Authority, Expertise, and Active Learning in the CS Classroom

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Abstract

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Active learning is a teaching practice that involves students in the learning process as more than mere passive listeners, and there is ample evidence of its benefits. Learning is placed more in the hands of the students rather than the teacher, and this affects the authority relationship in the classroom. Authority is commonly defined as being in power by virtue of one's position or title. Authority has also been defined by virtue of expertise. While the topics of authority and expertise have been discussed often, this work extends the discussion to an active learning environment in a Computer Science classroom. This study examines both authority and expertise in the context of an active learning space and observes the role that the two play in a tutorial session. The data used for analysis consists of video recordings of a lecture and four tutorials for an introductory programming course in an Australian university. The lecture and one tutorial are led by an instructor, whereas the other three tutorials are led by hired or former student tutors. These have been analyzed individually as well as comparatively, scrutinizing student participation and exchanges in the classroom (between student-tutor or student-student). Through detailed analyses of the recordings, this work comments on the effect of authority and expertise on the behavior, interaction, and active learning environment in a CS tutorial. While both authority and expertise significantly affect classroom interaction and participation, authority also impacts the student-tutor relationship and overall classroom environment. When the tutor is someone more like a peer, rather than someone in an authority position, students form a friendly and informal relationship with the tutor. The general classroom atmosphere is conversational and students collaborate on tasks. Moreover, when the tutor demonstrates expertise in the tutorial material, students ask fewer questions and seem to have a better understanding of the concepts. They are also able to work independently, building their own solutions. We make additional comments on the significance of authority and expertise in active learning.

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A special shoutout to my twin and cheerleader forever, Shradha. You are and will always be my favorite editor!

DEDICATION

To my parents, my North Star.

Chapter 1. INTRODUCTION

Active learning is a method of teaching where the students participate in the learning process instead of passively taking in information as is the case with straightforward lecturing. Introduced in the early 20th century by educators such as John Dewey, Maria Montessori, Jean Piaget, Gilbert Ryle and Lev Vygotsky (Wagstaff et al. 2015), active learning strives to have more direct student engagement and participation in the learning process. Student participation is defined by Bonwell (1991) as "when they are doing something besides passively listening." There has been extensive research and subsequent evidence that active learning works successfully in diverse fields, including STEM (Freeman et al. 2014; Michael 2006; Prince 2004; Prince & Felder 2007; Lund & Stains 2015). This is corroborated by observed factors such as improved performances in tests or better grades for students after implementing active learning strategies. Active learning puts the power and responsibility of learning more in the hands of the students, instead of primarily on the teacher. Thus, there is a change in the authority relationship in the classroom. While there has been sufficient research on the potential benefits of employing active learning based on student participation and performance, this work investigates other aspects of active learning that have not received as much attention in existing literature, such as:

1) What can be said about the social relationships that develop (between a teacher and students as well as among students themselves) in an active learning environment?

2) Do these relationships depend on who the teacher is? More specifically, does the "status" or *authority* of the teacher (e.g. a student tutor vs. an instructor teaching the course) influence the relationships that develop? How does it affect the learning environment?

3) How does the disciplinary *expertise* of the teacher influence the relationship and the overall learning environment?

The primary objective of this work is to contribute methodologically to the understanding of the active learning environment, especially the significance of authority and expertise in such an environment. In order to achieve this, we have addressed the questions raised above. We carried out a thorough analysis of video recordings of four CS tutorial sessions and one lecture, identifying any patterns or outlying occurrences in interaction or behavior in the classroom. Two of the tutorial sessions are conducted by one tutor, the third tutorial session is conducted by another tutor, and the fourth tutorial and lecture are conducted by the instructor of the course himself. We chose these sessions in order to diversify the authority relationships and levels of expertise that we examined. Instead of judging the teaching method or the student performance, this work comments on the social relationships developed in the classroom. By recognizing the effect that a teacher's authority or expertise has on the learning environment, this work also aims to impact the teaching practice by helping teachers to better understand the kinds of relationships that can be developed in active learning environments. Further, it can help us as a community to decide whether these relationships are what is desirable for both short-term and long-term learning.

Chapter 2 discusses existing literature on the key topics of this work: active learning, authority and expertise. It also sheds some light on the research methods that have been used. Chapter 3 provides a detailed description of the data set and the method of analysis. Chapter 4 comprises an individual analysis for each of the five video recordings. Chapter 5 consists of a comparative analysis of the video recordings and the consequent observations. Chapter 6 discusses the conclusions, limitations, and future work of this study.

Chapter 2. RELATED WORK

Active learning is a teaching methodology that involves students in the process of learning (Prince 2004). It was extensively promoted among liberal educators such as John Dewey, Maria Montessori, Gilbert Ryle, Jean Piaget, and Lev Vygotsky in the 20th century (Wagstaff et al. 2015). As Bonwell (1991) explained, active learning calls for students to participate in the teaching and learning process and is based on the belief that students must actively process information for any real learning to take place (Barak 2006). Caceffo (2018) defines active learning as "a student-centered paradigm" wherein students should be engaged in discussing concepts and solving problems (Johnson, Johnson & Smith 1998) in addition to listening passively, as is common in traditional lecturing.

Active learning is based on the theory of constructivism that emphasizes individuals constructing their own knowledge (Bransford et al. 1999). It involves the connection of new information and experiences with existing knowledge to reach a better understanding. As Mayer (2009) states, "Constructivist learning theory is the idea that learning involves actively building knowledge representations in working memory." Constructivism is a developmental approach of inquiry-based understanding and learning (Cobern et al. 2010). This opposes the theory underlying direct instruction which focuses on student learning through well-designed, systematic instruction (Stockard 2018). Active learning is therefore seen as a contrast to or radical transformation of traditional teaching practices (Prince 2004). As Barak (2006) explains, "Active learning puts the responsibility of organizing the learning in the hands of the learners" (Keyser 2000) and requires students to not only participate in various activities but also reflect on what they are doing.

Active learning incorporates student activities in the classroom and ensures their participation and involvement (Prince 2004). Some common approaches to implement active learning are problem-based learning, peer instruction, and collaborative learning (Caceffo 2018). There has been extensive research on the effect of active learning in various fields of education, in terms of knowledge gain and retention, skills built, student attitudes, and motivation (Tharayil 2018). The general consensus affirms that active learning is highly effective as compared to traditional lecturing, as it improves student learning and retention (Freeman et al. 2014; Michael 2006; Prince 2004; Prince & Felder 2007; Lund & Stains 2015). This is in accord with McConnell's observation (1996) that learning itself is not a passive act and in the same manner that faculty actively learn as they prepare lecture materials through readings, comparisons, and coherent synthesis into notes, students too can understand deeply and learn better when they are involved in the process.

Recently, the research on the effects of active learning has even been extended to the other side of teaching and learning, that is, the instructor's side. Caceffo (2018) observes that implementing active learning has brought a major overhead in preparing for lectures with respect to the time and effort that instructors put in. However, the benefits of implementing active learning greatly outweigh this overhead and it is being used increasingly. Due to the prevalence of active learning classrooms, recently Birdwell and his team have designed the Active Learning Classroom Observation Tool (Birdwell 2016) to allow reflection and feedback on an instructor's use of the space and technologies while teaching in an active learning space. There are also active learning classroom observation guides that can be used to develop better active learning environments and evaluate their effectiveness (Wieman 2016). To date, active learning has typically been discussed and evaluated in terms of student performance and participation (Hirschy & Wilson 2002, Cobern et al. 2010, Freeman et al. 2014). This work extends the discussion to include the social relationships formed in active learning spaces and the impact that authority and expertise have on them.

Authority as a concept has a strong relation to power and influence (Esmaeili 2015). Having authority is seen as having substantial responsibility, legitimate power, or dominance. There are many kinds of authority (Mesrabadi, Badri, & Vahedi 2010) such as legal authority (by virtue of position), specialty authority (by virtue of expertise), and reference authority (by virtue of relation). Harjunen (2014) remarks that while numerous educational studies discuss authority in the classroom from different perspectives, most also distinguish between pedagogical authority, that is authority involved in teaching and learning, and the authoritarian use of power. Further, Harjunen (2009 & 2014) notes a pattern of empowerment wherein students and teachers share power in the classroom. She observed that students grant consent to a teacher's pedagogical authority, based on the achievement of their demands.

Expertise is defined as exceptionally high or peak levels of performance in and knowledge of a field (Bourne 2014). Litzinger et al. (2011) observed expertise in the field of engineering education and noticed some differences between experts and novices. While experts have more knowledge and organize it based on general principles and key concepts, novices displayed superficial connections rather than organizing this knowledge along fundamental concepts. Ropo (2004) also observed that expertise can be characterized by asking more questions and discussing more examples in the classroom. There has been significant research to observe specialty authority, that is authority defined on the basis of expertise, in comparison to positional or institutional authority (Roth 2015).

Epistemology is the study of knowledge and justified belief (Steup 2018). It focuses on the nature of knowledge, ways of establishing claims as genuine items of knowledge (Siegel 2014), and who has authority to assert and evaluate knowledge claims (Greene, Azevedo, & Torney-Purta, 2008). This work discusses epistemology, that is, the creation and dissemination of knowledge in the domain of computer science education. Observing social relations and epistemology in computing education, Tenenberg and Chinn (2019) explain, “Learning occurs at its social genesis, the moment in which the learner enters into joint activity—and, hence, a social relation—with one or more individuals.” In a similar manner, we examine social relations in the tutorial sessions to understand both authority and expertise. Gupta et al. (2015) observed that knowledge analysis and interaction analysis can be integrated to provide multiple insights for any phenomena being investigated. We use elements of these qualitative analysis techniques while observing the tutorial sessions to understand the role of authority and expertise in the classroom. William Perry (1970) created a framework characterizing the intellectual development of students wherein he discusses the rules of adequacy in terms of knowledge and its evidentiary support. We refer to this in order to understand whether the tutors are providing satisfactory evidence to support their knowledge claims during student-tutor interactions.

This work examines the role that authority and expertise play in an active learning space in a Computer Science classroom, by observing the social relations formed and analyzing classroom participation and interaction. This is in line with Hurt, Scott, and McCroskey’s (1978) observation that there is "a difference between knowing and teaching, and that difference is communication in the classroom" (McCroskey 1983). Through this work, we contribute to existing literature on these topics by observing how authority and expertise shape classroom behavior and interaction, and further comment on their effect on student learning.

Chapter 3. METHODOLOGY

3.1 Data Set

We collected video and audio recordings of lecture and tutorial sessions for a first-year ‘Introduction to Algorithms and Programming’ course at an Australian university in 2016. As the first course in the CS program, it introduces the fundamentals of programming, problem-solving strategies, algorithms and their efficiency. The course was organized as follows. In each week of the 12-week term, there were two 50-minute lectures in a large lecture hall, led by one of the two instructors of the course. In addition, there was one 2-hour tutorial session and one 2-hour lab session. In the tutorial sessions led by tutors, students were given worksheets that had pencil and paper problems to solve and questions to answer, related to material discussed in the lecture. The tutors were given lesson plans along with the worksheets. The lab sessions were similar in structure. Students were asked to work on programming exercises with the guidance and help of a lab tutor.

Video and audio recordings were made of lectures, tutorials, and lab sessions during two weeks toward the end of the term. Because of human subjects issues, approximately half of the classroom was captured on video, which always included the instructor or tutor. Although we have recordings for 6 lectures, 8 tutorials, and 4 lab sessions, we focused on 1 lecture and 4 tutorial sessions for this work. These sessions occur in week 11 and 12 of the 12-week term and are led by the course instructor A or one of two tutors, G and S.

The session recordings we observed include a lecture by the instructor A, a tutorial where the instructor A himself serves as the tutor, two tutorials led by the tutor G and one tutorial led by the tutor S. We refer to the lecture by the instructor A in week 12 as A12L and the tutorial led by him in the same week as A12T. We refer to the tutorial led by the tutor G in week 11 as G11 and week 12 as G12. Similarly, we refer to the tutorial led by the tutor S in week 11 as S11.

We chose these particular sessions with the purpose of understanding the role of authority and expertise in a CS classroom. To examine the effect of authority, we observed the differences between a tutorial led by the instructor A (A12T) and the same tutorial led by the tutor G (G12). In order to further understand the instructor A's method of teaching and classroom environment as compared to the tutor G, we observed his lecture (A12L) and another tutorial by G (G11) as well. To examine the effect of expertise, we observed differences between the two tutorials led by the tutor G (G11 and G12) since they are contrasting in terms of his display of knowledge and comfort with the material. One proceeds relatively smoothly (G11), whereas he is less confident about the material in the other session (G12). In order to examine expertise more closely, we also compared G's second session (G12) with the same tutorial when led by the instructor A (A12T), who displays more knowledge in the same topics. Last, we used a tutorial led by another tutor S (S11) to verify our observations before making conclusive comments.

A12L:

This is a lecture led by the instructor, A in week 12. It covers the topics of algorithm efficiency, growth rate of functions, decision problems, and P, NP and NP-complete classes of problems.

A12T:

This is a tutorial led by the instructor, A in week 12. Seven students are present, with two visible in the recording frame. It covers the topics of vertex cover, cliques, P and NP classes of problems, and ASCII encoding. Refer to Appendix B: Tutorial 12 Worksheet for this session.

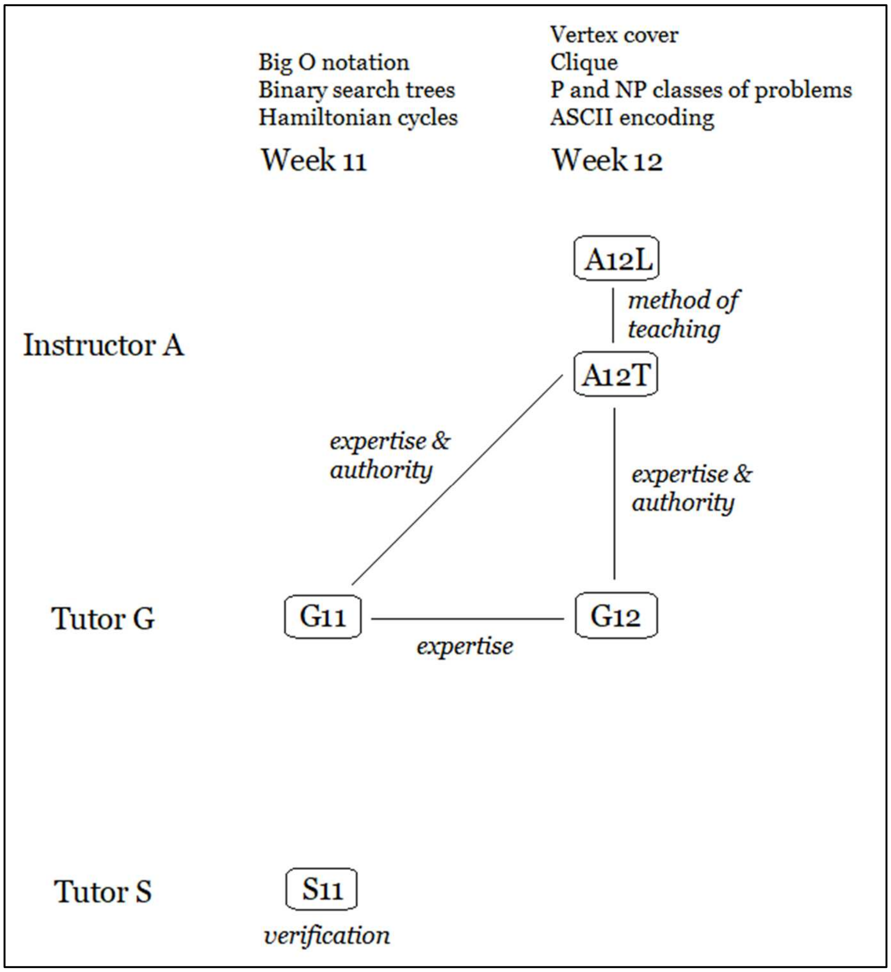

Figure 1: Reasons for choosing the sessions

G11:

This is a tutorial led by the tutor, G in week 11. Eleven students are present, with six visible in the recording frame. It covers the topics of Big-Oh notation, binary search trees, and Hamiltonian cycles. Refer to Appendix A: Tutorial 11 Worksheet for this session.

