Effect of Think-Pair-Share in a Large CS1 Class: 83% Sustained Engagement

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ABSTRACT

Think-Pair-Share (TPS) is a classroom-based active learning strategy, in which students work on a problem posed by the instructor, first individually, then in pairs, and finally as a class-wide discussion. TPS has been recommended for its benefits of allowing students to express their reasoning, reflect on their thinking, and obtain immediate feedback on their understanding. While TPS is intended to promote student engagement, there is a need for research based evidence on the nature of this engagement. In this study, we investigate the quantity and quality of student engagement in a large CS1 class during the implementation of TPS activities. We did classroom observations of students over a period of ten weeks and thirteen TPS activities. We determined patterns of student engagement in the three phases using a real-time classroom observation protocol that we developed and validated. We found that 83% of students on average were fully or mostly engaged. Predominant behaviors displayed were writing the solution to the problem (Think), discussing with neighbor or writing (Pair), and following class discussion (Share). We triangulated results with survey data of student perceptions. We find that students report being highly engaged for 62% during Think phase and 70% during Pair phase.

Categories and Subject Descriptors

K.3.2 [Computer and Information Science Education]: Computer Science Education.

Keywords

Think-Pair-Share; Student engagement; Observation Protocol

1. INTRODUCTION

Computer science instructors in large classes use techniques such as Peer instruction [20], [26], Just-in-Time-Teaching [16], and Inverted Classroom [13] to get students to be engaged with content. These instructional strategies are based on *active learning*, that is, students are engaged in specific activities, often collaborative, in which they "express their thinking via writing, speaking or other actions that go beyond listening and the copying of notes" [17]. In computer science education research (CSER), studies based on active learning methods have had a long history in lab instruction, such as those on pair programming [18],[21]while research on active learning techniques for large lecture classes has mainly concentrated on peer discussion [20], [26] in the CSER community. There is a need for research-based evidence from CS courses of different active learning techniques addressing a variety of instructional goals [17]. In this study, we investigate the quantity and quality of student engagement during *Think-Pair-Share* - an active learning method implemented in a large CS1 course.

The instructional goals in a programming course, in addition to conceptual understanding, are that students should be able to trace code, come up with programming logic (for example, write pseudo-code) and write programs. Classroom activities should have characteristics that allow students to reason through a problem, write open ended responses (such as pieces of code), work in groups and discuss solutions. Think-Pair-Share (TPS) is an active learning technique that satisfies these requirements [14][15]. The three phases in TPS are structured as follows: Think - the instructor poses a question to which students individually write their answers, Pair - students work on a well-defined task with their neighbor(s), and Share - students engage in a class-wide discussion, sharing their answers and reasoning, and debating alternate solutions. TPS is recommended as a teaching technique to engage learners in higher-order thinking, and as a feedback mechanism both for students and teachers [7]. However, TPS has not been widely researched and evaluated for objective evidence of student engagement or learning.

In this paper, we report the results of a field study to determine patterns of student engagement while implementing Think-Pair-Share in a large enrolment CS1 class setting. The goal of the present study is to characterize the nature of student behavior and engagement during the different phases of the activity. Our research questions are:

1. What behaviors do students engage in during the Think-Pair-Share activities implemented in a large class?
2. a) How much student engagement occurs during the Think-Pair-Share activity?
   b) How does the amount of engagement change as activity progresses?

We determined student engagement using a real-time classroom observation protocol that we developed and validated. The observation protocol contains codes related to student behavior in the different phases of the Think-Pair-Share activity. Two trained observers observed samples of students during thirteen Think-Pair-Share activities across ten weeks of the semester, and coded their behavior using the protocol. Analysis of observation data showed that our implementation of Think-Pair-Share results in 83% of the students displaying engaged behaviors for a majority of the time. We analyzed patterns of student behavior in the different phases of TPS and the transition of their behavior from one phase to the next. From these data we created an empirical model of student behavior and represented

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it as a state-transition diagram. We triangulated our observations with data from a survey questionnaire on student perceptions of engagement with content during from the Think-Pair-Share activity. We found that 62% of the students self-reported writing responses in the think phase and 70% reported discussing in the pair phase of the activity.

