Problem Solving in Science:

A Case Study of Year 7 Students' Attitudes, Collaboration and Solutions

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ABSTRACT

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PROBLEM SOLVING IN SCIENCE – A CASE STUDY OF YEAR 7 STUDENTS' ATTITUDES, COLLABORATION AND SOLUTIONS

This case study explored Year 7 students' attitudes to science, problem solving and collaborative problem solving. It further looked into possible relations between the students' attitudes, self-efficacy and success in solving science based problems, and whether there were differences in solutions when students worked individually and collaboratively.

The participants were the researcher's Year 7 mixed achievement male students during scholastic year 2017-2018. In the researcher's attempt to obtain a holistic picture of the students' attitudes and self-efficacy, a non-anonymous questionnaire, together with researcher's observations and field notes, students' discourse, behaviour, and self-reflections of four collaborative problem solving lessons, and group interview were used. The attitudes of four students having different attitudes and achievement levels were compared to their individual and collaborative problem solving processes and solutions. These data were also used to analyse the differences that some students had between their individual and collaborative solutions.

It was found that most students at Year 7 had positive attitudes towards science, problem solving and collaborative problem solving. Problems' type and utility value, students' achievement level and teacher's scaffolding had an impact on the students' engagement, collaborative problem solving process, and problems' solutions. All students despite their attitudinal dispositions benefitted from the collaborative problem solving process.

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ATTITUDES **PROBLEM SOLVING** **COLLABORATIVE PROBLEM SOLVING**
SELF-EFFICACY **SCIENCE EDUCATION** **CASE STUDY**

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28 May 2019
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08.02.2018

Dedication

I dedicate this dissertation to my husband Emanuel, our children Mattea and Adam, and my dad, for their love, support and encouragement.

A special dedication goes to my late mum whose courage and determination in the difficulties she encountered have taught me to be strong.

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List of Abbreviations

CPS	Collaborative Problem Solving
DLAP	Directorate for Learning and Assessment Programmes
FREC	Faculty Research Ethics Committee
IBL	Inquiry Based Learning
IMechE	Institution of Mechanical Engineers
MEE	Ministry for Education and Employment
MUT	Malta Union of Teachers
NCfHE	National Commission for Further and Higher Education
NSO	National Statistics Office
NSTA	National Science Teacher Association
OECD	Organisation for Economic Co-operation and Development
PBL	Problem Based Learning
PISA	Programme for International Student Assessment
PS	Problem Solving
PS 01	First Problem Solving Lesson - The Total Number of Plants
PS 02	Second Problem Solving Lesson - The Hidden Buzzer Challenge
PS 03	Third Problem Solving Lesson - The Heating Water Challenge
PS 04	Fourth Problem Solving Lesson - Monuments, Acid Rain and Acidic Bird Droppings
ROSE	Relevance of Science Education

Chapter 1: Introduction

1.1 Background

Over the past 19 years of teaching science and biology to students in Years 7, 8, 9, 10 and 11, I always aimed towards raising my students' science competence and achievement. However, getting to know that in Malta there is still a large number of children "with low literacy, numeracy, science and digital skills, … [and only a] low level of children who master higher-order thinking skills" (Ministry for Education and Employment, MEE, 2014, p. 5) was something that had personally affected me as an educator. It made me ask myself how successful was I in my moral and legal obligations towards these children. I feel strongly about facilitating their learning and preparing them for the future – a future workplace which may not yet exist when considering the very rapid changes that are occurring in information and expertise.

On considering what local employers are saying, the national employee skills survey report (JobsPlus, NCfHE and Malta Enterprise, n.d.) identified skills such as those related to oral communication, team-working, problem solving (PS), ability to multitask, planning and organisation as the most important skills that they look for. "To some extent, this also means that proficiency is not necessarily linked to qualifications, as the skills required are of a generic rather than a specific nature" (JobsPlus, NCfHE and Malta Enterprise, n.d., p. 95). Such a need is also expressed on the global level. The Organisation for Economic Co-operation and Development (OECD) note that, "complex PSS [problem-solving skills] are particularly in demand in fast-growing, highly skilled managerial, professional and technical occupations" (2014, p.13). They've also noted that much of today's PS work is carried out "by teams in an increasingly global and computerised economy" (2017, p. 3). Thus I feel that unless we focus on such aspects, we can't expect to be thoroughly successful in our students' future holistic formation.

I believe that whilst planning the way to go about the various cognitive aspects within our curricula and syllabi, we should be also aiming at fostering 21st century learning and transferable skills focused on PS, creativity, critical thinking, communication and collaboration amongst others. Over the past few years, I started experimenting with inquiry based, PS and collaborative learning techniques with my students. It used to be a matter of trials, errors, reflections and retrials as I had not received much training on these approaches within my initial teacher training.

As time was passing by, I started to notice that those students with whom such techniques were used, seemed to have a more lasting cognitive effect. Performance in assessments requiring the transfer of knowledge to new PS contexts was improving and success was not tied to particular topics. Relationships between the students and between the students and myself were also better.

I was also noting however, that at certain times, this approach was more challenging and demanding on both the students and myself. Some students would tend to give up prior to actually starting to solve their problems. As regards to collaborative tasks, some students had the tendency of talking past each other, not sharing or contributing their personal knowledge. Other student teams seemed to have a member who takes over all the thinking and hands on work while the others were passive recipients/followers. I would often question myself what was wrong and what adaptations I needed to implement. Other times, I would question whether it was the students' attitudes that was affecting the process of collaboration and/or PS within the science lesson.

Various attitudinal studies (such as Institution of Mechanical Engineers [IMechE], 2012; Osborne, Simon & Collins, 2003; Sjøberg & Schreiner, 2010) found that attitudes are influenced by a combination of factors such as the item's utility value, future career aspirations, teachers, or perception of topic being easy, difficult or fun. A number of these studies also indicated that students are failing to see real-world relevance of school science. These have thus instigated me to put forward the research questions found in the next section as part of my Master's in Education dissertation.

1.2 Research Questions

Within this study, I decided to focus on Year 7 students as I feel that this year group sets the background and general expectations for the remaining secondary school years.

The questions that I attempted to answer in this study were:

- What are Year 7 students' attitudes to science, problem solving and collaborative problem solving?
- Is there a relation between Year 7 students' attitudes, self-efficacy and success in solving science based problems?
- Are there differences in the solutions produced when Year 7 students work individually and collaboratively?

Answers to these questions could eventually give insights on how students and teachers be better assisted in collaborative problem solving (CPS).

1.3 The Research Strategy

A case study approach was employed. The participants were 13 mixed achievement Year 7 students in a boys secondary church school during scholastic year 2017 – 2018. My role within this study was dual as I was both the researcher and the teacher of the participants.

A non-anonymous questionnaire at the start of the data collection phase and other tools (personal observations, and the students' discourse, behaviour, solutions and self-reflections) during four PS lessons and group interview data were used to obtain a holistic picture of the students' attitudes rather than just their declared ones.

A sample of four students was selected for the second part of the study. Their attitudes were analysed in relation to their individual and collaborative PS processes and solutions. This also shed light on differences that some students had between their individual and collaborative solutions.

1.4 The Context of the Study

1.4.1 The Educational System in Malta

The educational system in Malta is spread over five levels. These are pre-primary, primary (Year 1 – Year 6), secondary (Year 7 – Year 11) which in certain schools is split between the middle and the secondary level, post-secondary, and tertiary. Except for tertiary education, these levels are catered for by three sectors – state, church and independent. Compulsory schooling is for students between the ages of 5 and 16 (hence Year 1 – Year 11).