G12:

This is a tutorial led by the tutor, G in week 12. Twelve students are present, with eight visible in the recording frame. It covers the topics of vertex cover, cliques, P and NP classes of problems, and ASCII encoding. Refer to Appendix B: Tutorial 12 Worksheet for this session.

S11:

This is a tutorial led by the tutor, S in week 11. Fifteen students are present, with seven visible in the recording frame. It covers the topics of Big-Oh notation, binary search trees, and Hamiltonian cycles. Refer to Appendix A: Tutorial 11 Worksheet for this session.

3.2 Method of Analysis

We examined and analyzed the recordings of the sessions above in order to understand the relationships that are established in an active learning environment, from an epistemological perspective (what is the relationship between the participants and knowledge or expertise) and a social perspective (what authority relationships are actually formed). The foremost goal of this examination was to detect any patterns in social interactions. Specifically, we used a combination of qualitative techniques to analyze the classroom sessions. For example, we analyzed the videos to observe not only the interactions in the classroom but also to assess the amount of interaction in each session, whether it was between student-student or student-tutor. We also observed the instructor and tutor's approaches toward the tutorial. This involved the topics covered, the ordering of these topics, examples given, questions asked and answered, and some behavioral characteristics such as their use of the whiteboard or whether they stand or sit while interacting with students (more formal or informal). In addition to this, we also noted their knowledge and confidence regarding the material in the tutorial, through their exchanges with the students.

We started out with individual analyses of each of the four sessions (A12L, A12T, G11 and G12) and noted any occurrences or events that seemed significant. Focusing on the interactions in the sessions, we then chose exchanges that indicated a direct or indirect effect of authority or expertise. For example, when a topic is expertly defined with an example, students ask fewer questions whereas when it is vaguely defined, students express more doubts and ask more questions. After analyzing the recordings individually, we began comparing the sessions with each other to make some key observations. We compared the sessions based on features such as the amount, nature, and topics of interaction. We also used some features from the Active Learning Classroom Observation Tool (Birdwell et al. 2016) such as the tutor's use of classroom equipment or space.

Beginning with A12T, we compared this with A12L to observe the instructor A's method of teaching in different settings (tutorial vs. lecture) as well as his expertise in the material being taught. Next, we compared A12T with G12 to observe the differences between a tutorial led by an instructor vs. a student tutor to better understand the role of authority. We noted differences in terms of the topics of interaction, amount of interaction as well as the knowledge or expertise displayed by the instructor vs. tutor. Further, we compared G12 with G11 in order to understand the tutor G's approach when teaching different topics and displaying varying levels of knowledge and comfort with the material. By comparing sessions where the tutor displayed knowledge or the lack thereof, we were able to investigate the role of expertise in the classroom. These comparisons resulted in a more focused analysis of some of the specific events that we had marked while individually analyzing each session. For example, we compared the same topic being discussed in the tutorial by the instructor (A) vs. the tutor (G), where one displays sufficient knowledge and the other, a lack of expertise. We also compared the same tutor (G) on his discussion of different topics, where the tutor expressed different levels of expertise. We also compared the topics of interaction in sessions led by the instructor (A) vs. the tutor (G) and examined the effect of authority on relationships. In this manner, we made observations about the effect of authority and expertise, individually and comparatively. We then compared and verified these observations against S11 to draw our final conclusion.

Chapter 4. ANALYSIS

4.1 Analysis of A12L

This lecture is led by the instructor, A, in week 12. It covers the topics of algorithm efficiency, growth rate of functions, decision problems, and P, NP and NP-complete classes of problems. The lecture takes place in a large hall, seating a hundred and fifty people. The instructor addresses the students from one end of the room, with two large screens behind him.

A starts the lecture by putting up his presentation and talks about the agenda for the day. After spending the first 12 minutes talking about growth rate and inefficient algorithms, he moves on to decision problems. He discusses the Hamiltonian cycle problem, followed by the vertex cover problem.

[00:12:10]

> (1.1) A: Now I'll introduce another problem called vertex cover. So, a vertex cover C is a subset of vertices in a graph such that for each edge, one of its vertices is in the vertex cover. So, for this graph ((A looks at his computer, screen projected for students)) the red vertices are the vertex cover ((A checks off each vertex on the screen)).

A defines vertex cover and discusses the vertex cover for a graph on the screen. Even though the vertices from the vertex cover are already highlighted in red, he marks them all of on the screen. Then he breaks down the definition further and shows how each edge in the graph has an endpoint that is part of the vertex cover. Having walked through the entire solution, he goes on to discuss vertex cover as a decision problem.

[00:12:58]

> (2.1) A: The decision problem is given a graph and an integer k, is there a vertex cover containing k vertices in this graph. Let's do an exercise.

A quickly defines what the vertex cover decision problem is and puts a question up on the screen for the students, asking them to submit their answers via an online poll. The question involves deciding whether the given graph has a vertex cover of size two or less. After waiting for 2 minutes, A checks the poll wherein majority of the class has correctly answered and starts explaining the solution to the students. Once again, he marks off every edge in the graph while demonstrating that each edge has one endpoint which is in the vertex cover. Moving on from this problem, he starts discussing cliques.

[00:16:52]

> (3.1) A: What is a clique? So, if we have a graph G, we say a clique is a subgraph of vertices such that there is an edge between every pair of vertices in the subgraph. For example, if you have three vertices ((drawing on screen)) and we have an edge between each pair of vertices, so this is a clique.

After defining clique, A draws an example of a clique explaining how it satisfies the definition. He then discusses another graph that he has projected on screen. He describes a clique for that graph and then he justifies this by demonstrating that there is an edge between every pair of vertices in this clique. Next, he defines the clique decision problem.

[00:18:15]

> (4.1) A: So, the clique decision problem is if we have a graph and an integer k, does there exist a clique of size k in the graph.

A defines the clique decision problem and puts up a poll for the students again, this time pertaining to the clique problem. After 2 minutes, he explains the solution and justifies the clique by showing that every pair of vertices in it is connected by an edge. After this, he spends another 5 minutes discussing the graph coloring problem and moves on to P and NP classes of problems.

[00:25:24]

> (5.1) A: Now let's discuss what is P class of problems and what is NP class of problems. So, P is the class of decision problems that can be solved in polynomial time.

A defines the P class of problems while emphasizing that it must be a decision problem. As examples to explain this further, he discusses decision problems like checking whether a target element is in a list or checking whether a list is sorted. He then goes on to NP problems.

[00:27:09]

> (6.1) A: This is P class of problems. So, what is NP class of problems? NP here does not stand for non-polynomial. NP means non-deterministic polynomial. So, NP is the class of decision problems whose solution can be verified in polynomial time. So, we're not saying the problem can be solved in polynomial time. What we're saying is that if someone gives us a solution to our problem, then we can verify whether that solution is correct or not in polynomial time. So, verifying the solution is easy.

A defines NP problems, explaining what NP stands for and clarifies that it does not mean the problem can be solved in polynomial time, just that a potential solution can be verified in polynomial time. He then discusses vertex cover as an example of NP problems. He describes how it is difficult to check if there is a vertex cover of size k in a graph but when given a solution, it is easy to check and verify this solution in polynomial time. He further explains that this solution is called a certificate. As some more examples of NP problems, A discusses clique, Hamiltonian cycle, and graph coloring problems. Next, he discusses certificates for various NP problems.

A spends the last 15 minutes of class discussing P being a subset of NP class of problems, explains why proving P=NP would be significant and defines complements of graphs. He also discusses how vertex cover can be reduced to clique in polynomial time and defines polynomial reduction on the basis of this example. Last, he discusses NP-completeness and how all these classes of problems relate to one another.

4.2 Analysis of A12T

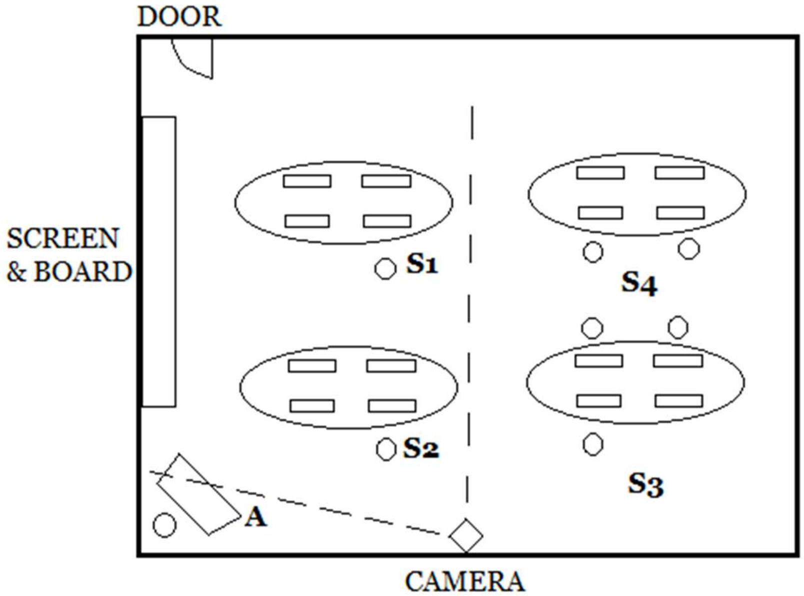

Figure 2: Classroom layout for A12T

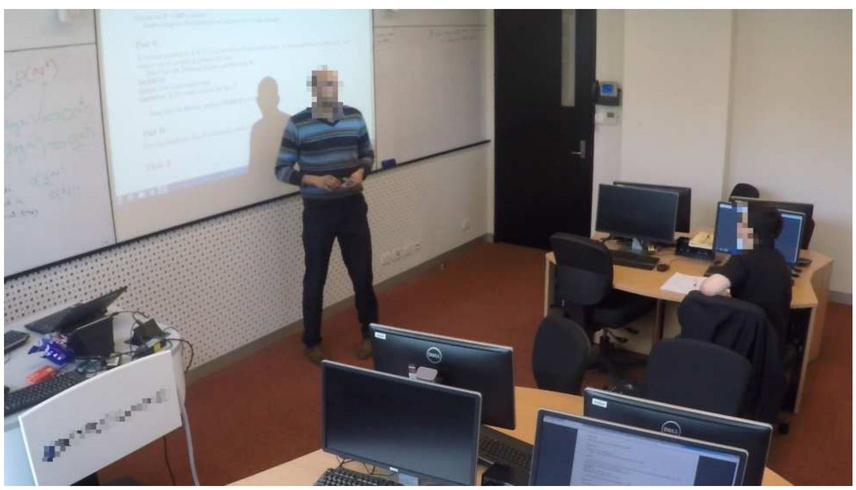

Figure 3: Scene from A12T recording

This tutorial is led by the instructor, A, in week 12. We will refer to A as the tutor throughout this section. It covers the topics of vertex cover, cliques, P and NP classes of problems, and ASCII encoding. Refer to Appendix B: Tutorial 12 Worksheet for this session.

Students talk amongst themselves while the tutor, A, sets up for the session. Some students are still coming in. After 5 minutes, A officially begins the tutorial, directly starting with the first task.

Task 1 [00:05:06]

[00:05:06]

(1.1) A: Okay, so let's start. The first concept that we will learn today ((walks towards the board)) is called vertex cover. So, given a set of vertices and if we have a graph ((drawing a graph on the board)). So, this is our graph ((points at the graph he drew)). The vertex cover is a set, subset of vertices in this graph such that for each edge u-v ((writing on board)) in the graph, one of – at least one of u and v is in this subset which we call vertex cover within G. So, if we have this graph ((points at the same graph that he drew earlier)), let's say we take these two vertices, is this a vertex cover? Does this cover all the edges?

The question involves finding a vertex cover for the given graph. Instead of simply reading the question, A starts with explaining the topic and uses the formal definition of vertex cover to do so. Following the definition, he gives them an example that some students, S3 and S4, answer correctly and then also proceeds to walk through the solution. He marks off each edge and shows how it has one endpoint in the vertex cover. A uses the board not only to draw the example graph, but also to verify that the proposed solution is in fact a vertex cover. S3 and S4 participate by answering his question and it is evident that they understand the concept. Next, he moves on to the graph in the tutorial.

[00:07:09]

(2.1) A: What is the vertex cover in this graph? Can we find the vertex cover in this graph?
(2.2) S3: 0, 2, 6, 5
(2.3) A: 0, 2, 6?
(2.4) S3: 5
(2.5) A: Okay so, that is correct. So ((pointing at each vertex in the graph)), it is 0, 2, 6 and then we could pick 5 or 3, right. So, if we pick 0, it covers these three edges ((indicating edges in graph on screen)), 2 covers these three edges, 6 covers these five edges and then 5 covers these three. So, our vertex cover in this graph is ((writing on board)) 0, 2, 6, 5.

Starting Task 1, Part A, A waits for the students to answer and a student, S3, gives the right answer. A then justifies the solution, that is the subset of vertices chosen as the vertex cover. He marks each individual vertex and then checks off every edge that is linked to it, eventually checking off all the edges (line 2.5). In this manner, he breaks down the entire solution and in turn also explains the process to reach the solution. He then goes on to Task 1, Part B.

[00:08:16]

> (3.1) A: The next concept is clique. ((writing on the board)) So, clique is a set of vertices C such that for every pair of vertices in this – every pair of vertices u and v in this set, there is an edge u-v in the graph. So, clique is a set of vertices such that every pair of vertices in this graph is connected by an edge in the original graph.

Right after defining vertex covers, A once again uses the formal definition to explain cliques. He writes the definition on the board as he speaks and then goes on to describe it an alternate way. After defining cliques, he uses the graph he had drawn earlier to demonstrate an example of a clique. In the same manner as he did with vertex cover, after discussing the definition and an example of clique, he asks the students to work on the tutorial question, Task 1, Part B [00:10:30]. The question involves finding the largest and smallest clique in a graph and A asks the students to work on solutions "individually" [00:11:01]. It is noteworthy that he directs the students to work by themselves. While some students work on the problem, A repeats the vertex cover and clique definitions to a student, S1, who came in late and brings him up to speed with the rest of the class. After 4 minutes, A explains the solution for Part B, showing the students the largest and smallest clique for the given graph.

We observe a pattern in his session wherein he defines a topic, discusses an example of it and then solves the actual tutorial question along with explaining the solution. Thus, he essentially repeats his explanation of the topic when he explains the solution.

After 17 minutes of the session, A discusses the concept of complement of a graph and asks the students to find a complement for a graph that he draws on the board. While students solve this, A walks around the room, checking on the students and clarifies student's doubts. Another 5 minutes later, he defines complement and explains the solution to students.

A starts discussing Task 1, Part C [00:23:29] that involves understanding the relation between clique and vertex cover and obtaining a clique from a vertex cover. First, he explains how Figure 2 in the worksheet is a complement of the graph in Figure 1. Then, he asks the students to find a vertex cover of size four in Figure 1 and a clique of size three in Figure 2. Next, he directs them to use these to try and understand a relation between the vertex cover and clique. After waiting for a few minutes, A starts explaining the relation to the students.

