Teaching and Learning of Divergent and Convergent Thinking through Open-Problem Solving in a Data Structures Course

Patil Deepti Reddy
IDP - Educational Technology,
Indian Institute of Technology Bombay
Mumbai, India.
deeptir@iitb.ac.in

Sridhar Iyer
IDP- Educational Technology,
Indian Institute of Technology
Bombay, Mumbai, India.
sri@iitb.ac.in

Sasikumar M.
CDAC,
Mumbai, India.
sasi@cdac.in

Abstract— **Divergent thinking is the process of generating multiple solutions for a given problem, while convergent thinking is evaluating and selecting accurate solution based on constraints, assumptions, and pros and cons analysis. Divergent and convergent thinking is an important thinking skill needed to generate novel or innovative solutions to a given problem. According to ABET guidelines, it is also one of the important skill to design an engineering solution to a given open problem. The training in developing both divergent and convergent thinking during multiple phases of problem solving can allow students to design a better solution. In this paper, we propose an intervention to develop divergent and convergent thinking skill through open problem solving in data structures course. The research methodology followed is Design Based Research (DBR) and the intervention proposed in this paper is operationalized and evaluated by following first cycle of DBR. A preliminary study was conducted on second year Computer Engineering students to study the effects of intervention. The results show significant improvement in learners' thinking in both divergent and convergent thinking during open-problem solving.**

Keywords—Divergent thinking, Convergent thinking, Open problem solving, Data Structures, Multiple solution generation.

1. INTRODUCTION

Divergent thinking is the process of generating different possible solutions for a given problem, while convergent thinking is evaluating and selecting accurate solution based on constraints, assumptions, and pros and cons analysis [12,7,5,13,14,8]. Both divergent and convergent thinking are important thinking skills to generate novel or innovative solutions to a given open problem. According to ABET guidelines, it is also one of the important thinking skill for developing engineering design competency. The students need to design an engineering solution or product by generating potential solutions by thinking from multiple perspectives and evaluate them based on pros and cons analysis and constraints [7, 13]. In Computer Science & Engineering(CSE) education, the divergent and convergent thinking skills are important in subjects such as software engineering, computer network, and data structures, in which a system or solution is to be designed for an open problem.

The content and procedures to taught to solve a simple problem may not help student in applying them to solve unfamiliar open problem. Today's workplaces demand people who can solve non-routine complex problems [2, 3]. This gap between academia and industry can be bridged by training and nurturing students to develop the cognitive thinking skills needed to solve an unfamiliar problem effectively [5].

In engineering design subjects like software engineering, students are taught to follow engineering design process having phases: requirement gathering, analysis, design and implementation. The engineering design process support convergent thinking as the focus is on evaluating and selecting the single correct solution. This process does not encourage student to do lateral thinking or brainstorming to generate divergent ideas and then converge to evaluate and select idea based on judgment, evidence, assumptions and principles. The integration of divergent and convergent thinking in each phase of engineering design process can enhance the creativity and quality of the product designed [9]. Thus training in synchronizing both divergent and convergent thinking can allow students to generate varied solutions and then select to get an innovative or creative solution [5].

In this paper, we propose an intervention to develop divergent and convergent thinking skill through open problem solving. The open problems posed are ill-structured, real-life problems and students are asked to apply data structures concepts to solve them. The intervention is based on systematic problem solving models used to solve engineering design and creative problems [5, 21]. The intervention aims to develop divergent thinking skills- looking at the problem from multiple perspectives and generating multiple solutions, and convergent thinking skills- identifying constraints, requirements, pros and cons analysis and justification of the selected solution. The intervention consists of question prompts to start with divergent thinking and gradually shifts to convergent thinking. For a given open problem, students are prompted to elicit multiple solutions, and then to converge by filtering the solutions based on constraints and requirements.

The research methodology used to design the intervention is Design Based Research (DBR). In this paper the design and evaluation of the intervention in first cycle of DBR is reported.

IEEE
computer
society

The broad research question investigated is: Does training on divergent and convergent thinking improve student open-problem solving ability? A preliminary study was conducted on second year Computer Engineering students to study the effects of intervention in improving student's open-problem solving ability by developing divergent and convergent thinking skill.

In next section, the research in divergent and convergent thinking is synthesized. Then the first cycle of DBR is reported to explain the design process of the intervention followed by evaluation of the intervention using experiment. Later the results are discussed and analyzed to refine the intervention in next cycle of DBR.

2. RELATED WORK

Divergent thinking is process of generating large number of ideas with focus on quantity and not on quality [12, 7, 5]. The sub-skills associated with divergent thinking are -*fluency:* the ability to generate many responses or ideas, *flexibility:* the ability to generate varied ideas from different perspectives, or the ability to change the form, modify information, or shift perspectives, *originality:* the ability to generate unusual or novel responses and *elaboration:* the ability to embellish an idea with details [19].

