Meaningful Learning of Problem Transformations for a Grid Graph

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***Abstract* - This paper presents an analysis of the problems faced while learning Inter-Domain transformations of problem solutions. Given the solution to a problem in one domain say Game Theory; one can slightly change it to solve a similar or even a completely different problem from another domain say Computational Biology. Our work focuses on a Grid Structure which is a special DAG (Directed Acyclic Graph) and presents the analysis of the problems that learners face while dealing with this DAG to solve Inter-Domain problems. We show that the solution to the Longest Path and Shortest Path problems in a DAG corresponds to the solution of diverse problems coming from different disciplines. The Manhattan Tourist Problem in Game Theory, Longest Common Subsequence problem in Algorithms, Longest Increasing Subsequence problem in Mathematics, the Sequence Alignment of DNA in Computational Biology, and a number of other problems from Graph Theory can be solved using the same Grid. Learners understand independent problems but find Inter-Domain transformations to be extremely difficult. Our work focuses on analyzing the problems that hinder meaningful learning in this perspective.**

Index Terms - Computational Biology, Directed Acyclic Graphs, Homology, Interdisciplinary Problems, Meaningful Learning, Problems of Learning, Sequence Alignment

INTRODUCTION

It is extremely difficult to understand the activities that take place in an individual's mind when he tries to learn new concepts and knowledge. Ausubel's Cognitive learning theory presents an important principle of meaningful learning [1]. The individual either performs rote learning or he meaningfully understands the concept to be learnt. Meaningful learning takes place when a learner tries to develop linkages of the incoming knowledge with the previously existing knowledge in his brain. Researchers have presented various different views regarding the processes that take place inside a human's brain when he tries to learn a concept [1, 2, 3 and 4].

Over the last few decades owing to high paced advancements in almost every field of life an enormous magnitude of knowledge is being frequently poured into the existing body of knowledge in this world. In order to help individuals to deal with such huge amount of knowledge we need to develop the intellectual tools and learning strategies so as to empower the learners to become self-sustaining and life long learners [5, 6].

To fulfill the above goal, a lot of researchers tend to address the following important issue: What are the problems that hinder meaningful learning? They rightly believe that if the problems creating hindrance to meaningful learning are figured out and remedied; the learners can be equipped with far better capabilities of independent as well as collaborative learning. Therefore not only psychologists rather many other scientists from different fields of academia are working on identification of problems that individuals face while understanding key concepts from diverse fields of life and academia [7, 8 and 9].

It has been observed that meaningful learning gets even more complex and difficult when a learner is simultaneously dealing with problems from multiple domains. This might just be due to the short term memory overflow but no clear evidence exists which explains the prospective issues that might hinder meaningful learning under a situation of dealing with problems that require simultaneous usage of knowledge from multiple domains.

In this paper we try to analyze and figure out the problems that a learner might face while learning inter-domain transformations of problem solutions. In other words there are cases in which given the solution to a problem in one domain say Game Theory; one can slightly change it to solve a similar or even a completely different problem from another domain say Computational Biology. Learners find a lot of difficulties in meaningfully learning such transformations where a slight modification can provide solutions to other problems which might apparently be completely different. We have based our study on problems that require a similar platform structure for their solution. The concept that we focus on is a grid like structure which is a special directed acyclic graph.

In order to meaningfully understand concepts, a learner might develop mental constructions. These mental constructions are in the form of networks of concepts and propositions, also termed as semantic networks or concept maps [1]. Meaningful learning takes place when an individual is able to subsume new concepts by establishing appropriate and rich connections of the newly acquired concepts with the previously existing knowledge in his brain [3]. In this paper we will frequently motivate our discussions using sample mental constructions in the form of concept maps.

The next section describes details of the grid structure under consideration. This will be followed by defining the exact problem and scope that we intend to address. We will then present the proposed strategy that we adopt to identify the problems that can hinder meaningful learning of inter-domain transformations of problem solutions. We will also discuss the experimental analysis on a group of 32 learners. We will conclude the paper by summarizing our findings and future work.

