Teaching Algorithms and Data Structures

A tale of two approaches

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ABSTRACT

In Computing Science, Algorithms and Data Structures (ADS) are fundamental as they give learners a solid foundation in programming. ADS require abstract thinking and problem-solving abilities from students instead of memorisation – of formula or procedures, for example - without a clear understanding of the concepts. This paper reveals how master's students ($n = 35$) perceived and experienced the different activities used to teach ADS in traditional lecture and flipped classroom environments. Results showed that the individual activities that scored higher were problem-solving and peer discussion in the flipped classroom. Regardless of the teaching approach, many students did not access the prior preparation teaching material mainly due to the lack of time. Findings also highlight the importance of communicating the intentions and pedagogical goals better. Findings have wider implication for practitioners facing the same challenges. It is hoped that the experiences reported in this paper can help practitioners to understand better the benefits and pitfalls that could emerge when converting an ADS class or similar to the flipped model.

KEYWORDS

Algorithms and Data Structures, higher education, large classroom, flipped learning, active learning

1 Introduction

In Computing Science, Algorithms and Data Structures (ADS) are fundamental as they give learners a solid foundation in programming. In a typical course, several paradigms for algorithm design are taught, including guidance about the use of each of them (Roughgarden, 2019). ADS course is notoriously difficult to teach (Liu et *al*., 2013) and other ways of teaching it are being investigated (Lokare & Jadhav, 2017; Shingan & Ugale, 2018). It requires abstract thinking and problem-solving abilities from students instead of memorisation – of formula or procedures, for example - without a clear understanding of the concepts. The course is often taught at undergraduate and postgraduate levels.

This paper is concerned with the experience of teaching ADS at Masters Level, to a mixed class of mainly software development and Information Technology students. The class also includes some students from non-computing science disciplines with no or less programming experience. The heavily content-driven sequential lectures are usually taught using the traditional lecture model in a teacher-centred environment. The content, which is quite dense, can be hard to understand given the speed at which the lecturer tries to cover all the concepts. Typically, students are expected to take notes and have opportunities to ask or answer questions. Students are supposed to do the tutorials that sometimes require implementations using a programming language and in this case, Java, outside the class; there is an extra one hour class contact to answer students' questions on tutorial/lab exercises.

This next section begins with the motivation for the change of practice. Then it provides a brief description of the flipped classroom. Some data based on a student survey and open-ended questions are provided. The final section provides some concluding remarks.

2 Background

During a normal lecture, the amount of time dedicated to activities that fostered interaction was very limited. In some sessions, adding extra problem-solving questions made it impossible to cover all the topics for the sessions. This was another source of concern as many students usually want to understand most of the course material during the face-to-face lectures (Dębiec, 2018). Additionally, it was difficult for the lecturer to determine the extent to which students engaged with the content during the class, how much they understood the concepts discussed in the lectures despite the weekly attempts to get them to leave anonymous notes on what they have learned or they still struggled with. That type of situation can lead to students' misconceptions to go unnoticed until it is too late (Lee & Lee, 2015). The only consistent issue that was mentioned during the first and only three weeks of feedback on teaching was the lack of extra time in class for more practical tasks that would explain complex concepts. The lecturer's concern was the lack of personalisation as the traditional approach to teaching ADS meant that the same teaching style and pace of the class were applied to all students regardless of their needs, hoping that they would all understand the concepts.

On the other hand, feedback from the first observation of the lecturer's teaching by a more experienced lecturer in week 6 confirmed the lecturer's own observations that the class became alive only during the problem-solving tasks. The observation feedback suggested making use of a flipped classroom to capitalise on the entire class time to help the students understand the concepts. The time would be utilised efficiently, and the lecturer would scaffold problem-solving through in-class activities in order to improve the students' assimilation of ADS concepts.