In contrast to divergent thinking, convergent thinking is associated with critical thinking where importance is given to systematically making decisions based on judgment, evidence, assumptions and principles or concepts [14, 8]. The focus is on systematically evaluating and selecting a single correct solution based on assumptions, constraints and principles. The sub-skills needed in convergent thinking are- pros & cons analysis of various solutions, making suitable assumptions for a given problem, selection of accurate solution based on constraints identified in a given problem and justifying selected solution [13].

Both divergent and convergent thinking skills are important in generating innovative or creative solutions for an open problem. These skills can be encouraged in engineering curriculum by incorporating following pedagogical changes:

1. Projects in design classes must have open-ended solutions [7].
2. Train students to think divergent to convergent in all phases of problem solving [5]
3. Encourage students to take different viewpoints while solving problems [6, 7].
4. Grading process should be based on problem solving process as opposed to merely on outcome [7].

2.1 Divergent-Convergent Problem solving models

Literature suggests numerous models of systematic problem solving categorized into engineering design thinking models and creative thinking models. The engineering design thinking models have following common stages – Establishing a need, Analysis of tasks, Design and Implementation. These are convergent models which are focused on evaluating and selecting a single correct solution thus resulting in designing a conventional solution. The cognitive psychology literature proposes creative thinking models which separate the idea generation and evaluation phases. The phases of creative process models are- Analysis, Generation and Evaluation [9].

The creative thinking models are more focused on divergent thinking while engineering design models are more focused on convergent thinking. To encourage engineering students to design better solutions it is important to integrate creative thinking and engineering design models.

Basadur[4 ,5] proposed an integrated model in which divergent and convergent thinking is incorporated in all three phases of problem solving- problem finding, solving and implementation. The study was done to investigate the effects of training in integrated problem solving model. The participants of the training were professionals at various levels from senior manager to junior engineers from various organizations. They were made to practice the cognitive process and techniques of divergent thinking to solve real-world, open creative problems. The attitude towards divergent and convergent thinking of the participants was measured before and after the training using survey. The increase in preference for divergence was significant for managers than non managers.

We have adopted the Basadur's integrated model to solve real-world, open design problems to train engineering students in developing both divergent and convergent thinking as shown below:

- Establishing a need and analysis of task (outcome is problem statement)
  - Divergence to convergence
- Design (outcome is design of the solution)
  - Divergence to convergence
- Implementation (outcome is the final product)
  - Divergence to convergence

In the first phase of problem solving- Establishing a need and analysis, student has to understand the problem and restate the problem statement. In this phase, divergence is encouraged using the design thinking principles stated as looking at the problem from different stakeholders viewpoints [6] and then converge to restate the problem based on the requirements and constraints of the problem.

In the second stage of problem solving- Design, the student start with divergent thinking by providing prompts to generate multiple solutions and then converge to evaluate and select the best solution among the solutions generated. During divergent thinking, students should be encouraged to use various divergent thinking techniques- *analogical thinking:* transfer an idea from one context to a new one, *brainstorming:* encourage to individually generate ideas with focus on quantity and not quality in less amount of time, *mind mapping:* variant of brainstorming, where ideas are represented in pictures as well as words and *attribute listing:* identify attributes of a subject and think up ways to modify, reverse, combine or improve on each [12]. Once the possible repertoire of solutions are available, perform pros and cons analysis and select a solution or filter them based on constraints, preferences, assumptions and converge to single solution.

In third phase of problem solving- implementation, the selected idea is to be implemented using appropriate technology. The divergent thinking is needed to list possible technologies to implement the idea and converge to select technology based on viability and feasibility at the user or client side.

2.2 Teaching Divergent and Convergent thinking in Engineering Education

Design is an important part of the engineering curriculum where the students need to develop the ability to solve open-ended problems to design an engineering solution or product [7, 13]. In Section 2.1 we discussed the engineering design

process and the importance of integrating both divergent and convergent thinking in all phases of design process to improve the quality of the product.

Training in an applied research organization and with manufacturing engineers showed improved performance in creative problem solving attitudes and practices [4]. These problem solving practices can be taught early during engineering education by training students to develop divergent and convergent thinking and synchronize the shift from divergent to convergent thinking. We have adopted the Basadur model to teach divergent and convergent thinking skills to engineering students by providing question prompts at different phases of open problem solving in data structures course. Basadur used survey to measure the attitudes towards divergent and convergent thinking, we propose to measure the sub-skills associated with divergent and convergent thinking before and after the training of using divergent and convergent techniques through open problem solving.

