Thinking, Pairing and Sharing to improve learning and engagement in a Data Structures and Algorithms (DSA) class

Patil Deepti Reddy[1], Shitanshu Mishra[2], Ganesh Ramakrishnan[3], Sahana Murthy[4]
[1,2,4]IDP in Educational Technology, [3]Department of CSE,
Indian Institute of Technology Bombay, India.
[1]deeptir@iitb.ac.in, [2] shitanshu@iitb.ac.in, [3]ganesh@cse.iitb.ac.in, [4]sahanamurthy@iitb.ac.in

***Abstract*—Literature has evidence showing that the active learning strategies used in classroom increase students' conceptual understanding well beyond the traditional classroom teaching. Active learning strategies become even more useful for teaching-learning of courses such as 'Data Structures and Algorithms', as such courses require to create time and space efficient algorithms using appropriate data structures to solve any ill-structured problem. Think-Pair-Share (TPS) is a classroom active learning strategy in which students work on individual activity, discuss with peers and share their newly discovered knowledge with class. In this paper, TPS is used with a goal to study its effectiveness on conceptual understanding and students' engagement in Data Structures and Algorithms course of second year engineering undergraduate. The field study was conducted using mixed-methods research design to study the effectiveness of TPS intervention. Pre-post test scores, observation protocol and student and instructor perception is used to measure the conceptual understanding, engagement and motivation respectively. The results show significantly high level of engagement during TPS activities as compared to traditional lectures. The posttest and pretest scores show that the learning gain is higher for the topics taught using TPS as compared to the topics taught without TPS. The qualitative data obtained from students and the instructor show desirable positive effect of TPS in affective, behavioral and cognitive dimensions on students.**

Keywords- Active learning, Think-Pair-Share, Data Structure and Algorithm, Conceptual Understanding, Student Engagement.

I. INTRODUCTION

The Data Structures and Algorithms (DSA) course requires students to connect different abstract concepts to solve ill-structured problems. In such subjects only understanding various data structures and algorithms is not sufficient to write an efficient program, but the student has to apply and analyze the different solutions and select the efficient one.

There is evidence showing that the active learning strategies used in classroom increase conceptual understanding well beyond the traditional classroom teaching [1, 2, 6]. Active learning shifts the student's role from mere spectator to active participant who can talk what they are learning, write about it, connect it to past experience and apply it to their daily lives [3]. In Computer Science, active learning techniques have successfully been used for students' improved programming skills [22], learning gains in upper level courses [23] and ability to choose a solution among reasonable alternatives [24].

Think-Pair-Share (TPS) is an in-class active learning strategy in which students work on individual activities, discuss with peers and share their newly discovered knowledge with class. TPS helps in eliciting and sharing different possible solutions from students. This helps students to analyze pros and cons of various solutions thus enabling conceptual understanding in DSA course. Previous research has shown empirical evidence of the effectiveness of TPS in introductory programming (CS1) course [6, 7]. The objective of the introductory programming course was to develop students' programming skills and translation of algorithms into programs. In this paper we have investigated the effect of TPS in DSA course, in which students are expected to develop efficient solutions.

We have investigated the effectiveness of TPS on conceptual understanding, students' engagement, and students' and the instructor's perceptions of TPS in DSA course of second year engineering undergraduate program. In this paper we answer following research questions (RQs):

RQ1: Does TPS lead to increased conceptual understanding in DSA course?

RQ2: Are students actively engaged during TPS activity?

RQ3: What are students' and the instructor's perceptions of learning - teaching with TPS?

A field study was conducted using single group, pre-post-test, using two topics: *priority queues and heaps,* and *AVL trees*. To study the effectiveness of TPS intervention, *priority queues and heaps* was taught using traditional lecture with no TPS and *AVL trees* was taught using TPS activity for the same group of students. The pretest and posttest were conducted before and after the study to measure the increment in learning due to the intervention. A classroom observation protocol [6] was used to record the students' behavior during TPS activity and also during traditional lecture. A perception survey and a structured interview were conducted to know the students' and the instructor's perception on TPS activity, respectively.