According to the National Statistics Office (NSO), during scholastic year 2016/2017 the student population distribution was:

- 56.8 % in state schools,
- 27.5 % in church schools, and
- 15.7 % in independent schools

(NSO, 2018, p. 11).

1.4.2 The Three Main Types of Schools

State schools have a coeducational system, where tuition is free of charge and students are provided with free textbooks up to secondary level (Malta Union of Teachers [MUT], 2017).

“Independent Schools are set up by individuals or non-profit parents’ foundations” (MUT, 2017, par. 3). Students have to pay for tuition and text-books. These schools are co-educational, and cater for pre-primary, primary, secondary and in some cases post-secondary level students.

Church schools are mainly Roman Catholic schools. Most of the school staff’s salaries are subsidised by the state, but students pay a donation to cover other school expenses. Students purchase their own text-books. Students can enter church schools if they have a sibling in the school, if either one of their parents works in the said school, through a ballot system or according to a predetermined number of special cases. Students in church schools are thus of a mixed achievement level, cultural and socio-economic status. Most church schools have single sexed students, where the majority of the student population does not change schools between primary and secondary. This study was held in a boys’ church school.

The NSO (2018) found that church schools have the highest average class sizes at both the primary and the secondary level. At Year 7, during scholastic year 2016/2017 this stood at 24.0 whilst those of independent and state schools were 19.3 and 19.9 respectively (NSO, 2018, p. 24). In science, classes are split into smaller groups to facilitate practical work. The maximum number of students in science classes is 16.

1.4.3 The National Curriculum Framework

The National Curriculum Framework (NCF) is amongst other things a policy instrument with information regarding implementation that responds to the “rapid changes in our education system driven by globalisation, ICT development, competition, shift of traditional values and new paradigms" (MEE, 2012, iii). It strongly promotes a CPS approach, where within all subjects, the cross curricular themes of "Learning to Learn and Co-operative Learning" and "Education for Entrepreneurship Creativity and Innovation" (MEE, 2012, pp. 9 – 10) are to be used.

One of the learning areas within the NCF is that of Science and Technology. Here an emphasis regarding how an inquiry based and PS pedagogy on an individual and collaborative level leads to the development of solutions and applications is made.

1.5 Dissertation Chapters Outline

There are five other chapters in this dissertation.

Chapter 2 reviews the literature where particular attention is given to problems, PS and CPS; the characteristics, techniques, challenges and pedagogies that utilise PS and CPS; how factors such as students' confidence in particular that obtained through self-efficacy and attitudes influence students in the science classroom.

Chapter 3 describes the participants, the research methodology and tools I used to answer my research questions. It discusses also the ethical aspects that I considered and which guided me throughout this research.

Chapter 4 attempts to answer my first research question where I unveil the attitudes of my Year 7 class, through a presentation, analysis and discussion of the data collected.

Chapter 5 attempts to answer the second and third research questions through the presentation of the findings and a discussion of four students' attitudes in relation to their PS processes and products.

Chapter 6 concludes the study with a summary of the main and secondary findings. It also outlines the study's implications and a number of recommendations are proposed. The study and its methods are criticised and suggestions for future research are identified.

Chapter 2: Literature Review

2.1 Introduction

Traditionally, in our education system we used to emphasise the need to follow instructions and learn a bucketful of content knowledge. This used to be the main attribute of a successful education. This however had problems such as those of a considerable number of students learning too little if they just listen to teachers' talk, and the teacher often interacting with a relatively small subgroup of students whilst the others become "invisible" (Hattie & Yates, 2014).

Nowadays, traditional teacher centred learning is not education's core value anymore. Knowledge of basic skills is needed, however we are to move "on to knowledge of core content and then to higher-order concepts and thinking skills to challenge, question and adapt knowledge" (Leadbeater, 2016, p. 35). In order to prepare our students for the future, we should aim at "equip[ping] young people to solve problems of all shapes and sizes. Problems that will not come with instructions" (Leadbeater, 2016, p. 5).

This shift in education requires that as educators, we provide opportunities for our students from "which they can learn in practice how to deploy knowledge in action, to work with others and to develop critical personal strengths such as persistence and resilience, to learn from feedback and overcome setbacks" (Leadbeater, 2016, p. 5). One way of doing this is through solving problems on the individual and the collaborative levels.

This chapter will thus initially give a review of the literature on problems, problem solving (PS) and collaborative problem solving (CPS); the characteristics, techniques, challenges and pedagogies that utilise PS and CPS. It will then look into how personal factors such as students' confidence in particular that obtained through self-efficacy and attitudes, influence students in the science classroom.

2.2 Problems and Problem Solving (PS)

According to Malta's National Curriculum Framework every child is entitled to "pedagogical approaches that ensure attractiveness to learning by doing and learning by means of cognitive skills that support understanding, and give importance to problem solving" (Ministry of Education, 2012, p. x).

The European Schoolnet (2018) also suggests that Science, Technology, Engineering and Mathematics (STEM) education should be integrative. This involves multidisciplinary teaching which is directed at fostering the students' problem framing and solving skills, as well as their ability to contextualise scientific concepts to real-life situations. Science should be "about solving problems, be that to create new knowledge, to answer empirical questions, to make something or to make that something work" (Roberts, as cited in Leite & Duorado, 2013, p. 1683).

2.2.1 Problems and their Classification

The understanding of the term problem may be somewhat varied. Within this study, I shall be using Hayes' (1981) understanding which states that a problem exists when the person who is trying to solve it, "perceives a gap between where he or she is and where he or she wants to be but doesn't know how to cross the gap" (p. i).

In literature, problem types have been found classified in various ways. For example, Watts (1991) distinguishes between three types of problem situations within the STEM classroom. These are:

1. "**Given** problems where the solver is given both the goal and strategies" (p.8; emphasis in original) such as arithmetic problems;

2. “**Goal** problems, where the solver is given the goal and nothing else” (p.8; emphasis in original), thus the students need to decide and develop their own strategies;

3. “**Own** problems, where the solver decides both the goal and the strategies” (p.8; emphasis in original).

Other researchers such as Mayer (1998), distinguish problems according to whether they are routine or non-routine ones. Routine problems are those with a simple solution which students “have already learned to solve” (p.49) and they just need to transfer the old method to the new problem. Non-routine problems are the more abstract or subjective problems that require a strategy as they “are not like any that they have solved in the past” (p. 49).

Another commonly used problem classification system used by various researchers such as Frederiksen (1984) and Mayer and Wittrock (2006) is that problems are classified according to whether they are:

1. Well-structured / well defined – where all the information to solve the problem is present at the start and a suitable procedure ensures a correct solution. Such problems include most school text-book problems (example finding the area of triangles, Ohm’s law or linear equations) and decision making ones where one is required to comprehend the problem having a number of clear alternatives and constraints and then make a decision that satisfies those constraints.

2. Ill structured / ill defined – where the problem is somewhat unclear, the information is not all available, there is no particular PS strategy and there may be more than a single correct solution.

Dostál (2015), Funke (as cited in Greiff, Wustenberg & Funke, 2012), the OECD (2014) and Scherer and Tiemann (2012) classify problems according to whether they are:

1. Static – where all information needed to solve the problem is known at the start, and
2. Dynamic/interactive – where the problem solver has to gather the problem's information by directly interacting with it prior to solving it. Such problems have changing conditions such as when one uses "technological devices [...] for the first time, especially if the instructions for using them are not clear or are not available" (OECD, 2014, p. 80). Such problems are rarely presented at schools.

Taconis, Ferguson-Hessler, and Broekkamp (2001) distinguish problems along the following dimensions;

1. Complexity – the number of variables / sub-problems involved,
2. Familiarity – the number of routine skills that can be used and the number of interpretations of new elements and processes involved,
3. Closed / Open – the number of solutions that are possible i.e. one vs multiple,
4. Amount of included information,
5. Type of cognitive activities needed – e.g. analysis, planning, execution, checking, hypothesis formulation, hypothesis testing.

