Abstraction, the Big Idea, and it's Significance in Science and Technology Education

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Abstract: This paper discusses the role of abstraction in science and technology education. It starts with a humble introduction of abstraction in general, while discussing the first few encounters of a learner with this idea. Significance of abstraction and the required motivation level of learner are also discussed. An expected change in the attitude of a learner at transition to higher studies is proposed. Thereafter the contribution of abstraction in the evolution of Computer Science and Engineering is discussed in some detail. Moreover a deduction of the Computer Science Curriculum is also shown along the same line as its evolution. Finally the paper concludes with emphasizing the importance of understanding links between different layers of abstractions.

Keywords: Abstraction, computer science, learner, link

I. INTRODUCTION

THE process of abstraction is so naturally embedded in us that we never notice it. Abstraction is very strongly associated, in some or other way, with all our learning process. Before, any further discussion let us see the meaning of *abstract* in general, as it appears in the dictionary [9].Existing in thought or theory rather than mater or practice, extract, summarize, theoretical, unapplied, pure, essence, outline, take away, remove details, draw out etc.

Humans, right from their early childhood, are expert in extracting meanings, summarizing observations and drawing inferences. Collectively we can say, humans are versed in *abstracting* ideas from the environment and circumstances. All our perception and memory is an outcome of this *process of abstraction* which is fully embedded in us. Human vision, one of our most powerful sensing mechanisms, is an excellent example of this process of abstraction. *What we perceive is always less than what we see!* When an image is formed at retina a large amount of processing takes place in the eye itself and only the *approximate* information is passed to our brain [6]. We can never perceive all the details present in an image. We can only retain the *essence* of the image. Our retention is of the major detail in the image; all the minute details are *removed*. We can consider this as a first level of abstraction which is actually the *extraction* of the important features of an object being observed. We don't need any practice to learn this art. However, there are some abstractions which is achieved only through some practice.

II. SOME EARLY ENCOUNTERS

Process of abstraction is so finely integrated into our thought process that a clear classification into different layers is only artificial. Following is a brief review of some of the very first abstractions, which appears difficult to an amateur learner. Though, only few of them are discussed we believe they are good representatives of a bigger class of abstractions.

A. Learning to associate meaning with symbols

Our understanding of the human brain is far from being complete. It's very limited in order to explain many of the interesting properties such as memory and recall mechanism. It is known from the studies that a significant amount of *abstraction* takes place before storing any information in the brain. However the exact storage mechanism is not known [6]. Once we store the information we need some sort of querying mechanism to recall it next time. This is where, we believe, a *second layer* of abstraction is needed. Though, this abstraction comes only through some practice. We create this abstraction by practicing to associate symbols/words to the meaning extracted. Instead of specifying the exact shape, size, texture and colors we now use only the name of objects, we wish to recall. In this process we sacrifice some details; we *approximate* the shape, size, texture etc. and map similar appearing objects to the some symbol/word. This way of representing the real life objects/ideas is more compact and words are now capable of representing a large amount of information. The loss of minute details is a big loss with respect to the information content; however, an unavoidable loss, as our brain can not process all the details presented to it by the environment. To work with this huge data generated by the surrounding and conclude something significant this *second abstraction* is absolutely essential. We can not work with the ideas if we don't have a compact representation for it. Every idea/object must have some compact representation. This second abstraction, we are talking about, is created by learning any natural language. It is no more embedded in us and everyone will agree that learning a language comes only with some practice. Most of this learning happens in our early life during the age of 4-5 years. This abstraction layer is the most significant for all our thought process which involves manipulation of symbols and relationship between them.

B. Numbers, Arithmetic and Algebra

Mathematics, in its pure form, is too abstract for a beginner to comprehend. There fore, it is always introduced by showing its relationship with real objects.

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For example, we motivate a child about the ideas of comparison and counting by citing some real life objects. Only then, we introduce the concept of *numbers* as a tool for counting.