The learning objectives of teaching divergent and convergent thinking skills are:

1. Student will be able to solve an open-ended problem by generating multiple ideas or solutions without focus on quantity rather than on quality.

2. Student will be able to do pros and cons analysis of all the solutions based on the constraints or assumptions identified.

3. Students will be able to select the most suitable solutions based on the constraints or assumptions identified. J42w

4. Student will be able to justify the selection of solution.

2.3 Teaching Divergent and Convergent thinking in Computer Science & Engineering(CSE) education

Based on the analysis of current work in Computer Science & Engineering(CSE) education most of the technology enabled innovative are focused on teaching content or concepts and less on developing skills needed for an engineer to sustain in industry. The teaching techniques used are game based learning or visualization used to teach fundamentals of programming [16], the working of an algorithm or process like packet transfer in computer network [11].

We further analyzed the teaching of the data structures course and found that most of them are based on teaching content –programming in data structures, data representation and operations of various data structures, working of algorithm using animation or simulation [20, 23]. The problem based learning approach is used to develop skills to construct counterexamples[10] and to find the optimal selection function for a greedy algorithm [22]. Some studies are based on developing conceptual understanding using Think-Pair-Share activities in Computer Programming course and data structures course [17] with focus on generating multiple solutions and analyzing in collaboration. Still the students as individuals are not trained to think divergent to convergent in a systematic manner to solve open-ended problems. Thus, it is seen that open problem solving using divergent and convergent thinking is used rarely in CSE education in spite of its importance in generating innovative and better solutions.

The divergent and convergent thinking in open problem solving can be used in teaching the CSE courses whose course outcomes are aligned to the outcomes of divergent and convergent thinking like computer networks, circuit design,

software engineering and data structures. In these courses, open-ended design problems can be asked, for example in computer network course the open-problem posed is "design a computer network for the college campus to connect computers in all departments".

We have chosen data structures course to teach divergent and convergent thinking skills as the course outcome: "Student should be able to design solution by identifying appropriate data structure to solve a real-life problem" matches with learning objectives of divergent and convergent thinking skills.

For example, the following open, real-world problem can be posed to students assuming the student has knowledge of data structures:

"Given a bank, that has thousands of customer records and wants to build an online service for its customers to check their account details online. The requirement of the online service is that the customer should get the response quickly once the request is given. Design an efficient solution for the above stated requirement."

There can be different solutions to the above problem. Some of them are listed below:

1. Use an array data structure to store the records in the order the customer account was created and use linear search algorithm to retrieve the customer account details when requested. This solution will take at the worst case $O(n)$ time to search and generate response.

2. Use hash table to store the customer records using customer id as the input to hash function to get the address of customer record. This solution in best case takes $O(1)$ time, but in worst case if the collisions are more for a particular address, then the response time may be high.

3. Use balanced binary search tree to store customer records and use binary search algorithm to retrieve customer record. This solution takes $O(\log n)$ time in all cases to search a customer record.

In this problem the students are required to generate multiple solutions and analyze to find the efficient one based on the requirements. Students may not be able to solve such real-world, open-ended problems efficiently as they might not have understanding or skills in using appropriate divergent and convergent techniques. The intervention to develop this thinking skill is discussed in next section 3.

3. DESIGN OF THE DIVERGENT & CONVERGENT INTERVENTION

We followed a Design Based Research (DBR) model to design an intervention. DBR is an iterative process with design-evaluate-redesign phases [1, 18]. The DBR cycle consists of four stages-Problem Analysis, Solution Development, Evaluation and Reflection as shown in figure 1. In problem analysis phase- the problem is identified by working with practitioners and literature analysis is done to find how other researchers have addressed the problem and suggested the principles and theory to approach the problem. Next, solution development phase is used to design an intervention based on design principles suggested in literature to address the problem or to propose a new strategy, and then collect data in real world context to analyze and redesign the intervention by following multiple iterations of DBR.

Figure 2 describes how we applied design based research in first iteration to develop the intervention. In problem

analysis phase, the open, real world problem was posed to students in Data Structures course and the problem identified is that students could not come up with multiple solutions and justify the efficient solution. To analyze the problem of teaching open problem solving and developing divergent and convergent thinking, literature survey was done to identify the techniques, processes and principles to teach or develop these thinking skills.

The intervention is based on the Basadur's systematic problem solving model having multiple phases-Understanding the problem, Problem solving and Implementation, and integrating divergent and convergent thinking in each phase. The design of the intervention is in form of worksheet for solving open-ended problem in Data Structures. The worksheet has set of question prompts to encourage and train students to think from divergence to convergence in all the phases of open problem solving.