2.1 Flipped Classroom Concept

Flipping or "Inverting the classroom means that events that have traditionally taken place inside the classroom now take place outside the classroom and vice versa" (Lage et *al*., 2000, p. 32) and was first used to teach an economics course. It is an instructional approach that assigns lectures outside of class in order to maximise the time spent in class to foster peer and student-teacher interactions and student engagement. The flipped classroom can allow the teacher to personalise the students' education (Bergmann & Aaron, 2012). With this approach, the lectures are pre-recorded, allowing students to watch them and listen to the explanations. The entire class period is then used to help students with the misunderstood concepts. It is well-aligned with the hands-on practice required in computer science (Lockwood & Esselstein, 2013) and is gradually being used in higher education with encouraging results in student learning performance (Chang & Hwang, 2018; Davies et *al.,* 2013; Fulton, 2012; Latulipe et *al.,* 2013). Flipped classroom also develops students' higher-order thinking (Flumerfelt & Green, 2013) and can foster peer interactions (Roach, 2014).

For computing science (CS) education, the flipped classroom can be used to leverage social interaction and peer instruction (Maher et *al*., 2015). A review of the flipped classroom method in CS education identified many benefits: increases learning performance, positive attitudes, increases engagement, more discussions, enforces cooperative learning and better learning habits. However, the review also highlighted that students could be unreceptive with the flipped learning structure (Giannakos et *al.,* 2014). Within the specific context of ADS, this pedagogical model has been used to improve the undergraduate students experience and learning outcomes in ADS (Lee & Lee, 2015); implement an innovative approach to ADS lab exercises for postgraduates where the problem, ways & means and answers are open instead of working on predefined problem statements (Sujatha et *al.,* 2012).

The purpose of this study is to understand how MSc students' perceived and experienced the different activities used to teach ADS in traditional lecture and flipped classroom environments. It compares two instructional approaches to inform teaching practice. The objectives are to determine (a) which method of instruction the students prefer, (b) if applying changes to the instruction methods would impact the students, (c) if students engage in more preparation before class (DeLozier & Rhodes, 2017), and (d) which of the class activities students find most effective and/or perceive favourably in both teaching methods.

3 Materials

This study conforms to a quantitative design. However, it also embeds qualitative data by including students' comments.

3.1 Participants and settings

The study involved postgraduate students. Traditionally, the student cohort comes from various strands but mainly IT and Software Development. For MSc Software Development, ADS is mandatory and elective to other students. The format the course is a two hours lecture and a one hour tutorial per week for ten weeks. The students experienced two different approaches to learning ADS topics. Firstly, students were exposed to the traditional way this course has been taught from week one to week seven, with regular PowerPoint slides with one or two problem-solving tasks per lecture where students were encouraged students to work in groups. The intention was to break the lecture hours into manageable learning slots and making sure that they understood the concepts. The teaching material was always available online a week before each lecture. However, the updated slides with the problem-solving tasks and solutions were only uploaded after the lecture.

On week 7, the lecturer informed the students of the flipped classroom approach that would be implemented from week 8 and would focus the entire two hours lecture on solving problems, discussion and demonstration where necessary. All of those who attended the lecture on week 7 ($n = 45$) supported that idea of the flipped classroom. An email was also sent to remind the entire class of the change in the teaching approach. In week 8 to week 9, the pre-recorded lectures (and their PowerPoint slides) were uploaded on Moodle three days before each session. Students were advised to watch them before attending the lectures. The class then had enough time to focus on problems based on these two weeks topics (Maps and Hash-tables), and revisit topics from the previous weeks. The in-class activity learning objectives were to apply the concepts to solve open-ended problems in groups. Figure 1 presents an example of a problem in the flipped classroom, which would have taken too much time to solve in the traditional setting. It covers multiple concepts. It challenges student knowledge on the stack, array, singly linked list, their design, operations and time complexities. The same lecture room was used for both instructional approaches. At the end of the flipped classroom (week 9), students were asked to take a paper survey. Within the University's ethical guidelines, they were advised that it was voluntary and not to include any information that could help to identify them and that, data gathered would remain confidential and anonymous.