STRUCTURE OF THE GRID UNDER CONSIDERATION

The grid that we use is a special form of directed acyclic graph in which edges can be directed in either left to right direction, top to bottom direction or top-left to bottom right.

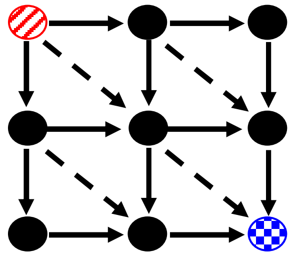

FIGURE 1.GRID UNDER CONSIDERATION
SAMPLE STRUCTURE OF THE GRID GRAPH WHICH IS A SPECIAL FORM OF DAG. ALL THE INTER-DOMAIN TRANSFORMATIONS OF PROBLEM SOLUTIONS WILL BE CARRIED OUT ON THIS STRUCTURE

Figure 1 shows the structure of the grid graph under discussion. The graph has a single source node at the top-left corner (shown filled with slanting lines) where there are no incoming edges, and a single sink node at the bottom-right corner (shown filled with checker board pattern) from which no edges are outgoing edges.

Depending on the problem to be addressed the number of nodes in this graph can change, but the orientation of the edges will remain the same. Another thing which might vary is the presence of diagonal edges. These edges might or might not be present in every case that we discuss. This being the reason, the diagonal edges are shown dotted. The graph can be a weighted graph. We will shortly mention that the weights on the edges of the graph are an essential factor that helps in achieving the problem solution transformations.

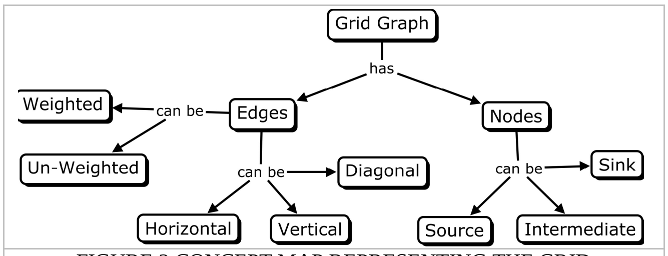

FIGURE 2.CONCEPT MAP REPRESENTING THE GRID

A mental construction that should be present in the mind of a learner is reflected in Figure 2. It actually shows various physical concepts relevant to the grid. In the inter-domain transformations of problem solutions we will show that if a learner is able to meaningfully relate these physical concepts to the concepts in the problem which he is addressing, then the solution becomes comprehendible, evident and understandable.

SCOPE OF OUR STUDY AND DETAILS OF THE TRANSFORMATIONS

To carry out our study, we have selected three problems from different domains that use the grid graph as the common structure and have tried to identify the problems that the learners face in the inter-domain transformation of problem solutions in scope of these three problems. Here we first discuss the three problems briefly. This discussion is important as it serves as the prerequisite for the work which is presented in this paper.

I. Manhattan Tourist Problem from Game Theory

This problem has been phrased differently by different people. An interesting statement of this problem is as follows:

Given a city with some of the roads which are very exciting and pleasing where as other are normal roads. A tourist wants to travel from a special place say A in the city to a special place say B but on his way he wants to cover maximum number of interesting and pleasing roads. Furthermore the roads in the city are considered to be unidirectional and of the same structure as the structure of directed edges in the grid graph of Figure 1 [10]. We will soon show how this problem is mapped onto the concepts of the grid graph.

II. Longest Common Subsequence from Algorithms

The problem of Longest Common Subsequence (LCS) is to find a longest subsequence which is common to two given strings. Consider the following example:

String 1 = ATCTGAT
String 2= TGCATA

Here TCTA is the subsequence which is common to both the strings [10]. Notice that the alphabets in the subsequence may not be consecutive alphabets within the given strings. We will provide a mapping of this problem to the grid graph as well.

III. DNA Sequence Alignment from Computational Biology

Given two DNA sequences our problem is to find the homology that is the similarity between the sequences to find out that how closely the genes of the DNA under consideration match with each other. The more the matching the more similar the species are to which the two DNA sequences belong [10]. Again this problem can be solved using the grid graph.