2.2.2 Explaining the term Problem Solving

There are different ways in which problem solving has been defined and explained. Most of these include the aspect of having an inquiring attitude about a theoretical or practical difficulty which leads to the enrichment of one's knowledge (Kupisiewicz, as cited in Dostál, 2015; Mayer & Wittrock 2006). Other theorists also refer to one's inner conflict with her/his surroundings which result in a source of motivated activity whilst looking for new approaches (Linhart, as cited in Dostál, 2015). Other explanations focus on the use of one's background knowledge and skills to assess other goals and associated actions, select from these alternatives and work on the chosen goal oriented action (Luckin, Baines, Cukurova, Holmes, &

Mann, 2017). Thus the cognitive processing to achieve one's goals is used to transform the given state into a goal state (Mayer & Wittrock, 2006).

The OECD investigated students' PS in its Programme for International Student Assessment (PISA) in 2012. The definition as regards to the PS competency used was that a PS competency refers to the individual's

> capacity to engage in cognitive processing to understand and resolve problem situations where a method of solution is not immediately obvious. It includes the willingness to engage with such situations in order to achieve one's potential as a constructive and reflective citizen (OECD, 2017a, p.6).

Thus PS is not about just being academically highly achieving.

> It requires persistence to overcome setbacks; a sense of animating purpose to drive you on; collaboration to engage the ideas and insights of other people; empathy to understand the needs of others; the ability to turn ideas into action, to test and [to] improve them (Leadbeater, 2016, p. 6).

2.2.3 Pedagogies involving Problem Solving

In 1996, Pushkin argued that,

> students need to learn beyond the "right answers", but they need to learn how answers develop and how answers can be potentially right … how can we expect our students to become critical thinkers when their learning environment fails to nurture critical thinking? (p.27).

More than a decade later, Azzopardi (2008) criticized the science class of the time as still stuck in the "tradition of knowledge transmission and outdated and irrelevant curricula rather than one that seeks to induce a critical understanding of science" (p. 10). The Rocard, Csermely, Jorde, Lenzen, Walberg-Henriksson, & Hemmo (2007) report also suggested that "teaching should concentrate more on scientific concepts and methods rather than on retaining information only" (p.9).

As science teachers we can accomplish their recommendation by using various pedagogical methods that promote PS. Inductive and progressive teaching methods, like inquiry-based learning (IBL), problem-based learning (PBL), project-based learning and design-based learning, can be used to foster a deep understanding and prepare students to apply their knowledge in new situations (OECD, 2014, p. 28). This is because "self-regulated learning and metacognition especially knowledge about when and how to use certain strategies for learning … [and PS will be promoted. Students will be prepared] to reason effectively in unfamiliar situations and to fill gaps in their knowledge by observing, exploring and interacting with unknown systems" (OECD, 2014, p. 28).

In the next two sections I shall discuss in more detail the pedagogies of IBL and one of it sub-sets PBL.

2.2.3.1 Inquiry Based Learning (IBL)

Linn, Davis and Bell (2004) defined inquiry as "the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments" (p. 4).

Maaß and Doorman (2013) have identified several facets of IBL. They note that during IBL,

> students inquire and pose questions, explore and evaluate. Learning is driven by open questions and multiple-solution strategies. Teachers are proactive: they support pupils who are struggling and challenge those who are succeeding through the use of carefully chosen strategic questions. In the classroom, a shared sense of ownership exists (p. 887).

Both Linn et al. (2004) and Bell, Urhahne, Schanze and Ploetzner (2010) have given due importance to the collaborative aspect within the IBL pedagogy. They believe that through IBL within the collaborative setting, "students acquire knowledge of how to do science as a common endeavour, they learn about the nature of science and the scientific content" (Bell et al., 2010, p. 350).

Through IBL students "tend to reflect more on their own everyday direct experiences of the world around them when using scientific knowledge" (Gatt &

Armeni, 2014, p. 1583) as this is not detached from reality. This leads to an increase in students' interest, attitudes and attainment levels at different levels of schooling and in students with different abilities (Rocard et al., 2007) including those with social emotional behavioural difficulties (Camenzuli & Buhagiar, 2014).

IBL targets different student future aspirations as well. It provides students with the basic scientific literacy skills but also equips those who want to become scientists with the process and cognitive skills that are needed for becoming drivers of research and innovation (Gatt & Armeni, 2014).

It has also been reported that IBL has positive effects on the teacher due to stimulating the teachers' motivation (Rocard et al. 2007). Another benefit reported by Aquilina (2015) is that its use allowed her to take a secondary role and be more of a facilitator of learning.

2.2.3.2 Problem Based Learning (PBL)

PBL is a type of IBL pedagogy where real-world problems having more than a single correct solution are used as the starter point (Hmelo-Silver, 2004). Jolly (2017) suggests that problems should be ill-structured and carefully designed to engage, appeal, appear real, and are stimulating and thought provoking for the students. She specifies that the problems presented to students should be "grounded in compelling societal, economic, and environmental issues that affect people's lives and communities … should be 'doable' … [and] must allow for multiple acceptable approaches and solutions" (Jolly, 2017, Criteria for Selecting Real-World Problems, par. 3-6).

During PBL, students engage in collaborative learning about both content and thinking strategies in order to solve their problem (Hmelo-Silver, 2004). PBL is thus an active teaching strategy (Silva, Bispo, Rodriguez & Vasquez, 2018). Students are not passive but become active self-directed learners where they "apply their new knowledge to the problem and reflect on what they learned and the effectiveness of the strategies employed" (Hmelo-Silver, 2004, p. 235). The teacher's role is that of facilitating the learning process rather than that of transmitting knowledge.

Amongst research on the impacts of PBL, Ferreira and Trudel's (2012) results on forty-eight students in three regular high school chemistry classes "indicated a significant [improvement] in student's attitudes towards science, PS skills, views of the learning environment … and a sense of community in the classroom" (p. 23). Silva et al.'s (2018) study amongst ninety undergraduate students in the decision making and managerial development course showed that PBL had positive effects on student learning due to promoting the combination of theory and practice, which improved the motivation to learn. Their students identified the practical aspect, teamwork and the presence of an entrepreneur/manager in the PBL classes as factors that facilitated learning. Their study, however, also identified that the time required and teamwork were perceived as factors limiting students' learning.

2.2.4 Techniques used during Problem Solving

In order to solve problems, one should first perceive a problematic situation as a problem. This occurs when s/he has developed the "ability of problem awareness" (Dostál, 2015, p. 2800). If one does not "see" the problem, s/he will not realise what would be causing the difficulty or which obstacle is to be overcome and s/he would not be able to solve it. According to Dostál (2015), the "perceptibility of the problem" (p. 2800) may be influenced by factors that are:

- within the problematic situation such as lack of knowledge or inappropriate verbal utterances, and
- outside the problematic situation such as noise levels or visual impairment.

The willingness to solve a perceived problem occurs after having evaluated the problem's circumstances and due importance is given to it (Dostál, 2015). Thus as educators, whilst planning the problems that we are going to assign our students we are also to plan appropriate resources and methods that might motivate students to reach this problem solving willingness state.

During PS, students intertwine their knowledge (both the domain and the general based) with cognitive activities made of their skills repertoire (Taconis et al., 2001). This involves interpreting the given information and constructing "an internal representation of the task and the goal to be reached" (Taconis et al., 2001, p. 444). There is search in the long-term memory of particular strategies and knowledge that is related to the problem which eventually results in (a) an external product e.g. a solution or diagram and (b) an internal product known as learning (Taconis et al., 2001).