The results of posttest indicate higher conceptual understanding using TPS than traditional lecture. The percentage of students actively engaged [6] is high during TPS activity than traditional classroom teaching. The student perception survey shows that the students have perceived the TPS activity to be helpful for their learning and are motivated to learn more topics using TPS. The instructor perceives that TPS is not only beneficial for students' learning and engagement, but it also naturally suits the teaching – learning of DSA course.

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II. Related Work and Theoretical Basis

A. Active Learning Strategies

Active learning strategies are explicitly based on research on teaching and learning of the subject, they incorporate classroom activities that require all students to express their thinking through speaking, writing, or other actions that go beyond listening and copying of notes and have been repeatedly tested in actual classroom settings [18]. Examples of active learning strategies are TPS, Role Playing, Jigsaw, Peer Review, Discussion, Problem Solving using Real Data, Just-in-time Teaching, game based learning and interactive lectures [4]. In Computer Science, commonly implemented active learning techniques are Peer Instruction [2], pair programming [4], process oriented guided inquiry learning [16] and inverted classroom [17].

B. Active Learning Strategies to teach DSA

Prior studies have proposed many active learning strategies to teach Data Structure like competitive game [8], problem based learning [9] and daily worksheet (anti-quiz) [10]. Competitive game was used to motivate students to learn the fundamentals of programming in an introductory data structure course. Students solve programming assignments in DSA using web based competitive game environment. Instructor allows student to solve assignments in tool that ranks the student code with other student code thus creating competition. This is an individual activity and home activity, where the intervention or help from instructor is not present thus putting high cognitive load on students

In another study, authors used daily worksheet (anti-quiz) [10] to teach students how to program in DSA. The instructor redesigned the course to allow students to think about the logic of the problem given in daily worksheet. The instructor taught for 15-30 minutes, followed by daily worksheet (anti quiz) for 30-45 minutes. Subsequent homework is given so that students explore the concepts in more detail. During anti-quiz, students can discuss, refer books, work cooperatively to complete the work correctly.

C. Think-Pair-Share

TPS is a learning technique [11] popularly used in various domains like Psychology [12], English [13], and Computer Programming [6, 7]. TPS helps students to develop thinking skills, and other collaborative skills of communication and interaction. It allows instructor to shift his/her role from teller to knowledge facilitator by promoting the students to think individually, interact with neighbor and share their ideas with whole class. In this activity each student is actively engaged in learning, rather than being a mere spectator in a traditional class.

TPS is a structured cooperative active learning strategy consisting of three phases: Think, Pair and Share. In think phase, instructor asks a broad question, with a clear deliverable for a student. A student is given couple of minutes (2-3 minutes) to think about their answer to the question. Next, in the pair phase, instructor poses a follow-up question and allows each student to discuss their answer with his/her neighbor for a few minutes (5-10 minutes). Finally, in share phase, invite the pairs to share their solution with the class (5- 10 minutes).

TPS allows the student to understand the concept, as in think phase they have to apply the concept to solving a problem individually. The student understanding of the concept deepens while discussing the solution with neighbor, as the student can freely ask doubts to a peer and explain the solution to each other. The share phase helps students in analyzing the pros and cons of their own solution with others' solutions. TPS can be conducted in a short span of 10-15 minutes, for any level from school to college, for any domain, and is effective for small class as well as large class.

TPS as compared to problem based learning or game based learning takes less time of 15-20 minutes and can be completed in a single class. TPS activity is well structured and each phase covers different aspects of active learning strategies like thinking phase allows self discovery of new knowledge, pairing phase inculcates collaboration and team work, and sharing phase allows sharing different solutions with the class.