In brief, the order of presenting ideas to a child is very crucial. The desire to learn a topic must be generated first by introducing, as early as possible, the practical side of the subject and some of its most interesting applications. Only then, the ideas shall be introduced. The pace at which topics are introduced is also of great importance. We shall postpone the introduction of any new topic, until students have acquired some freedom and readiness in the use of symbols/ideas already presented. This readiness comes only with time and continuous practice from learner's side.

Once we learn numbers the next obvious topic is Arithmetic. Arithmetic deals with the *explicit* numerical quantities connected by the sign + and -. Quantities to which the sign + is prefixed are *additive* and those to which the sign – is prefixed are *subtractive*. In arithmetic the sum of the additive terms is always greater than the sum of the subtractive terms; and if the reverse were the case the result would have no Arithmetical meaning. In Algebra, however, the sum of the subtractive terms may exceed the sum of the additive terms. This freedom is achieved due to a process of *abstraction* which yields Algebra from Arithmetic. Now let us see the following two fundamental rules from Algebra [2] to further illustrate the need of abstraction.

Rule-1: When a number of Arithmetical quantities are connected together by the sign + and -, the value of the result is same in whatever order the terms are taken. This also holds in the case of Algebraic quantities.

Rule-2: When an expression within brackets is preceded by the sign -, the brackets may be removed if the sign of every term within the brackets be changed.

Are these Rules valid? If the Rules are valid are they absolutely essential? We feel very comfortable about the above two rules. They seem to be obvious and we readily accept it, probably, because it always worked and produced consistent results when we used them. We never questioned its validity, including the first time it was introduced. When we learned these rules emphasis was given to the *process* of using it rather than the *concept* behind it. Probably, we were not matured enough to raise the question of validity or significance at that stage.

We can do all the arithmetic and algebra without using these rules, however, the process becomes too lengthy and involving [2]. Every time to evaluate even a simple expression we will need to associate some physical meaning to the terms and use the very primitive conception of addition, subtraction, multiplication and division. For a complex expression the task of evaluation becomes so involving that it is practically not feasible. Therefore, to make our life easy we abstracted these rules from the observations we had. Use of these rules is practically unavoidable, though theoretically not necessary.

There is no harm using the rules; provided, at least once, we explore the connection of these seemingly abstract rules to the fundamental observations [2]. This increases our faith in using those rules; moreover our knowledge of the rules becomes mathematically justified and complete. This is referred, in this paper, as *establishing link* between the different abstraction layers.

C. Concept of imaginary Quantities: Complex Numbers

Integer is an extension of the Natural number system. Prior to this extension, idea of negative numbers appeared to be absurd. Concept of fraction was accepted due to the abstraction of Integers to Rational numbers. Further extension carried the Rational numbers into the Real number system and the existence of Irrational numbers was readily accepted. From our experience we know that each of these generalizations were essential for the development of Science and Technology. We use mathematics to model an event and also to predict its outcome. Most of the events, we model, have its origin in some natural phenomenon. All the measurements related to a natural event produce real quantities. The outcome of these events is also real. Real numbers are sufficient in such circumstances. Therefore we are tempted to belief that the process of *generalization* might have come to its natural end and no more abstraction is needed. This was the common belief for many years [3]. However today we see yet another abstraction in the form of Complex number, which enables the acceptance of Imaginary quantities (square root of negative numbers).

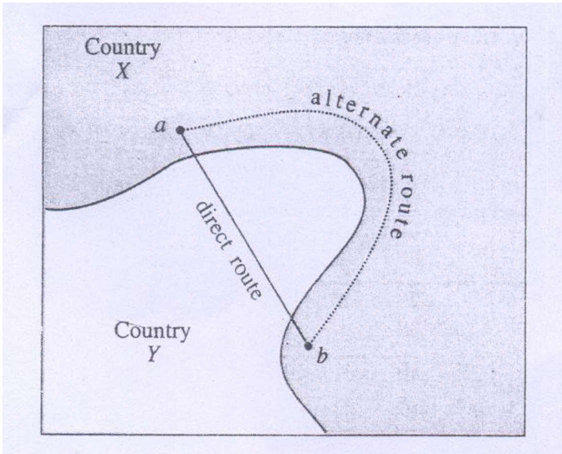

Fig.1. Use of complex numbers can reduce the work [1].