Whilst solving problems, the process is to be given its due importance. As teachers, we cannot just focus on the external product. The OECD (2014; 2017a) within PISA 2012 and 2015 identified and assessed four groups of cognitive PS processes which need not necessarily be sequential or all required to solve a particular problem. These PS processes are:

- **Exploring and understanding** the situation of the problem by observing it, interacting with it, researching it and finding its limitation or obstacles.

- **Representing and formulating a hypothesis.** This involves using various representations (e.g. symbols, tables, graphs or words) to show aspects of the problem situation. A hypothesis is then formulated about the relevant factors in a problem and the relationships between them, to build a coherent mental representation of the problem situation.

- **Planning and executing** the solution to a problem. This may entail the clarification of the general goal, the establishment of sub-goals, etc.

- **Monitoring and reflecting** on the information provided in the problem, the strategy adopted, progress, feedback, and the solution.

(OECD, 2014; 2017a; 2017b)

Linhart (as cited by Dostál, 2015) identifies a "phase of verification" (p. 2802) during the PS process. This involves the "verification of the discovered property or method and its use in other problems of the same order" (p. 2802).

The actual techniques that students may use within the above processes may vary. Antonietti, Ignazi, and Perego's (2000) metacognitive study on PS methods amongst undergraduate Italian students described and identified the following five methods:

1. Means-ends analysis which is sometimes referred to as working backwards, hill climbing or sub-goaling. It occurs when the student persistently holds and processes in her/his working memory the (a) present problem, (b) goal, (c) associations between them, (d) problem-solving operators that could reduce differences, and (e) any intermediate goals (Sweller, van Merriënboer & Paas, 1998).

2. **Brainstorming** where a large number of possible solutions are tentatively provided. The successful use of brainstorming utilises four rules which are avoiding criticism, saying/writing all the things that come to mind, trying to produce as many ideas as possible without paying attention to their quality, and trying to develop and combine ideas (Göçmen & Coşkun, 2019).

3. **Trial and error** where the solution to a problem is found by attempting to combine elements of a problem in different ways. Morphological analysis and forced relations are methods that are based on this technique. The student then, "relate[s] the critical elements of the situation systematically to each other and consider[s] which suggestions rise from such links" (Antonietti et al., 2000, p.2).

4. **Analogy** which is based on finding similarities in two or more situations in different domains which were successful and embedding them in the new problem situation (Antonietti et al., 2000).

5. **Visualisation** which is a process that restructures the problem at hand. The main features of the problem are considered and understood. The student then tries to see it from a different point of view (Antonietti et al., 2000).

In the latter four goal-free strategies, students can use any operator to solve a problem (Sweller et al., 1998). Such strategies proved to be more efficient due to reducing the cognitive load and facilitating schema construction in the students' science PS (Sweller et al., 1998) as shall be discussed in the next section.

2.2.5 Cognitive Load Theory and Problem Solving

The cognitive load theory provides guidelines that assist in the presentation of information in a way that optimises learning (Sweller et al., 1988). It uses aspects of the information processing theory and limitations due to the working memory load to describe what happens during learning. Its principles as summarised by Van Merriënboer and Sweller (2005) are that:

- we have a limited working memory that saves around seven bits of information, but functions on only between two to four elements at a time;
- the working memory can deal with information for only a few seconds. This information would be lost following 20 seconds unless revived by repetition;
- these capacity limits apply only to new information obtained through sensory memory;
- recovery of information from the long-term memory has no known limitations;
- this dramatically changes the characteristics and the content of what is happening within the working memory;
- long term memories exist in the form of cognitive schema that can change in degree of complexity and automation;

- expertise arises from knowledge stored within schema, and not from the ability to engage in reasoning using elements that are not coherent and organised within the long term memory;
- the complex schemata one develops will organise knowledge and dramatically reduce the working memory load

(pp. 148 - 149).

According to Taconis et al., “a schema has both process and content aspects” (2001, p. 446). Content aspects deal with “how knowledge is structured and organized in memory, … whereas the process aspects are focused on how these structures are developed, updated, and used” (Taconis et al., 2001, p. 446). Thus schemata are in a continuous process of refinement and restructuring – they are not fixed (Taconis et al., 2001).

I believe that all these principles affect how our students in the mixed ability classroom process the problems that we assign to them. Some students may perceive a pattern as just one piece of meaningful chunk, whilst others would perceive the same pattern as a large number of relatively unconnected facts (Van Merriënboer & Sweller, 2005). Thus during PS, our students may experience high and/or excessive cognitive load as their working memory has to deal with a large amount of interacting elements due to new or unorganized information (Phan, Ngu & Yeung, 2017).

Van Merriënboer and Sweller (2005) also distinguish between the “intrinsic cognitive load” (p.150) which deals with the intrinsic nature of the learning task itself and the “extraneous cognitive load” (p.150) which is the manner in which the task is presented. They suggest that extraneous cognitive load may be imposed on the student such as when there are weak PS methods, when they have to merge information that is distributed in place or time, or when they need to search for information that is needed to complete the task. Extraneous cognitive load can also occur by the learning context such as when teachers talk too much to their students. Thus as teachers, when we are aware of such extraneous cognitive loads on our students, we should change our instructional methods and lower this cognitive loading – only then will our methods be appropriate and efficient (Schunk & Meece, 2005).

2.2.6 Helping Students in PS

As teachers, we may decrease students' extraneous cognitive load during PS by:

- substituting conventional problems with goal-free problems that provide students with an a-specific goal;
- replacing conventional problems with worked examples that are to be studied;
- changing conventional problems with completion problems. Partial solutions are given and the student must then complete it;
- substituting a written explanatory text and another source of visual information such as a diagram (unimodal) with a spoken explanatory text and a visual source of information (multimodal);
- replacing multiple sources of information (frequently pictures and accompanying text) with a single, integrated source of information;
- replacing multiple sources of information that are self-contained (i.e., they can be understood on their own) with one source of information

(Sweller et al., 1998).

Taconis et al.'s meta-analysis (2001) and Greiff, Wüstenberg and Funke (2012) found that the most successful interventions are those that stimulate both the construction of an adequate knowledge base and its skilful use. Various researchers (Fredericks, 2005; Lyle and Robinson, 2001; Polya, 1957) have suggested models that as teachers we can use to guide our students in solving problems. Mainly intended for numerical type of problems but can be extended to hands on and written problems, these models involve helping students:

1. Understand the problem – its nature and related goals. This may involve asking them to frame the problem in their own words;

2. Describe any difficulties and constraints they have;

3. Identify and select one or more strategies to solve the problem. This may involve amongst others:
    a. creating visual images of the problem and potential solutions,
    b. engaging in some trial and error PS,
    c. creating tables as these enable students to group and organize data in relation to the problem,
    d. using manipulatives as the shifting of objects can also aid students in developing patterns and organizing elements of the problem,
    e. working backward, and
    f. looking for patterns by creating a list of ideas which can be used to determine regularities, patterns, or similarities between problem elements;

4. Try out the solution and:
    a. Keeping a record of their thoughts and strategies used;
    b. Keep on working on their strategy/strategies until it is evident that it will not produce any results. At this point they should be willing to use another strategy / strategies;
    c. Carefully assessing and monitoring their steps to solving the problem;
    d. Feeling comfortable in putting the problem aside for a while and dealing with it at a later time;

5. Self-assess the result / solution

(Fredericks, 2005, pp. 152 – 155).