[00:27:07]

(4.1) A: Let's think about this. So, we have a graph and we have a complement ((walks to the board)). If I find the vertex cover of this graph ((points at the graph on screen)) – so what is the vertex cover of this graph? Does D and E form a vertex cover of this graph?
(4.2) S3: No.
(4.3) S4: No ((talks at the same time as S1)), I'm sorry.
(4.4) A: No or yes?
(4.5) S3: No, yes.
(4.6) S4: Yes.
(4.7) A: Yes, because they cover all the edges. Now, ignore D and E, the remaining vertices, do they form the clique in the other graph?
(4.8) S3: Ah, yes.

A asks the students to apply what they have learnt until then, when he asks them to guess a vertex cover for the graph. He then directs them to check if the other graph (complement of the previous graph) has a clique, when excluding the vertices from the vertex cover. Right after this activity, he goes on to explain the relation between clique and vertex cover.

[00:27:50]

> (5.1) A: So, the observation is this – ((writing on board)) we have vertex cover problem, we'll see the details later. Vertex cover problem says is there a vertex cover of size k in a graph G. Clique problem says is there a clique of size k in graph G. So, the relationship between vertex cover and clique is – if n is total number of vertices in the graph – then the answer of this ((points at the vertex cover problem definition he had written earlier)) is the same as the answer of ((pointing at the clique problem definition)) is there a clique of size n minus k in the complement of the graph. Which means in the original graph, to answer the question is there a vertex cover of size k in the graph, we can solve this by computing the complement of the graph and checking if there is a clique of size n minus k in this graph or not.

After making the students compare a vertex cover in one graph with a certain clique excluding those vertices in the graph's complement, A goes on to explain the actual relation between these problems. We understand that A was attempting to demonstrate the relation through his earlier activity, instead of just telling the students this directly. Through this method, A encourages the students to understand the working/process behind all the concepts that they are learning. As seen in line 5.1, he explains the relation with the problem definitions and also applies this relation to answer the question in the tutorial. Task 1, Part C involves obtaining a clique from a vertex cover. A explains this relation another time, giving the students more time to process this. He also gives them an example graph and demonstrates the relation on the board with this example. He repeatedly asks the students if they are understanding the concept or whether they have any questions but the students are silent. A then describes another example and asks the students to use the relation to solve it. It is confirmed that S3 and S4 have understood the concept since they participate by answering correctly.

Having spent 7 minutes discussing the relation between the two problems, A uses this opportunity to introduce another concept – reduction [00:34:50]. He explains how using the vertex cover solution to find a clique is equivalent to reducing one problem to another problem. In this manner, he teaches them an extra topic that is not part of the tutorial but relevant to the current discussion. Soon after, they move on to Task 2.

Task 2 [00:36:48]

[00:36:48]

> (6.1) A: The next concept is what is a P problem and what is an NP problem ((writing on board)). By P, we mean polynomial, polynomial time. The polynomial time complexity is a complexity that can be bounded by a polynomial n raised to k – n is the input and k is some constant.

A starts Task 2 directly with explanations of P and NP problems. He builds up to their definitions by explaining smaller concepts first. As seen here, he explains what P stands for and what polynomial time really means before defining P class of problems. He gives multiple examples of functions that have a polynomial time complexity and also introduces non-polynomial time with exponential functions.

[00:39:02]

> (7.1) A: So, P stands for polynomial but NP does not stand for non-polynomial. NP stands for non-deterministic polynomial, which we will see soon.

A tells the students exactly what P and NP stand for early in the discussion but he breaks down the actual definition of these problems to smaller concepts and builds the solution here on, starting with decision problems.

[00:39:32]

> (8.1) A: What is a decision problem? So, a decision problem is problem for which answer is yes or no. So, is this a decision problem? ((pointing at the vertex cover problem definition he had written on the board earlier)) Vertex cover problem? Yes, because the answer is yes or no.

A defines decision problems and again follows the definition with some examples like the vertex cover and clique problems. He relates new concepts with topics that he has already taught and in turn, ensures that students will be able to understand these concepts. Having defined decision problems, A moves on to defining P class of problems.

[00:40:16]

> (9.1) A: What is P class? A decision problem – problem that can have yes or no answer – a decision problem that can be solved in polynomial time.

After defining decision problems and polynomial time to the students, A discusses the definition of the class P. Then, he through some examples of problems in the class P, such as checking whether a number is odd. He breaks down the example one concept at a time. A asks the students if checking whether *n* is an odd number is a decision problem and the students agree. Then he asks them to figure out the time complexity for checking if a number is odd and guides them to think about how to solve this problem. The students agree that it only involves a single step and A explains how this means the problem would have a polynomial time complexity. Thus, he demonstrates how this problem would be in the class P. After discussing another example about searching for a number in a given list, A moves on to NP.

[00:45:34]

> (10.1) A: So, this is what we mean by P class. Now, what is NP class? So, NP class is a decision problem, it must be a decision problem again, a decision problem for which the certificate – I will explain what is a certificate – certificate can be verified in polynomial time.

Once again, A breaks down the definition of NP, emphasizing that it must be a decision problem and further explaining what a certificate is. He defines certificates using examples like vertex cover and clique, topics they have just learnt. By relating certificates with these problems, students are able to understand that the certificate is a means to verify the solution. We see this when students answer his questions. A explains that it is difficult to solve an NP problem but if given a certificate, it can be verified in polynomial time. He then goes to explain that every problem in the class P is also in the class NP, and uses their definitions to justify this. A repeats that problems in the class P are those that can be solved in polynomial time, and problems in the class NP are those where a given solution or certificate can be verified in polynomial time. Further, he explains that since problems in P have a polynomial-time solution, they can be verified in polynomial time. Thus, problems in the class P are also in the class NP.

After 7 minutes of discussing NP and having covered Task 2 – Parts A, B and C – A starts discussing Part D [00:52:50]. This involves figuring out the complexity class of Knapsack, *n*-Queens and Traveling Salesman Problem. A first writes out the decision version of the Knapsack problem and asks whether it is in the class NP. Students S3 and S4 correctly answer "yes" and demonstrate that they understand the concept. Next, A asks them to think about the certificate for this problem and proves how given this certificate, they would be able to verify it in polynomial time. In the same manner, A discusses the n-Queens problem. He defines its decision version, then discusses a certificate for it and uses this certificate to justify that it is in NP. After spending 9 minutes on explaining the previous two problems, A asks the students to work on the Traveling Salesman Problem themselves [01:01:19]. As the students work on this, he walks around the room and tries to clarify doubts among them. 6 minutes later, he explains the solution for this to them and then moves on to Task 3.

<u>Task 3</u> [01:09:09]

A starts discussing Task 3, Part A with the students and asks the students how to convert a decimal number to binary. Student S2 answers with one method of conversion (using the powers of 2) and A solves an example using this method with input from S2 and S4. Then, A explains another method of conversion (using the remainders on division by 2). Within 3 minutes, they move on to

Part B, discussing the ASCII table, and A explains how they can use this to encode words and numbers in ASCII and how this is further converted to binary in the computer.

After this, they start on Task 3, Part C [01:14:48]. The task involves converting a sequence of ASCII numbers to characters, i.e. decoding ASCII. When A asks the students to attempt the question, he realizes that the ASCII table given in the tutorial is not descriptive enough for the task.

[01:14:59]

> (11.1) A: You might want to get a better ASCII table because this doesn't cover all the characters.

A then proceeds to find another table on Google and puts it up on the screen for the students to refer to. A immediately realizes the problem with the ASCII sheet and corrects it for them before they begin solving the question. He encourages the students with an incentive when he promises a chocolate to the student who solves this first. As the students work on the problem, A walks around, observing them and addressing any doubts that they have. After 9 minutes, S2 has the right solution and A gives him some chocolates, but then distributes them among the rest of the students as well. Although one student has the right answer, A allows the others to continue working on their solutions and works on something at his computer. About 5 minutes later, he gives them the final solution, which is the pseudocode of the Collatz conjecture. A reminds the students that it is an algorithm only if it always terminates in a fixed number of steps, and they then discuss whether this terminates for any input number. After demonstrating that the pseudocode will end with 1 for several, different input numbers, A introduces the Collatz conjecture [01:32:53]. He describes this conjecture to the students and using this description, he explains why Part C is not an algorithm but a process. Next, A moves on to discuss the puzzle of the week from the previous tutorial and builds the final solution with inputs from the students. They spend the last 5 minutes of the tutorial discussing this and then we see students leaving.

Review

This tutorial session is led by the course instructor, A, and we observe a pattern to his teaching. He always starts with defining a topic, explains it further with multiple examples and eventually moves on to the question in the tutorial. Then, he gives the students about 5 minutes to work on the problem themselves before explaining the solution to them in detail. We see this with vertex cover, clique, and P and NP classes of problems. Not only does he use formal definitions, but also breaks down the topics into smaller concepts. We see this when he defines the complement of a graph and polynomial reduction while discussing Task 1, Part C (obtaining a clique from a vertex cover) and again when he defines decision problems, polynomial time and certificates while discussing P and NP classes of problems during Task 2. Throughout the session we observe his knowledge and confidence in the material being discussed.

We also notice that there is not a lot of interaction in this tutorial, whether it is between student-tutor or student-student. For a major part of the session, it is just the tutor addressing all the students and explaining various topics. Therefore, the tutorial appears to be more like a lecture with direct instruction. The students do not participate in his discussions when he asks them their thoughts on topics or questions pertaining to the material. There are also rare instances when students express any confusion and even when they do, their doubts are not related to definitions or their understanding of the material. Instead, they attempt to work on the problems independently and have questions regarding problem solving strategies and how to apply what they have learnt to the problems. Thus, any interactions between student-tutor are limited to the material in the tutorial.

4.3 Analysis of G11

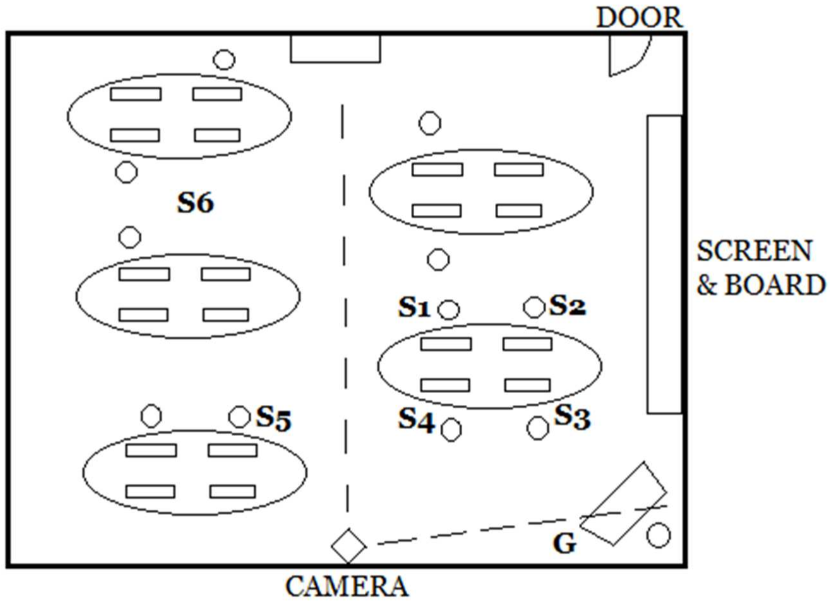

Figure 4: Classroom layout for G11

Figure 5: Scene from G11 recording

This tutorial is led by the tutor, G, in week 11. It covers the topics of Big-Oh notation, binary search trees, and Hamiltonian cycles. Refer to Appendix A: Tutorial 11 Worksheet for this session.

Before the tutorial session has officially begun and students are still coming in, student S4 is sitting at the front desk with G, and discussing his grade on an assignment. G expresses that he thinks the grader has been "a little harsh" and how he himself would have "given full" marks. S4 still can't understand why he has been marked down, so G reads the comments and explains that the grader thought S4 didn't have enough comments. G further describes that whoever is grading decides what too many or not enough comments are and that while the grader thought S4's were not good enough, G himself thinks that they were fine. As G reassures S4, S4 wonders if he should discuss this with the grader. G encourages him to do so, believing that his score might go up, and G also assists the student with the email ID of the person to contact. G takes a personal interest in his student's problems, even though he was not the grader in this case and it is evident that he is involved with his students beyond the tutorial or its material.

Following this, G addresses the students who missed the previous week's session and informs them about the session being recorded for research and also explains which half of the room is in the camera frame. After this, he introduces the first topic for the day.

[00:04:44]

(1.1) G: Still got a few minutes before we start, but basically what we're looking at today is complexity – how to solve complexity, how to count complexity and how to talk about algorithms in terms of efficiency. Up until this point, I've told you don't worry about efficiency ((S1 smiles)), now we're going to start worrying about it ((S2's mouth falls open)). So, my question is ((G walks away from his desk, moving towards students)) what have you seen about complexity so far? Anything at all? ((S1 nods)) Has there been a lecture about it?
(1.2) S1: Yeah, a lecture today.
(1.3) G: Today?
(1.4) S1: Yeah. ((S1 nods))
(1.5) G: Okay, so some people, all of you should have seen it in theory ((S1 smiling)). Who's listening to it later? ((G smiling, S1 and S3 raise their hands))

G outlines the first task, describing it as how to "solve" and "count" complexity. Neither of these words is precise. G reminds the students how until then they were told not to worry about efficiency, and when he goes on to describe that now they would be "worrying" about efficiency, S2 appears to be genuinely concerned as her mouth falls open. G goes on to ask students what they know about complexity and S1 mentions that they had a lecture about it just that day. G says that all the students should know it from having attended the lecture, but he is well aware that a lot of them just listen to recordings later. S1 smiles at this, and he and S3 accept that they will be listening to the lecture later. The students are honest and frank with G, indicating a comfortable and friendly relationship with him.

Right after this exchange, G walks over to his computer and continues speaking.

[00:05:33]

> (2.1) G: Don't worry, I'll try to explain it the best way I can. The way that they were asking me to explain it is they wanted to do it mathematically but I don't know how many mathematical minds I have here with me today ((S1 smiles, S3 turns to look at G, smiles and raises her hand mouthing "me" and S5 raises his hand)) Yeah, I know you're mathematically inclined, you're an astrophysicist ((G laughs and walks over towards students, S1 smiles)). But a lot of people here won't be, alright? When they're saying that if you choose some number, we can show that it bounds the function within some amount by graphing it together and demonstrating – it's just a whole lot of hula, alright? ((S1 smiles))

G assures the students that he will try to explain complexity as best as he can and describes that the way "they" wanted him to explain it is very mathematical. He expresses his concern about everyone not being mathematically inclined and this is immediately followed by two students, S3 and S5, raising their hands to show that they have mathematical minds. G laughs and accepts that he's aware of this since the student is an astrophysicist and S1 smiles at this, while some other students can be heard laughing. In this moment, we see there's an informal environment in the classroom between the students and tutor. G then goes on to explain that "they" want him to demonstrate through graphs how some number can bound the function and describes this as "hula." The way that G talks about this entity, "they," directing him how to explain, we understand that he is referring to some higher authority that has set guidelines and expectations for him. G continues:

[00:06:02]

> (3.1) G: I think there's an easier way of trying to understand what Big-Oh notation is, about complexity. So, does anyone remember when I've ((G walks over to his computer)) talked about how many steps it takes to solve a problem? I've talked about it a couple of times, few times, right? ((no response from the students)) So, when I say that is – how Big-Oh or ((G walks towards students)) complexity is all about asking how much thinking is involved to arrive at some useful conclusion, right? To come to some result. How much thinking is involved and how can we show that it's that amount.

