare and contrast can lead to deeper insights if our attention is focused on a variety of similarities and differences and take time to think about what these similarities and differences show. This skill is very useful in

- Making decisions
- Classifying objects – concrete and abstract
- Evaluating different approaches and solutions
- Searching for opportunities to improve through hybridization of different approaches taking positives of various alternatives.

Compare and contrast is so natural that we use it very frequently in our daily life. However, we are not thorough in doing it and some of the common mistakes are:

- We identify only a few similarities and differences
- We identify only superficial similarities and differences
- We make rough and imprecise judgments of similarity or difference
- More importantly, we don't draw out all (but just a few) implications of the similarities and differences we have identified.

The compare and contrast can be conducted effectively and the above problems avoided by trying to answer the following five questions about the two subjects being compared:

1. **How are they similar?**
2. **How are they different?**
3. **What similarities and differences seem significant?**
4. **What categories or patterns do you see in the significant similarities and differences?**
5. **What interpretation or conclusion is suggested by the significant similarities and differences?**

To illustrate the effectiveness of the above thinking map 5 questions) for compare and contrast, let us reconsider the job selection problem discussed earlier and see how skillful compare and contrast differs from a casual compare and contrast. You have two offers of job, one in your native town Dammam and the other in Riyadh. Some features of Dammam job are: salary 130K, established company, car but no accommodation, the work is related to your degree, while those of Riyadh job are: Salary 120K, new company with regional headquarters in Dubai, car and accommodation, work related to your degree.

In a casual compare and contrast, you look at the following significant factors in making a decision.

1. Salary
2. Place (close to native place)
3. Company
4. Perquisites
5. Nature of work

At a cursory look, the offers have similar strength in 1 and 5 with Dammam job on a better side. The two offers differ in 2 3, and 4, the second job has better perks (car and house) while the first job is in your native town. Since housing in your native town may not be so important, you may decide to go with Dammam job in view of established company, better salary and close to home.

In a skillful compare and contrast, you will also look at other possibly significant above factors in making your decision, like

6. Detailed nature of work
7. Growth prospects
8. Opportunities to learn

The thinking map and the following graphic organizer used in skillful compare and contrast

require you to look into as many relevant factors as possible bringing out many things explicit.

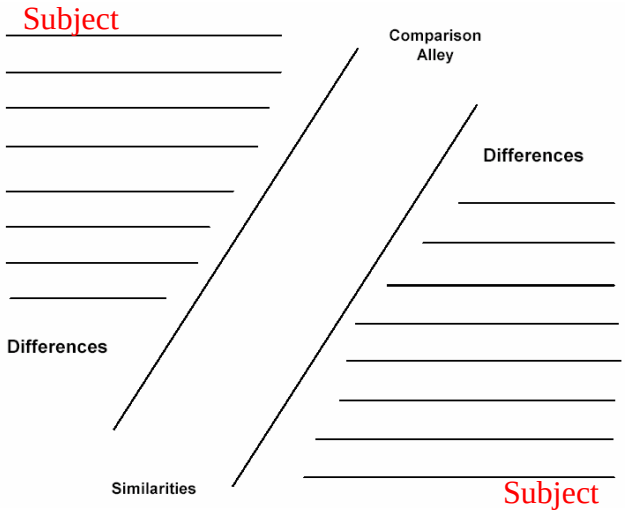

Figure 1: Graphic Organizer for open compare and contrast

Investigating further on the detailed nature of work, growth prospects and opportunities to learn, you may discover that work at the Riyadh job is on cutting edge technology giving a lot of scope for learning new things and thereby rapid growth in career. Therefore, you decide to go with the Riyadh job, which is good in the long run. In other words, skillful compare and contrast avoids the pitfalls of short-sighted decisions.

4.2 Thinking Actively

We illustrate the thinking skill by conducting an open compare and contrast on stacks and queues after introducing them and discussing their implementations.

1. **How are they similar?**

   Typical responses:

   Both Stacks and Queues are subclasses of Linear Lists.

   Both Stacks and Queues are ordered (by position, not by value) collection of data, i.e., data can only be accessed in one particular order.

   The following operations are common.

   Initialize

   Size

   Full

   Empty

2. **How are they different?**

   Typical responses:

   a. Stacks maintain a Last-In-First-Out order, while queues maintain the First-In-First-Out order of elements.

   b. All access to a stack is restricted to one end of the list, called the top of stack. Insertion and Deletion both take place at the top of the stack. On the other hand, insertion of elements is carried out at the 'Tail' of the queue and deletion is carried out at the 'Head' of the queue.

   c. Queues are more difficult to implement than stacks, because action happens at both ends.

   d. Typical applications of Stacks

   Page-visited history in a Web browser

   "Undo" sequence in a text editor

   Chain of method calls in the Java Virtual Machine or C++ runtime environment

   e. Typical applications of Queues

   Waiting lines

   Access to shared resources (e.g., printer)

   Multiprogramming, threading

   Breadth-first search

3. **What similarities and differences seem significant?**

   Typical responses:

   The differences a, d and e are very significant.

4. **What categories or patterns do you see in the significant similarities and differences?**

   Typical responses:

   In general, stacks are more suitable when we keep track of partially done operations (procedures), where the most recent one is handled before the older operations.

   In general, queues are more suitable when we serve the agents (e.g., threads) on first-come-first-basis.

5. **What interpretation or conclusion is suggested by the significant similarities and differences?**

   Typical responses:

   There are applications, where stacks are more suitable than queues and the vice versa.

In particular, stacks are useful when the access should be restricted to last-in-first-out (LIFO) basis, while queues are useful when the access should be restricted to first-in-first-out (FIFO) basis.

4.3 Thinking about Thinking

Let us stop thinking about stacks and queues and focus our attention on what we did to think about these two data structures by answering the following questions to reflect on the thinking process and internalize the thinking skill.

- What kind of thinking did we do?
- What did we do to compare and contrast stacks and queues.
    - What did you think about first?
    - Then next, next…?
- How the compare and contrast process was different from just identifying and listing similarities and differences?
    - Is this better? How is it better?
- Was the graphic organizer useful?
    - What way was it useful?

4.4 Immediate Transfer and Reinforcement

To reinforce this thinking skill introduced to the student in the class, we give an essay writing homework to compare and contrast (a) doubly linked lists and singly linked lists, or (b) iteration and recursion. This homework helps towards immediate transfer of the skill to a different situation. For later reinforcement of the thinking skill, we use this skill later in the semester to compare and contrast (a) infix notation and postfix notation, and (b) depth-first traversal (DFT) and breadth-first traversal (BFT) algorithms for graphs. We also give homework assignments and exam questions covering compare and contrast.

5. Conclusion

In this paper, we described our experiences in infusing critical thinking skills into a course on data structures. In particular, it is shown that critical thinking skills like compare-and-contrast can be naturally introduced in the course content. The benefits from the infusion of critical thinking skills into course content include the following:

1. Improved thinking skills in the students:
2. Lively classroom atmosphere:

   In view of the active learning techniques used in the course, student participation naturally improved.
3. Improved communication skills:

   Because of the writing they have to do for critical think assignments, students communication skills improved.
4. Improvement in teaching skills:

   After adapting active learning and critical thinking skills, we achieved some improvement in framing the questions. For example, the question “compare and contrast AVL-trees and B-trees” from exam paper of a few years back has become “compare and contrast AVL-trees and B-trees stating (a) similarities, (b) differences and (c) under what conditions their behavior is the same” in the recent years.

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