Taconis et al.'s meta-analysis (2001) adds that interventions that focus on the process and the external product such as immediate feedback and external guidelines and criteria also have a positive effect on the learning outcome. Mayer (1998) in turn emphasised the need of practicing solving problems in context. Kirschner, Paas, Kirschner, and Janssen (2011) found that the extraneous cognitive load present in PS could be decreased by allowing students to work collaboratively as shall be discussed in the next section.

2.3 Collaborative Problem Solving

2.3.1 What is Collaborative Problem Solving?

During Science and PS lessons, as educators we often encourage students to work collaboratively in groups. Collaborative Problem Solving (CPS) is “the process of a number of persons working together as equals to solve a problem” (Luckin et al., 2017. p. 9).

The OECD notes that CPS tasks are important for students, and thus in their PISA 2015 studies the CPS competency was assessed. The definition used for this competency is:

> the capacity of an individual to effectively engage in a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills and efforts to reach that solution (OECD, 2017a, p. 6).

A number of interaction skills are thus to be used concurrently. These are to support and co-ordinate the group’s thinking with one’s own, until achieving a commonly agreed goal.

2.3.2 Benefits of Collaborative Problem Solving

Three distinct advantages of CPS over individual PS that OECD (2017b) identify are that during CPS:

- labour can be divided among team members;

- a variety of knowledge, perspectives and experiences can be applied to try to solve the problem;
- and team members can stimulate each other, leading to enhanced creativity and a higher quality of the solution.

(p. 46)

Kirschner et al. (2011) also reported that the extraneous cognitive load that is often attributed to PS can be reduced when students work in groups of three that are well motivated. Each of the group's members would initially have multiple limited working memories. These valuable task-relevant information and knowledge "can be consciously and actively shared (i.e. retrieving and explicating information), discussed (i.e. encoding and elaborating information), and remembered (i.e. personalising and storing information)" (p. 588). Kirschner et al. (2011) linked this to Wegner's transactive theory where the group members can act as external memory helpers for each other, and where everyone can gain from each other's knowledge and expertise if a good shared understanding and awareness of who knows what in the group is developed.

Collaborative work enables students to listen to the ideas and explanations from others. According to Luckin et al. (2017) this may help them to:

- develop an understanding of areas that are missing from their own knowledge;
- elaborate and internalise their new understanding as they process the ideas they hear from others (citing Damon, 1984 and Wertsch and Stone, 1999);
- engage actively in the construction of ideas and thinking as part of the co-construction of understandings and solutions

(p. 20).

When students explain their ideas to their peers, they will articulate, clarify and explain their meaning (Gillies & Ashman, 2003). At times they also need to re-structure their explanation. These aspects enable them to:

- re-examine their ideas and understanding of the topic leading to a better learning performance (Gillies, Nichols & Burgh, 2011, p. 247), and
- strengthen their understandings and/or ideas. This makes them more aware of what they know and do not know (Howe, Tolmie, Anderson, & Mackenzie, 1992) thus facilitating the process of self-reflection.

Other reported positive aspects of CPS over individual PS are that its output will:

- eventually be greater than the sum of the outputs of the individual members (Schwartz, 1995; OECD, 2017a),
- lead to a positive attitude to schooling (Johnson and Johnson, 2002; Kyndt, Raes, Lismont, Timmers, Cascallar, & Dochy, 2013),
- lead to an improved social climate within the classroom (Johnson and Johnson, 2002; Kyndt et al., 2013),
- prepares students for the future workplace (Luckin et al., 2017).

2.3.3 Requirements for Effective Collaborative Problem Solving in the Classroom

According to documents published by the OECD (2017a; 2017b), the four PS processes identified within PISA 2012 (discussed in Section 2.2.4) are still required for CPS. Within PISA 2015, OECD (2017a; 2017b) identified three further competencies:

- establishing and maintaining a shared understanding **-** where the group members' knowledge and perspectives are identified. A shared vision of the problem states and activities is then determined;
- taking appropriate action to solve the problem; and
- establishing and maintaining team organisation**.** This requires understanding each member's role, following the rules of engagement for one's role, monitoring group organisation, and easing the needed changes to optimise performance, solve conflicts or other hurdles.

Within PISA 2015, these three major CPS competencies were crossed with the four PS processes. This resulted in a matrix of twelve specific CPS skills as shown in Table 2.1.

Table 2.1: The twelve assessed CPS skills within PISA 2015.

		Collaborative problem-solving competencies		
		(1) Establishing and Maintaining Shared Understanding	**(2) Taking appropriate action to solve the problem**	**(3) Establishing and maintaining team organisation**
Problem-solving processes	**A) Exploring and understanding**	**(A1)** Discovering perspectives and abilities of team members	**(A2)** Discovering the type of collaborative interaction to solve the problem, along with goals	**(A3)** Understanding roles to solve the problem
	(B) Representing and formulating	**(B1)** Building a shared representation and negotiating the meaning of the problem (common ground)	**(B2)** Identifying and describing tasks to be completed	**(B3)** Describing roles and team organisation (communication protocol/rules of engagement)
	C) Planning and executing	**(C1)** Communicating with team members about the actions to be/being performed	**(C2)** Enacting plans	**(C3)** Following rules of engagement (e.g. prompting other team members to perform their tasks)
	D) Monitoring and reflecting	**(D1)** Monitoring and repairing the shared understanding	**D2)** Monitoring results of actions and evaluating success in solving the problem	**(D3)** Monitoring, providing feedback and adapting the team organisation and roles

Note. Reprinted from *PISA 2015 Results (Volume V): Collaborative Problem Solving (p.50),* by OECD Publishing, Paris. Retrieved from http://dx.doi.org/10.1787/9789264285521-en

Succeeding in the CPS process thus as shown in Table 2.1, requires features based on both the individual and the team.

2.3.4 Is Collaborative Problem Solving Really Collaborative?

When people in groups perceive the other/s as similar to themselves, they tend to extend a level of empathy. If on the other hand they cannot put themselves in the place of the other, then there would be an empathy gap. When this gap occurs, the relationship breaks down and results in behaviours such as bullying, feeling of authority and so on (Hattie & Yates, 2014).

Kutnick and Blatchford (2014) reported that even though students may be seated in a group arrangement in their classroom, only a small proportion of their time was used for collaborative learning activities. Collaborative learning in our classrooms is successful when students are "working **as** a group rather than just working **in** a group, and [there is] individual accountability, so that every single student is individually accountable as well as collectively accountable so you can't have any passengers" (Wiliam, 2017, 0:10; emphasis in original).

Luckin et al. (2017) add that if there is "the wrong attitude, skills or set-up, a group task can result in an interaction that is one-sided or where a person dominates and imposes their view" (p.11). As educators thus, we should create the circumstances that make collaborative work easier and sustained. CPS should be structured well due to the various barriers that both students and even teachers may experience. Some features identified by Duplass (as cited in Farzaneh & Nejadansari, 2014) include:

- attention to the group's processing where students reflect on the way their team operated during the activity;
- evaluation where both the individual and the group are assessed; and
- teacher supervision who monitors the activity of the team and ensures that the students are not deviating too much from the assigned task. The teacher should also be able to answer questions that might be raised and guide students through the discussion.

2.3.5 Challenges of Collaborative Problem Solving

Potential challenges that students may experience whilst working on CPS tasks identified by OECD (2017a; 2017b) and Graesser, Kuo and Liao (2017) are:

- tasks might not be divided equitably or efficiently, resulting in students working on tasks for which they are not suited or do not like;
- having participants that may not contribute their fair part to the group, while others may prioritise their own goals over the group's goals;

- conflict may arise between group members, that may deter the development of creative solutions;
- participants might not co-ordinate tasks effectively and thus lead to a loss of time and decreased productivity.