G believes he has an easier way of explaining Big-Oh notation. He reminds the students about some previous discussions they have had regarding the number of steps involved in solving a problem. However, the students do not respond and G starts describing Big-Oh or complexity as the amount of "thinking" involved in reaching a result. While G initially defines complexity more formally as the number of steps, he switches over to the term "thinking," one that he uses often ([00:08:28], [00:08:45], [00:09:54], [00:10:41], [00:11:19]) as the session progresses. He does not explain that Big-Oh is a type of notation used for complexity and instead uses the terms interchangeably.

G then asks the students if they have any doubts about the previous week's material, before they start discussing Big-Oh. After waiting for a minute where the students are silent, G goes on to repeat his definition of Big-Oh as the number of steps required to reach a conclusion. He then types something on his computer, which is projected on the screen for the students, and asks them how much thinking is involved to “halt” or “stop” or “actually do what it’s supposed to do.” There is no response from the students, and it appears they do not understand his explanation. G explains what he has typed and repeats his question.

[00:08:40]

(4.1) G: So, I have a list, it has some items. In it, I’m going to print every item, that’s what it does. How much thinking is involved to solve it? To do this thing?
(4.2) S3: Two.
(4.3) G: Two? ((S3 nods and S1 raises his hand))
(4.4) S3: Two thinkings.
(4.5) G: Two thinkings? Okay. Interesting ((G smiles)). Yeah? ((G calls on S1))
(4.6) S1: It’ll be depending on the length of the list.
(4.7) G: Yeah, it depends on the length of the list, alright? So, it’s not two thinkings ((G addresses S3)), alright? ((S3 nods))

G describes that he is just printing all the element of a list. Once again, he asks how much “thinking” is involved. A student, S3, even responds with two “thinkings” instead of saying something like two “steps” in the same way that G has been explaining it. In this exchange, we can see how his role as a tutor influences student learning. Although G has a good understanding of the concept, we see that he lacks expertise in the material with his use of “thinking” over “steps” and this consequently impacts what and how the students are learning. After S1 answers correctly that the number of steps depends on the length of the list, G repeats his answer and clarifies that S3’s answer was wrong, which S3 accepts as well. Another student, S5 expresses a doubt about the problem following this.

[00:09:09]

(5.1) S5: So, if the list is one, then?
(5.2) G: What?
(5.3) S5: If we assume the list is one?
(5.4) G: If we assume the list is one, it’s not useful.
(5.5) S5: Okay, just why not?

> (5.6) G: It's called ((G raising voice)) Big-Oh, not Small-Oh, alright? When you think Big-Oh, think very large inputs, like astronomically large.

After G says that the problem complexity depends on the size of the list, S5 asks what would happen if the list had just one element. G says that it would be useless to consider that case. When S5 wonders why, G explains that Big-Oh, emphasizing on it being called "Big," involves considering extremely large inputs. He then goes on to explain that if the list is empty, it is difficult to guess how the function will behave since there is nothing. Further, he explains how his example of printing the elements in a list depends on the number of elements in the list since they carry out the print function for each element in the list. He asks the students whether they are following him, and S3 nods while S1 smiles in agreement.

Next, he asks the students to figure out the complexity or "thinking" that goes into linear search in a sorted list of n elements [00:11:16]. They spend the next 9 minutes discussing this problem. G waits for the students to suggest some answers and directs them towards the right solution. He explains how there are three correct solutions and eventually goes on to describe the different complexities for the best, worst, and average cases. He also explains what these cases are based on the location of the number being searched.

Having discussed two examples, one about printing all the elements in a list and another about linear search in a sorted list, G asks the students whether they want any more examples or want to move on to the problems in the tutorial's worksheet. A student, S2, asks for another example and G obliges by starting a discussion about selection sort [00:20:18]. After 2 minutes of this discussion, a student, S6, guesses the complexity to be n – the length of the list being sorted. G remarks that it is a good instinct and walks around the classroom checking on the rest of the students. Observing that they are close to the final answer, he encourages them to continue.

[00:21:55]

(6.1) G: You guys are really getting this. ((G smiles)) That's some good stuff over there.

G realizes that the students are understanding the concept of complexity and continues to listen to all their ideas and helps them build up to the final solution of n^2 steps. When G asks the students if they understand this, student S5 asks him to explain how it is that selection sort takes n^2 steps and we realize that S5 has not understood the concept entirely yet.

<u>Task 1</u> [00:32:36]

Having spent almost 13 minutes on selection sort, G asks the students to start working on Task 1, Part A which involves figuring out which is the more complex of two algorithms. While the students work on this problem, G tries to explain complexity in terms of different function graphs in Excel, to clarify S5's earlier doubt about the number of steps in selection sort, even though S5 was asking about why in particular selection sort takes n^2 steps. After 15 minutes, G finally starts discussing the solution to Task 1, Part A with the students. He discusses the complexities for each of the algorithms and leads the students to the final answer, that is the more complex algorithm of the two.

<u>Task 2</u> [00:52:30]

Next, they start work on Task 2. G explains the concept of binary search trees (BST) to the students and then asks them to solve Task 2, Part A wherein they have to draw all binary trees having four nodes. The students spend the next 8 minutes working on this, while G walks around the classroom observing their solutions and directing them when they are stuck or have an incomplete answer. Eventually, he gives them the final solution by drawing each possible tree on the screen and they move on to Task 2, Part B [01:05:00]. This question requires the students to figure out which tree it is easier to search for elements in, and some students who are not in the frame make different guesses. The students are able to work independently on the problem, and G guides them whenever they need help. Within 3 minutes, they move on to Part C and G comments on a chocolate bar that student S3 is eating. Once again, we see friendly and informal banter in the classroom with G. Task 2, Part C requires the students to come up with the running time for a BST and the students try to work through this. G walks among the students, clarifying their doubts and explaining the problem to them. When S5 guesses $n^{1/2}$ as the running time, G directs the students toward the solution by asking them to think of a function that is similar. After discussing this for another 10 minutes, G finally gives them the answer, that it is the logarithm function and they go on to Part D [01:20:08]. This task involves guessing which of the previous trees can be heaps and the discussion goes on for 3 minutes, ending when G asks if any of the students need reminders about heaps and none of them respond.

Task 3 [01:23:38]

After spending about half an hour on Task 2, they progress to Task 3. G introduces the task which involves Hamiltonian cycles (HC) and asks the students if they remember what that is from a discussion some weeks ago. S1 correctly defines HC, following which G asks the students to write an algorithm to demonstrate that a graph has a HC and also give the algorithm's complexity. He reminds the students that they have 37 minutes to solve this and allows them to work on the algorithm while he walks around the room, checking on them and helping them proceed. When S5 complains that he cannot understand this, G suggests that he should break down the problem by just writing an algorithm first and then figuring out its complexity. S5 then expresses his confusion regarding the algorithm as well.

[01:33:09]

(7.1) S5: Can I use brute force?
(7.2) G: Then write it.
(7.3) S5: Brute force?
(7.4) G: Just write it. Write me a brute force algorithm that does it.
(7.5) S5: Okay. So, if I just wrote down the definition–
(7.6) G: No, that's not how it works. Now, I want you to write me something that does it. You did really well on the assignment, you should trust your coding skills. ((G walks away from S5, S5 laughs))

G encourages S5 to try a brute force approach to the algorithm and reassures him that he can do this task since he turned in a good assignment. It is evident that G has formed close relationships with his students, reminding them of their strengths. Soon after, as G is walking around the room, he comments that he loves S5's sunglasses and we see the friendly atmosphere of his session again. For the next 15 minutes, G observes all the students and discusses their algorithms with them. Then, he goes over to his computer and sits down too. After 10 minutes, while students are seen continuing work on their algorithms, G puts up two algorithms on the screen. He reminds them that these are both algorithms for HC that they had discussed in earlier weeks. He explains how one of these has a linear complexity and the other has an exponential complexity. Following this, the students continue working and S5 discusses his idea for finding a HC with G. G again encourages him to attempt writing this out.

[01:54:01]

(8.1) G: Try something first, I want you to write me something. We've only got a couple minutes left and then you're freeee! ((G extends the word in a singsong manner))

G understands that the students must be excited to be done with the session and appears to be so himself with the manner in which he almost sings "free." G asks the students to fill out "review sheets" but cannot recall whether they are tutorial or workshop review sheets. It is clear that the general environment of the classroom is informal and comfortable with the way he responds to his own confusion.

[01:54:28]

(9.1) G: It's Monday, give me a break ((G laughs, students heard laughing)). I'm a professional teacher, this is what I do.

G makes a funny excuse regarding his confusion and the students laugh at this too. Soon after this, he informs the students that they can leave and how the next session will be their last one.

[01:55:32]

(10.1) G: Next week is our last week together.
(10.2) S5: Party! ((students heard laughing))
(10.3) G: No, not party. Bring questions.

From the exchange, we can see that the students are just as comfortable making humorous remarks around G and we understand that this is the general atmosphere of the classroom. The session wraps up with G collecting review sheets from the students as they leave.

Review

This session is led by a tutor, G, and we observe variations in his knowledge and comfort with the material from one task to the other. He is confident of the material being discussed during Task 1 (time complexity and Big-Oh notation) but his definition of complexity as the "thinking" involved in an algorithm raises a lot of questions among the students. When a student asks him to explain the complexity of selection sort, G attempts to do so but is unable to and we see him lacking in sufficient expertise in this topic. However, when they are working on Task 2 (binary trees), we see G take more control over the session. He tries to clarify doubts and not only does he encourage and point students toward the right answer, but also explains complete solutions for problems like Part A and C. Thus, he displays significant knowledge in this topic.

We notice that this session is quite interactive right from the start, whether the interaction is related to the material being covered or not. A student discusses material unrelated to the tutorial while he talks to G about his grades on an assignment right in the beginning of the tutorial. We see such conversations between tutor-student quite often in this session, like when G comments on a student's chocolate bar or towards the end of the session, when he jokes with the students. The general environment during the tutorial is friendly and informal. We observe that the students are comfortable around G. When it comes to interactions pertaining to the tutorial material, there are constant discussions before and during Task 1 but this reduces during Task 2 and 3. Students appear to be working independently during the next two tasks and ask fewer questions. A majority of their questions during Task 1 are related to definitions and understanding of the concepts. But during Task 2 and 3, they attempt to solve the problems and their questions revolve around working out and building up solutions.

4.4 Analysis of G12

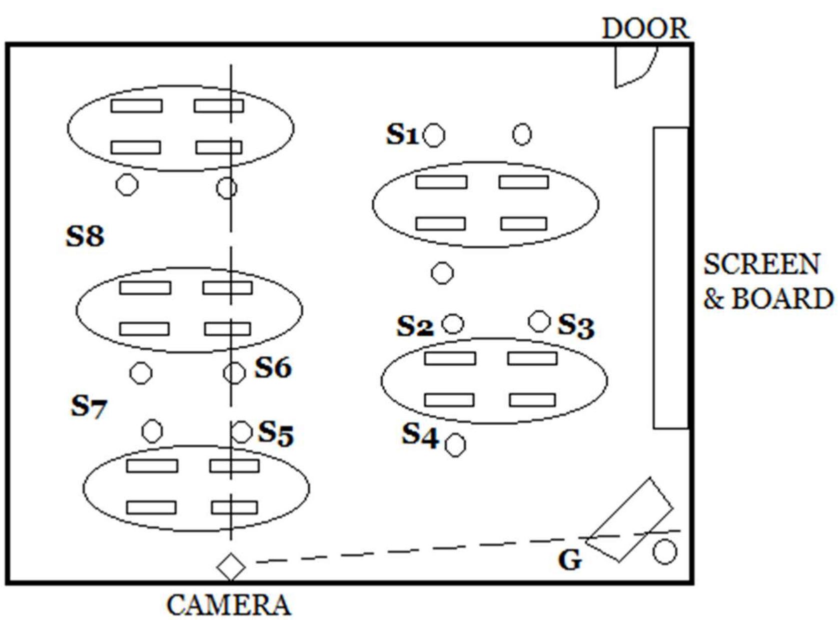

Figure 6: Classroom layout for G12

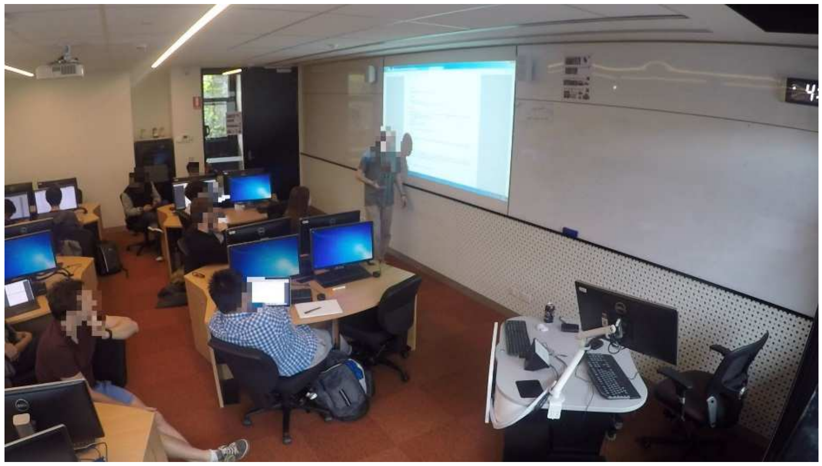

Figure 7: Scene from G12 recording

This tutorial is led by the tutor, G, in week 12. It covers the topics of vertex cover, cliques, P and NP classes of problems, and ASCII encoding. Refer to Appendix B: Tutorial 12 Worksheet for this session.

Students are still coming in since the tutorial has not officially started but G introduces one of the topics that is going to be discussed that day: P and NP classes of problems.

[00:00:45]

> (1.1) G: Today is going to be either one of the most informative or the most draining experiences of your time here.
> (1.2) S3: Why is that?
> (1.3) G: Because we're going to be discussing P vs NP. P vs NP is really difficult, even I had trouble understanding it. I don't know how to describe it. I can give you the short which is–
> (1.4) S3: Yeah–
> (1.5) G: That is what I'm gonna give you ((students laugh)) but actual, like, calculation not as much.

G starts the session by setting up an expectation with the class that the day's session is going to be challenging in terms of the amount they will learn or have to apply (line 1.1). On being questioned by a student, S3, about his reasoning, G responds with the topic (P and NP classes of problems) that is going to be discussed and explains that it's a tough topic, one he struggled with himself. He then goes on to express his doubts about explaining this topic to the students, in turn revealing that he might not have enough expertise in P and NP classes of problems (line 1.3). Thus, he really begins the session with the revelation regarding his lack of sufficient knowledge or understanding of the material to be discussed that day.

G spends the next 5 minutes discussing how no one has solved the P vs. NP problem and that if they do "all problems can be mapped to all other problems" and therefore "solved in linear time." They also briefly discuss how P and NP came about, and G mentions that it was first brought up in a letter between von Neumann and Kurt in 1957. A student, S5, jokes about proving something to get money, and then G and he talk about proofs that would earn them money, probably the Millennium problems. G once again declares that "today is a very hard slog" [00:06:31] and outlines the topics for the session.

[00:06:46]

> (2.1) G: In all honesty, some of the things that they've asked me to go through, I don't actually understand myself. I cannot show you that a decision problem exists in P or NP, just don't know. I can describe to you the P and NP problem, I can describe to you what P and NP is but I don't know the math to show that to you, unfortunately ((G shrugs)) and I'm sorry about that but it's how it is ((S5 looks away and S2 hangs his head)).

The tutor, G, once again confesses that he himself does not really understand some topics he has been requested to discuss. This occurs multiple times ([00:01:05], [00:07:05], [00:43:18], [01:09:20]) as the session progresses. He explains how he can define what the problems or classes of problems are but not the actual reasoning behind those. He apologizes for his lack of knowledge, and it is evident that he is aware of his limited expertise. Students S2, S3, and S5, who are listening to him intently, are visibly concerned. However, after his apologetic shrug, they have disappointed looks on their faces.