The proposed worksheet for data structures course is scoped to two phases of open problem solving: Phase 1-Understand and Analyze the Problem and Phase 2-Problem Solving. The implementation phase which is the third phase of problem solving is out of scope for the in-class paper based worksheet.

The open-ended problems are based on real-world problems and students were asked to select an appropriate data structure to solve. The open-problem posed by the instructor in class assuming that students have knowledge of data structures and its operations is:

The local automobile retail shop sell parts for different car models- oil, filters, brakes, batteries and. The shop owner notices that if any part is getting out of stock then there is a risk of losing customers. So he wants to have a software developer create an inventory control program that tracks the quantity of all the parts and creates a report of the parts that needs to be ordered so there is minimal risk of items getting out of stock. Each night the program creates report of the parts whose quantity is below certain value, so that they can be ordered to bring the stock levels back up to the right number.
Come up with multiple possible solutions by using appropriate data structures and operations for solving the above problem. Justify which solution is most efficient for above stated problem.

For the above problem, in first phase- Understanding the problem, the student has to understand the problem from multiple users' perspectives to find the data and operations used in the system and then evaluate to identify the problem statement based on constraints and requirement given in the problem. Later in second phase, student has to generate multiple solutions using various data structures and evaluate and justify the selected solution.

The worksheet with question prompts posed in each phase is as shown in figure 3. In phase 1-Understand and analyze the problem, in step 1.1, students are prompted to list entities and actors in a given problem, for example for the above problem, actors are shop owner, software developer and customer, and entities are shop, items, inventory system. In step 1.2 and 1.3, list the data and operations from each actor's perspective, for example, shop owner will deal with data- items specifications and quantity, and operations-search the item, find item with quantity below threshold and order the item. In step 1.4, identify the requirement, for example the requirement is-software program to find the items whose quantity is below the threshold. Finally in step 1.5, 1.6 identify the data and operations to solve the requirement, for example, the data items needed are- name, quantity and operation are- search the item whose quantity is below threshold, update the quantity.

In phase 2- Problem Solving, step 2.1 and 2.2 will allow students to generate multiple solutions using various data structures to represent data and perform operations identified in step 1.5 and 1.6.

In phase 1, the steps 1.1 to 1.3 are operationalized using the principles of design thinking which states that designer should understand the problem by being part of the system and thinking from the stakeholders' perspectives. In the worksheet the student is prompted to look at the problem from multiple perspectives: customer, employees, engineer, and management to list the data to be stored and operations to be performed. This will help to design a human-centered solution which is aligned with requirements of the problem stated [6]. In phase 2, the steps 1.4 to 1.6 allow to converge by identifying requirements and selecting the data and operations needed to solve the problem.

In phase 2, the steps 2.1 and 2.2 use the divergent thinking technique of attribute listing and modifying one of the
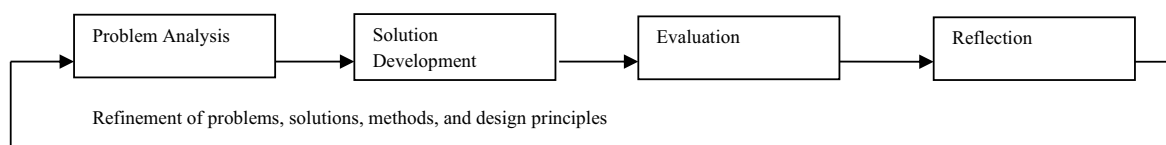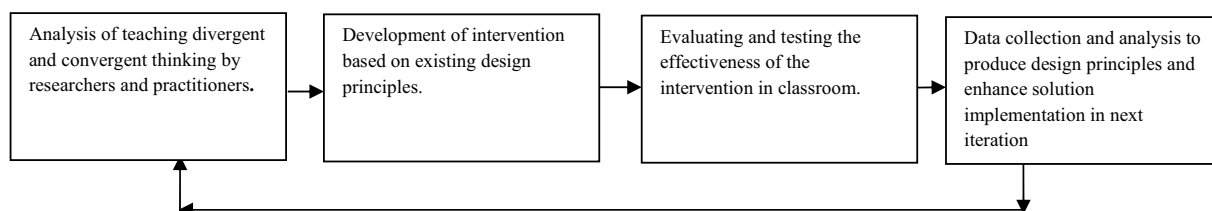

Figure 1. Stages in each cycle of DBR

Figure 2. First cycle of DBR in creating intervention to teach divergent and convergent thinking skill.

attribute to generate multiple solutions [12]. In the data structures subject, the attributes that can be modified are data structures and algorithms. In the worksheet the student is prompted to list desirable data structures and generate solutions using each data structure. The step 2.3 allows student to converge by listing advantages and disadvantages of using each data structure and selecting the solution by filtering based on requirement and constraints. This step develops the critical thinking skill as students have to make decisions based on assumptions, requirements and constraints for a given problem.