Graesser et al. (2017) add that certain team members might waste time with irrelevant discussions and diffusing responsibility in completing tasks. Such aspects may result in poor "communication, unhappy and resentful team members, and an inefficient use of resources" (OECD, 2017b, p. 46).

According to Janis (1982), certain teams on the other hand try to reach consensus at any cost. This results in them engaging in a premature convergence or closure of discussion to suppress conflicts and any appraisal of alternatives with the result of "group think" (Janis, 1982, p.8). This tendency thus interferes with effective group decision making.

Other challenges reported by Luckin et al. (2017) are:

- the dominance of individually driven and assessed education systems;
- difficulties due to teachers' busy workloads and high-risk demands of their time and skills;
- teachers' scepticism about the benefits of CPS due to management and control issues;
- limited teacher training and confidence;
- teachers' difficulties in designing tasks that both stretch and support students;
- lack of students' CPS skills and uncertainty about their capacity to work together; and
- students' concerns about CPS due to it being risky and emotionally stressful if it results in disputes, persistent conflicts and public embarrassment (citing Jarvenoja et al.) and not liking to work with others.

2.3.6 Collaborative Problem Solving and Transversal Skills

Whilst supporting and stretching students in their CPS, various transversal skills will be enhanced. The National Science Teacher Association in the US (NSTA) states that the science classroom can offer a rich context for developing many of the 21st century skills such as learning and innovation skills, adaptability, complex communication/social skills, non-routine PS, self-management / self-development and systems thinking. These skills apart from preparing students to the future's workforce, also gives them the [transversal] life skills they need to succeed (NSTA, 2011). This seems to support White and Harrison's (2012) claim that "those with STEM qualifications have better job prospects and a wider choice of rewarding careers … [since] STEM qualifications are often valued for these transferrable skills" (p.2).

Locally, the National Employee Skills Survey Report (JobsPlus, NCfHE and Malta Enterprise, n.d.) notes that the National Reform Programme of Malta for 2016 is trying to ensure that education is responsive to the needs of the labour market. This recently published survey report identified the skills listed below as the most important. Note that the percentage values indicated are "based on all responses collected from employers" (p. 87) but may vary according to the size of the company (e.g. medium-sized company employers identified PS skills as the most important skills in their workforce at 82.8%). The skills in bold are those that I feel can be developed through CPS as part of science education:

78.7% - oral communication skills
78.6% - team-working skills
74.4% - English language skills
72.3% - customer handling skills
70.1% - problem solving skills
68.8% - ability to multi-task
68.4% - planning and organising skills.

This survey also reports that the lack of transversal skills seems to be considered by employers as a cause that is also limiting the proficiency of its employees. It notes that "[t]o some extent, this also means that proficiency is not necessarily linked to qualifications, as the skills required are of a generic rather than a specific nature" (JobsPlus, NCfHE and Malta Enterprise, n.d., p.95).

2.3.7 Assessment in Collaborative Problem Solving

Traditionally, assessment systems demanded that students attain the knowledge that the assessment systems prescribed (Leadbeater, 2016). However, ideally assessments should be designed to aid students acquire also the 21st century and transversal skills they need to succeed.

Silva et al. (2018) in their proposal of structuring PBL for the undergraduate management degree program cited Macdonald and Savin-Baden, and Woods. They identified various assessment techniques that could be implemented. Amongst these, techniques which would be appropriate for the assessment of Year 7 students' collaborative learning and CPS are:

- presentations (individual / group based),
- self-assessment, peer assessment, open group assessment, and/or teacher assessment,
- written assessments,
- a group's solution to the problem,
- concept maps of the knowledge acquired

(p. 166).

Whilst assessing CPS, the quality of the problem's solution is often used as a main criterion. Objectively assessing the group activities results however is different from assessing the individual learning within the collaborative learning setting (Graesser et al., 2017). On considering whether the collaborative solution is better than that obtained by a group of independent individuals, one ought to specify if the proper unit of analysis of the assessment is the group or the individual. A focus on the individual may be better for following the performance of the individual, giving feedback, and providing recommendations. A focus on the group however may be better to assess the more holistic emergence of the processes in the group as a whole (Theiner & O'Connor, 2010).

2.4 Students' Confidence

In Section 2.4 and Section 2.5, I shall be focusing on how success in science, PS and CPS may be influenced by various personal factors such as those related to confidence and attitudes.

Confidence in science is described as "the extent to which a student is confident and feels successful in science class" (Wang & Berlin, 2010, p. 7). According to Hattie and Yates (2014), through students' replies, as educators we "infer a level of confidence from [their] vocal expression and behavioural signs such as latency or speed of response ... we are tuned to pick up information from voice and behaviour" (p. 215). As teachers, we eventually use the feedback obtained from the displayed confidence and decide on how we are to proceed.

Hattie and Yates (2014) identify three levels in which confidence has been investigated:

- perceived competency,
- self-esteem, and
- self-efficacy.

These three levels involve beliefs about one's self-worth (Hattie & Yates, 2014).

2.4.1 Confidence through Perceived Competencies

Perceived competencies deal with how much one feels that s/he is good, competent, or clever about herself/himself or particular skills.

Various studies (Bolinger & Stanton, 2014; Naughton & Friesner, 2012; Porat, Blaub, & Barak, 2018) however show that students' perceived competencies are often not aligned with their actual competency indicators.

Younger children often overestimate what they can do (Schunk & DiBenedetto, 2016). As children develop, there will be a development of their information processing and they become better in weighing and combining sources of self-efficacy information, assessing the task needs and comparing them to their perceived abilities. Other variables that Schunk and Meece (2005) attribute to this decline in students' confidence include the family's capital, greater competition with peers, more norm-referenced grading, a decline in teacher attention to learner progress and school transitions.

2.4.2 Confidence through Self-Esteem

Self-esteem is one's beliefs about his/her own self-worth (Hattie & Yates, 2014). It is linked to various positive traits such as school achievement, motivation, and sociability. Various self-esteem theories state that if one tries to increase students' self-esteem, then things such as crime and teenage pregnancies would be alleviated (Hattie & Yates, 2014).

Gniewosz, Eccles and Noack (2015) note that the relationship between self-esteem and perceived competencies depends also on the values, beliefs, behaviours and feedback in one's life circles – not just that obtained from school. Hattie and Yates (2014) explain this by using an example where the family values academic performance, and the student has a low perceived competency. They state that then the student's self-esteem tends to suffer. If on the other hand, the family does not value academic performance and the student has a low perceived competency, then that student's self-esteem would not be affected (p.218).

This supports Baumeister, Campbell, Krueger, and Vohs (2003) who identified various cracks in the self-esteem theory. In their study, they concluded that

> most of the evidence suggests that self-esteem has no impact on subsequent academic achievement…. Some findings even point (again weakly) in the opposite direction, suggesting that high or artificially boosted self-esteem may detract from subsequent performance. (pp. 13-14)

2.4.3 Confidence through Self-efficacy

Self-efficacy is one's confidence level about being successful in a particular task. It is based on the self's actual judgement and depends on one's expectancy that s/he will cope with the task presented (Hattie & Yates, 2014). Self-efficacy influences achievement, motivation, learning and self-regulation, and it depends on the interactions between behaviours, personal factors, and environmental conditions (Bandura, 1997; Schunk, 2003) as will be discussed in the next section in more detail.

2.5 Self-efficacy

One's perceptions of his/her efficacy does not depend on "the number of skills [one has], but with what [s/he] believe[s] can do with what [one has] under a variety of circumstances" (Bandura, 1997, p. 37). A number "of personal, social and situational factors affect how [the] direct and socially mediated experiences are cognitively interpreted" (Bandura, 1997, p. 79).