Another noticeable fact is G's mention of "they" (line 2.1), "they" being some higher authority that has put forth an agenda for the tutorial, one that he doesn't consider himself well-equipped for. However, since he has been asked to discuss certain topics by this higher authority, he is still going to try to go through them to the best of his abilities, which involves describing the terms even if he cannot explain the reasoning.

After this confession, G finally starts with Task 1.

<u>Task 1</u> [00:07:17]

G starts with vertex cover, Part A, and a student S7 informs him that they discussed it in the lecture that day. G then asks the students to define it and S2 gives the formal definition of vertex cover.

[00:07:37]

> (3.1) S2: A vertex cover is a subset of the vertices of a graph such that each of the edges in the graph is connected to at least one of the vertices in the– ((S2 looks at other students to help him complete)) What was it called? ((looks at G))
> (3.2) S6: Cycle?
> (3.3) S7: Cycle?
> (3.4) S2: No no, in the–
> (3.5) G: Cover.
> (3.6) S2: Cover, the cover.
> (3.7) G: So, the idea is that you can access all edges. Some set of nodes that accesses every edge.

While the student gives a formal definition, one that he has possibly been taught in the lecture that day, G tries to explain the basic idea of a vertex cover to the students in simpler terms. Students question this "access" (line 3.7) about whether it must be direct or indirect access and G tries to clarify this using the graph from the tutorial that is on the screen. On being asked for another example by S5, G draws a new graph on the board and explains what a vertex cover would be for that graph. He then goes on to discuss how a vertex cover can be of any size and there are many vertex covers for a graph. He also says that if they take every single node of a graph, that can also be a vertex cover. Hearing this comment, S7 asks a question regarding the exam.

[00:12:19]

> (4.1) S7: If they ask us this in the exam, can we be like a smart ass and just like put all the nodes down?

The language S7 uses here while addressing the tutor, G, makes us realize that there is a friendly and comfortable environment in the classroom, even though G is an authority figure.

Soon after, they start discussing cliques, Part B [00:12:44]. S6 tries and struggles to define a clique but then G takes over.

[00:12:57]

> (5.1) G: It's a subset where every node has access to every other node.

G once again defines clique in his own words over using the formal definition. He then goes on to explain this with an example that he draws on the board and further explains clique with the literal meaning as a close group of friends. He then relates this definition to the problem by describing the biggest clique as finding "the largest group of friends that all know each other" [00:14:16]. When he asks what the smallest clique is, S6 answers "one person" and S5 laughs and points at G, indirectly saying that G has no friends. Again, we see students being informal and friendly with the tutor. They continue discussing different examples of cliques, including the graph in the question and after almost 5 minutes, they start with Part C [00:18:15].

The students start reading the question and spend 2 minutes just laughing and discussing the pronunciation of the letter H. G explains the question to the students [00:20:18] and asks them to discuss how to obtain a clique from a vertex cover for a graph (Task 1, Part C). While students discuss the problem among themselves, we see G sitting with a student, S1, who came in late to the session, and repeating the definitions for vertex cover and clique to him. A minute into his description, another student joins them. After spending 5 minutes with them, G walks over to another table and talks to another student, clarifying the student's doubts. He spends the next 7 minutes walking around the classroom, observing and assisting students with the problem. Then, he sits down with another student, S4, who joined the session late. G spends the next 6 minutes explaining vertex cover and clique to S4, thus bringing him up to speed.

Following this, G heads back to his computer, and S7 and G have a spontaneous discussion about snacks that they were supposed to bring each other. S5 joins this discussion by offering G his last cracker. Again, we see that the students have a friendly and informal relationship with G that goes beyond the tutorial or its material.

After 39 minutes of the session, G asks if anyone has figured out the solution to Task 1, Part C and two students, S2 and S7 have solutions. G hears S7's solution and while he is not satisfied with it, S6, S7, and G joke about graphs having gender after S7 says "she" while talking about a graph. Subsequently, there is more laughter in the classroom and we see that G's session has a very friendly and comfortable atmosphere. After this, S2 describes his solution [00:41:40] and G agrees that it makes sense. He tries to clarify S2's solution to the rest of the students, first explaining what a complement is, and then talking about taking the complement of the graph. G continues with line 6.1 below.

[00:42:49]

> (6.1) G: –from that, create a cover and if you have a cover that is size k, it shows that there's a clique of size k

(6.2) S2: No
(6.3) G: No?
(6.4) S2: n minus k
(6.5) G: Okay, n minus k
(6.6) S7: What's n?
(6.7) S2: n is the size, the number of vertices in the graph G.
(6.8) S5: Oh! I get it. ((S5 smiles))
(6.9) G: Yeah? ((G smiles))
(6.10) S5: Yeah, just a little. ((S5 looks hesitant))
(6.11) G: No, that's alright, that's fine. 'Cause I still don't get it, as long as you guys get it, doesn't matter ((G is laughing and students are watching him seriously))

G appears to have understood S2's solution considering the way he is explaining it to the students but he stands corrected by S2 when he makes a mistake talking about the size of the graph. It is evident that some students aren't following the discussion or understanding the solution when S7 asks something basic like what *n* is and S2 answers. When another student S5 excitedly exclaims that he understands the solution, G looks happy as well. But when he prompts the student further, S5 is almost immediately hesitant and unsure of his earlier claim, confessing that he does not understand the solution completely. G assures S5 that it's alright since he still doesn't understand the solution himself and humorously claims that it doesn't matter as long the students get it. While G is laughing about his lack of knowledge not affecting the tutorial, since some students are understanding the topic anyway, none of the students smile. G, once again, declares and demonstrates that he doesn't have a strong understanding of the topic himself to be able to clarify doubts among the students.

They spend the next 2 minutes discussing this problem and how to answer it on the exam. G tries to help them as much as he can and then makes another confession.

[00:44:24]

(7.1) G: Sorry I can't really explain this any better, it's just one of those problems that I just don't get, at all. ((S6 laughs))

G apologizes for not being able to explain the problem further. Again, he himself expresses his lack of knowledge regarding this problem and goes on to read the solution off his computer. After discussing the complement of a graph for a minute, they move on to Task 2.

<u>Task 2</u> [00:45:37]

G starts with Task 2, which involves decision problems being classified as P or NP (Task 2, Part A). He doesn't offer much detail when defining decision problems to the students as is shown below in lines 8.1-8.3.

[00:45:47]

> (8.1) G: Basically, if you want to turn anything into a decision problem, it's can I do this?
> (8.2) S7: Yes or no?
> (8.3) G: Yes or no. Like it just turns into a Boolean question, yes or no, true or false.

After this, G directly asks the students to explain what they understand about P and NP problems. S6 says "anything solved linearly" is P, and S3 says "yes or no problems" are P. S6 also describes NP as any complex problem involving searching "like backtracking and sudoku" [00:46:59]. They are evidently confused and have no real understanding of the concept of P and NP classes of problems. G doesn't help much with clarifying since, as he declared before, he himself does not understand this well. But he goes on to try and define P and NP to the students.

[00:47:20]

> (9.1) G: Problems that are in NP are very difficult to find a solution to but it's very easy to validate if the solution is correct. If it's in P, it's both easy to find and easy to validate. That's the short of it.

G tries to explain what P and NP problems are by directly using formal definitions, but does not explain what it means to "validate" (line 9.1). He then chooses to use an example to make his point.

[00:47:48]

(10.1) G: For the Traveling Salesman Problem, can we find an optimal path that allows us to visit every city across the minimum number of traversals? ((students are silent)) Well, yes we can, we absolutely can solve it. But it would be NP–
(10.2) S6: NP.
(10.3) S7: NP.
(10.4) G: But finding whether or not a solution is optimal, well not to say optimal, is a good solution–
(10.5) S7: Is a valid solution?
(10.6) G: –is a valid solution
(10.7) S7: Would be in P?
(10.8) G: –would be in P.

While students unanimously agree to G's explanation of Traveling Salesman Problem being an NP problem, G struggles with explaining what P is in comparison (lines 10.1, 10.4, 10.6 and 10.8). According to his description, validating a solution is "in P." G only gives the students an overview, instead of real details, and the knowledge gap is evident in the discussion that immediately follows this.

[00:48:18]

(11.1) S6: We pretty much would need to find all the Ps of that to find the optimal solution.
(11.2) G: Sort of. You're not finding P, just describing how hard it is to do something. Right? There's no P to find.
(11.3) S6: So, P and NP stand for?
(11.4) S7: P for problem and NP for n problems?
(11.5) G: Well, no that's not what it stands for. P stands for polynomial time and NP stands for non-deterministic polynomial. ((S6 and S7 laugh))

Based on G's description of P and NP, a student S6 comments that they would have to find "P" and G corrects this misconception, explaining that they just have to figure out how difficult "something" is. G gives a better description here but his use of a vague word, "something" over "problem" doesn't make much sense to the students. Instead, in their confusion, they wonder what P and NP stand for. While G gives the students an exact answer, it is noteworthy that he had not mentioned this himself when he first started the discussion about P and NP. Furthermore, he does not relate what P and NP stand for, with their definitions, whereas this could bring the students some much-needed clarity. Right after this, he asks them to classify the problems that they have studied into P and NP. The students demonstrate that they still do not understand P and NP.

[00:48:53]

(12.1) G: So, with that in mind though, I want you to talk about all the problems we've been talking about this semester and tell me where they lie.
(12.2) S7: Like all the problems are in NP and if we want to find whether they're valid, it's a P?
(12.3) G: Is that true?
(12.4) S7: Hopefully yes?
(12.5) G: I don't know. Discuss it.

When G asks them to classify the problems, S7 suggests that all the problems they have discussed lie in NP and asks whether validating them would be P. Instead of clearing this confusion, G questions the student, only to have the student wonder if what he said is true. Again, G provides no conclusive answer and leaves the students to discuss among themselves. From this exchange, we can see that the students are deeply confused, as they do not demonstrate understanding the basic idea of P and NP. While they try to ask for help (line 12.2), G, having inadequate knowledge himself, does not provide any support.

After spending another 10 minutes on discussions of the same kind, about classifying the knapsack and linear search problems, a couple of students (S6 and S7) seem to have made some progress. S6 has reached the conclusion that NP problems may or may not have a solution but it can be validated and P problems always have a "true" solution.

G asks the students to come up with some problems that are in P and some in NP [00:52:51]. As the students start working on this, S5 expresses that the room is getting cold but some other students are heard saying they find it alright. This leads G to offer S5 his jacket and again, we see that G is friendly and informal with the students. G then goes on to ask S5 if he is following the topic.

[00:54:08]

(13.1) G: ((G talking to S5)) Are you understanding this so far?
(13.2) S5: Not particularly.
(13.3) G: What's got you fuzzy?
(13.4) S8: I still can't understand the distinction between the two. I'm reading a Wikipedia page so I might understand in a minute.

It is seen that some students (S5 and S8) still have not been able to understand the difference between P and NP. They are seeking another authority, Wikipedia (line 13.4), to be able to clarify their doubts, since G has not been able to help them and also expressed his lack of expertise in the material.

Meanwhile, S5 and G discuss the Traveling Salesman Problem as an example of a problem in NP, and then S8 asks for examples of problems in the class P. G suggests linear search and any standard mathematical problem. They go on to discuss how P is in NP and this results in the following exchange.

[00:56:54]

(14.1) S8: When does it stop being P and become NP? ((S8 laughs))
(14.2) G: That's an excellent question.

We see that S8 is genuinely confused and cannot understand how P and NP are different. While G acknowledges her question, he does not answer it and continues his discussion with S5 about an example of NP.

They continue discussing problems such as finding the total number of all possible numbers and finding the largest possible number, and try to classify these problems. This leads the discussion to NP-hard and NP-complete problems. G does not try to explain these classes of problems. While the students have not completely understood P and NP, G projects a diagram onto the screen, that shows the relation among P, NP, NP-hard, NP-complete and other classes of problems. After 6 minutes of this discussion, G introduces the "controversy" of P being equal to NP, and the students wonder how that is possible since P and NP are different concepts.

The discussion eventually winds down and G asks the students to classify the *n*-Queens and Traveling Salesman Problem [01:06:28]. Soon after, he projects another diagram onto the screen that talks about some more classes of problems. They discuss this for the next 3 minutes and then G asks them if they feel confident about classifying the problems they have studied so far and S3 and S4 say they are not, while other students are quiet. We see that the students are unsure of their own understanding of the topic. However, G goes on to discuss reducing problems to other problems for the next 3 minutes. Then, he mentions how the students can meet another person, "David" (presumably an instructor), to understand reduction better. After this, they begin to discuss how monkeys on typewriters, or random number generators, can eventually write all the Harry Potter books. Another 2 minutes later, G wraps up the discussion to start Task 3. Therefore, we see that G does not try to elaborate further on P and NP, even though the students have not understood the concepts. Instead, he has some entirely different discussions with them.

<u>Task 3</u> [01:15:30]

G explains that Task 3, Part A is about converting any number to binary and asks the students how they would do this. He also tries to explain Part B and then asks the students to write an algorithm for both these problems [01:17:55]. While the students work on this, G walks around the room and sits down with students who need some clarification. He encourages them to write algorithms instead of just discussing them and 7 minutes into Task 3, S7 describes his solution for Part A [01:22:45]. G agrees that his solution is right and then goes on to sit with S4 and assist him with the problem. He continues to walk around the room and help students, and eventually explains how to convert a number to binary by solving an example on the board [01:26:41].

For the next 5 minutes, students continue working on the problems. Meanwhile, G goes around the room, observing the students and clarifying their doubts. Seeing that they are all progressing well, G happily exclaims that he taught them something that day "at least" (line 15.1).

[01:31:00]

> (15.1) G: At least I taught you something today ((G is smiling)). Today's really dense, there's a lot of stuff in this.

G states that he was not able to assist as much that day, or that the students may not have learnt much due to his lack of expertise in the topic, but tries to make everyone feel better by explaining how they covered a lot of material in that tutorial.

Students work on their algorithms for another 5 minutes and then start discussing their doubts with G for the upcoming exam. One of these also involves NP-complete problems, and G tries to understand the definition himself before explaining it to the students [01:41:25]. About a minute later, their discussion leads them to NP-hard problems. G looks up NP-hard on Google and tries to explain the concept to the students for the next 3 minutes. He then asks the students if they have any more doubts. S5 is unclear about a question on insertion sort and G tries to clarify this for him. Soon after, students start packing up and leaving [01:50:15].

As students are leaving, one student comes up to G and asks him to recommend a course that she can take next semester [01:50:43]. G suggests two different courses. Another student asks G when he needs to pick his major and what happens if he does not pick one [01:52:26], and G explains that he should discuss this with the office since it is their work. A third student asks G to explain the difference between Computer Science and IT [01:53:18], and after G describes this, he asks him if he should study CS or Commerce. Following this discussion, he also asks G for his recommendation between Advanced Computer Science and Data Science. A fourth student asks G to explain the difference between Software Engineering and Computer Science. These discussions go on for 10 minutes. Thus, we see multiple students having personal discussions with G and understand that the students find him approachable and friendly. We also realize that some students look up to him for guidance and suggestions as an authority figure.