2. RELATED WORK

2.1 Active Learning Techniques in STEM Education Research

Active learning methods comprise instructional strategies in which students engage with the content by writing, talking, reflecting and expressing their thinking. Many active learning techniques have been evaluated repeatedly in different settings, with the aim of garnering objective evidence of improved student engagement or learning. In fact the definition of active learning methods used by physics education researchers explicitly includes that the method is based on research in the teaching and learning of that discipline[17]. A key research-based active learning technique being used in CS classrooms is peer-instruction [20][26]. Empirical studies of peer-instruction in CS courses have shown that students in a class taught via peer-instruction score significantly higher grades than an equivalent traditional lecture-based class [20], while studies in other STEM disciplines have shown similarly strong results over long periods of implementation [8]. Research on other active learning methods by CS education researchers include the investigation of student interest and learning with Just-in-Time-Teaching [16], student engagement in inverted classrooms [13], and learning effectiveness and student enjoyment from studies on pair-programming [18]. In this study, we add to the research into active learning strategies in computer science by evaluating how TPS fosters student engagement in a large CS1 class.

2.2 Think-Pair-Share

Think-Pair-Share is a collaborative, active learning strategy, in which students work on a problem posed by the instructor, first individually, then in pairs or groups and finally together with the entire class. Group formation in Think-Pair-Share is done informally, students typically turn to their neighbors and begin discussing the task at hand. Introduced by Lyman in 1981 [14] Think-Pair-Share has been extensively recommended and used by teachers at both the college and school levels [3][10]. Instructors favor Think-Pair-Share because it is perceived to be relatively easy to implement. Depending on the nature of the task in the Think-Pair-Share activity, it can be used in different stages of the instructional sequence.

Think-Pair-Share affords the benefits of small-group collaborative learning in a large lecture class, requires students to think about course content, can develop higher order thinking skills and allows students to formulate their reasoning individually before sharing with others [4]. Another important benefit of Think-Pair-Share is that it offers a mechanism of formative assessment [19], [7] in a large classroom. It provides students prompt and descriptive feedback on their understanding, both from their peers and from the instructors. It also provides instructors an immediate feedback on the quality of student understanding. Students and instructors can use this feedback to modify their learning and teaching respectively.

Think-Pair-Share technique draws its benefits from several theoretical bases including interactive engagement or active learning [17], cooperative learning [10], and wait-time [27]. Cooperative or collaborative learning from peers, based on social constructivist theories [30], lies at the heart of many active learning strategies, since it allows students to express their reasoning, engage in scientific debate, and reflect upon their own thinking. A certain amount of 'wait-time' is recommended during instructional activities, in which the instructor deliberately gives silent thinking time after a question is posed and after a student gives a response. This is done during the Think phase of TPS when the instructor poses the problem and gives students some wait time to work on it.

Studies of using TPS have been reported by instructors in psychology [5][29] and as part of broader studies on cooperative learning [10]. However, unlike peer instruction and other active learning techniques, there is a lack of research studies on TPS in computer science as well as other STEM disciplines.

2.3 Determining Student Engagement

Student engagement is one of the most widely researched indicators of the attractiveness of the teaching-learning process. While it is a desirable goal, defining it is elusive and so it is operationalized in different ways such as student satisfaction, enjoyment, involvement in learning, classroom participation, perseverance and so on. Engagement can be measured using instruments such as surveys and classroom student observations, each of which target different aspects of engagement.

Several validated and reliable survey instruments exist to measure the cognitive and behavioral aspects of student engagement [1], [9], [12]. There have also been several studies that measure in-class engagement from direct observation of student behavior in class using observation protocols [2], [11], [24], [28]. In this study, we choose to measure engagement using classroom observations of student behaviors as this offers a direct and rich picture of student engagement. We then triangulate the observation data with a student survey as well.