3.1 Outcome of the intervention

The intervention is designed to improve the open problem solving ability by developing divergent and convergent thinking in different phases of problem solving. This will improve the understanding of when and how to apply appropriate thinking skill in the process of solving open problem.

4. EVALUATION

To evaluate the effectiveness of the intervention a study was conducted on second year Computer Engineering students. The methodology used to conduct the study is explained in this section.

4.1 Research question(RQ)

The broad RQ investigated during the study is: Does training on divergent and convergent thinking improve student open-problem solving ability? We investigated this RQ by examining the specific RQ defined as: do scaffolding using question prompts as an intervention for improving divergent and convergent thinking affect problem solving ability in terms of-

  i.   generating multiple ideas or solutions with focus on quantity rather than on quality.

  ii. doing pros and cons analysis of all the solutions based on the constraints or assumptions identified.

  iii. selecting the most suitable solutions based on the constraints or assumptions identified.

  iv. justifying the selected solution.

4.2 Participants

The study was conducted in a class of 40 students in Data Structures course. The students were second year Computer Engineering undergraduates studying in an engineering college affiliated to Mumbai University.

4.3 Experimental Procedure

The study conducted was pre-post test on same group of students. It is assumed that students have knowledge of different data structure and algorithms. The procedure followed for the study is as follows:

  - Pre-test: The open-ended problem was posed without intervention. The problem posed does not

Worksheet activity on solving open problem		Divergent & Convergent Thinking
Open Problem: *The local automobile retail shop sell parts for different car models....*		
Phase 1. Understand and analyze the problem:		
1.1	**List all the entities and actors (Nouns):** entities are the existing real things or objects, for example person, organization, table, etc. To list entities look for nouns in the above problem	Divergence
1.2	**List the data generated from the perspective of each entity listed in step1.1:** data is the information like customer entity will have data: customer-id, name, age.	
1.3	**List all the operations that are performed on above data from the perspective of each entities listed in step1.1:** operations are the actions performed on the data set, like customer places an order or cancels an order.	
1.4	**What is the requirement in above problem:** requirement is the task to be achieved in above stated problem.	Convergence
1.5	**Identify the data (listed in step 1.2), needed to solve the above requirement:**	
1.6	**Identify the operations out of the list in step 1.3, needed to solve the problem:**	
Phase 2. Problem solving:		
2.1	**List the desirable Data Structures that can be used to solve the above problem:**	Divergence
2.2	**For each DS, give solution to solve requirement given in step 1.4 using data and operations identified in step 1.5 and 1.6 respectively:** **Solution 1:** **Data Structure and data:** **Operations & Algorithm:** **Solution 2:** **Data Structure and data:** **Operations & Algorithm:** … **Solution N:** **Data Structure and data:** **Operations & Algorithm:**	
2.3	**Identify the efficient solution based on constraints (space, time, complexity) and requirement in the problem. Justify?**	Convergence

Figure 3. Intervention for teaching-learning of divergent and convergent thinking skill.

has a single correct answer and can be solved in multiple ways. The students were instructed to write multiple solutions by using appropriate data structures and operations for solving the problem and justify which solution is most efficient. The students were given 15-20 minutes to solve the problem. The sample of solved worksheet of pre-test is shown in figure 4.