Review

This session is led by a tutor, G, and we observe his lack of knowledge and general discomfort pertaining to the material in the tutorial. He is aware of this himself and starts the session, admitting his lack of expertise. While they go through Task 1 rather smoothly, Task 2 brings about a lot of confusion and chaos. G explains topics in Task 1 (vertex cover and clique) with a very generalized description and we see more definitions like this as the tutorial progresses. G attempts to use more formal, textbook definitions during Task 2 when they are discussing P and NP classes of problems but does not give a single, coherent example. He directly introduces these topics without explaining any basics (such as decision problems or polynomial time) beforehand and as a result, the students do not have any clarity and ask many questions. Therefore, G displays an overall lack of expertise and confidence in these concepts.

We notice that this session is interactive throughout, whether the interaction is between tutor-student or student-student and relating to the tutorial material or not. The students have many questions throughout the tutorial but a majority of them come up during Task 2. These questions are all related to definitions and basic understanding of P and NP classes of problems. Thus, we realize the students have not been able to understand the topics at all. Further, we see G struggle to explain these better and he is therefore unable to completely clarify any doubts. G acknowledges this himself when he exclaims “At least I taught you something today,” after being able to explain decimal to binary conversion during Task 3. The tutor-student exchanges are not limited to the tutorial material and we see this when students discuss future courses and personal plans with G toward the end of the session. Throughout the session too, we see intermittent banter among the students with G about food and the room feeling cold. The students are comfortable with G, and the general atmosphere of the classroom is friendly and conversational. We also observe the students interacting a lot among themselves during this session, especially during Task 2 when they are trying to make sense of P and NP classes of problems.

4.5 Analysis of S11

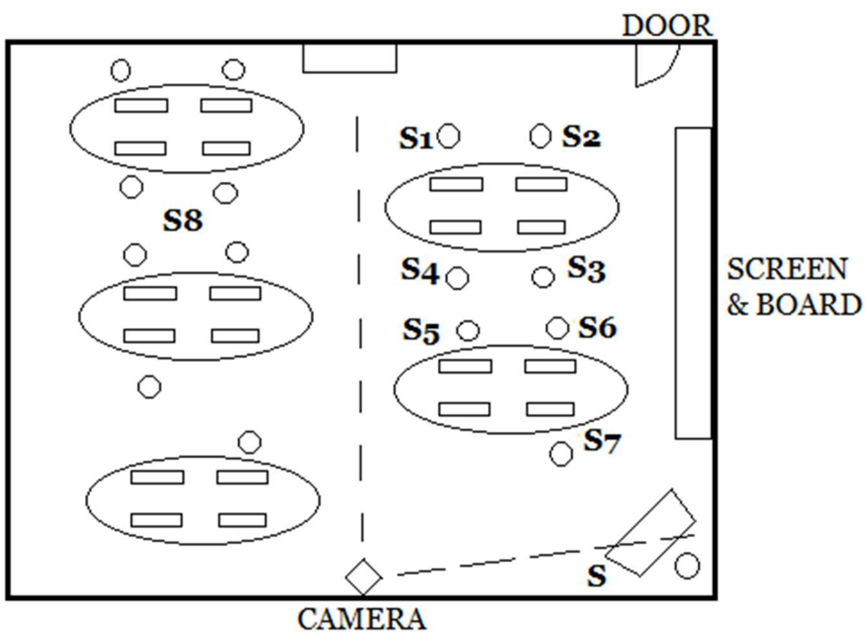

Figure 8: Classroom layout for S11

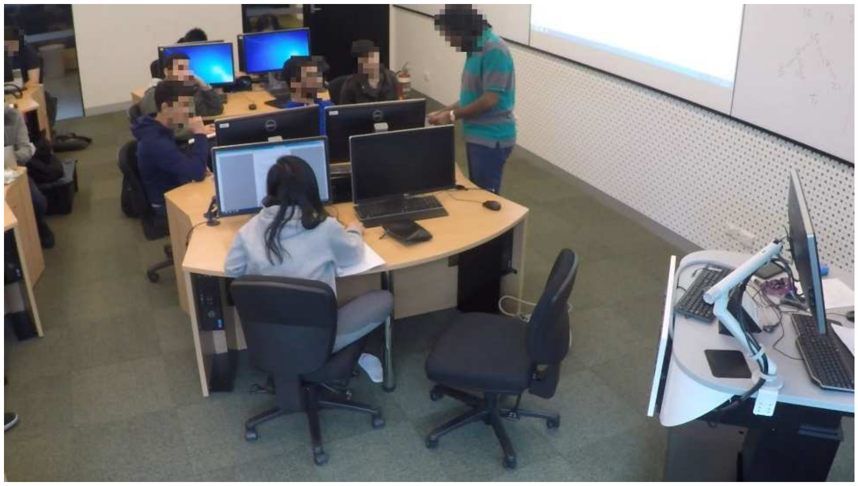

Figure 9: Scene from S11 recording

This tutorial is led by the tutor, S, in week 11. It covers the topics of Big-Oh notation, binary search trees, and Hamiltonian cycles. Refer to Appendix A: Tutorial 11 Worksheet for this session.

S spends the first 2 minutes of the session asking students to sign an attendance sheet, while waiting for latecomers. He then begins the tutorial directly with Task 2.

<u>Task 2</u> [00:04:10]

Referring to the previous tutorial wherein they discussed binary search trees (BSTs), he asks the students to create BSTs based on a list of numbers. He splits the students in the classroom into two groups and asks one to create a BST with the original list and the other to do this with the list in reverse order. Over the next 4 minutes, he asks both the groups to present their solution BST and explains their mistakes. Thus, we see that S encourages group work. He then asks the students to recollect what a binary tree and level of a node is. While a student S6 tries to answer both these questions, S corrects him and explains both the topics with a formal definition. He also acknowledges that S6 was not completely wrong by telling him, “you were right on the track but your wordings were not completely okay" [00:10:39]. We realize that S is particular about technical terms in definitions.

S discusses both these topics as well as the height of a tree. S6 makes an incorrect guess and S5 attempts to define the height of a tree as the "longest path from root to leaf" [00:11:35]. S accepts this as the right answer but refines the definition in terms of the level of nodes:

[00:11:54]

> (1.1) S: That's correct, but definition as per levels is the vertex with the maximum level is the height of the tree.

Once again, we see that S is particular about terms used in definitions. As an example, he asks the students to find the level for all the nodes and the height for the two trees that they had earlier created in two groups. Again, he encourages them to work together on this problem in groups. The students work on this for the next 3 minutes with constant discussions among themselves. Meanwhile, S walks around the room, checking on their solutions and tries to direct them towards the right one. After waiting for the students to come up with the solutions themselves, S explains the answers for both trees.

Following this introduction and review of BSTs, S starts with Task 2, Part A [00:17:31]. This problem involves the creation of all binary trees that can be formed with four nodes. S reads the question and discusses two examples of binary trees having four nodes. After this, he asks the students to work on the problem themselves. Several students are seen discussing the problem in pairs (S5 and S6, S4 and S7, S3 and S6). After spending 4 minutes on this problem, S asks the students to pair up and work. Again, we see S encouraging group work. While students try to build as many trees as are possible with four nodes, S walks around the classroom and assists students with any doubts. Another 4 minutes later, S starts discussing the students' answers. S5 is the first student to complete his solution, so S asks him to draw all the trees that he has created on the whiteboard. He also asks the rest of the students to review S5's solution and correct him if he repeats or misses any trees. Once again, we see S encouraging collaboration among the students as they evaluate one another's solutions and build the final solution together.

After 35 minutes of the session, they finish Task 2, Part A and S asks the students how many BSTs can be created with four nodes. A student S4 asks S for some guidance to work towards the answer.

[00:36:25]

(2.1) S4: How do you do it?
(2.2) S: Use your common sense.
(2.3) S4: It's not that common.
(2.4) S6: Yeah, I think we all figured that out last week. ((S3, S4, S5, S6, S7, and S laugh))

When S4 is unable to figure out how to proceed with the question, he asks S for help. S suggests that S4 should use his common sense and S4 admits that it is not common since he does not understand this problem. Hearing this exchange, another student S6 agrees and comments that they all realized this during the previous week. This prompts laughter among some students as well as the tutor S. We see that the students are comfortable making casual, humorous remarks around S. The general atmosphere in the classroom is friendly and informal.

Next, they move on to Task 2, Part B [00:37:24]. S asks the students to recollect some related concepts that they had studied in the previous week, such as finding an element in a binary search tree. Students attempt to define these topics, following which S gives a formal definition and explains the topic in more detail. He also discusses an example and then asks the students to solve a related question, such as drawing all possible BSTs for a certain list of four elements. As the students work on this problem, S walks around the room trying to guide them towards the solution.

After 5 minutes, a student S4 presents his answer, and S corrects his solution with input from other students S5, S6, S7, and S8. He also explains the mistakes in S4's approach simultaneously. In this way, S again encourages all the students to build the solution together. This discussion continues for 12 minutes, after which they proceed to Task 2, Part C [00:50:29].

Since Part 3 is related to complexity, S asks the students to define Big-Oh and after they attempt to do so, he explains the concept as an estimate of the time taken by an algorithm in the worst case. He also explains how complexity is defined in terms of the size of input, *n*. He does this with the example that sorting ten elements is faster than sorting a hundred elements. He discusses some more examples for the next 7 minutes and then asks the students to guess the complexity of selection and insertion sort in Big-Oh notation [00:57:58]. S repeats that *n* is the size of input and walks around the room, trying to clarify doubts. Meanwhile, students work together in groups and discuss their solutions with each other. S6 guesses the complexity of selection sort as $O(n^2)$ and explains his solution to S3 and S7. 3 minutes later, S acknowledges that S6 has the right answer and explains this with an example. The example involves finding the smallest number in a list, and then repeating this process for the remaining elements, much like the selection sort algorithm (without actually swapping the numbers to be in the right positions). While trying to explain how they get n^2 steps, S asks the students to recollect the formula for calculating the sum of integers 1 through *n*. A student S8 tries to define the formula but changes his answer several times. This prompts S to make the following remark:

[01:06:52]

(3.1) S: This is a good example of how to screw up your answer. ((S, S1, S6 laugh))

S8 appears very confused since he constantly switches between addition and subtraction operations while defining the formula to calculate the sum of the integers from 1 to *n*. S makes light of the situation by referring to this incident as an example of a bad answer. This comment is met by laughter among the students S1 and S6. Some other students can be heard laughing as well. Thus, we see that S interacts with his students in an informal manner and they share a friendly and comfortable relationship.

After this, students continue working on the complexity of insertion sort [01:09:40] and wrap up this discussion within 3 minutes. They then move on to Task 2, Part C [01:12:32] which involves guessing the time complexity for finding an element in a BST. The students are able to correctly and promptly answer this in a minute. Next, they discuss Part D for 4 minutes, and start Task 1.

<u>Task 1</u> [01:17:27]

S begins Task 1 by justifying his modified ordering of the tutorial tasks for the session, i.e. why he started with Task 2 before Task 1. He explains that Task 2 involved discussing complexity in detail, which is the main concept involved in Task 1. Having already discussed the topic with S, students start working on Task 1 independently. Task 1 involves counting the number of steps in two algorithms and then finding their complexity. Less than 3 minutes later, S again asks the students to pair up and work on the problems together. Students S1 and S2 pair up and S3, S6, and S7 work as a group. Meanwhile, S goes around checking on all the students and guiding them towards the right answer. After 8 minutes, S begins discussing the solution to Task 1, Part A. He asks every pair to present their solution and uses these to build the right solution. Similarly, they discuss Part B and reach the final solution. Soon after, they start working on Task 3.

Task 3 [01:35:01]

Task 3 is about Hamiltonian cycles, and S starts this task by asking the students to recollect and define Hamiltonian cycle. S6 tries to answer and then S moves on to Hamiltonian path. Again, a student S8 tries to answer. After listening to the students' definitions, S defines both Hamiltonian path and cycle. They then start working on Task 3, Part A [01:36:20]. Once again, S discusses all student answers and using these, he demonstrates that there are multiple Hamiltonian cycles. He explains how it is difficult to find Hamiltonian cycles and introduces "difficult classes of problems" as the NP class of problems [01:42:10]. He then briefly discusses P and NP classes of problems with the students. After 2 minutes, the students continue to Part B [01:44:12]. This problem involves discussing how to find a Hamiltonian cycle in a graph. S6 suggests an approach and S tries to explain this to the rest of the students. After 3 minutes, they start discussing the complexity of the proposed solution. A student S8 appears hesitant to share his answer but S encourages him by saying that everyone makes mistakes. Students have varying answers like $O(n)$, $O(n^2)$, and one even guesses $O(n^n)$. S acknowledges that the last answer is the right complexity and then tries to explain this to the rest of the students. He also describes that this is not polynomial running time and is therefore computationally hard. Again, he introduces the NP class of problems with a formal definition and cites the Hamiltonian cycle related Task 3, Part B as an example of this. Further, he mentions that they will be discussing this in the coming week. In this manner, S tries to relate material that they have already covered with newer topics.

Review

This session is led by a tutor, S, and we observe that he has knowledge of the material being discussed. He relates the tasks in the tutorial to materials that they have discussed in previous sessions or introduces relevant fundamental concepts. We also notice that he follows a pattern throughout the tutorial. At first, S asks the students to recollect concepts that they have discussed before. After the students try defining these themselves, he explains the concept with examples. While doing so, he uses formal definitions and is seen directing the students to do so as well. Having shared some basic knowledge relevant to the task, he prompts the students to attempt the problems themselves. S encourages the students to work quick by often trying to see which student or group has an answer first. He remains on hand to discuss and clarify doubts among the students and encourages them to work in groups. He then discusses various students' answers and incorporates all their input to build the final solution together.

We observe that S consistently encourages group work and collaboration among the students. He directs them to work on problems in groups or pairs and eventually builds complete solutions with all the students' input. S also encourages the students to work independently, without his input. The session is interactive throughout, be it student-tutor or student-student interaction. While students constantly discuss and work on problems together, S is either addressing the whole class while explaining a concept or solution, or he is walking around the room assisting students that have doubts. Students have questions about their solutions, implementation or need some direction to solve the problem. It is rare that a student asks a question that pertains to the definition or understanding of a concept. The students are involved and actively participate in discussions in the classroom, especially when S asks questions. We notice that the students are comfortable around S and share an informal relationship with him. The overall environment of the classroom is friendly and interactive.

Chapter 5. DISCUSSION

In the previous section, we discussed the tutorials (G11, G12, A12T) individually and noted significant occurrences and exchanges in each. Based on our observation of the tutorial sessions, we assembled a set of specific features. We then used these observed features to compare the sessions against one another. Refer to Table 1 for this comparative analysis. We also used some features from ALCOT – Active Learning Classroom Observation Tool (Birdwell et al. 2016) to compare the sessions further. Refer to Table 2 for this comparison.