III. Implementation

A. Course Format

The study was conducted in a DSA course with 90 second-year undergraduate engineering students, from diverse engineering majors. The course was conducted over 14 weeks in spring 2014 semester, with two 90 minutes lectures per week, quizzes and end semester exams.

B. Conducting TPS in DSA course

The DSA course aimed at teaching creation and manipulation of data structures: arrays, lists, stacks, queues, heaps, hash tables, balanced trees, tries, graphs, and sorting and searching algorithms. These data structures and algorithms aim at developing solution to a problem which is efficient in terms of running time and memory space requirements. For example, the problem below is posed to students while teaching searching algorithm and assuming student know working of all the 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 create and analyze all possible solutions and find the efficient one based on the requirements. TPS is a suitable strategy for teaching – learning of this type of problems, as it elicits various possible solutions from each student, allows sharing them with whole class and analyze pros and cons of these solutions. These activities help students to make connections between various concepts.

Problems which were posed for TPS activities in DSA were of the following types:

1. Problem that can be solved using multiple data structures and algorithms.
   For example, after teaching priority queues and heap data structure, following problem can be posed: *"Consider an operating system where processes are waiting in a queue with their execution time. The CPU scheduler has to pick a shortest job first for execution. Solve this problem with appropriated data structure and algorithm."*
2. An open problem that demands change in current solution to improve efficiency. For example, after teaching linear search and before teaching binary search technique, pose a problem to find an efficient technique to reduce time to search an element.

TPS activity can be conducted in various topics of DSA, in which problems having the above properties can be created.

C. TPS Implementation

During the DSA course, TPS was conducted over 12 lectures across topics like hashing, trees, binary search trees, AVL trees, and pattern matching. In a class of 90 minutes, the TPS activity was preceded by a 15-30 minutes introduction of the topic. A sample implementation of TPS in the topic of AVL trees is shown below:

1. *Think phase*: The instructor posed a broad problem which has multiple solutions and can be solved by every student. The example of such problem is: "write an efficient algorithm to sort the given numbers". The students worked on the problem individually for 1-3 minutes. The think phase question on topic AVL tree is given in table I.
2. *Pair phase*: The instructor gave another question related to the problem in the think phase, such that it stimulated discussion among students. An example is: "explain and justify your solution with neighbor, and work towards the common solution". The students worked with one of their neighbors to perform the task in 5-10 minutes. The instructor walked around the class to encourage discussion and to answer queries. The pair phase question on topic AVL tree is given in table I.
3. *Share phase*: The instructor encourages students for class wide discussion by allowing students to share their solutions with whole class. The instructor may start the discussion by asking few pairs to discuss their solution with whole class. Students with solutions other than those already presented were encouraged to present their ideas. The students were also encouraged to analyze and discuss the pros and cons of the various proposed solutions. The discussion lasted for 10-15 minutes based on the diversity of the solutions. The share phase question on topic AVL tree is given in Table I.

TABLE I. AN EXAMPLE OF QUESTIONS POSED IN TPS ACTIVITY

TPS Phases/Topics	**TPS Implementation (Topic -AVL Trees)**
Think Phase	What will be the general procedure for rebalancing an imbalanced tree following an insertion? Write down all the steps of your general procedure.
Pair Phase	Explain your solution and check your neighbor's solution in terms of following points: 1. Whether the tree is balanced? 2. Whether the BST property is satisfied after rebalancing? Discuss and come up with common solution."
Share Phase	Share and discuss your unique solution with class

D. Traditional Lecture

Some topics such as priority queues and heaps were taught using traditional lecture without TPS activity. During the traditional lecture of 90 minutes, the instructional design was comprised of following order of activities.

- Introduction of the topic (15-30 min)
- Instructor solves a problem, where students will listen and observe the process.
- Instructor poses a similar problem for students to solve.
- Students will solve the problem individually.