  - Post-test: Later, immediately after the pre-test, same open-ended problem was posed with intervention. The students were asked to follow the question prompts to
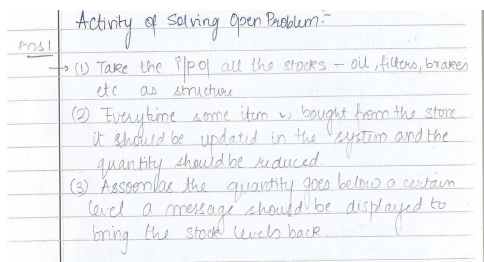
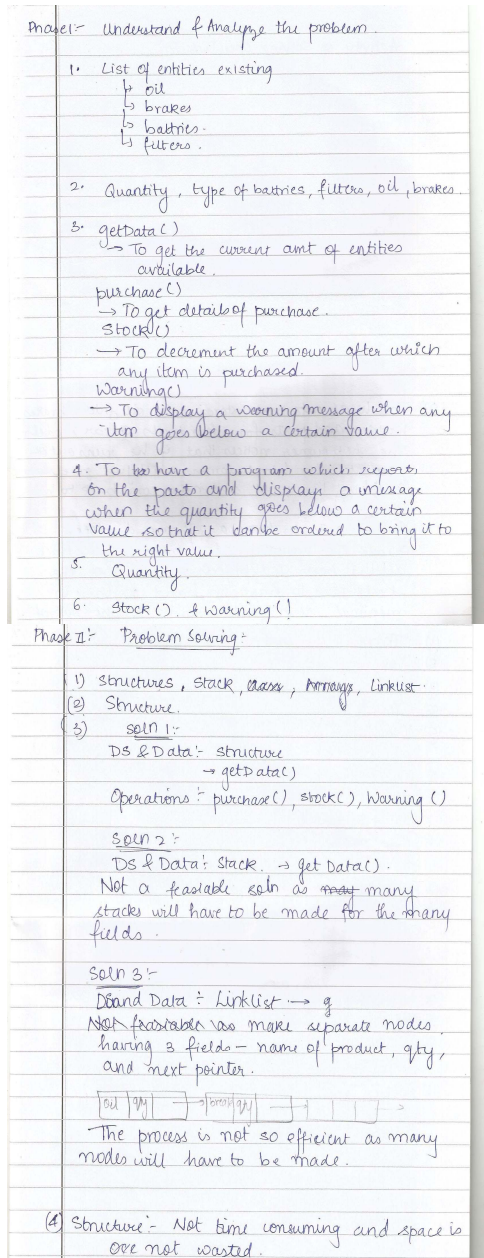Figure 4. Sample of solved worksheet during Pre-test

Figure 5. Sample of solved worksheet during post-test

solve the problem. The students were given same time of 15-20 minutes. The sample of solved worksheet during post-test is given in figure 5.

The students actively solved the problem individually on worksheet for both pre and post test. The instructor did not played an active role during the study.

4.4 Data Collection and Analysis

The data collected are the scores of the pre and post-test worksheets. The purpose of the pre-test and post-test was to assess the students' ability to view problem from multiple users' viewpoint, identify data and operations to solve the problem, identify requirement and constraints, write multiple solutions and select and justify the most desirable solution, while solving the open-problem. The divergent thinking ability is measured on the basis of four sub-skills: fluency, flexibility, originality and elaboration, while convergent thinking skills are measured on basis of sub-skills: identifying constraints, assumptions, pros and cons analysis, selecting the solution and justifying the selected solution.

A rubric was designed to measure the sub-skills of divergent and convergent thinking acquired during open problem solving as shown in figure 6. The range of score for each steps in the worksheet are high, medium, low with marks 3,2,1 respectively. The pre and post-test worksheets were analyzed using same rubric. The rubric reliability was validated by the instructor teaching data structures course and research scholars having computer engineering background from educational technology department.

5. RESULTS

The pre-test scores and post-test scores for each sub-skill were evaluated based on rubric given in figure 6. The average scores out of 3 for each sub-skill for pre and post-test is shown in table 1. The t-test was conducted to compare the performance of pre and post-test as shown in table 1.

TABLE I. SCORES OF DIVERGENT AND CONVERGENT THINKING

	Divergent Thinking				Convergent thinking	
	Fluen-cy	*Flexi-bility*	*Origi-nality*	*Elab-oration*	*Pros and con analysis*	*Justifica-tion*
Pre-test (Average)	1.16	1.02	1.21	1.47	0.02	0.02
Post-test (Average)	1.71	1.55	1.23	1.44	0.44	0.47
T-Test (p-value)	0.0008	0.001	0.86	0.88	0.0004	0.00003

6. DISCUSSION

The RQ is answered by comparing the scores of divergent and convergent thinking sub-skills of pre and post-test.

Results show significant improvement from pre-test to post-test in divergent thinking and convergent thinking in terms of fluency (p<0.01), flexibility (p<0.01), pros and cons analysis of various solutions (p<0.01) and justifying the selection of best solution (p<0.01). The results are not significant in terms of originality, which shows that divergent thinking does not guarantees creation of original or creative