3. IMPLEMENTATION

3.1 Course Format

The setting for our study was a large enrollment CS1 class. The instructional goal was to teach programming concepts and skills to a population of 450 first year undergraduate students, across various engineering disciplines, excluding CS majors. The topics addressed were: control structures such as conditionals, iteration, functions and recursion, data structures such as arrays, matrices, strings and queues, object-oriented structures such as classes and inheritance. The C++ programming language was used as the medium to develop programming skills in the students. The course was conducted over 14 weeks in Spring 2013, and was organized into lectures, labs, and exams.

Lectures. The students were divided into two batches for the lectures. Each batch had two lectures per week, of one and half hours each. The classroom had large auditorium style seating with fixed chairs and benches, leading to constraints for students discussions and for instructor movement around the class. The lectures were taught by a single instructor; there were no Teaching Assistants in the lecture. Attendance ranged from 120-150. The course did not have recitation sessions, so mini-tutorials for developing problem-solving skills were incorporated into the lecture itself.

Labs. The students were divided into 5 batches for the labs, which were of two hours duration per week and consisted of programming exercises. The goal of each lab was to get the students to apply the concepts and skills learnt in the lectures.

3.2 TPS Intervention in Lectures

One challenge to effective teaching-learning in a large class lecture setting as described above is that some students may tune out, while others may engage in distractions such as using their mobiles or talking to each other on off-task topics. An important goal in such a setting is to keep students engaged with the content, the instructor and each other. One way to achieve this goal is to use active learning techniques such as Think-Pair-Share, whose benefits have been described in Section 2.

In addition to the recommended benefits [7],[4], we chose TPS for the following reasons: CS1 being an introductory programming course, two key learning outcomes are that students should be able to analyze a given program and write programs for the given tasks, in addition to acquiring conceptual knowledge of programming constructs. For most tasks, multiple valid solutions (programs) may be possible. So it is desirable that students also be able to analyze the pros and cons of various solutions. Hence we need a format of active learning that: (i) encourages a student to come up with his/her idea of the solution first, (ii) allows students to work with each other for detailing so that they do not feel daunted by the task, and (iii) discuss pros and cons of multiple solutions. We found that TPS had a natural good fit for meeting these requirements.

Most lectures, on an average, had two TPS activities. The overall structure of the activities had the prescribed phases - Think, Pair, Share - operationalized in a CS1 course as follows:

Think phase. The instructor posed a question, such as predict the output of a given program, or write the pseudo-code for a given problem. The students worked individually on the task, for about two minutes.

Pair phase. The instructor gave a task related to the Think phase, such as check your neighbor's solution, or work with your neighbor to write the detailed code for the given problem. The students worked with one of their neighbors to complete the task, in three to five minutes. The instructor walked along the aisles, encouraging discussion and answering queries.

Share phase. The instructor facilitated a class-wide discussion related to the tasks in the Think and Pair phases. Students' responses in the Think and Pair phases formed an important part of the discussion in this phase. For example, in a discussion on what is the correct prediction for the given program, significant time was spent on what changes are required in the program to get the other outputs predicted by students, and pros and cons of various solutions created by the students. Students participated in the discussion to verify their solution, propose alternate solutions, and discuss 'what-if' scenarios. This phase was open-ended, lasting from three to ten minutes depending on the intensity of the discussion. At an appropriate point, the instructor transitioned from this phase into the next topic.

Before the first TPS activity of the semester, the instructor described to the students the structure of the activity and what was expected of them. Thereafter it was found that the problem statement was sufficient to cue the students to what was expected of them. For the first 3-4 sessions, the instructor explicitly encouraged the students to write their responses during the Think phase. Thereafter, the students did not need any cueing for any of the phases.

3.3 Example TPS Activities

We present two examples of TPS activities in this section, one corresponding to each of the key learning outcomes mentioned above (Section 3.2).

Example 1 corresponds to learning outcome "students should be able to analyze a given program".
Problem statement – "Predict the output of the following program:

```
int main() { int A[4], *p;
for (int i = 0; i < 4; i++) A[i] = i;
p = &A[0]; cout << *p << " " << *(p +=2) << *(p+1)
+ *(p-1) << endl; }"
```

Think (2 minutes): Individually, students drew the memory arrangement and wrote down their prediction of the output.
Pair (2 minutes): Students examined if their neighbor's solution matched with theirs. If not, they discussed and came up with a solution that both agreed upon.
Share (3-5 minutes): Instructor elicited a few responses, then ran the program to show the output. He asked students to propose modifications in the code that could result in the other responses that came up. Instructor ran the modified versions, discussed the output of each and summarized the key concepts.