IV. METHODOLOGY

A. Participants

The study was conducted in a class of 90 students in DSA class. The students were second year engineering undergraduates studying in highly selective institute of technology in the country. The students were from diverse engineering majors like computer science, mechanical engineering, aerospace engineering, etc. The total number students enrolled in the course were 90, but the study included only 42 students who took the post-test at the end of the semester.

B. Research design

An ideal research design for such a study would be quasi-experimental design in which there are two equivalent groups: control and experiment group. The experimental group gets TPS intervention and control group does not. However, our study was conducted in a field setting (real-life classroom), where the above design was not possible as the course had no lab hours and thus making two different groups was difficult. Also, we wanted to implement the study in-situ, focusing more on real-life contexts that a teacher can relate to. So we chose a design where treatment across equivalent topics was compared on a single group.

The field study was conducted using single group, pre-post-test, two-topic research design to study the effectiveness of TPS intervention. This design alternates intervention and no-intervention on the same group of students for two different topics. The effectiveness of the intervention is measured by comparing the behavior of the group with and without intervention.

The above design could give rise to confounding factors. While it is not possible to completely confirm that the confounding factors did not play a role, we took steps to minimize the threats to validity arising from them. Below, we examine each possible confound and describe how we addressed them to minimize their effects:

1. The topics may not have equal complexity.
   The topics selected for our study are AVL trees taught with TPS and Priority queues and Heap taught using traditional lecture method with no - TPS. The topics selected are independent of each other and the instructor's judgment was that the topics were of equal complexity.
2. There is dependency between the two topics, i.e., one topic is a prerequisite for the other.
   The teaching of AVL trees and heaps in any order does not affect the learning as the concepts are completely different and not dependent on each other. Care was taken to avoid topics which were dependent on each other.
3. The order of teaching of both topics affects learning.
   This is similar to the issue of dependency between topics, and care was taken to minimize it. For example, Binary Search Trees (BST) was not chosen since the order of BST and AVL matters, as teaching of BST helps in understanding AVL trees.
4. The post-test questions are not of equal complexity for both topics.
   The pre-test and post-test questions for both the topics had same complexity.

For both topics, the pre-test was conducted to measure students' conceptual knowledge of both topics: AVL trees, heap and priority queue, before the treatment. Later post-test was conducted to measure the conceptual understanding immediately after the treatment. The TPS study consists of following steps:

- Instructor sets the learning objective (LO) and assessment questions.
- Plan TPS activity for a topic which has multiple solution approach.
- Conduct TPS for the planned topic.

The equivalent topic was taught using traditional lecture, where instructor teaches and solves the problems but no active learning happens. The posttest was conducted on both topics to check if the LO is achieved.

C. Data Collection and analysis

The instruments used are pre-post test, observation protocol, student perception survey and instructor interview.

1. Pre-Post Assessments

Pre and post-tests were used to test the conceptual understanding of a student on selected topics taught using TPS and without TPS. The questions designed for test were ill structured problems with multiple solutions. As the problems do not directly address a particular concept, the procedural knowledge is not enough for the student to solve the problem. The conceptual understanding is required to recall and apply multiple concepts, and create the efficient solution. A sample question in one of the tests was:

"You have n distinct numeric keys in an array and for some other purpose, the keys are stored in an AVL tree, in a Heap as well as in a HashMap (you can assume any hashing function). Which data structure will you choose to implement the following method countAllInRange(k1,k2) that computes and returns the number of entries with key k such that k1 <= k <= k2. Since the three data structures are already provided, you can ignore the time complexity of populating that data structure."

One pretest was conducted on the two topics selected for the study and a posttest each was conducted immediately after the two topics were taught using TPS and without TPS. The purpose of the tests was to test the effect of teaching with and without TPS on student learning.

Pretest and posttest were conducted to evaluate the dependent variables: conceptual understanding, ability to solve ill-structured problems in RQ1. The questions and rubric for evaluating pre and post-test answer sheets was validated by the instructor.