Table 1: Comparison of the sessions

Observed Features	G11	G12	A12T
Tutorial lead	Tutor – G	Tutor – G	Instructor – A
Term week	11	12	12
Topics discussed	Big-Oh notation, binary search trees, and Hamiltonian cycles	Vertex cover, clique, P and NP classes of problems, and ASCII encoding	Vertex cover, clique, P and NP classes of problems, and ASCII encoding
Appendix reference	Appendix A: Tutorial 11 Worksheet	Appendix B: Tutorial 12 Worksheet	Appendix B: Tutorial 12 Worksheet
Level of expertise tutor demonstrates	High during Task 1 and 2	Low during Task 1 and 2, high during 3	High throughout the session
Type of definitions and explanation of topics (formal vs informal)	Informal definitions, generalized explanations	Generalized explanations for majority of the session, formal definitions during Task 2	Formal, textbook definitions, further explained by breaking down topics into smaller concepts
Use of examples	Two examples discussed during Task 1, none for Task 2 and 3	One example discussed for each topic during Task 1 and 3, none for Task 2	At least two examples discussed for every topic and sub-topic during Task 1 and 2, one example discussed for Task 3
Solutions discussed	Tutor discusses student's solutions for most problems in Task 1 and 2, gives complete solution for Task 2, Part A	Tutor discusses student's solutions for problems in Task 1 and Task 3 Part A, tries to explain solutions for some problems in Task 2	Tutor gives complete solutions for all problems and explains them

Student participation	Students ask some questions, attempt the problems themselves and solve most of Task 1 and 2 with some input from tutor	Students ask many questions, attempt the problems in Task 1 and 3 themselves, and solve parts of these with input from tutor	Students ask very few questions, attempt the problems themselves
Amount of tutor addressing or "lecturing"	Only while introducing topics related to Task 1 and explaining solution to Task 2, Part A	Only while introducing topics related to Task 1 and 3, and some of Task 2	While defining and explaining every new topic, sub-topic, example and solution
Amount of student-tutor interaction	Much interaction before the session starts, during Task 1 and some during Task 2 and 3	Much interaction before and during Task 1, Task 2 and towards the end of the session after Task 3; some interaction during Task 3	Very little interaction during the tasks
Topics of student-tutor interaction	Mostly asking questions pertaining to the material – about conceptual understanding during Task 1 and problem-solving during Task 2 and 3; answering tutor's questions; some general discussions about the outline for the session, attendance, food; one personal discussion about grades	Mostly asking questions pertaining to the material – almost all about definitions and conceptual understanding; answering tutor's questions; many general discussions about the outline for the session, temperature, food, research problems; four personal discussions about future courses and career plans	Mostly answering tutor's questions; a couple of questions pertaining to the material; no personal discussions
Nature of student-tutor interaction (formal vs informal)	Informal, friendly, conversational	Informal, friendly, conversational	Formal, to-the-point
Participants in student-tutor interaction (individual vs class discussions)	Some individual exchanges but most discussions across the class	Many individual exchanges, multiple discussions with groups but most discussions across the class	Very few individual exchanges but most discussions open to entire class
Amount of student-student interaction	Some during Task 1 and 2	Much during Task 2, some during Task 1 and 3	Very little throughout

Table 2: Comparison of the sessions using ALCOT

Features from ALCOT	G11	G12	A12T
Use of classroom equipment	Whiteboard used during Task 1 and 2 while giving examples and explaining solutions	Whiteboard used during Task 1 and 3 while giving examples	Whiteboard used during all the tasks, i.e. throughout the session
Use of classroom space	Tutor stands near the whiteboard, facing students during most of Task 1, walks around the classroom, among students during most of Task 2 and 3, and spends some time at his desk during all the tasks	Tutor stands near the whiteboard, facing students during most of Task 1, walks around the classroom, among students during most of Task 2 and spends most of Task 3 at his desk	Tutor stands near the whiteboard, facing students or at his desk during most of the session and walks around the classroom, among students for a few minutes during tasks
Level of classroom management (control over topics) displayed by the tutor	Tutor is comfortable with the material during most of Task 1 and 2, but unable to clearly explain topics and answer some student questions during Task 1	Tutor is comfortable with the material during most of Task 1 and 3, but struggles with Task 1, Part C and throughout Task 2	Tutor is comfortable with the material throughout the tutorial

Now, we discuss our observations pertaining to expertise and authority separately and indicate their role in the CS classroom. These observations include the amount of interaction, the atmosphere of the classroom, explanations and discussions of critical topics in the tutorial, student-tutor interactions about topics beyond the tutorial, and other features as mentioned in Table 1 and 2. We also indicate how expertise and authority affect active learning.

5.1 Expertise

There are marked differences in the demonstrated expertise of the individuals leading the various tutorials. These are the instructor A in A12T and the tutor G in G11 and G12. Starting with A12T, there are multiple instances where A demonstrates his knowledge of the material being covered in the tutorial. Refer to A12T §4.2 excerpts: 1 (defining vertex cover), 3 (defining clique), 5 (obtaining a clique from a vertex cover), 6 (defining polynomial time complexity), 8 (defining decision problems), 9 (defining P class of problems) and 10 (defining NP class of problems). Not only does A formally define these topics, but he also explains several examples of each. He breaks down topics such as P and NP classes of problems into smaller concepts like polynomial time, decision problems, and certificates. He then discusses the related problem in the tutorial. After allowing the students to work by themselves for a few minutes, he explains the entire solution to them as well. A is confident of the material being discussed and in control of the discussions. He is comfortable while explaining topics, repeating explanations or answering questions raised by students. According to Litzinger (2011), organization of knowledge around fundamental concepts is evidence of expertise and according to Ropo (2004) so is the use of multiple examples. These are both characteristics that we see in the instructor A. He starts every task by defining the basic concept or topic it is based on. He uses a formal definition and breaks this down into subparts if required. He then goes on to discuss a minimum of two examples for every topic, before moving on to the problem in the tutorial. We confirm that A not only does this during the tutorial, but also during the lecture (A12L §4.1). It is evident that A demonstrates expertise in the material being discussed in the tutorial and lecture.

In contrast, when the same tutorial is led by G (G12), there are only two instances where he is able to explain the topic with examples. Refer to G12 §4.4 excerpts: 3 (defining vertex cover) and 5 (defining clique). While G appears comfortable with these topics, he defines them in a very generalized manner and discusses just one example of each before moving on to the related question in the tutorial. As the tutorial continues, there are many instances where G is not confident of the material and unable to explain a topic in its entirety. Refer to G12 §4.4 excerpts: 6 (obtaining a clique from a vertex cover), 8 (defining decision problems), 9 (defining NP class of problems) and 10 (explaining Traveling Salesman Problem as an example of NP). As a result of his lack of knowledge about this material, the students are unable to understand these concepts. This is evident in G12 §4.4 excerpts: 6 (discussing solution to obtain clique from vertex cover), 11 (student asking what P and NP stand for), 12 (students trying to understand P and NP classes of problems) and 13 (students differentiating between P and NP). There is also an incident where a student asks G when a problem "stop[s] being P and become[s] NP" (refer to G12 §4.4 excerpt: 14). While G acknowledges this question as an "excellent question," he does not answer it. Furthermore, G himself confesses his lack of knowledge multiple times throughout the tutorial. Refer to G12 §4.4 excerpts: 1 (G admits he had trouble understanding P and NP), 2 (again admits he does not understand P or NP and how to prove which class a decision problem is in), 6 and 7 (admits he does not understand how to obtain a clique from a vertex cover "at all"). Towards the end of the session, G himself acknowledges that he was unable to teach the students much that day (refer to G12 §4.4 excerpt: 15). Through most of the session, G demonstrates a lack of knowledge and control over discussions in the classroom. It is evident that G lacks expertise in a majority of the topics discussed in the tutorial.

However, when G leads another tutorial (G11), we see that he has significantly more knowledge in the topics being discussed. Refer to G11 §4.3 excerpts: 3 (explaining Big-Oh notation), 4 and 5 (discussing the complexity for printing all elements in a list), and when he explains binary trees during Task 2, Part A. G initiates the discussions in the classroom and steers them toward relevant topics. He is able to explain concepts, examples or problem solutions in great detail. This session, therefore, resembles the tutorial led by A (A12). G is able to answer student questions and encourages them to work through problems themselves (refer to G11 §4.3 excerpt: 7). At one point, G exclaims that the students are understanding the topic of Big-Oh notation (refer to G11 §4.3 excerpt: 6). This is in stark contrast to his other tutorial (G12) wherein he acknowledges he was not able to teach the students a lot.

Having established A's expertise in A12T, G's lack of expertise in G12 and significant expertise in G11, we comment on other differences between the sessions. These differences are in terms of the amount of interaction, the topics of interaction, and overall student participation. We notice that there is much student-tutor interaction, and students have more questions in both of G's sessions as compared to A, with most being in G12. On closer inspection of the nature of these questions, we discover that most of the questions in G12 pertain to understanding the concepts involved in the tutorial, especially P and NP classes of problems (refer to G12 §4.4 excerpts: 6, 11, 12, 13, and 14). Unlike G12, the majority of questions in G11 are related to problem-solving strategies, i.e. how to apply their knowledge toward solving the problems (refer to G11 §4.3 excerpts: 5 and 7). The few questions raised in A12T too are of the same kind. It therefore appears that students have a better conceptual understanding in G11 as compared to G12 since they rarely have questions about basic topic definitions. There is significantly less student-tutor interaction as well.

Next, we notice that A gives the students some time to work on every problem themselves before explaining the solution himself. The students attempt to solve these problems independently, without any input from A. G does this for most part of G11 too. He asks the students to solve the problems and after waiting for a while, discusses the solution with them. However, in G12, G is constantly discussing the tutorial problems and trying to clarify doubts raised by students while they work on solutions. Students are seen working independently, without his input, only during the latter part of Task 3. There is therefore almost constant student-tutor interaction in G12. Again, it appears that students have sufficient understanding of topics in G11 and A12T as compared to G12, since they are able to work independently.

We also observe that there are several instances where the students struggle to understand concepts such as P and NP during G12. They ask basic questions such as what P and NP stand for or what the difference between the two is, but they fail to reach a conclusive understanding. To further the evidence that students have not understood concepts in G12, G himself acknowledges that he did not teach the students much during that session (refer to G12 §4.4 excerpt: 15). While we do not have direct evidence that students are understanding concepts during A12, we do have evidence for G11. This is when G himself acknowledges "You guys are really getting this." (refer to G11 §4.3 excerpt: 6).

Thus, we can see that expertise seems to affect student-tutor interaction and students' ability to work independently. It also seems to indirectly affect students' understanding of the concepts being discussed. When the tutor demonstrates expertise, there is less student-tutor interaction and students have fewer questions. The few questions that they do have are related to applying their knowledge toward solving the problem. They also attempt to solve the problems independently, with little to no input from the tutor. However, when the tutor lacks expertise, students have more questions and these are related to basic definitions of topics. They also need more guidance from the tutor when they try to solve the problems. Therefore, there are more exchanges between student-tutor overall. These factors in turn indicate the effect of expertise on students' conceptual understanding. When the tutor displays expertise, students are seen to have a better understanding of the material being discussed.

Tutorials are set up as an active learning environment wherein students take initiative and work on problems themselves. We see students working on problems independently and building their own solutions in the case of a tutor demonstrating expertise. This follows the constructivist approach of active learning, where students construct their own understanding, by relating new ideas with existing knowledge. However, when a tutor lacks expertise, students require more input and guidance to solve problems. Therefore, we observe that a tutor displaying expertise tends to create an active learning environment that encourages students to work independently and construct their own solutions.

5.2 Authority

We know that there is a difference in the formal authority between the instructor A and the tutor G. A, being a course instructor, has a different relationship with his students than other tutors by virtue of his title and position. In order to differentiate between a tutor (G) and an instructor leading a tutorial (A), we refer to the instructor leading the tutorial as the "instructor-tutor". While A does not make any indications about his level of authority in the tutorial (A12T) or lecture (A12L), G refers to a superior authority in both the tutorials (G11 and G12). In G11, he mentions that "they" wanted him to explain the topic of complexity in a certain manner (refer to G11 §4.3 excerpt: 2), and in G12, he discusses that "they" asked him to go through specific topics (refer to G12 §4.4 excerpt: 2). G makes both these claims before the students, and we notice that there is a higher authority that has put forth some guidelines and expectations for him. Knowing and observing that the instructor-tutor and tutor have different authority positions, we comment on other differences between the same tutorial when it is led by A (A12T) and G (G12). These differences are in terms of the amount of interaction, the involved participants, and the topics and nature of interaction. Additionally, we compare these observations against another session led by G (G11).

We notice that in the session led by A, there is not much participation or interaction in the classroom, be it student-tutor or student-student. Students rarely ask the instructor-tutor any questions and when he raises questions too, only two of the students try to answer. A also directs them to work on problems individually, which minimizes any interaction among the students. A does not move around among the students very much either. The session seems rather lecture-like with the instructor simply addressing the students. In contrast, when the tutorial is led by G, students are actively involved in discussions in the classroom. They ask a multitude of questions throughout the session, rarely giving G the opportunity to raise any questions. G also encourages the students to discuss problems among themselves (refer to G12 §4.4 excerpt: 12) and develop solutions together. This in turn seems to result in more student-student interaction in the classroom. G then walks around the room, among the students and discusses their ideas as well.

Next, we notice the topics of student-tutor interaction. In A12T, these exchanges are limited to the material in the tutorial. A starts the session directly with the first task in the tutorial. However, G always begins his tutorials by discussing the outline for the session (refer to G11 §4.3 excerpts: 1 and 2, and G12 §4.4 excerpts: 1 and 2). They discuss the material in the tutorial and topics related to it such as when P and NP were first mentioned or the application of cliques and Hamiltonian cycles in the real world. There are also many conversations about unrelated topics such as food, the temperature of the room, or research questions that would earn them a lot of money if answered. Some students even have personal discussions with G about their grades (one student in the beginning of the session G11, §4.3) or future courses and career plans (four students in the end of the session G12, §4.4). Therefore, student-tutor interactions in sessions led by G go much beyond the material in the tutorial.

Furthermore, we also observe the nature of these student-tutor interactions. While such interactions are formal in A12T, they are friendly and casual in the sessions led by G. We notice that students are comfortable with G since they have personal conversations with him regarding grades or their future (G11 and G12). One student asks G for his recommendations in order to decide her courses (G12, §4.4). Students are also honest and frank in their conversations with G. When G asks how many students miss lectures and listen to them later, two students admit to this (refer to G11 §4.3 excerpt: 1). Besides this, there are multiple instances where students and G make informal, humorous remarks during their conversations (refer to G11 §4.3 excerpts: 2, 8, 9, and 10, and G12 §4.4 excerpts: 4, 14, and 15). In contrast, there is not a single instance of these kinds of conversations in A12T. It is evident that G has created a friendly and conversational environment in his classroom in G11 and G12.

Through these comparisons, we can see that authority position seems to affect interaction, student participation, and the overall atmosphere of the classroom. When the tutorial is led by someone in an authoritative position, such as the instructor of the course, the amount of student-tutor or student-student interaction is considerably less. Students rarely ask questions and do not participate when asked questions by the tutor. Even when they do, it is a formal exchange, pertaining to the material in the tutorial. They also work individually on problems and do not participate in group discussions. Thus, the general environment of the classroom is more like a lecture with direct instruction (Stockard 2018). However, when the tutorial is led by someone who is more like a peer, the amount of interaction across the tutorial is much higher. Student-tutor interaction is frequent, with students raising many questions. These interactions are not limited to the material in the tutorial but cover a wide variety of topics. The conversations are informal and comfortable, with many personal discussions between student-tutor. Students also participate in group discussions and work together on problems. Hence, the overall environment of the classroom is friendly and encourages conversation.

Tutorials are used to create an active learning environment wherein students interact and work together to solve problems. When the tutor is someone more like a peer, we see students working together and interacting more with each other, than when the tutor is someone in an authoritative position. In the latter case, students work individually, interact less, and the tutorial closely resembles a lecture employing direct instruction. One of the approaches of active learning is collaborative learning, where students are encouraged to collaborate and work together to gain knowledge. Therefore, we observe that a tutor who is more like a peer, instead of someone in an authoritative position, tends to create an active learning environment that encourages collaboration and conversation among students.