Example 2 - corresponds to learning outcome "students should be able to write programs for given task".
Problem statement - "Recall the drag-and-drop game demo that we saw in the last class. You and your neighbor have to now create this game. One of you has to write the script (code) for the 'trashcan' object (sprite) while the other writes the script for the 'falling trash' sprite."
Think (3 minutes): Individually, students wrote the pseudo-code for their chosen sprite.
Pair (5 minutes): Along with his/her neighbor, each student wrote the code to interface his/her sprite with its counterpart written by the neighboring student.
Share (8-10 minutes): Instructor elicited responses from a few pairs and discussed their solution details. Pairs that had used different approaches from the ones discussed were encouraged to speak. Instructor summarized some solution approaches and their pros and cons.

4. METHODOLOGY

4.1 Sample

In each instance of TPS, two observers observed ten students each for a total of twenty students. Thus we have observed 15%-20% of the class during each TPS activity. The students to be observed were sampled in two stages. The first step was cluster sampling to identify the region of the classroom to observe. The classroom had stadium style seats placed in a V-shape. This meant that there are a fewer seats in the front of the class than the back. For this reason, we chose to observe students from the middle rows as these are the typical students in a class (the back rows were generally unoccupied). Once the clusters were defined, the first observer chose one cluster randomly and the second observer chose another cluster as physically away from the first as possible to ensure maximum coverage of different types of students. From a cluster, each observer randomly sampled ten students in his/her range of vision to observe.

16 lectures during the semester had at least one TPS activity each. We observed 7 such lectures and a total of 13 activities. We used data from 8 TPS activities to create, validate and establish reliability of the protocol. In this paper, we report the

observations and findings from the remaining 5 TPS activities, repeated across 2 batches of students. The total number of sampled students and the total number of observations during each phase in each activity is shown in Table 1.

Table 1. Details of student sampling for observations

Activity		1	2	3	4	5	Total
No. of students observed		49	50	47	41	41	**228**
Total no. of observations	**Think**	91	90	59	93	93	**426**
	Pair	184	164	141	113	123	**725**
	Share	157	149	141	113	116	**676**

Since each observer chose a different cluster and changed his/her choice of cluster in each lecture, we claim that the 228 observed students (Table 1) whose findings we are reporting here, are distinct. This means that we have observed over 50% of the class at some time during the semester and so our findings are generalizable to the entire class.

4.2 Instruments

4.2.1 Observation protocol

Literature suggests that students' engagement can be inferred from their classroom behavior [2], [11], [24], [28]. We developed the Classroom Interactive Engagement Observation Protocol to observe students' behavior during TPS activities in the class and infer engagement in each phase of the activity, thus answering both our research questions. A screenshot of part of our observation protocol is shown in Figure 1. This is a real-time observation protocol, that is, an observer present in the classroom observes a student for a fixed time interval, marks all student behaviors (from a pre-defined list) seen within that time and then moves on to observe the next student. Some of the student behaviors in the final version of our protocol are: writing in notebook, reading own or neighbors' notes, reading the screen, talking to peer, listening to peer and so on. For a complete list, see the observation protocol in Figure 1.

Pair Phase Observations

	codes	students	1			2			3			n		
		observations	1	2	3	1	2	3	1	2		1	2	3
observation protocol	W	Writing in notebook.			x	x						x		
	RN	Reading own or neighbours notes.											x	
	RS	Reading the screen.	x						x					x
	T	Talking to peer on topic.		x						x	x			
	L	Listening to peer on topic												
	IQ	Ask question about the problem posed												
	IP	Group discussion, more than two people.												
	IR	Respond to teacher question.												
	LN	Looking at own or neighbours laptop.												
	OS	Out of seat.												
	MO	Playing with mobile, tablet, pen etc.												
	F	Fidgeting in seat.												
	LA	Looking around room.					x	x						
	SA	Staring away.												
	HD	Head down/ sleeping.												
	TF	Talking off topic with peers												
	LD	Looking down; doing other work.												