The scope of our work will therefore be to pinpoint problems that hinder meaningful learning when the learners are taught the above concepts and the Inter-Domain transformations that link the solutions of these problems from various domains.

We now present the details that how the grid graph can be helpful for establishing the solution of all the three problems listed above. We will also provide mental constructs that should be present in a learners mind to understand these transformations and the links between them.

I. Solution to the Manhattan Tourist Problem from Game Theory

Consider the city to be represented as a grid graph. The nodes in the graph represent various intermediate interchanges and turns in the city, while the edges represent the unidirectional roads of the city. The special place A where the tourist is present corresponds to the source of the grid and the destination special place where the tourist wants to reach corresponds to the sink of the grid. Now assigning the weights to the edges is a crucial step. Let us propose one strategy to put the weights. Mark all edges that represent interesting and exciting roads to be of weight 1 and all other edges to be of weight 0. Now the Manhattan Tourist Problem reduces to the problem of finding longest path in a DAG from the source node to the sink node. Another way in which the problem can be addressed is to put -1 weight on the edges which represent interesting roads and +1 weight on all other edges and then find the shortest path from the source to the sink. Both these strategies can work. Notice that just by knowing that which concept in the given problem maps to which concept of the grid graph, the solution to the problem was reduced to a simple problem of finding longest or shortest path in a DAG the algorithms for which are already available [10].

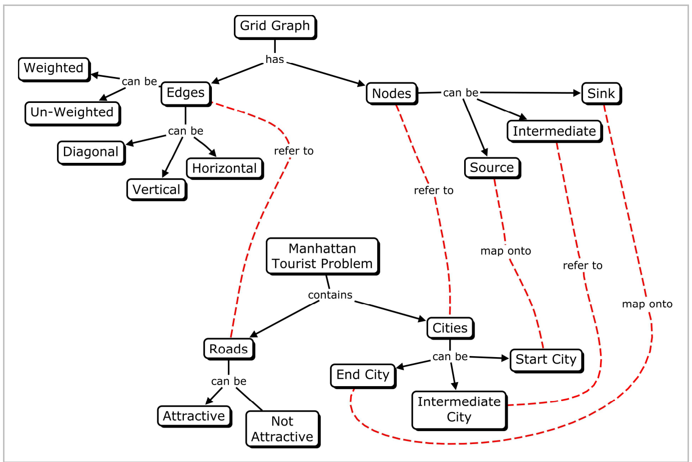

FIGURE 3.CONCEPT MAP REPRESENTING SOLUTION OF MANHATTAN TOURIST PROBLEM USING THE GRID

Figure 3 shows the mental constructs that we think should be present in the learners mind along with appropriate linkages.

II. Solution to the Longest Common Subsequence Problem from Game Theory

There can be various metrics that determine the similarity between two strings. Some of them focus on finding the matching alphabets; others are based on computing the edit distance which suggests that how many minimum insertions and deletions of alphabets from one of the strings will make it exactly the same as the other given string. The lesser the insertions and deletion, the more the similarity between the strings. A structure that helps in understanding this notion is called an alignment matrix [10].

Before presenting the solution of LCS in a grid graph lets first quickly get to know what the alignment matrix is. Consider the strings below whose similarity has to be computed.

String 1 = ATGTTAT
String 2 = ATCGTAC

An alignment matrix contains two rows as shown below [10].

A	T	-	G	T	T	A	T	-
A	T	C	G	T	-	A	-	C

These rows contain the given strings in a specific format. Columns that contain the same letters in both the rows are called matches. The columns containing one space are called indels with the columns containing the space in the top row called insertions and the columns with a space in the bottom row deletions. For example in the above alignment matrix deleting a C from String 2, inserting a T after T, then inserting a T after A and deleting the last C will convert string 2 to string 1. Hence four insertions/deletion operations.