***Analysis*:**

A paired sample t-test was conducted on the difference in pre- and post-test scores for topics taught with TPS and

Topic: Divide and Conqure												
Student number	**Student 1**			**Student 2**			**Student 3**			**Student 10**		
Behaviours/ Time (seconds)>>>	10	110	210	20	120	220	30	130	230	100	200	300
Reading/Listening: Looking at the screen or instructor. RS	x				x	x						x
Reading: Student reads own/peers' notes. RN							x	x	x		x	
Writing: Student writing in his notebook. W			x							x		
Talking: Talking to neighbour (discussion among 2 people) T		x										
Listening: Listening to neighbour L				x								

Figure 1. Observation protocol

without TPS and the effect size was calculated. The relative gain [1] between the pre and post-test scores was calculated for each topic - taught with TPS and without TPS.

2. Observation protocol

An observation protocol was used to record the behavior of a student in the classroom. This protocol was developed and used in CS1 study [6] to observe and measure student engagement during TPS activity. The same protocol was used in this study to observe the student classroom behavior during both with and without TPS activity. A screenshot of the observation protocol is shown in Fig. 1. It has a predefined possible set of behaviors, which were revised by observing students in actual classroom initially for few lectures.

The observers sat in the class in the positions such that the set of students to be observed were clearly visible. The observers used observation protocol to log the behavior of 10 students, where each student was observed for 10 seconds and his behavior was marked against the list of behaviors in the protocol. Next, the observer performs the same tasks for next student, till all the 10 students are observed. This cycle was repeated 3 times for same set of students. There were two observers during the study. They observed different set of students, sitting at different places. The class strength was approximately 50, thus one–third of the students were observed. The observations were recorded during the TPS and no-TPS activities.

The observation protocol was used to measure the dependent variable engagement (RQ2). The observation protocol used was validated by matching the behaviors of same set of students by 3 different observers at the same time before the study.

Analysis:

Percentage of active engagement behavior from the recorded observations during traditional lecture and TPS activity were obtained and compared.

3. Student Perception Questionnaire

Student perception survey was used to triangulate our findings on student engagement and learning. The questionnaire had 4 Likert scale question items on how TPS activity helped them to understand the concepts, affected their interest and motivation. The questionnaire also had two open ended questions on benefits and disadvantages of using TPS activity. The perceptions of the students of using TPS were captured using this survey to answer RQ3.

Analysis:

Frequency distributions of the Likert scale options selected by the students were compared. In addition to this the response to the open ended question were qualitatively analyzed and the codes corresponding to affective, behavioral, and cognitive components were obtained to infer the student views on benefits and disadvantages of TPS.

4. Instructor's interview

We conducted a structured interview to obtain the instructor's perception about TPS. The interview contained three open-ended questions: *(1) How was the TPS beneficial; (2) What were the challenges with TPS; (3) How was the TPS suitable in the Data Structures and Algorithm course.*

Analysis:

The Interview was transcribed and qualitative content analysis was performed to investigate the effect of TPS on cognitive, behavioral, and affective dimensions. Codes were obtained to answer what are the benefits and challenges associated with TPS. Other than these categories, codes were also obtained to answer what are the implications of TPS to pedagogy according the instructor's perspective.

V. RESULTS

A. Test Scores

The pretest and posttest were of 20 marks each, with 10 marks allotted to each topic: Heap and priority queue (no TPS), and AVL trees (with TPS).

The analysis of difference between mean of the pre and posttest scores for both topics is shown in Table II. The results show that relative gain is higher for topics taught using TPS than topics taught without TPS. The differences between pre and posttest mean scores are statistically significant for both topics taught with and without TPS ($p<0.001$).

The analysis of difference between post-test scores of topics taught using TPS and without TPS was done by calculating p-value which is 0.06 and effect size which is 0.59, in the range of medium to high [19].

B. Student's Engagement

Students' engagement is measured by determining the frequency distribution of overall behaviours observed in class for topics taught using TPS and without TPS. There were total 6 observations each for TPS and without TPS. In each observation 10 students were observed in 3 cycles.