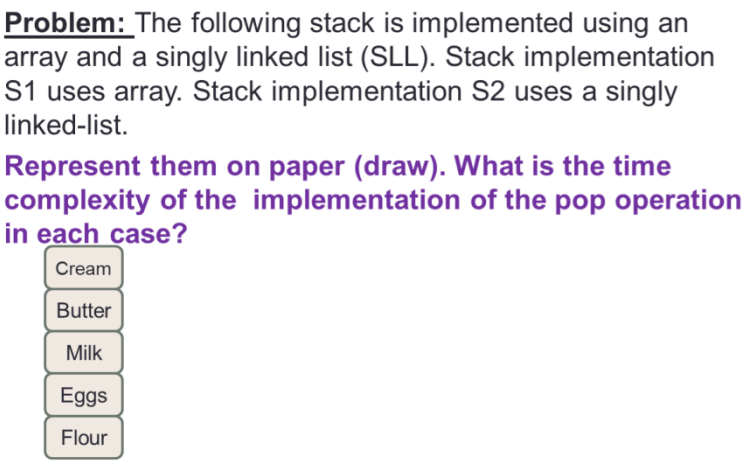

Figure 1: Example of a problem-solving question

3.2 Data collection Analysis

Students were asked to complete a post-course survey at the end of week 9. The survey (see Table1) comprised nine questions, including two 5-items scales and two open-ended questions. The first scale comprised of 7 items. Students were asked to rate the effectiveness of the individual activities in both traditional lecture and the flipped classroom. The second scale, with 15 items, was devised to measure their perception of the value, depth of understanding, and enjoyment of the individual activities in traditional lecture and flipped classroom. The scales required the students to rate the effectiveness and perception of the like-to-like activities on both approaches on a scale of 1 (very ineffective) to 5 (very effective). The 7th item in scale 1 and the last three items in scale 2 involved the out-of-class flipped classroom activity of watching pre-recorded lecture video. The two open-ended questions were included to help with the interpretation and explanation of the students' views about their experience of both teaching approaches. They inquired about students' likes, dislikes and enabled them to provide suggestions. The student responses were coded, organised into themes, and finally put into categories. These are to be interpreted within the context of this paper. The qualitative data inclusion was an effort to minimise any initial bias that the quantitative survey could bring. The author used descriptive statistics to analyse data using R packages. Data from open-ended questions were used to supplement students' views on their experience of the teaching approaches.

4 Findings

4.1 Survey results

Students who took the survey (n = 35), consisted of 19 males and 14 females. Their age range was between 22 and 44. Two students did not declare their gender and their age. There were 14 non_UK students (EU and Overseas) and 21 home students (UK). More than half (68.57%) read their lecture slides before the traditional lecture approach, while only 8 students (22.86%) watched the pre-recorded videos before attending the classes during the flipped classroom approach. The majority of items in the scales received positive ratings above 3, with average ratings above 4, and with low standard deviations, an indication of consistency in ratings (Table 1).