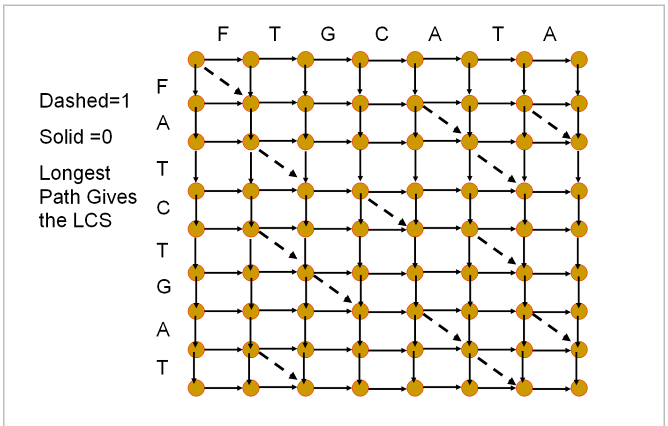

FIGURE 4.LCS REPRESENTED ON A GRID

Now consider a grid graph which can be labeled as shown in Figure 4. If we put +1 weight on the diagonal edges where the strings are matching, assign a weight of 0 to all other edges and then find the longest path from the source to the sink. This longest path will try to pass through maximum number of diagonal edges and hence will give us the path whose length will be equal to the maximum number of matching alphabets in the strings. We can get the actual sequence by traversing back from the sink to the source. Even if we want to find the edit distance between the two strings as a different similarity metric, that can also be done using the same formulation. Notice that edit distance was found through the alignment matrix. If you closely observe the grid and the alignment matrix, you can infer the relationship between the two. The alignment matrix represents a path from the source to the sink in the grid [10]. Matching symbols in both stings correspond to the diagonal edges, while indels correspond to horizontal and vertical edges. Therefore not only the longest common subsequence problem rather other string matching problems can also be solved by using the grid graph. In formulating all these assignment of weights to the edges and the selection of appropriate existing algorithm (longest path, shortest path) are the crucial steps which require innovation and skill which comes with meaningful learning.

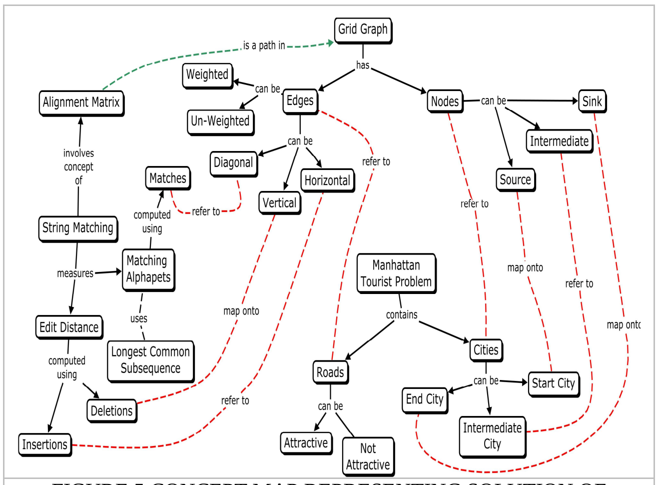

FIGURE 5.CONCEPT MAP REPRESENTING SOLUTION OF MANHATTAN TOURIST PROBLEM, LCS AND STRING MATCHING PROBLEMS BY A GRID GRAPH

Figure 5 shows the mental constructs that we find essential to be present in the learners mind to meaningfully learn this solution.

III. Solution to the DNA Sequence Alignment Problem from Computational Biology

To solve the DNA Sequence Alignment Problem using the grid graph we use the obvious mapping that DNA Sequences can be represented by strings of alphabets A, T, G, and C. Hence the solution to the sequence alignment will be nothing more than that of the string matching problem.

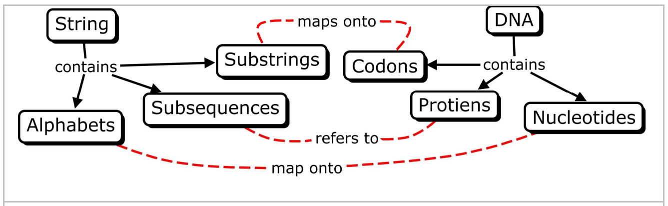

FIGURE 6.CONCEPT MAP REPRESENTING MAPPING OF MOLECULAR BIOLOGY CONCEPTS TO CONCEPTS IN STRINGS

Another thing which we think should be present in the learners mind is the mapping shown in Figure 6. After having this mapping and the knowledge of computing the LCS by a grid graph, finding the similarity between two given DNA sequences shouldn't be a problem. Depending on our approach to find the similarity, assign weights to the edges of the grid and find accordingly the shortest or the longest path depending on the criteria we used to assign the weights.