The benefit of abstracting real numbers to complex systems can be best described [1] by an analogy with two neighboring countries X and Y, as shown in Fig. 1. Our aim is to travel from *City a* to *City b*. Shortest route is through Country Y, although the journey begins and ends in Country X. We may, if we desire, perform this journey by an alternate road that lies *exclusively* in X, however this alternate road is longer. In mathematics we have a similar situation with real numbers (Country X) and complex numbers (Country Y). All real-world problems must start with real numbers, and all the final results must also be in real numbers. But the derivation of result is considerably simplified by using complex numbers as an intermediary. It is also possible to solve all real-world problems by an alternate method, using real numbers exclusively, but such procedure would increase the work needlessly. Today we see complex number as an essential tool while dealing with a large number of problems originating in the study of control systems, quantum mechanics, signal analysis, fluid dynamics etc. We already started thinking beyond complex numbers.

Researchers are now exploring the concept of *quaternion* and its possible applications.

D. Physical Sciences: Unified Theory

The ultimate goal of physical science is to capture the underlying structure in the Universe that can explain all the phenomenon of nature. We are always in the search of theories that can explain more number of observations than the previously known theories. This process of transition from one theory to another can also be seen as an attempt of generalization. In this process of generalization we are finally in search of a Unified theory that can explain every phenomenon in the Universe. The Laws in physical sciences are given as relationships between already defined physical quantities. At this point one should be very careful in distinguishing between *definitions*, *assumptions* and *Laws*. No definition can be absolute in pure sense. We always define new idea in term of the previously known ideas. This is true in physical sciences as well. We define new physical quantities in terms of already known physical quantities. Assumptions are the set of statements in a theory which is considered to be always true. No one can question the validity of assumptions. However a theory with less number of assumptions is always considered to be a better theory. Laws in a theory are useful statement or relationships that generalize observations and experimental results. For a theory to be successful all the laws must be deducible from the assumptions. Some theories are difficult to understand than others. This difference is due to the assumptions. If the assumptions match with our intuition we feel comfortable and it is easy to understand the theory.

E. Change in attitude: Self Motivated

In most of the modern theories the assumptions seems to be abstract and unreal. However we accept these theories because they explain a bigger set of phenomenon with less number of assumptions. Theory of relativity and Quantum theory are good examples of this category. The tools used in these theories are rich in structure and it takes quite some time to feel comfortable using it. These areas are very abstract to work with. We can not find immediate connection with reality; however in some cases the final conclusions can be verified by performing experiments. Therefore, a high motivation level is needed to work in these fields. Most of the contribution to the field comes from Mathematician, because they are habituated to this kind of rigorous and abstract analysis. Students willing to peruse higher studies in these fields need to develop a similar taste. The readiness to accept abstraction and work with it is therefore the key skill for success in the higher studies.

III. ABSTRACTION AND COMPUTING

When we look at the Modern digital computers, it is very hard to believe that the underlying logic behind it was discovered some 70 years back. We have come up with the faster version of computers with ever increasing memory capacities, however their *power of computation* is still the same as Turing Model introduced in 1930's. The development of various models for computing devices is the best example of working with abstract ideas [7]. Major portion of the research, regarding best possible computing model, took place much earlier to the realization of even the very primitive digital computers. The only significant improvement, we have seen in last seven decades, is in terms of compact, reliable and faster hardware for computing.