Table 1: Student survey average responses

Teaching Methods	Survey Item	Mean	SD	N
Effectiveness of the activities during regular Lectures	A few problem-solving questions in the lecture's PowerPoint during lecture	4.00	0.92	35
	Discussing questions with your peers in the lecture	3.74	1.05	35
	Demonstration in the lecture	3.8	1.06	35
Effectiveness of the activities during flipped classroom	Practice problem-solving questions in lecture room (for nearly a full two hours)	4.31	0.74	35
	Discussing questions with your peers in the lecture room	4.00	0.89	35
	Demonstration in the lecture room	4.08	0.84	35
	Pre-lecture work: watching videos before class	3.27	1.09	30
Perception of the activities during regular Lecture approach	A few problem-solving questions in the lecture's PowerPoint during lecture: This is a valuable use of time	4.08	1.02	35
	A few problem-solving questions in the lecture's PowerPoint during lecture: It provides a deeper understanding of the topic	4.28	0.81	35
	A few problem-solving questions in the lecture's PowerPoint during the lecture. It is an enjoyable way to be taught	4.14	0.93	35
	Discussing questions with your peers in the lecture room is a valuable use of time	3.65	1.11	35
	Discussing questions with your peers in the lecture room provides a deeper understanding of the topic	3.65	1.09	35
	Discussing questions with your peers in the lecture room is an enjoyable way to be taught	3.74	1.12	35
Perception of the activities during Flipped classroom approach	Practice problem-solving questions in lecture room (for nearly two hours) is a valuable use of time	4.00	1.09	35
	Practice problem-solving questions in lecture room (for nearly two hours) provides a deeper understanding of the topic	4.14	0.94	34
	Practice problem-solving questions in lecture room (for nearly two hours) is an enjoyable way to be taught	4.08	0.85	34
	Discussing questions with your peers in the lecture room is a valuable use of time	3.73	1.19	34
	Discussing questions with your peers in the lecture room provides a deeper understanding of the topic	3.82	1.09	34
	Discussing questions with your peers in the lecture room is an enjoyable way to be taught	3.85	1.11	34
	Pre-lecture work – watching videos before class: is a valuable use of time	3.53	1.32	32
	Pre-lecture work – watching videos before class: provides a deeper understanding of the topic	3.53	1.24	32
	Pre-lecture work - watching videos before class: is an enjoyable way to be taught	3.24	1.25	33

There were no statistically differences in the effectiveness and perceptions of the teaching activities scales between the traditional lecture and flipped classroom. Table 2 below presents the paired sample descriptive statistics for the effectiveness and perceptions scales during both teaching approaches.

Table 2: Paired samples descriptive statistics of subscales

		Mean	N	Std. D
Pair 1	Effectiveness of the activities in the normal lecture	11.54	35	2.466
	Effectiveness of the activities in the flipped classroom	12.40	35	1.834
Pair 2	Perception of the activities in the normal lecture	24.18	33	4.440
	Perception of the activities in the flipped classroom	23.94	33	4.603

Table 3 presents a descriptive analysis of individual items. Regardless of the teaching method, the highest-rated items in term of the effectiveness and positive perception of teaching activities are those related to problem-solving. A likewise comparison of the items in the effectiveness of the activities (scale 1) shows that more students found practising problem-solving questions and discussing questions with their peers more "effective" and "very effective" in the flipped classroom (89%, 77%) than in the traditional lecture style of teaching (77%, 71%). The percentage was the same for both in terms of demonstration (69%). Results also highlight that the percentages of students who found these three activities (problem-solving, discussion and demonstration) "very ineffective" and "somewhat ineffective" during the lecture were higher than the ones for the flipped classroom.

The second scale measured the "Perception of the value, depth of understanding, and enjoyment of activities for both approaches". Most students "agreed" and "strongly agreed" that having a few problem-solving questions during the lecture is a valuable use of time (83%), and provides a deeper understanding of the topic (83%) as compared to 76% and 74% in the flipped classroom for the same activities. However, students enjoyed problem-solving activities in a flipped classroom more than in the lecture with 82% and 80% respectively. Students also felt that discussing questions with their peers in the flipped classroom was an enjoyable way to be taught (68%), provided a deeper understanding of the topic (68%) and was a valuable use of time (65%) in comparison to these activities in the traditional lecture (63%, 60%, 60%). Watching pre-recorded videos before class (not included in Table 3) was an activity that was done during the flipped classroom weeks. In term of its effectiveness, only 13 out of 30 students (43.3%) found it effective or very effective. In terms of the perception scale, of the 32 students who rated that item, 56.25% agreed or strongly agreed that that activity provides a deeper understanding of the topic, is a valuable use of time (53%), is an enjoyable way to be taught (43.75%).