Overall engagement

The overall engagement of students was analyzed over all the three cycles of observation in single observation sheet. The students were classified into actively engaged, passively engaged or not engaged behaviours [6]. In the observation sheet which had 3 observations for each student, if the students' observed behaviour was 2 or more times active then the overall behaviour is classified as active, similarly for passive and not engaged behaviour.

The classification of behaviour into actively engaged, passively engaged and not engaged during both traditional lecture and TPS activity is listed in Table III. During

TABLE II. ANALYSIS OF DIFFERENCE BETWEEN PRE AND POST-TEST SCORES FOR BOTH TOPICS.

TOPIC	PRE-TEST (MEAN) OUT OF 10 MARKS	POST-TEST (MEAN) OUT OF 10 MARKS	ABSOLUTE GAIN POST-PRE(MEAN)	RELATIVE GAIN POST-PRE(MEAN)	P-VALUE POST-PRE(MEAN)
HEAP(NO TPS)	2.3	3.7	1.4	0.18	0.00
AVL(TPS)	1.5	4.8	3.25	0.38	0.00

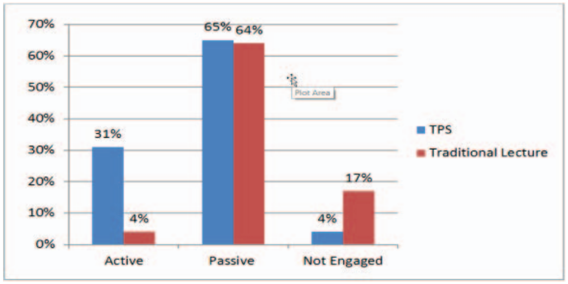

Figure 2. Comparison of overall behaviour during TPS activity and traditional lecture.

traditional class, if a student was listening or writing or pointing to slides or interacting with the instructor, then the student is classified as actively engaged. Similarly, during TPS activity if a student is writing in think phase, which is a desirable behaviour, then the student was classified as actively engaged. The percentage of overall behaviour over total behaviours is calculated in each observation sheet in both traditional lecture and during TPS activity.

The average percentage of students actively engaged is 4% in traditional classroom teaching, while during TPS activity it is 32%, thus inferring that active engagement is high during TPS activity, as shown in Fig. 2. Similarly the number of students in the non-engaged category was 4% in the TPS group, while it is 17% in the non-TPS group.

C. Students' Perceptions

The student perception survey had 4 Likert scale questions with 5 points: Strongly Agree /Agree /Neutral /Disagree /Strongly Disagree. The frequency distribution of the Likert scale options selected by students are calculated and plotted in Fig. 3. The results show that:

- 77 % student agreed that TPS activity helped in learning the concepts deeply.
- 55 % students agreed that they were engaged during TPS activity.
- 70% students were motivated to learn more topics using TPS.
- 36 % students agreed that TPS helped them to solve quiz and exam questions

In the survey, two open ended questions were asked: 1) List

TABLE III. CLASSIFICATION OF BEHAVIOUR INTO OVERALL BEHAVIOUR FOR TRADITIONAL CLASS AND DURING TPS ACTIVITY

Overall behaviour	Behaviours for Traditional Lecture	Behaviours for TPS
Actively Engaged	Listening and writing, pointing to slides, interacting with instructor	*Think*: Writing *Pair*: Writing, discussing, interacting *Share*: Writing, discussing, interacting
Passively Engaged	Listening or writing	*Think*: reading, talking *Share*: reading *Pair*: reading, listening
Not Engaged	Playing with mobile, head on desk, looking around.	