Figure 1 Observation protocol and instrument

To create our instrument, we surveyed literature [23], [6], [22], [25] of existing validated observation protocols for classroom observations and identified a superset of behaviors that are likely to occur in an active learning classroom. The superset was then pruned by an unstructured observation of a TPS activity to identify relevant student behaviors in our large class. Using this pruned behavior list we created a first version of our protocol which we piloted during one of the TPS activities.

In the pilot, we found that there were additional behaviors, which were not present in the first version of our instrument. One example of such a behavior is students writing the program for the problem in the TPS activity on their laptops. Since the observers were seated such that they could see the students laptop screens, they saw that students were indeed coding and not doing off task activities. Another example of an added behavior is students playing games on their mobiles and tablets. These behaviors were included, and the second version of the instrument was again tested during a TPS activity and this process was repeated until the set of behaviors for the different engagement levels saturated. Thus our instrument has been verified for construct validity.

This validated instrument was then tested for inter-rater reliability between observers observing the same set of ten students for the same time interval during a TPS activity. The percentage agreement among observers was found to be 90% which is accepted to be a good figure for observation protocols.

4.2.2 Survey Questionnaire

To triangulate our findings, we used a second instrument in our study. This was a survey to measure self-reported student engagement during the TPS activities. The goal was to answer the research question "How much engagement occurs when TPS is implemented in a large class?" by measuring the fraction of students who reported being engaged during the TPS activity.

The survey had three questions on engagement – one question asking the students how frequently they were engaged in writing in the think phase, another asking how frequently they were engaged in discussing in the pair phase and a final question which asked their opinion on whether the TPS activities caused them to stay interested in the content of the lecture. All the questions were to be answered on a five point Likert scale.

4.3 Procedure for data collection

4.3.1 Observation data collection

The goal of the observation study was to observe as many students as possible for as long as possible to infer a behavior pattern of engagement. There were two observers and their starting times were aligned. Each observer observed ten students in an activity. Each student was observed for a period of three seconds and his/her behavior(s) was recorded before moving to the next student. After one cycle of ten students, the observer returned to the first student and began another cycle. In all, three cycles were scheduled in each phase, for a total of nine cycles per activity. Depending on the type of problem, there were slight variations on the duration of the phases. Hence the number of cycles actually completed varied from six to eleven per activity.

The observers sat at locations from where they were able to see the students' actions and facial expressions clearly. However, they were not too close to the students being observed and took care to be unobtrusive in their observations, in order to minimize Hawthorne effect. The observer did not make any judgment on how engaged a student was during the observation and merely recorded as many behaviors as he/she could observe in the observation time interval. For example, if a student was talking to a neighbor and writing in his notebook, both were recorded by the observer.

4.3.2 Survey data collection
An online survey was conducted for our students on several aspects related to the class. Questions pertaining to the TPS activity were separated out and analyzed.

4.4 Analysis
We first classified the collected observed behaviors as desirable and undesirable behaviors. Desirable behaviors were those that indicated engagement. These were identified from existing observation protocols, and by determining appropriate student actions for our setting. Desirable behaviors include reading notes, reading the screen, writing in notebook, talking and listening on topic, asking the instructor a question, responding to an instructor question, group discussion and looking at laptop. The remaining behaviors were classified as undesirable.

We structured the analysis at three levels. The raw data comprise of behaviors of individual students observed at multiple instances of time across a TPS activity. Analysis performed on this data is called the behavior-level analysis. Next, the observed behaviors were aggregated across time and students to obtain the engagement of the class during each TPS activity. This is called the class-level analysis. Finally, the observed behaviors were aggregated to extract engagement patterns of a student across time. This is the student-level analysis. The behavior-level and student-level analyses provide answers to research question 1 while the class-level analysis answers research question 2.

5. RESULTS
5.1 Behavior Distributions
We first perform a behavior-level analysis to determine the frequency distribution of all the behaviors observed in all the TPS activities for each phase. We then identify the prominent behaviors in each phase and compare them to the desirable behaviors for that phase. Figures 2a, 2b and 2c show this analysis for the Think, Pair and Share phases respectively.