Table 3: Descriptive analysis of individual items of effectiveness and perception scales

Teaching Methods scales	Survey Item	Rate 1&2	Rate 3	Rate 4&5
Effectiveness of the activities during regular Lectures	A few problem-solving questions in the lecture's PowerPoint during lecture	6%	17%	77%
	Discussing questions with your peers in the lecture	17%	11%	71%
	Demonstration in the lecture	14%	17%	69%
Effectiveness of the activities during flipped classroom	Practice problem-solving questions in lecture room (for nearly a full two hours)	3%	9%	89%
	Discussing questions with your peers in the lecture room	9%	14%	77%
	Demonstration in the lecture room	0%	31%	69%

Perception of the activities during regular Lectures	A few problem-solving questions in the lecture's PowerPoint during lecture: This is a valuable use of time	11%	6%	83%
	A few problem-solving questions in the lecture's PowerPoint during lecture: It provides a deeper understanding of the topic	3%	14%	83%
	A few problem-solving questions in the lecture's PowerPoint during the lecture. It is an enjoyable way to be taught	9%	11%	80%
	Discussing questions with your peers in the lecture room is a valuable use of time	14%	23%	60%
	Discussing questions with your peers in the lecture room provides a deeper understanding of the topic	17%	23%	60%
	Discussing questions with your peers in the lecture room is an enjoyable way to be taught	17%	20%	63%
Perception of the activities during Flipped classroom approach	Practice problem-solving questions in lecture room (for nearly two hours) is a valuable use of time	9%	17%	74%
	Practice problem-solving questions in lecture room (for nearly two hours) provides a deeper understanding of the topic	3%	21%	76%
	Practice problem-solving questions in lecture room (for nearly two hours) is an enjoyable way to be taught	3%	15%	82%
	Discussing questions with your peers in the lecture room is a valuable use of time	18%	18%	65%
	Discussing questions with your peers in the lecture room provides a deeper understanding of the topic	15%	18%	68%
	Discussing questions with your peers in the lecture room is an enjoyable way to be taught	15%	18%	68%

4.2 Open-ended question responses

Many students explained why they did not do any preparatory work (pre-read PowerPoint slides or watch pre-recorded lecture) before attending the classes. Additionally, 69% of students who took the survey answered the open-ended questions. Despite not being strictly quantitative, their comments were categorised to provide the number of respondents per theme.

The main reason for students (n=27) who did not engage in prior preparation before attending the flipped classroom was the lack of time due to other course assignments (85%). Meanwhile, in the traditional lecture (n = 11), 45.5% stated the same lack of time and also their preference to learn everything in the class instead of having to prepare beforehand. Table 4 presents the reasons students did not prepare before attending the classes. Some students reported not being aware of the requirement to access the content outside of the class in both instructional methods.

Table 4: Students' reasons for not engaging in preparation before class in each instruction methods

Reasons for no prior preparations	**Flipped Classroom (*n* = 27)**	**Traditional lecture (*n* = 11)**
Lack of time due to assignments	85% (23 students)	45.5% (5 students)
lack of awareness of the need to prepare beforehand	7.4% (2 students)	9% (1 student)
Prefer to learn by attending lectures	3.7% (1 student)	45.5% (5 students)
Read slides for Flipped classroom	3.7% (1 student)	

What did you dislike and like the most about the traditional lecture approach?

Of the 24 students who specified what they liked (Figure 2), 31% liked that they could receive a more detailed explanation of the concepts during the lecture because the materials were covered in the class. It meant that they did not need to prepare before the class as Student R10 summarises: "*... not needing to have to read the slides/book before class to follow along*." (Student R10)