A. Software abstractions: A top view of computing

The discipline of computer science which deals with the abstract model of computers is known as *Theory of Computation*. Most of the work in this field is again attributed to mathematicians. They worked on various model of computers, irrespective of its realization, and tried to analyze their computation power. *Computation power* of a computing device is measured in terms of all the different classes of problems that can be solved using that device. Various models were suggested by researchers. However when classified, based on the computation power, many of the different appearing models turned out to be equivalent. Finite state automata, Pushdown automata and Turing machine are the models that encompass almost all the models that were proposed during that time [4]. Communicating with the device was another big issue in computation theory. In general, all these models have few control states, a memory element and some transition rules to change the configuration of the device. All the models that came before Universal Turing machines were embedded in nature. They could perform only a specific kind of task. There was no provision of programming the device to perform a task. The idea of programming became feasible with the search of Universal Turing machine. This was a huge leap, as we could use the same device for different purpose. Now the main emphasis turned to the aspect of *efficiently instructing* the device to get a work done. Our desire to instruct the device in a language, which is similar to our own language, led us to another layer of abstraction. Concepts of *programming languages* and *Compilers* are the results of this abstraction. At this stage we could instruct our device to get some work done. However we had to take care of many other issues like I/O, resource utilization, scheduling, memory management, data management etc. All these issue forced the programmers to be an expert of Computers. This difficulty in handling the device was taken care by yet another abstraction that we know as Operating Systems. With the development of OS the task of interacting with the Computers became easy and as a result we witnessed a sharp increase in the number of users of this device. Now this device came into the hands of common people. The scope of this device broadened from scientific computing to gaming and other mode of entertainments. Today digital entertainer is a more appropriate nomenclature for digital computers.

B. Hardware abstractions: A bottom up view

There is a completely different way of looking at digital Computers. We call it bottom up view. Here we start with the basic physics and try to arrive at the actual hardware of Modern Computers [8]. In other words, we are interested in exploring the feasibility of a computing device starting from the knowledge of basic physics. Following are the possible steps in this bottom up abstraction.

At the bottom most layer, we have huge number of electrons and other elementary particles interacting with each other. At this subatomic level the interactions are best described using the law of quantum physics. However the description of a system with so many components using the quantum physics becomes practically impossible.

Here comes the first abstraction. Instead of locating and studying individual electrons, we study their motions in large groups and try to approximate their behavior in the form of Kirchhoff's Law. This large scale movement of charged particles is known as electric current. We can predict and control currents in a given circuit using these laws.

Next abstraction comes from the study of semiconductor devices. We use these devices to create diodes and transistors. Further these components are connected in suitable way to implement some very primitive Logic Gates. More complicated logic functions are created using these fundamental Gates [5]. Continuing in the same way integrated circuits can be manufactured and used for the development of Arithmetic, Logic and Control Units for the computing device. Using the same logic we create sequential circuits which act as memory for our computing devices. Once we have memory and Control Unit we are capable of realizing any of the abstract models we discussed.

IV. AN OBVIOUS DEDUCTION

From the above discussion it is clear that a study of Computing is full of abstractions. An important issue is selecting between top down and bottom up approach. A bottom up approach seems to be more obvious, since a student entering an Engineering course is expected to be familiar with the basic physics. He can appreciate the initial layers of bottom up abstraction very easily. However strictly following the bottom up approach expects a lot of patience from the student side. He needs to wait for long time before he can learn using this device. This may create some passiveness in the students. Students must introduce to the different facilities provided by a modern computer. This can be achieved by designing an introductory course emphasizing the most interesting and exciting application of the Digital Computers. Moreover, we can also introduce students to one of the programming languages. This will further enhance their interest and knowledge about the capabilities of computers.

At this stage, students start feeling comfortable with computers. They start believing about the feasibility of such a device. This is the proper time for introducing some more abstract subjects like Automata theory, Compilers, Algorithm, and OS. At this stage they will be motivated and matured enough to deal with the complex and abstract aspects of computing.

V. CONCLUSION

Curriculum for Computer science and Engineering must reflect the different abstraction layers discussed in this paper. Moreover the order of presenting the topic shall be given special attention. Some suggestion regarding the order is presented in the last section. Special care must be given to establishing the link between the different layers of abstractions as it enhances the belief of students in working with the abstractions. Moreover, the pace at which topics are introduced must provide sufficient time to a learner for adapting to the newly introduced abstraction layers.

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