Figure 7 shows the complete mental constructs and linkages which we propose to be present in the learners mind after having studied these three problems and their solutions using the grid graph.

Having discussed the transformations that are required to map all these three problems to a grid graph and presenting the mental constructs which we propose should be present in a learners mind while meaningfully understanding these transformations, we now discuss the experiments we carried out to find out that what problems do learners face while trying to meaningfully learn these concepts.

It is interesting to note that not only the solution of academic problems are mapped to the grid graph rather many real world problems like, traffic scheduling problem, project resource planning, optimal navigation problem can be mapped to grid graphs once we get to know the correct assignment of weights to the edges and appropriate modification to the structure of the grid graph.

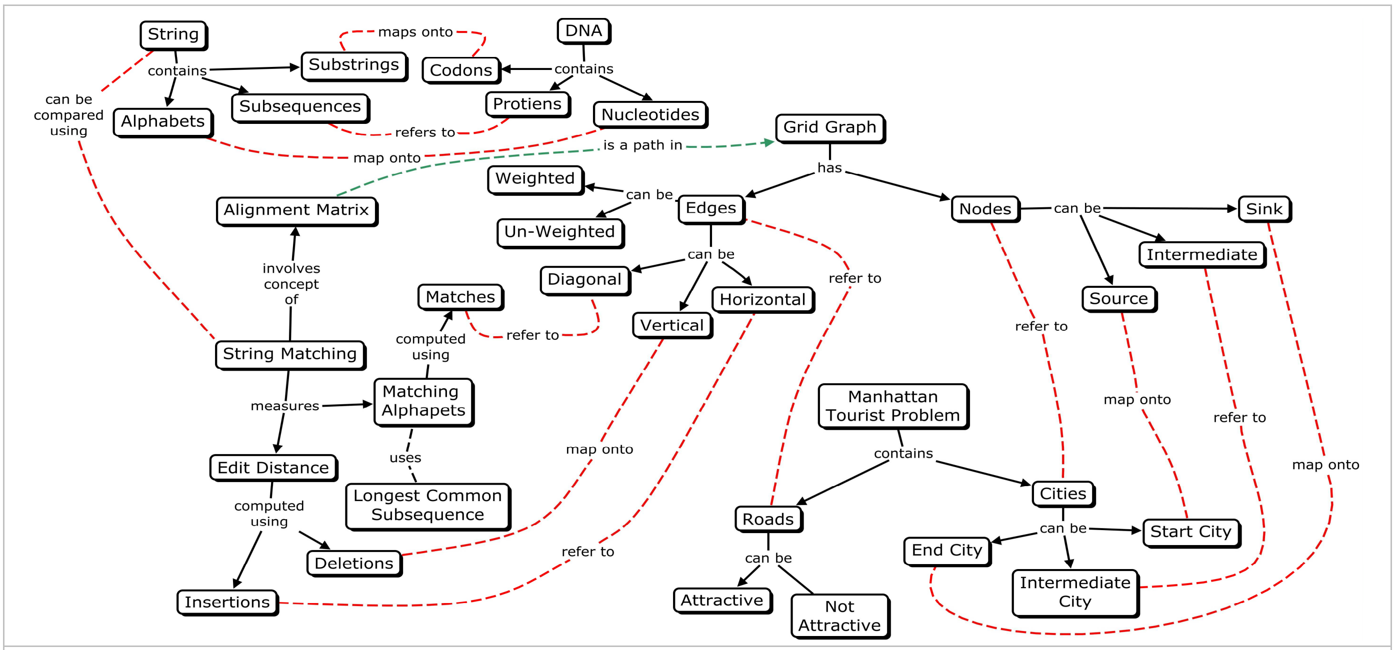

FIGURE 7.CONCEPT MAP REPRESENTING SOLUTION OF MANHATTAN TOURIST PROBLEM, LCS, STRING MATCHING PROBLEMS AND DNA SEQUENCE ALIGNMENT PROBLEM BY A GRID GRAPH

Our Experiments and Hypothesis About the Problems Faced by Learners

To find out the prospective problems in meaningful learning in this perspective, we adopted the following strategies and conducted the experiments on a group of 32 students to support our claims.