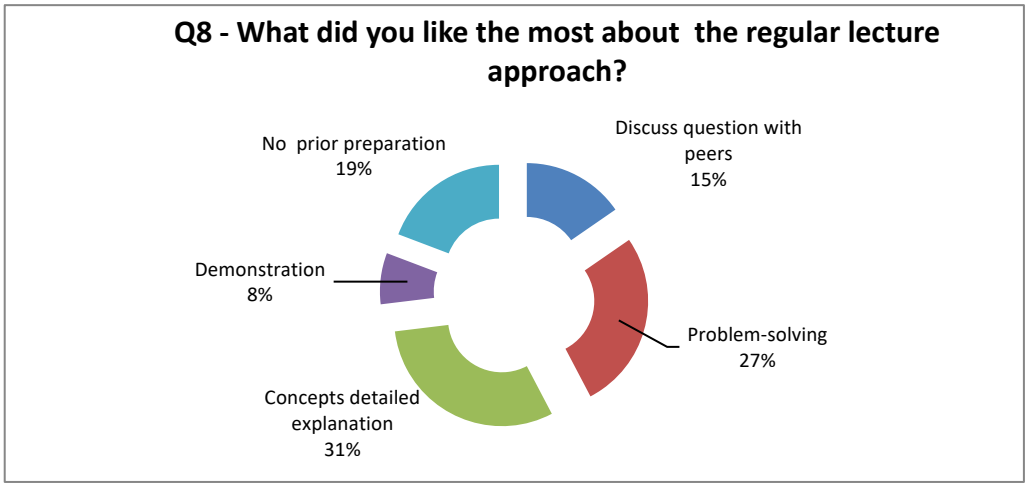

Figure 2: What students like the most about the traditional lecture approach?

The things students disliked the most were related to time. They felt that time was wasted on simple questions (Students R12, R18, R21,), they did not have more time for practical tasks (Student R25), the lectures were too long as "*concentration depletes after 2 hours regular lecture*" (Student R30). Meanwhile, Student R9 was critical of the "big" amount of content that had to be learnt in a two-hour lecture. Furthermore, the "dry" topics caused a lack of engagement (Student R15), "*... Dislike: big amount of content had to be learnt in a two- hour lecture*" (Student R9). While student R17 disliked the lecture because of confusing examples, that student also found that discussing with peers helped diffuse the confusion: "*First in slides, confusing examples made lectures hard to follow, but discussion and reviewing textbook helped"* (Student R17). On the other hand, Students R11, R28, and R32 disliked peer discussion, preferring working on their own and seeking the lecturer's help when necessary as captured in Student R11' comments*"... I do not like to discuss questions with others because I can work them out on my own. I prefer to talk to you for help*" (Student R11).

What did you dislike and like the most about the flipped classroom approach?

Most of the students who provided an answer to that question liked "Problem-solving" the most (44%), followed by peer discussion (22%). (See Figure 3) as the following comment summarises: "*I did like having sessions dedicated to problem-solving in groups, very useful."* (Student R18). Some students (15%) liked the preparation materials (pre-recorded videos) because they save time (Student R3), can be watched many times and are available all the time (Student R24, R26) and "primes the mind to take in information" (Student R31). Meanwhile, Student R19 remarked that talking to peers helped them stay engaged while student R30 thought that flipped classroom was more engaging and provided a deeper understanding of the knowledge; that approach of teaching enhanced learning (Student R21) as it provided a deeper understanding of how to solve these questions (Student R32); it was also more enjoyable (Student R13) and more engaging (Student R15).