Worksheet steps	Divergent and Convegent Thinking Sub-skills	Levels of skill acquired		
		3:High	2:Medium	1:Low
Phase 1: Understanding the problem				
Step 1.1, 1.2, 1.3	Fluency	Student was able to list many possible data items and operations from most stakeholders' perspective.	Student was able to list data items and operations from few stakeholders' perspective.	Student was able to list data items and operations from single stakeholders' perspective.
Steps 1.4, 1.5	Identify constraints	Student identified most of the constraints and assumptions correctly.	Student identified some of the constraints and assumptions correctly	The constraints identified were partially correct.
	selection of solution component	Student could select most of the components correctly	Student could select some of the components correctly	The components identified were partially correct.
Phase 2: Problem solving				
Steps 2.1, 2.2	Fluency (count)	Student was able to generate >= 3 solutions.	Student was able to generate 2 solutions.	Student was able to generate 1 solution.
	Flexibility (Varied or diverse)	Most of the solutions were based on varied concepts.	Some of the solutions were based on varied concepts.	Few of the ideas were based on varied concepts.
	originality	The ideas are similar to 20 % of the ideas generated by others.	The ideas are similar to 40 % of the ideas generated by others.	The ideas are similar to 60 % of the ideas generated by others.
	Elaboration	The ideas are clearly and correctly explained at more detailed level by showing the data representation, operations, input and output data of each operation, and steps to perform the operation.	The ideas are clearly and correctly explained at more abstract level by showing the data representation, operations, input and output data of each operation, without the steps to perform the operation.	The ideas are not clearly explained.
Steps 2.3	Pros and cons analysis	The limitations and advantages on most of the parameters of the solutions' concepts analyzed.	The limitations and advantages on some of the parameters of the solutions' concepts analyzed.	The limitations and advantages of few concepts analyzed
	Justified selected solution	Justified the selected solution based on most of the constraints and assumptions and explained using evidence.	Justified the selected solution based on some of the constraints and assumptions.	Selected the solution without considering the constraints or assumptions.

Figure 6. Rubric to measure divergent and convergent thinking

solutions but develops the potential in thinking towards creativity or innovations.

The results are not significant in terms of elaboration, thus showing that students are able to write the solution in detail both in pre and post-test. In next iteration of DBR, the design will incorporate instructions to help students in writing solutions in detail.

In pre-test, most of the students could write only one solution in detail and they found difficult to write multiple solutions as shown in sample worksheet of pre-test in figure 4. Also, they were not able to do the reasoning to justify how their solution is better. This shows that students do not had the understanding or skills in using appropriate divergent and convergent techniques to solve real-world, open-ended problems efficiently during pre-test.

The results of study show that question prompts to think from divergent to convergent in multiple phases of problem solving helped students in writing multiple solutions and to justify the selected solution. In the first phase-understand and analyze the problem, the question prompts to explore the problem from multiple viewpoints of stakeholders helped to identify the data and operations to be performed on the data. Then they were prompted to identify requirements and constraints needed to solve the problem. This process of systematically shifting from divergent to convergent thinking helped to understand the problem. Before moving to second phase of problem solving, students had the knowledge of which data and operations are needed to solve the problem. As shown in the sample worksheet in figure 5, the student is able to abstract the solution in term of data and operations needed to solve the problem in step 5

and 6 of phase 1.

In second phase students were prompted to use different data structures to represent the data and algorithm to perform the operations. This thinking process helped students to write multiple solutions with more clarity of solution in terms of data representation and operations to be performed using various data structures which are not seen in pre-test worksheet of the same student in figure 4. Then, once multiple solutions were generated, student were prompted to do pros and cons analysis based on time, space and complexity of each solution and then select and justify how the solution is best for the given requirement and constraints. As shown in sample worksheet in figure 5, the student is able to write 3 solutions using structure, stack and linked list and has made an attempt to justify that structure is efficient in terms of time and space complexity. This process of systematically solving the problem and shifting from divergent to convergent thinking improved the quality of the solution and clarity on why the solution is best.

During post-test, convergent thinking improved but still the scores are low. After analyzing the pros and cons analysis and justification given by students in post-test, we found that students had difficulty in comparing and contrasting different solutions. For example, if two solutions are generated, one using array and another using linked list then array and linked list should be compared and contrasted based on time, space and complexity of operations and justify which one is most desirable for the given problem. The comparison is that array is most suitable for search and traversal operation and linked list is more suitable for insert and delete operations. The justification is that array is selected because for the above problem, insertion and

deletion of records are few and search and traversal of records is performed at large, thus array is more suitable than linked list in terms of time complexity. To improve the student's ability to evaluate and select a solution based on pros and cons analysis, an explanatory feedback in terms of counter example can be given to clarify the concepts.

In next iteration of DBR, the design has to be improved using following points-

i. Develop a computer based tool based on the intervention for divergent and convergent thinking.

ii. For each step in the worksheet, identify the instructional strategy (hints, feedback, question prompts, simulations) appropriate to trigger the cognitive and meta-cognitive processes of the students.

iii. Generate counter examples during problem solving phase to help in doing pros and cons analysis and selecting the best solution.

To investigate whether students have acquired the divergent and convergent thinking skills, delayed experiments should to be conducted on additional open problems without scaffolds for a same set of students who received the training.