In each phase, we classified the desirable behaviors further into active and passive [11]. In the think phase, writing in notebook and talking with neighbor were considered active behaviors, while reading notes was considered passive engagement behaviors. In the pair phase talking and listening to neighbor and writing were considered active, while looking at the screen or notes was passive. In the share phase, writing in notebook and discussing with neighbors were active behaviors while following class discussion and looking at laptop were passive.

As we see from the pie-charts, in the think phase, the predominant behavior was writing (47%), followed by 'looking active and the latter passive. In the pair phase, the dominant behaviors were talking (30%) and writing (23%), both of which were active and desirable behaviors. Finally, in the share phase, the predominant behavior was 'following instructor discussion' (60%), a passive desirable behavior, followed by 'writing in notebook' (10%), an active desirable behavior. We note that in the think and pair phases a majority of behaviors were active, while in the share phase the majority of behavior was passive.

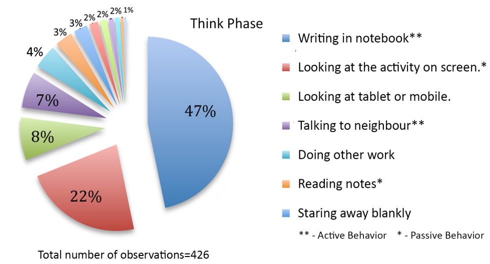

Figure 2a: Behaviors during think phase

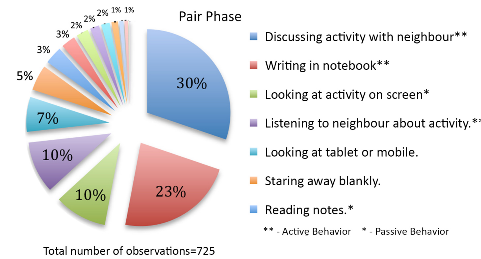

Figure 2b: Behaviors during pair phase

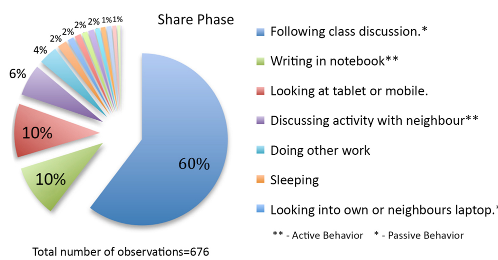

Figure 2c: Behaviors during share phase

5.2 Overall engagement
From the observed behaviors, we zoomed out to be able to make inferences about the overall classroom engagement. To do so, we began by identifying, from among the twenty students observed in each TPS activity, those who displayed desirable behaviors in all cycles of a phase. These were categorized as 'fully engaged'. Similarly we identified those who displayed desirable behaviors in fifty percent or more of the cycles. They are categorized as 'mostly engaged'. Students who showed desirable behaviors in less than fifty percent of the cycles were categorized as 'sometimes engaged'. Those who displayed only undesirable behaviors in all cycles were categorized as 'never engaged'. The percentage of students in each category was calculated and this calculation was repeated for all phases and all activities. The variation of the percentage of students in each category in each phase between five different TPS activities is shown in Figure 3. The percentage of students in each category and each phase was then averaged across all TPS activities to obtain average engagement across the semester. This result gives us a picture of the overall engagement of the class in the three phases of a TPS activity and is shown in Table 2.

Table 2. Average Engagement throughout the semester

No. of students = 228	Think	Pair	Share
Fully engaged	71.83%	62.03%	68.43%
Mostly engaged	9.86%	21.23%	16.57%
Sometimes engaged	2.91%	9.53%	7.00%
Never engaged	15.39%	7.21%	8.01%

The engagement (fully+mostly) in the think phase lies between 70% and 95% depending on the problem, in the pair phase it varies between 75% and 90% and the share phase also between 75% and 90%. As we see from these results, there is not much variation across the different problems. The overall average engagement of the class, in terms of percentage of students fully & mostly engaged in the TPS activities conducted throughout the semester comes to 83%.