TABLE I
QUESTIONS FOR THE EXPERIMENTS

Ask learners about correspondences. Given a problem, what concept of a problem maps to what physical feature of the Grid Graph
Having taught Edit Distance as the similarity measure, ask the learner to modify the algorithm, as well as the Grid Graph weights to come up with an answer in terms of Matches For Example What should be the algorithm? Longest Path? Shortest Path? What should be the weights on horizontal edges? What will these weights represent? What should be the weights on the vertical edges? What will these weights represent?
Having taught Longest Common Subsequence, ask the learner to solve the longest increasing subsequence problem using the Grid Graph For Example What should be the two strings? What should be the weights? What edges do we need? Horizontal and Vertical? Diagonal? Etc…

We taught these transformations to the learners and then tried to devise questions that apparently seem to be totally different problems but can just be solved by slight modifications to the grid graph weights, labeling or in some cases to the structure of the grid graph itself. We will just phrase a few of our designed questions and will not include detailed solution to our questions in this explanation as it is not required. We made various questions of varying difficulty. Table 1 lists three of them.

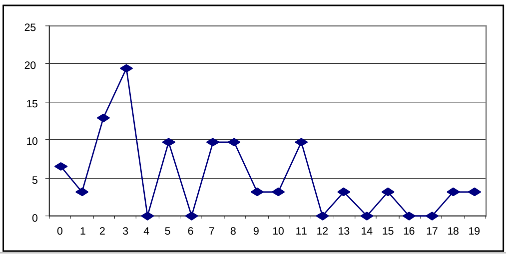

FIGURE 8. STUDENTS' PERFORMANCE IN SOLVING THE LOCAL DNA SEQUENCE ALIGNMENT QUESTION.

We devised other interesting questions like Local DNA Sequence Alignment as opposed to Global DNA Sequence Alignment problem. Figure 8 shows the results of students' performance to the Local DNA Sequence Alignment [10], [11] Problem where they had to come up with an algorithm to find a sub-region within the Global DNA sequence which is locally similar. The horizontal axis shows the number of marks scored and the vertical axis show the percentage of students scoring these marks. Notice that very few of them were able to reach the solution. This was for sure a difficult problem for them as they had to make changes to the structure of the grid graph [10]. The results clearly show that the students weren't able to make the correct change to the structure in general. We discussed that with the students and found out that the prior knowledge regarding the structure of the grid graph was hindering them to modify the already learnt structure. Hence the bias caused by the prior knowledge also matters a lot in meaningful learning and this bias should be kept to a minimum.

We posed the questions in table 1 to the learners in course exams, structured interviews and think aloud protocols. The collected data was used to build our hypothesis about the identification of problems that hinder meaningful learning. Having asked these questions and analyzing the results in light of cognitive psychology we observed that learners usually try to rote learn a given transformation and don't pay actual attention to what is the underlying phenomenon which yielded that transformation.

We asked the learners to develop concept maps of the learnt knowledge and found that in most of the cases though the learners were able to identify the individual concepts independently but were not able to develop the correct propositional links between the concepts. This suggests that they tend to learn the concepts independently and do not pay a lot of attention to the similarities and differences between those concepts and the inter-relationships of those concepts are overlooked while learning.

A few of the learners were totally blank when presented with new concepts. Many learners were confused when they were asked to find the longest increasing subsequence from a given sequence of numbers using the grid graph.