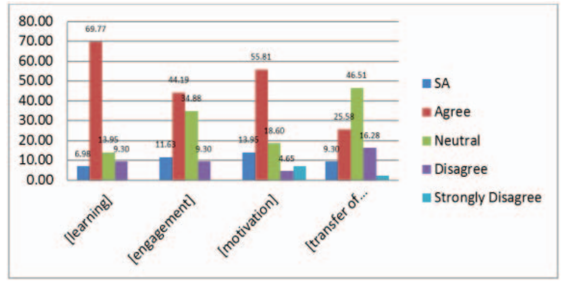

Figure 3. Frequency distribution of Likert scale options selected for each questionnaire in student perception survey

two advantages of TPS activity; and 2) List two disadvantages of TPS activity. Content analysis of the responses was done to categorize the student's opinion on benefits and disadvantages of TPS. The categories and number of students responded for each category is shown in parenthesis as follows:

Benefits:

- Allows to think (7)
- Get to know different opinions/approaches (2)
- Clears the concept (1)
- Peer learning and sharing helps (9)
- Helps to remain active (2)

Disadvantages:

- Time consuming(10)

Most of the students perceived that TPS helps to understand the concepts deeply, as it allows them to think and know various solutions, this strengthens the claim that TPS has positive effects on students' learning. Students also think they were actively engaged during TPS activity, which is in alignment with the engagement results.

D. Instructor's Perception about TPS

In this section, we discuss the benefits and challenges in using TPS in Data Structures and Algorithm course as perceived by the instructor. We also discuss the instructor's perception of implications of TPS to pedagogy, and its usefulness specific to the Data structures and Algorithm course. After the qualitative content analysis of the instructor's interview we have obtained the benefits of TPS along affective, behavioural, and cognitive (ABC) dimensions [20]. The results of the qualitative study are compiled in Fig. 4.

Benefits

As shown in Fig. 4, we found that TPS has positive effects along affective, cognitive, and behavioral dimensions. The instructor found that TPS initiates and encourages students to think. The pair and share phase helps students in learning multiple solutions to a problem and to look at the problem from different perspectives. In addition, the TPS activity boosts students' thinking when they are stuck during problem solving as they get to hear or share with their peers. The effects of TPS in the behavioral dimension, as perceived by the instructor are that TPS encourages collaboration and sensitivity among students. TPS helps in improving the motivation of students for engaging in content.

Challenges

According to the instructor, the pair and share phases are time consuming as there are multiple solutions which take a lot of time to be covered in a class, and this leads to less course coverage. Another challenge with TPS is when achievers who do not find much challenge in the problem, and during pair and share phases TPS leads them to boredom and restlessness if they already know the answer/ solution to the questions.

Implications for pedagogy

As far as the implications of TPS to pedagogy is concerned, the instructor found that TPS can help in improving dialogue with students, and TPS also helps in understanding the student thought process and background knowledge. TPS helps in estimating students pace of learning, as sometimes students act on the concept faster or slower than thought by an instructor. This can help instructor to alter the pace of teaching accordingly.

TPS in Data Structures & Algorithms course

The instructor perceived TPS to be useful for teaching all the topics of the DSA course. According to the instructor TPS is also useful specifically for DSA because:

- DSA has many abstract concepts.
- DSA is more inter-disciplinary, it brings in ideas from more than one fields.
- It is important in DSA that students view multiple perspectives to a problem, and can come up with multiple solutions to a problem.
  For example sorting can be solved in multiple ways in terms of computing intensive and memory intensive tradeoff.

VI. Discussion

Effect of Think-Pair-Share activity on students' conceptual understanding (Research Question 1) is answered using the difference of students' post and pre-test scores, and the student perception survey. The posttest scores of the topics taught with TPS and without TPS show that the difference is not significant ($p = 0.06$). But, non-significance does not mean 'no effect'. Literature suggest that small studies will often report non-significance even when there are real effects, which a large study would have detected [21]. Since the t-test does not show the magnitude of the size, we calculated the effect size, which shows the magnitude of the difference as ***Medium to High*** with value 0.59 [19], thus showing evidence of positive effect of TPS on students' learning. The relative gain of scores between pre and post-test for topic taught using TPS was twice higher than topics taught without using. This positive effect is further substantiated by the students' responses to the perception questionnaire. The survey results show that most of the students perceive that TPS helped to understand the concepts deeply, as it allows them to think and know various solutions.