Figure 3. Overall engagement of students across different problems discussed through TPS

5.3 Behavior model across phases

Using the aggregates of the number of students in each category in each phase, we next determined the percentage of students who transitioned from category A in one phase to category B in the next phase. To do so we counted the number of students who were in category A in one phase and category B in the next phase. This enabled us to develop the empirical model of the students' behavior during a TPS activity shown in Figure 4.

The circles in the diagram represent the four engagement categories or "states" of the student during each phase of the activity. The number in the circles represents the total number of students in that "state" during that phase. The percentages indicate the percentage of the total number of students (228) in this category. The rectangles on the lines connecting state A in one phase to state B in the next phase represent the "transition probabilities" i.e., the percentage of students who go from state A in one phase to state B in the next phase. Note that these are not actual probabilities, but empirical percentages.

From this model we observe that there is an upward movement in engagement from the think to pair phase and some drop in engagement as well. In particular 29% of the students who were never engaged, 60% of the students who were sometimes engaged and 47% of students who were mostly engaged in the think phase became fully engaged in the pair phase.

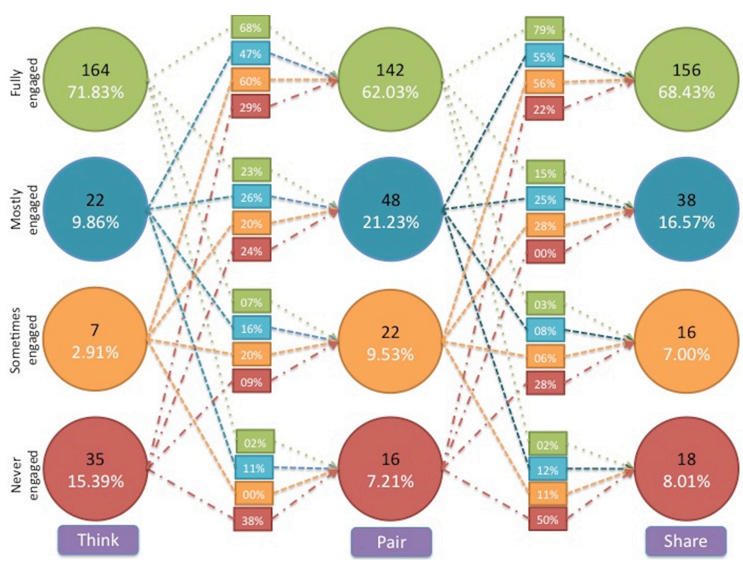

Figure 4: Student behavior model

Next in the transition from the pair to share phases, we again observe that some poorly engaged students become highly engaged in the share phase, and vice-versa. Specifically, while 5% of the fully engaged students in the pair phase become less than 50% engaged in the share phase, 84% of the students who were only sometimes engaged became mostly or fully engaged in the share phase. Thus we find that the overall engagement level is maintained. This gives us a complete picture of student behavior across all phases of a typical TPS activity.

5.4 Survey Questionnaire Analysis

The responses for two questions related to TPS activity from the online questionnaire are shown in Figure 4. 336 students responded to the questionnaire. The data show that nearly 62% of students reported spending a high percentage of time writing during the think phase and 70% of students reported spending a high percentage of time discussing with their peers during the pair phase. This triangulates well with observation data as we explain in Section 6.