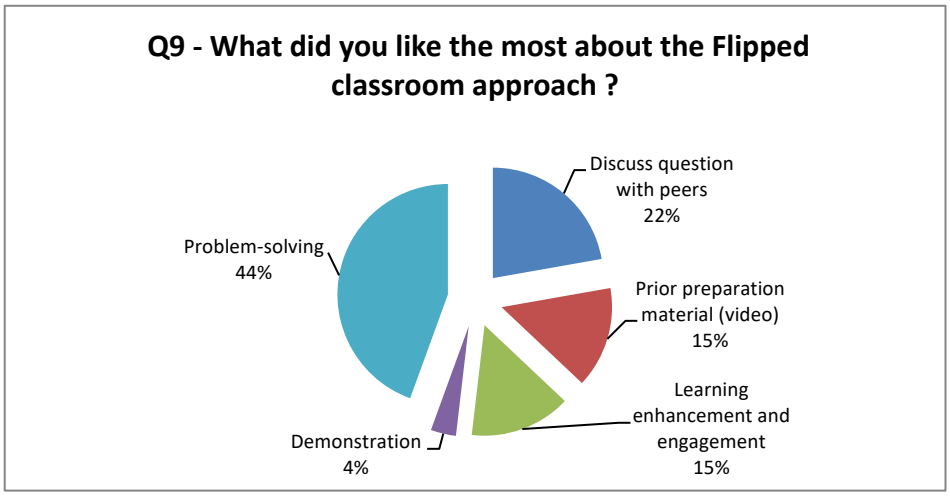

Figure 3: What students like the most about the Flipped classroom approach

On the other hand (see Figure 4 below), two students disliked the fact that they had to change their learning style. For example, Student R13 enjoyed the flipped classroom more than the normal lecture but struggled to adapt to the new teaching approach and suggested the lecturer get them used to that approach from week one. Many did not have time to prepare before attending the class.

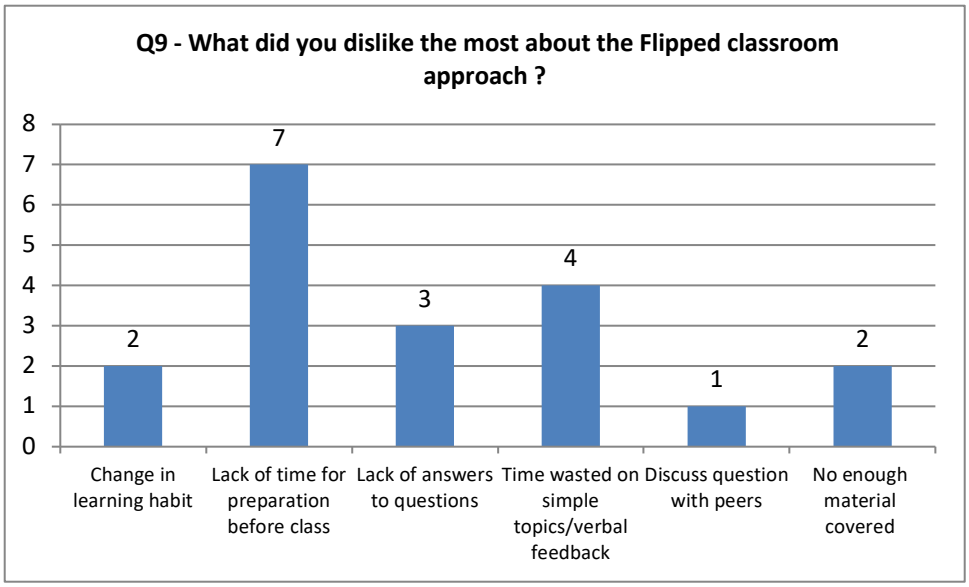

Figure 4: What students dislike the most about the Flipped classroom approach

Teaching method preferences

There were 16 students who mentioned their teaching method preferences in their comments, 50% of them would prefer a flipped classroom (preferably from week 1), followed by a mixture of lecture and flipped classroom (31%), for example, 1 hour lecture and 1 hour flipped classroom, and Traditional Lecture (19%). For instance, Student R20 "liked the opportunity to work as a group" and "learnt a lot". However, there was a feeling that much material was not being covered; hence, some student's preference for a mixed teaching approach:

> "I liked the opportunity to work as a group. I felt I learnt a lot. I do not think it would work to have all lectures like this because we don't cover a lot of material. I would prefer to have the regular lectures and then tutorials in the flipped class approach." (Student R20)

Student 5 gave a similar account but would still prefer a flipped classroom despite not having time to do any preparatory work.

> "I found flipped class very useful, but I didn't have time to watch the videos beforehand, so I'm not sure how good it would have been if the whole semester had taken this format. A mixture of the two is probably the best approach, but I personally would prefer more flipped classes." (Student R5)

Student R7 who disliked "Theoretical teaching," thought that the flipped classroom was a better approach because solving questions furthered the understanding of the topics: *"I liked solving questions to further my understanding about the topic. This was a better approach"* (Student R7).