Bandura claims that we operate within an "interdependent causal structure involving triadic reciprocal causation" (as cited in Bandura, 1997, pp. 6-7). This means that

- internal personal factors in the form of cognitive, affective and biological events,
- behaviour, and

- environmental events

function as interacting factors that affect one another directionally as shown in Figure 2.1.

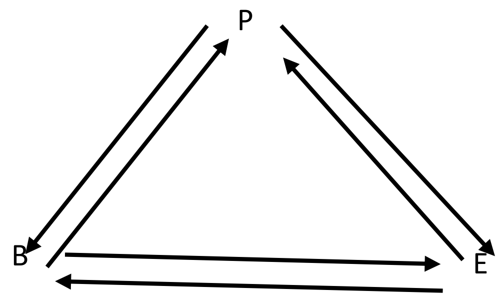


Figure 2.1: The relationships between the three determinants in Bandura's triadic reciprocal causation. P represents internal personal factors, B represents behaviour and E represents the external environment (Source: Bandura, 1997, p. 6)

These three determinants may not be of equal strength, and their influence varies under different circumstances and with possible time lags.

Based on the social cognitive theory, various social cognitive theorists (such as Bandura, 1997; Schunk, 2003; Schunk & Meece, 2005; Sheu, Lent, Miller, Penn, Cusick, & Truong, 2018) explain how self-efficacy beliefs are synthesised from the influence of four main sources as described below.

2.5.1 Source 1: Enactive Mastery Experiences

The learner successfully performs the target behaviour by "acquiring the cognitive, behavioural and self-regulatory tools for creating and executing effective courses of action to manage ever-changing life circumstances" (Bandura, 1997, p. 80). I believe that as teachers we should persuade our students that they can apply the rules and strategies of particular skills consistently and persistently. If one is to build a resilient sense of efficacy, s/he needs to experience overcoming obstacles through a persevering effort (Bandura, 1997).

2.5.2 Source 2: Vicarious Experiences

People often learn from observing models who demonstrate how particular tasks should be performed. This enables observers identify certain principles, rules or responses that result in successful performances (Bandura, 1997; Schunk & DiBenedetto, 2016).

Personal efficacies are altered when one's capabilities are compared to those of others. Zimmerman and Ringle (as cited in Bandura, 1997) wrote that when models express confidence in themselves when facing difficulties, a higher sense of efficacy and perseverance will be instilled in the observers that will be doubting themselves when encountering problems. On the other hand, negative effects tend to be more pronounced when skilled persons are observed to succeed with difficulties. The observers tend to re-evaluate the task and attribute it as being more difficult to what they initially assumed (Bandura, 1997).

2.5.3 Source 3: Verbal (or Social) Persuasion

Students can also develop their self-efficacy beliefs from social persuasions. These occur when one expresses his faith in the student's capabilities for example when saying "I know you can do it" (Bandura, 1997). Such verbal / social persuasions should however be within realistic bounds (Bandura, 1997), from credible people and believable as the persuaders must help in synthesising the student's beliefs that success is attainable (Schunk & DiBenedetto, 2016).

Attention should be given to the amount of positive feedback that as teachers we give our students. Pomerantz and Eaton (2000) found that as children grow older, they tend to interpret teachers' observable positive behaviour as a sign of incompetence on the child's side. They also noted that, when there is praise for successfully completing a difficult task, students may view it as an indication of self-competence, however if praise is given to an easy task, then that may be interpreted as an indication of incompetence.

2.5.4 Source 4: Physiological and Affective States

Self-efficacy may be altered from physiological signals such as sweating or heartbeat rate, and emotional states such as anxiety and stress (Bandura, 1997). Strong emotional reactions to a task give indications about an expected achievement or failure. Negative reactions, may lower self-efficacy and trigger additional stress and agitation so much that very often they will lead to a poor performance (Schunk & DiBenedetto, 2016).

2.5.5 Effects of Self-Efficacy on Problem Solving

Once students are presented with a task such as a problem, their mind performs an efficacy assessment (Hattie & Yates, 2014), the result of which has effects on their:

- choice of activities;
- behavioural settings;
- the effort and time they spend when there are obstacles and aversive experiences;
- learning;
- self-regulation;
- achievement

(Bandura, 1997; Schunk & DiBenedetto, 2016).

In positive efficacy assessments, students exhibit:

- a willingness to undertake the task such as the problem even when known to be difficult;
- mobilisation of available effortful resources to match the perceived difficulty level;
- a willingness to increase effortful resources in response to setbacks; and

- a shift in their attentional focus onto the demands of the task rather than dwell on personal or emotional reactions

(Hattie & Yates, 2014, p. 220).

Bandura suggests that when a person has a high level of self-efficacy, s/he approaches "difficult tasks as challenges to be mastered rather than as threats to be avoided" (1997, p. 39). Such students tend to work more diligently to master the task and thus create a productive classroom environment. On the other hand, those with low efficacy may attempt to avoid it, which eventually can disrupt the classroom (Schunk, 2003, p. 160).

High self-efficacy people will have more active coping efforts, which will eventually eliminate their inhibitions if they persist in subjectively threatening activities. Should high self-efficacy people experience failure, they would attribute it to insufficient effort thus supporting a "success orientation". This "outlook enhances [their] performance accomplishments, reduces stress, and lowers vulnerability to depression" (Bandura, 1997, p. 39).

Moores and Chang (2009) reported that when there are very high efficacy levels which lead to overconfidence, there will be a negative effect on the eventual student's performance. Thus they recommend the use of more frequent performance feedback. This enables students to recalibrate their self-efficacy towards a better self-assessment ability.

On the other hand, if a person avoids what s/he fears, or stops his/her coping efforts prematurely, then s/he will retain his/her self-debilitating expectations and defensive behaviours (Bandura, 1997).

2.5.6 Collective Self-Efficacy

As discussed in Section 2.3.1, students in the science classroom may need to work in teams in order to complete a task. Thus one should also consider the collective self-efficacy which can be defined as the perceived capabilities of the group, team, or larger social entity (Bandura, 1997). The collective efficacy thus is not the average of the individuals' self-efficacy but it refers to the group's perceived capabilities to achieve the same goal by working collaboratively.

2.6 Attitudes

Various definitions related to attitudes could be found (Di Martino & Zan, 2001; Kind, Jones & Bramby, 2007; Osborne et al., 2003; Qaisar, Dilshad & Butt, 2015). These definitions are based on either a:

- simple definition – i.e. describing whether there is the positive or negative emotional disposition associated with the subject such as those by McLeod (1992), and Osborne et al. (2003), or
- multidimensional definition - where the emotional disposition, the beliefs, and the behavioural tendency toward the subject are considered as found in di Martino and Zan (2001) and Kind, Jones and Barmby (2007).

For the purpose of this study, I will be using a multidimensional definition which based on Hart's (1989) definition for attitudes towards mathematics will be **the emotions (which may have positive or negative values), the beliefs and the students' behaviour towards science, problem solving and/or collaborative problem solving**. This decision was taken as:

1. attitudes are automatically formed from the beliefs a person holds (Kind et al., 2007),
2. research highlighted a mismatch between students' declared beliefs and their beliefs in practice (Di Martino & Zan, 2001), and
3. there is a statistically not significant correlation between attitudes based on the simple definition with achievement (Ma & Kishor, 1997).

2.6.1 *Attitudes to Science*

Various studies such as those by Azzopardi (2008), the IMechE (2012), Osborne et al. (2003) and Sjøberg and Schreiner (2010) have looked into the factors that affect students' attitudes to science. These attitudes are influenced by a combination of external and internal factors such as gender, utility value, future career aspirations, or topic perceived as being easy, difficult or fun. White and Harrison's review of the literature identified the following main factors as contributors to students' attitudes towards science:

- the student's parents and family;
- teachers, teachers' enthusiasm and teaching quality;
- direct contact with those working in the science field and work experience;
- careers professionals (who often fail to present the full range of science-related options due to not having a scientific background themselves); and
- socio-economic status

(2012, pp 3 – 6).