5.3 Verification

We observe a tutorial led by another tutor, S, in week 11 (S11). We do this, keeping in mind the features from Table 1 and 2. S demonstrates expertise in and comfort with the material throughout the tutorial. He relates tasks to fundamental concepts and uses formal definitions while explaining these. S discusses three examples for Task 2 and two examples for Task 3 as well. S waits for the students to attempt the problems themselves before building the final solution with all their inputs. Students ask few questions pertaining to solving the question and barely any about topic definitions. They try to work independently, without any input from S. S encourages the students to work in pairs or groups and the students collaborate on their solutions. They do this for all the tasks and once all the students have some solution, S discusses all their answers and the final solution. S uses the whiteboard while explaining concepts, examples or solutions. He also makes the students present their solutions on the whiteboard. He stands near the whiteboard and addresses the students when he is explaining concepts in the beginning of a task or solutions at the end of a task. At all other times, he walks around the classroom among the students, observing their work and assisting them. There is a lot of student-tutor interaction before tasks when S reviews concepts that have been discussed in previous sessions, during tasks when students ask questions, and toward the end of tasks when S discusses students' solutions and explains the right solution. While the students do not have many questions, the ones they have are about implementation or directions to solve problems. They rarely have questions about conceptual understanding. They also do not have any personal discussions with S, but they make informal, friendly remarks. As such, the students actively participate in the classroom, be it answering S's questions or discussing solutions among themselves. There is a lot of student-student interaction; students collaborate during all the tasks. S encourages group work while solving problems and when they discuss solutions, he asks students to review each other's solutions as well.

Next, we compare our previous observations against S11. As discussed before, the organization of knowledge around fundamental concepts is evidence of expertise (Litzinger 2011) as is the use of multiple examples (Ropo 2004). Having seen both these characteristics in S (refer to S11, §4.5), we establish that he displays expertise in the material being discussed.

1) We concluded that when a tutor demonstrates expertise, there is less student-tutor interaction in terms of students asking questions. In comparison, there is more student-tutor interaction in S11 but it involves students answering the tutor's questions or presenting their solutions to him. We see that students still ask fewer questions in S11 and these questions only pertain to implementing their knowledge. Thus, we confirm this conclusion.

2) We concluded that when a tutor demonstrates expertise, students try to solve the problems independently, with little input from the tutor. We see this in S11 when students work on problems independently, rarely requiring assistance from S. S encourages the students to attempt the problems themselves and it is only after they come up with solutions, that he explains the right answer. Thus, we confirm this conclusion.
3) We concluded that when a tutor demonstrates expertise, students seem to have a better understanding of the material being discussed. We see this in S11 where students raise fewer questions overall. Most of these questions are about applying their knowledge towards problem solutions and there are extremely few about conceptual understanding. Students attempt to work on the problems independently, without any input from S. They are also often able to answer questions raised by S correctly (refer to S11 analysis, §4.5). Thus, we confirm this conclusion.
4) We concluded that when a tutor demonstrates expertise, it affects the constructivist approach of active learning, wherein students work independently and construct their own solutions. We see this in S11 where students attempt to work on problems and build solutions themselves. Therefore, we confirm this conclusion.

We know that S, as a tutor, is someone more like a peer, in terms of his authority position and relationship with the students. This is similar to when the tutorial is led by the tutor G and different from when the tutorial is led by the course instructor A.

1) We concluded that when a tutorial is led by someone who is more like a peer, i.e. a tutor over an instructor, there is more interaction across the session, be it between student-tutor or among students. We see this in S11 where students are constantly discussing solutions among

themselves as well as with S. They also discuss definitions of related concepts with S. Hence, we confirm this conclusion.

2) We concluded that when a tutorial is led by someone who is more like a peer, student-tutor interactions are informal and comfortable and the overall environment of the classroom is friendly. We see this in S11 when students exchange humorous remarks with S (refer to S11 §4.5 excerpts: 2 and 3). Hence, we confirm this conclusion.
3) We concluded that when a tutorial is led by someone who is more like a peer, the topics of student-tutor interaction are not limited to the tutorial and students have personal discussions with the tutor. We see no discussions beyond the tutorial material in S11. Thus, this conclusion cannot be confirmed.
4) We concluded that when a tutorial is led by someone who is more like a peer, students participate in group discussions and work together. We see this in S11 where students consistently work and discuss solutions in pairs or groups. In fact, this is encouraged by S himself. Hence, we confirm this conclusion.
5) We concluded that when a tutorial is led by someone who is more like a peer, it affects the collaborative learning approach of active learning, wherein students engage in conversation and collaborate on solutions. We see students collaborating as they work together on problems and interact throughout S11. Therefore, we confirm this conclusion.

Chapter 6. CONCLUSION

The primary goal of this research has been to understand the role of authority and expertise in a CS classroom. We examined recordings of three tutorial sessions, covering various concepts, led by different tutors. One is the instructor of the course, A, and another is a tutor, G. A and G differ in their authority position and demonstrate varying levels of expertise in the materials being discussed in the tutorial. Based on these recordings, we made observations about the effect of authority and expertise on interaction (between student-tutor or among students), student participation, the classroom environment and student-tutor relationship. After this, we observed how authority and expertise affect active learning. At last, we verified our observations against a fourth tutorial session, led by another tutor S.

Through our analysis, we made several conclusions about the role of authority and expertise in the classroom and active learning in general. These conclusions answer the three research questions we had raised earlier. The term "teacher" refers to the individual leading the tutorial. This could be a tutor such as G or S, or a course instructor such as A.

1) What can be said about the social relationships that develop (between a teacher and students as well as among students themselves) in an active learning environment?

   In an active learning environment, such as the tutorial sessions, we have observed that students interact more with each other as well as the teacher. They actively participate in classroom discussions, often directing the topic of discussion as well. They are more involved in the learning process as they collaborate with other students, answer questions raised by the teacher or seek clarification for doubts. Students develop a friendly or formal relationship with the teacher, depending on who the teacher is, and this influences their interaction as well. However, they work independently, with little to no input from the teacher. As for the relationships between students, they work in groups and interact more as a result. Thus, they depend on one another while learning.

2) Do these relationships depend on who the teacher is? More specifically, does the "status" or *authority* of the teacher (e.g. a tutor vs. an instructor teaching the course) influence the relationships that develop? How does it affect the learning environment?

   Yes, the student-teacher relationships are affected by the authority position of the teacher. When the teacher is someone in an authoritative position, such as a course instructor, the students develop a formal relationship with the teacher. There is less interaction between the student-teacher and among the students as well. Students rarely ask questions and work on tasks individually. Student-teacher interactions are formal and limited to the material being discussed. However, when the teacher is someone more like a peer, such as a tutor, the students develop a friendly relationship with the teacher. There is a lot more interaction between the student-teacher and among students as well. Students collaborate and work together on tasks in groups. Student-teacher interactions are informal and comfortable and related to material being discussed but not limited by it. Thus, the overall environment is friendly and conversational when the teacher is someone more like a peer. This also encourages the collaborative learning approach of active learning, since students interact more and collaborate with each other.

3) How does the disciplinary *expertise* of the teacher influence the relationship and the overall learning environment?

When the teacher lacks expertise, there is a lot of student-teacher interaction and students ask many questions about the material, especially related concept definitions. Students also seek assistance while working and are dependent on the teacher. They do not understand the material very well either. In contrast, when the teacher demonstrates expertise, there is less student-teacher interaction in terms of students raising questions pertaining to the material. Students are able to work independently, building their own solutions without much input from the teacher. Students demonstrate a better understanding of the material. Therefore, teachers displaying expertise are beneficial for the constructivist approach of active learning, since students work independently and construct their own solutions.

Thus, we have seen how authority and expertise influence interaction in a CS classroom. We have also commented on their effect on active learning.

6.1 Limitations

Our research is limited to tutorial sessions of a single CS course, in one university, in Australia. Therefore, our findings are restricted by the size and origin of the data. We handpicked a subset of these recordings (four sessions) to get sufficient evidence of the effect of authority or expertise and narrowed our data set further. In addition to this, the sessions were recorded toward the end of the school term. Thus, the relationships between student-teacher or student-student had already been established. While analyzing the recordings, we had no knowledge of the educational background of the students in the classroom or their prior relationships with each other. The sessions also differed in the number of participants and their communication styles, which influenced our observations.

We understand that teaching and learning are continuous, dynamic processes. Our analysis is based purely on the recordings, which are events occurring in a certain time frame. Thus, our conclusions are specific to that point in time.

6.2 Future Work

This research can be carried out over a larger data set, starting with all the recordings we have collected. Additionally, it can be expanded to include more courses, universities, and locations. In this manner, we can diversify the scope of the research. We can also observe classroom sessions throughout the term to be able to comment on the development of relationships and not just the relationships themselves. With knowledge about the participants in the recordings, we can observe features such as the performance of the students. Thus, we can comment on the effect of authority or expertise taking other such features into consideration.

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APPENDIX A: Tutorial 11 Worksheet

Algorithmic Problem Solving – Tutorial 11.

Objectives

The **objectives of this tutorial** are:

- To introduce Big-O notation for simple functions.
- To get familiar with Binary Trees, Binary Search Trees and cost of their operations.
- To be able to find a Hamiltonian cycle in a graph.

Task 1

Part A

Count the number of steps taken by the following programs using the Simple Computation Model given in Lectures. (To check if your count is correct, count the number of steps taken when $n = 1$ and $n = 2$ by each of these programs.)

```
def program1(n):
    count=0
    i=0
    while i<n:
        j=0
        while j<n:
            count+=1
            j+=1
        i+=1
    return count
```

and

```
def program2(n):
    count =0
    i=0
    while i<n:
        j=i+1
        while(j<i+3):
            count+=1
            j+=1
        i+=1
    return count
```

Part B

State the complexity of `program1` and `program2` in Big-O notation.

Task 2

Part A

In groups, draw all binary trees with four nodes. Label the levels of the tree and give its height.

Part B

Revisit the algorithm for finding an item in a Binary Search Tree discussed in Tutorial 10.

For each tree, identify the node(s) that will take the most comparisons to find and the node that will take the least comparisons to find.

Using this information, identify the best of these trees in terms of minimising the maximum search time.

Part C

Using Big-O notation give the best and worst cases of searching in a BST and their running time.

Part D

Which of the trees identified in Task 2A can be heaps? What can we say about the height of a binary tree that is a heap?

Task 3

Part A

Find a Hamiltonian cycle in the graph given in Figure 1. Write down the vertices in the order they appear in the cycle.

Can you find a Hamiltonian cycle in the graph given in Figure 2? Explain.

Part B

Consider the decision problem **HAMILTONIAN CYCLE**.
Input: Graph G
Question: Does G have a Hamiltonian Cycle?

Write an algorithm for deciding if a graph has a Hamiltonian cycle. What is the complexity of your algorithm?

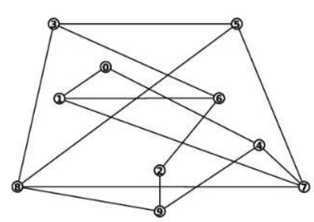

Figure 1: Graph G

Puzzle of the week

There is a magical tap in the Faculty of Information Technology. When the tap is opened an infinite flow of numbers come from it (numbers flow one at a time). The faculty decided to arrange a competition to develop an algorithm such that the algorithm should report the k biggest numbers (k is fixed) came out of the tap at any instance in time. The winner is the person whose algorithm takes the minimum time to execute.

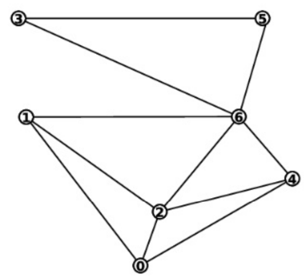

Figure 2: Graph H

APPENDIX B: Tutorial 12 Worksheet

Algorithmic Problem Solving – Tutorial 12.

Objectives

The **objectives of this tutorial** are:

- To be able to find vertex covers and cliques in graphs.
- To show that a given decision problem is in **P** or **NP**.
- To understand the **P** vs **NP** problem.
- To discuss how programs can be encoded in bits.
- To discuss the problem of deciding if a given algorithm terminates.

Task 1

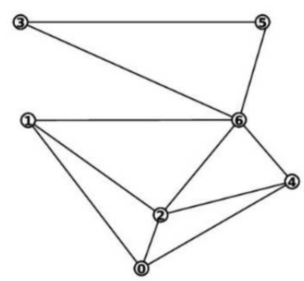

Figure 1: Graph H

Part A

Find a vertex cover for the graph in Figure 1.

Part B

What is the size of a largest clique in the graph in Figure 2?
What is the size of a smallest clique in this graph?

Part C

The graph $\overline{H}$ is the complement of the graph H if $\overline{H}$ and H have the same vertices and every distinct pair of vertices, u and v, are adjacent in $\overline{G}$ if and only if they are not adjacent in G. For example, the graph in Figure 2 is the complement of the graph in Figure 1.

Consider the following decision problems:
VERTEX COVER
Input: Graph G and number k
Question: Does G have a vertex cover of size k?

CLIQUE
Input: Graph G and number k
Question: Does G have a clique of size k?

These problems are in **NP**.

Suppose you had an algorithm to solve **VERTEX COVER**. Explain how you could solve **CLIQUE** using this algorithm.

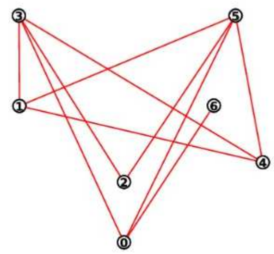

Figure 2: Complement of Graph H

Task 2

Part A

Give examples of decision problems in **P** or **NP**.

Part B

Discuss the **P** vs **NP** problem.

Draw a diagram that portrays our current view of this problem.

Part C

A decision problem is in **P** if it can be *solved* in polynomial time. A decision problem is in **NP** if any "yes"-answer can be *verified* in polynomial time.

Show that the following decision problem is in **P**:

SEARCH
Input: List L and target item
Question: Is the target item in the list L?

Show that the decision problem **CLIQUE** is in **NP**.

Part D

Give the complexity class of the decision version of the Knapsack, n-Queens and Travelling Salesperson problems.

Task 3

Table 1 gives part of the ASCII table. We can encode words by encoding each character by its ASCII value. Numbers can be encoded in their binary format. Instructions in the computer can also be encoded in this way. This gives us a way of representing a program as a list of bits.

Part A

Write an algorithm to convert an integer to binary.

Part B

Write an algorithm to convert an ASCII number to characters. [Refer Table 1].

Part C

Using Part B convert the following into characters.

```
65 108 103 111 114 105 116 104 109 32 67 111 108 108 97 116 122 40 110 41 10
119 104 105 108 101 32 40 110 62 49 41 32 32 123 10
32 112 114 105 110 116 32 110 10
32 105 102 32 40 110 32 37 32 50 32 61 61 32 48 41 32 123 110 60 45 110 47 50 125 10
32 101 108 115 101 32 123 110 60 45 51 110 43 48 125 10
125
```

Can you decide if this process will always terminate?

Symbol	ASCII	Binary Representation
A	65	01000001
B	66	01000010
C	67	01000011
D	68	01000100
E	69	01000101
F	70	01000110
...	...	...
Z	90	01011010
a	97	01100001
b	98	01100010
c	99	01100011
d	100	01100100
e	101	01100101
f	102	01100110
g	103	01100111
h	104	01101000
...	...	...
z	122	01111010
(	40	00101000
)	41	00101001
>	62	00111110
<	60	00111100
{	123	01111011
}	125	01111101
\	92	01011100
+	43	00101011
%	37	00100101
-	45	00101101
0	48	00110000
1	49	00110001
2	50	00110010
...	...	...
9	57	00111001
LF	10	00001010
Space	32	00100000

Table 1: Some of the ASCII table.

Puzzle of the week

Suppose that we have a collection of small villages in a remote part of the world. We would like to locate radio stations in some of these villages so that messages can be broadcast to all of the villages in the region. Since each radio station has a limited broadcasting range, we must use several stations to reach all villages. But since radio stations are costly, we want to locate as few as possible so that all the villages can receive the broadcasts. How can we solve this problem?