5 Discussion and Conclusion

The purpose of this study was to understand how postgraduate students' perceived and experienced the different activities used to teach ADS in traditional lecture and flipped classroom environments.
There were no statistically differences in the effectiveness and perception of the teaching activities between the regular lecture and flipped classroom. This is consistent with other studies that have reported no statistical difference between teacher-centred lecture-based class and a student-centred active learning class (Bateiha, Marchionda & Autin, 2020). Analysis of the individual items showed that the teaching activities that scored higher in terms of "strongly agree and agree" were problem-solving and peer discussions in the flipped classroom. This was also captured in students' comments.

The pre-recorded lectures motivated only a minority of students, mainly due to other assignment workloads. The lack of time in prior preparation could be justified by the fact that flipping the classroom was done at a time when students' assessment workload was high, towards the end of the semester. This was reflected in their low attitudes and perception scores of pre-recorded videos. Nonetheless, the finding is not surprising as students tend to have a negative perception of some aspects of teaching when they are loaded with assessment toward the end of the semester (Davenport, 2018). That lack of time for prior preparation seems to indicate a perceived reduction in their organised study time. The incorporation of a new out-of-class activity was disturbing that order. Not watching pre-recorded videos has also been highlighted in the literature as an issue in a flipped classroom (Burke & Fedorek, 2017). One way to deal with it is the introduction of an out-of-class quiz or a quiz at the beginning of each class bearing a very small percentage of grades to ensure that they engage in out-of-class preparation.

However, results also showed that nearly a third of respondents never accessed the PowerPoint presentations and any other material before the classes during the traditional lecture despite not being overloaded with assignments in the first few weeks when the traditional instruction ran. The materials were usually made available on Moodle a week before each lecture. While most reported the lack of time as the main reason, for others, it was because, even without any preparation, they could still catch up in the class. This explains why "no prior preparation" was one of the things students liked the most about the lectures. They also commented that they liked the lectures because they could receive a more detailed explanation of the concepts. Literature also reports that students want to understand most of the course material during the face-to-face lectures (Dębiec, 2018). In the flipped classroom, the students were expected to engage in prior preparation, in class, the main focus was on solving many problems, and therefore, there was no need to go over all the topics in more detail as in the traditional lecture with one or two problems. It could be the reason why in the survey, most students perceived that problem-solving in the lecture provided a deeper understanding of the topics and as such, was a valuable use of time, more than in the flipped classroom.

Students' comments revealed that most students preferred a flipped-classroom approach. However, as the introduction of a flipped classroom meant changing their learning habit, some of them struggled to adapt and suggested the implementation of such a teaching method be made from week one of the course. Early implementation could influence students' adoption of new learning habits in light of new instructional practices as sometimes, students can be unreceptive with the flipped learning structure (Giannakos et *al.,* 2014). Additionally, students felt that problem-solving activities were most effective in the flipped classroom. This could be explained by the fact that they had prolonged interaction with their peers to discuss those problems and help each other. This could also be the reason they thought that problem-solving was an enjoyable way to be taught much more in the flipped classroom than when used in the lecture. Their comments reinforced that what they liked the most about the flipped classroom approach was problem-solving and discussion with peers. In terms of student engagement, the flipped classroom received the most positive remarks in the open-ended questions.

The importance of communicating the intentions and pedagogical goals better cropped out as some students reported not being aware they had to access the learning material outside of the class. In the future, such communication should be made clear. Some students did not want to work in groups. In order to engage everyone in group activities, students should be assigned to a group from week one to create an environment of mutual support. Flipped classroom fosters independent learning which is crucial in computing science in this field of fast ever-changing technology development. It is a good approach for building scaffolds for sense-making and knowledge generation. The author cannot make any generalisations to some larger population group. However, lessons learned can be transferred to a similar context. The experiences reported could aid the practitioners better to understand the benefits and pitfalls that could surface when converting an ADS class or similar course to the flipped model.

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