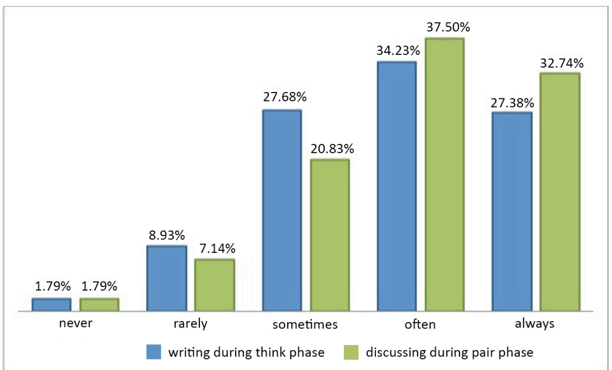

Figure 4: Survey questionnaire analysis

6. DISCUSSION

Our first research question, "What behaviors do students engage in during the Think-Pair-Share activities implemented in a large class?" was answered by the behavior-level analysis. From the pie-charts in Figs. 2a, 2b and 2c, we see that a range of behaviors are displayed by students. In addition, each phase of the Think-Pair-Share activity has predominant behaviors that students engage in. While the specific predominant behaviors are different for each phase – 'Write in notebook' for Think phase, 'Discuss with neighbor' for Pair phase and 'Follow class discussion' for Share phase – each of these is a desirable behavior from an instructor's perspective and indicate that the student is engaged and on-task in the activity.

From the class-level analysis, we were able to give a quantitative measure to the engagement level during a classroom activity. Table 2 and Figure 3 help us answer our second research question: "How much student engagement occurs during the Think-Pair-Share activity?" We found that the percent of the class which is fully or mostly engaged is between 70% and 95% in any phase of any activity. This leads to an average of 83% of the class which was either fully or mostly engaged during the semester. This high level of engagement was a result of a large number of desirable behaviors in each phase.

We triangulated our observation protocol findings with data from a student perception survey. 27.5% of students reported writing always in the think phase of the activity. This is comparable to our observation data which shows that 29% of the students were observed writing throughout the think phase. Similarly, 33% of the students reported discussing always in the pair phase. Our observation data indicate that 24% students were discussing throughout during this phase. Note that students who have finished their task before the end of the phase may be doing off-task activities and recorded as non engaged by our protocol, which is a valid measurement. The fact that some students are ahead of the game and hence non-engaged is important for the instructor while designing TPS activities, but is beyond the scope of this paper. Further we find that 38% of students, display desirable engagement behaviors in all three phases at all times (fully engaged). While this may be more a function of the students themselves rather than the activity, we now have a concrete number for this that other studies can use for comparison.

We can use the student behavior model we developed to make predictions. For example, there is a 0.72 probability that a student will show an engaged behavior like reading, writing, talking or listening throughout the think phase (fully engaged state), but only a 0.15 probability that a student will be disengaged throughout the think phase (never engaged state). The model makes similar predictions for student engagement states in the other two phases as well.

Further, the model predicts the probability of a student transitioning from one engagement state to the next and helps us answer: "How does the amount of engagement change as activity progresses?" (RQ2b). According to the model, there is a high probability (0.68) that a fully engaged student in the think phase will remain fully engaged in the pair phase. However there is a 0.32 probability that the student will move to a lower engagement state. We may use this to infer that there are students who don't prefer to always discuss their solution with their peers. Similarly, there are significant probabilities (0.47, 0.6 and 0.29) that students from lower engagement states in the think phase move into a higher engagement state in the pair phase. This indicates to students who may not have done the individual activity but learn by discussion with their peers.

We have established the validity of the above results primarily by applying a systematic procedure for sampling, observation and analysis. Our sampling process and observation schedule capture an accurate view of the entire class across all TPS activities, as we took care to ensure their representativeness. Our data analysis procedure had several measures of reliability checks built in, across different raters and problems. In addition, we use triangulation from survey data.

7. CONCLUSIONS

The goal of this field study was to understand student behavior in an implementation of an active learning strategy, Think-Pair-Share, operationalized for a large CS1 class. While there have been studies in psychology education [5][29] on using TPS in the classroom, engagement numbers have only been weakly mentioned in literature [7]. Our study is the first of its kind to generate such numbers. Other contributions include a validated instrument that researchers can use for conducting observational studies for active learning strategies in a classroom The student behavior model can be used for further research to make and test predictions.

A major instructional implication of our study is that Think-Pair-Share is a suitable strategy to use for CS instructors who intend to incorporate active learning techniques in their courses. A TPS implementation, similar to ours, has recommended characteristics such as students working in small groups, expressing their reasoning and receiving prompt feedback. Our findings regarding the engagement behavior patterns of students support the benefits of TPS strategy. Finally, further research on the nature of the TPS problems and the observation data can lead to the development of a framework to guide an instructor to systematically incorporate TPS in a large CS class.

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