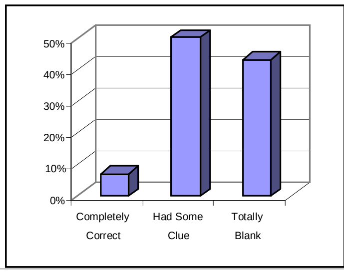

FIGURE 9.RESPONSE OF THE STUDENTS TO THE LONGEST INCREASING SUBSEQUENCE PROBLEM

They were stuck with the prior knowledge that the grid graph can be labeled using two sequences while in the problem of finding the longest increasing subsequence only a single sequence of numbers is provided. The solution to this is that sort these numbers and place them as the second sequence in the grid and again find the longest path from source to the sink. But very few people were actually able to figure out the solution easily. The results are shown in Figure 9. This reflects that previous knowledge serves as a functional fixedness while meaningfully learning the transformations.

Moreover a major problem that learners face is the assignment of weights to the edges. This is primarily because they rote learn the assignments of the weights without focusing on the fact that the label which they have assigned as a weight to an edge represents something in the concepts of the problem. For example when we assign +1 to edges corresponding to the interesting roads in the Manhattan Tourist Problem the learners tend to pay least attention to the fact that what this +1 corresponds to rather once the label is put on the edge they just think of this problem now as a problem of longest path in graph theory and don't realize that these weights correspond to some concept from the problem at hand.

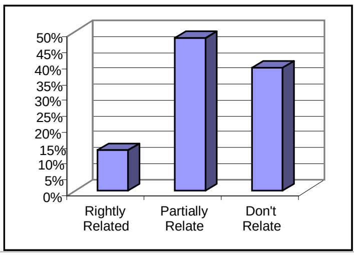

FIGURE 10. SURVEY RESULTS DEPICTING IF THE LEARNERS RELATE THE SYMBOLS USED IN THE SOLUTIONS TO ACTUAL REAL WORLD PHENOMENON

We posed various questions to the students and found out that only 13% of them correctly related the symbols on the edges to the concepts in the problems, 46% were able to relate the symbols to some extent where as 41% of them had no idea of the relation of the symbols to the concepts of the problem at hand. Figure 10 shows the results of this survey in this regard.

Another thing that hinders meaningful learning is the tendency of the learners to think about the solution as canned procedures rather than meaningfully understanding the concepts that are depicted by those weights. We also notice that the style in which the learners are taught also matters. We taught a group of 16 learners using conventional model that is taught them solutions to Manhattan Tourist Problem, LCS, String Matching and DNA Sequence Alignment independently as isolated concepts and without exploiting the similarity and differences between the problems. Corresponding to it we taught another group comprising 16 learners using the concepts of super-ordinate learning. We taught them Grid Graph as the super-ordinate concept and incrementally built their knowledge by adding the problems one by one as we added in various concept maps above.

Our experiments yielded that those students who were taught using grid graph as the super-ordinate concepts were better able to establish the linkages between various problems and hence performed better on unseen problems too. Hence the way a concept is taught also contributes to the amount of meaningful learning that a learner can achieve.

CONCLUSION AND FUTURE WORK

An analysis of the problems faced by learners while meaningfully learning Inter-Domain transformations of problem solutions is presented in the paper. We first motivate the discussion by providing the details of a grid graph, problems from different domains and transformations which were taught to the learners. The paper includes step by step mental constructs that we propose to be present inside a learners mind if meaningful learning has to be achieved. We propose a strategy of posing unseen questions which apparently seem totally different but can be solved using a slight modification to the transformations on the grid which were previously taught to the learners. We conclude that lack of establishment of correspondences between concept in the problem and the concepts in the grid can be a major reason which hinders meaningful learning. Furthermore the previously existing knowledge in the learner's brain can also serve as a functional fixedness to resist meaningful learning. The idea is that the students develop unnecessary constraints in order to design the solution to a problem. These constraints are usually developed when they are unable to think unconventionally. They go with a conventional thinking style primarily induced into them by their previous knowledge and conventional teaching and hence fail to solve simple problems. The strategy of teaching the concepts also serve as a factor for students to experience functional fixedness. A better strategy can be to teach in exactly the same manner as we want the mental constructs in the users mind to develop.

In future we plan to give an elaborated reasoning and results to support our hypothesis. We are also focusing on a few more problems from computational biology which require meaningful learning but learners usually rote learn the solutions to those problems and don't tend to meaningfully learn them.

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