Benefits of TPS

Cognitive Dimension

- Learning multiple ways of solving a problem.
- Getting Multiple perspectives to a problem
- Initiating thinking.
- Getting time to think.
- Developing/ introducing a new concept.
- Coming out of cases of getting stuck during problem solving.

Behavioral Dimension

- Encouraging students to collaborate outside the class.
- Developing a culture of sensitivity and cooperation among students.
- Getting weak students active.

Affective Dimension

- Developing motivation for engaging in content.

Challenges with TPS

- Boredom and restlessness for high achievers.
- Less course coverage.

Implications for Pedagogy

TPS helps instructors in:

- Engaging in dialogue with students.
- Know how students with different background think.
- Understanding student's background.
- Estimating pace of teaching- learning.

Figure 4. Benefits, Challenges, and implication for pedagogy as perceived by the instructor

Since this study was conducted only for one pair of topics, the valid conclusion we can draw is that the topic *AVL trees* taught using TPS has higher gain than the topic *Heap* taught using traditional lecture. While we cannot claim strict generalizability, we have reason to believe that TPS is better for DSA as it elicits multiple solutions from students which are shared with the whole class. In addition to higher gains on learning outcomes, we use data on students' perceptions and classroom observations (taken for topics with and without TPS, other than AVL trees and Heaps), as well as literature on higher benefits of TPS in programming course, to recommend to teachers that TPS helps in improved learning.

The second research question "Are student actively engaged during TPS activity?" is answered using the analysis of observation protocol. The percentage of students actively engaged is 4% in traditional classroom teaching, whereas during TPS activity it is 32%. The non-engaged behavior, which is 4 % in TPS and 17 % in traditional lecture also show that non-engaged behaviors- playing with gadgets, sleeping, and looking around reduced during TPS activity. This shows that TPS activity has resulted in higher level of students' engagements compared to traditional lecture. This result is triangulated by students' perception survey which shows that majority of students agree that they were engaged during TPS activity.

The qualitative analysis of the instructor's interview show that TPS has desirable positive effect on students in all three dimensions, viz., affective, behavioral, and cognitive. According to the instructor TPS helps students in learning, encourages students' thought process, scaffolds students' problem solving process, inculcates a culture of sensitivity and collaboration, and increases students' motivation for engaging with the content. One of the challenges reported by the instructor is that TPS is time consuming because of pair and share phase, as there are multiple solutions to be discussed in a class. Another challenge perceived by the instructor was that high achievers may get bored during pair and share phases. At the same time the instructor also asserted that TPS had desirable effects on lower achieving students.

As far as usefulness of TPS specifically to DSA domain is concerned, the instructor perceives that TPS is "naturally" suitable for courses like Data Structures and algorithms. The instructors comments *"...Designing an algorithms is definitely more interdisciplinary to me than... ....in a course like Data Structures and algorithm, it* (TPS) *fits more naturally"*. The instructor asserts that the DSA course is based on multiple fields like math, linear algebra, calculus, and designing algorithms, and perceives that this multidisciplinary nature allows student to solve a problem in multiple ways using their prior knowledge, during TPS.

The study conducted was a field study on a single group, pre-post-test using two topics, with one topic taught using TPS and another using traditional lecture without TPS. The study could have been repeated with another two topics. This would further strengthen the claim that TPS has positive effect on learning and conceptual understanding.

VII. Conclusion

The study was done to investigate the effect of TPS activity on student engagement, conceptual understanding and student perception in DSA course. The results are triangulated with different data sources, and show high engagement level during TPS activity and more learning for topics taught using TPS compared to learning without TPS.

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