7. CONCLUSION

Divergent and convergent thinking skills are important in open problem solving to find better solution. The intervention was designed using first DBR cycle to develop the divergent and convergent thinking using question prompts in all phases of open problem solving. The study to evaluate the intervention show significant improvement in solving open problem. The results and responses given by students were analyzed to find areas of improvement in the design of intervention for next cycle of DBR.

8. REFERENCES

[1] Amiel, Tel, and Thomas C. Reeves. "Design-based research and educational technology: Rethinking technology and the research agenda." Journal of Educational Technology & Society 11.4 (2008): 29-40.

[2] Autor, Frank Levy and Richard .J. Murnane, "The Skill Content of Recent Technological Change: An Empirical Exploration", The Quarterly Journal of Economics, Vol. 118, pp. 1278-1333, 2003.

[3] Autor, and B. Price, "The Changing Task Composition of the US Labor Market: An Update of Autor, Levy and Murnane (2003)", mimeo, June 21, 2013.

[4] Basadur, Min, and Carl T. Finkbeiner. "Measuring preference for ideation in creative problem-solving training." The Journal of applied behavioral science21.1 (1985): 37-49.

[5] Basadur, Min, Mitsuru Wakabayashi, and George B. Graen. "Individual problem solving styles and attitudes toward divergent thinking before and after training." Creativity Research Journal 3.1 (1990): 22-32.

[6] Brown, Tim. "Change by design." (2009).

[7] Cooperrider, Bryan. "The importance of divergent thinking in engineering design." Proceedings of the 2008 American Society for Engineering Education Pacific Southwest Annual Conference. 2008.

[8] Cotton, Kathleen. "Teaching thinking skills." Northwest Regional Educational Laboratory, School Improvement Program, 1991.

[9] Howard, Thomas J., Stephen J. Culley, and Elies Dekoninck. "Describing the creative design process by the integration of engineering design and cognitive psychology literature." Design studies 29.2 (2008): 160-180.

[10] Jagadish, Iyer Sridhar. "A method to construct counterexamples for greedy algorithms."Proceedings of the 17th ACM annual conference on Innovation and technology in computer science education. ACM, 2012.

[11] Janitor, Jozef, František Jakab, and Karol Kniewald. "Visual learning tools for teaching/learning computer networks: Cisco networking academy and packet tracer." Networking and Services (ICNS), 2010 Sixth International Conference on. IEEE, 2010.

[12] Liu, Zhiqiang, and Dieter J. Schonwetter. "Teaching creativity in engineering." International Journal of Engineering Education 20.5 (2004): 801-808.

[13] Madhuri Mavinkurve, " Development and assessment of engineering design competencies" (Doctoral thesis), 2015.

[14] Niu, Lian, Linda S. Behar-Horenstein, and Cyndi W. Garvan. "Do instructional interventions influence college students' critical thinking skills? A meta-analysis", Educational Research Review 9 (2013): 114-128

[15] OECD, PISA. "Results: Creative problem solving–Students' skills in tackling real-life problems, volume V." (2012).

[16] Ramon Lawrence, "Teaching Data Structures Using Competitive Games", IEEE Transactions On Education, Vol. 47, No. 4, November 2004.

[17] Reddy, Patil Deepti, et al. "Thinking, Pairing, and Sharing to Improve Learning and Engagement in a Data Structures and Algorithms (DSA) Class." Learning and Teaching in Computing and Engineering (LaTiCE), 2015 International Conference on. IEEE, 2015.

[18] Reeves, Thomas C. "Design research from a technology perspective."Educational design research 1.3 (2006): 52-66.

[19] Runco, Mark A., and Selcuk Acar. "Divergent thinking as an indicator of creative potential." Creativity Research Journal 24.1 (2012): 66-75.

[20] Timothy A Budd, Oregon State University, School of EleEngr and Comp Sci Corvallis, "An Active Learning Approach to Teaching the Data Structure Course", Proceedings of the Thirty-Seventh SIGCSE Technical Symposium on Computer Science Education, 2007.

[21] Treffinger, Donald J., Scott G. Isaksen, and K. Brian Stead-Dorval. "Creative problem solving: An introduction." Prufrock Press Inc., 2005.

[22] Velázquez-Iturbide, J. Ángel. "Refinement of an experimental approach to computer-based, active learning of greedy algorithms." Proceedings of the 17th ACM annual conference on Innovation and technology in computer science education. ACM, 2012.

[23] Warendorf, Kai, and Colin Tan. "ADIS-An animated data structure intelligent tutoring system or Putting an interactive tutor on the WWW." Proceedings of Workshop" Intelligent Educational Systems on the World Wide Web" at AI-ED. Vol. 97. 1997.