There is a mainly positive attitude among young people towards science (and technology), even though those coming from the richest countries i.e. Japan and Northern Europe tend to be somewhat undecided (Sjøberg and Schreiner, 2010, p.7). Various researchers (Kind et al., 2007; Osborne et al., 2003) however recommend that one ought not generalise about the term attitudes to science. This is because distinctions are to be made between various contexts such as attitudes towards science at school, "real" science, and/or science in society; and the attitude towards science is a construct which includes various perceptions. For example, the attitude towards school science may include perceptions about the science teacher, anxiety towards science, the science's value, self-esteem in science, motivation, enjoyment of science, peers', friends' and parents' attitudes towards science, the classroom environment, achievement and fear of failing (Osborne et al., 2003).

Local and international studies have shown that students' attitudes towards science drop and shift towards the negative side as students progress from the entry into middle school to the time they leave the secondary school (Azzopardi, 2008; Borg, 2013; Calabrese Barton, Kang, Tan, O'Neill, Bautista-Guerra, & Brecklin, 2013; Galea, 2008; Ing & Nylund-Gibson, 2017; IMechE, 2012; White & Harrison, 2012). The IMechE, found that following their primary school science experience, "[y]oung people, particularly boys, generally expect secondary school science to be exciting (eg 'explosive') but [then] often perceive it to be dry and unrelated to real life" (2010, p.2). When this happens, their engagement in science beyond the middle school years becomes progressively more difficult (Calabrese Barton et al., 2013) and such attitudes are often carried into adult life (IMechE, 2012; Oon & Subramaniam, 2018; Sjøberg & Schreiner, 2010).

The 2003 international Relevance Of Science Education (ROSE) project showed that the areas of students' least interest were those areas that were close to what is found within the students' science curricula (Sjøberg & Schreiner, 2010). This could be related to the IMechE (2010) finding that UK students fail to "see the real-world relevance of school science" (p. 16). Similarly, at the local level, Gatt and Azzopardi (2013) found that despite Year 8 students being aware of school science topic items that included the technical terms learnt in their science class, these students failed to recognise the role of science in issues involving personal decisions or having strong political connotations. The IMechE (2010) propose that a contributing factor to this negative school science attitude could be related to the "transmissive nature of current UK science education" (p. 16). They articulate that when teachers do not provide students with opportunities of direct engagement (such as those obtained through discussion, debates and autonomy), the students will be alienated and frustrated with the "passive learning, memorization, or the irrelevance of the content" (p.16) rather than be intellectually challenged. They continue that this will eventually hinder the students' interest in pursuing their studies in the STEM field.

On turning one's attention to future science career aspirations, the OECD found that the more developed countries students' perceptions, are that such professions are less attractive (OECD, 2006; 2008; Sjøberg & Schreiner, 2010).

Many students do not wish to have jobs involving science, and that science is perceived as not being relevant to the actualisation of their careers. Science is viewed to be useful to the minority who aspire to become scientists (Azzopardi, 2008; Gatt & Azzopardi, 2013; Osborne & Collins, 2001; Sjøberg & Schreiner, 2010) - a phenomenon that Jenkins and Nelson (2005) named as “important but not for me” (p. 41), in their article bearing this same title.

2.6.2 Attitudes to Problem Solving

Within the science lessons, students are often asked to solve problems. Such tasks have their own attitude attributes as well. Dostál (2015), states that the willingness to solve a problem is affected by:

- motivational and emotional factors, and
- the probability that the aim is achieved.

According to Nicholls, Cobb, Wood, Yackel, and Patashnick (1990), positive attitudes towards solving problems, are instigated by the individual’s ego-involved goals or task-involved goals. Dweck (2000) referred to these goals as performance goals and mastery goals respectively. Other researchers such as Sansone and Harackiewicz (2000) have identified the students’ extrinsic and intrinsic motivation respectively to explain these goals.

Ego-involved goals are those goals where the student tries to maximize evaluations related to her/his competence and minimise those that show lack of competence using phrases such as “Will I look smart?” or “Can I outperform others?”. Such students try to outperform their peers and tend to do those problems that they know can be mastered (Eccles & Wigfield, 2002, p. 115). Sansone and Harackiewicz (2000) found that extrinsically motivated students, engage in tasks for reasons other than solving the problem such as obtaining rewards.

Task-involved goals are those goals in which students focus their attention on mastering the problem and increasing their competence using phrases such as “How can I do this task?” or “What will I learn?” (Eccles & Wigfield, 2002, p.115). Students who show this type of intrinsic motivation tend to select challenging tasks, be more focused on their progress than on outperforming others, and exhibit learning that is driven by curiosity or interest (Sansone & Harackiewicz, 2000). Positive outcomes associated with high levels of trait like intrinsic motivation include the easing of positive emotional experiences, high academic achievement, the use of appropriate learning strategies, and having mastery-orientation to cope with failure (Eccles & Wigfield, 2002).

According to Sansone and Harackiewicz (2000), if there is a high initial intrinsic motivation in a task but is accompanied by extrinsic rewards that are not dependent on solving the task, important, tangible, expected, and lacking in information about students’ competence, then the extrinsic rewards are likely to reduce the subsequent intrinsic motivation for the task.
Huang, Chiu and Hong’s (2016) study on Taiwanese students from elementary up to high school reported that attitudes towards PS are positively correlated to the students’ perception of knowledge enrichment and thinking-skill enhancement.

Nicolaidou and Philippou (2003) found that attitudes (and self-efficacy) are positively related to students ’achievements in solving problems, and that the relation between attitudes, (self-efficacy) and PS is reciprocal.

2.6.3 Attitudes to Collaborative Problem Solving

Various studies show that students generally exhibit positive attitudes towards collaborative as compared to individual work (OECD, 2017b; Qaisar et al., 2015). This is manifested by a general positive feeling towards learning, an increased self-esteem and perseverance on the task when working collaboratively (Schmitz & Winskel, 2008).

Qaisar et al.’s (2015) collaborative group work study amongst middle school maths students in Pakistan, found that collaborative group work also improved their students' beliefs about learning. They concluded this, due to their students stating that:

- all students can learn mathematics (compared to 'not everyone can learn' in the individual setting),
- they are learning more, and
- they are able to ask their friends multiple times should they not understand something.

Qaisar et al. (2015) hypothesised that the improvement in attitude whilst solving problems collaboratively may be due to students feeling that they can depend on their peers for help, which also resulted in an increase in their students' confidence.

Within PISA 2015's CPS results, some attitudinal differences were noted to be linked to particular factors such as gender. OECD (2017b) found that "girls in almost every country and economy tend to value relationships more than boys" (p. 17; p.107). This was concluded due to having more girls for example stating that they are good listeners, enjoying seeing their classmates being successful or taking into account what others are interested in. Boys on the other hand tend to give more value to "the instrumental benefits of teamwork and how collaboration can help them work more effectively and efficiently" (OECD, 2017b, p.166) such as in making better decisions, and increasing their personal efficiency.

OECD (2017b) add that apart from gender differences, positive collaborative PS relationships in the science classroom were found to positively depend on the relationship students have with their parents, the amount of participation in collaborative classroom activities such as explaining one's idea in the science class, arguing about science questions, participating in class investigation debates and doing practical laboratory experiments, and the development of a sense of belonging within the class where there is no fear.

Other out-of-school activities that affect students' attitudes to collaborative work include playing video games and accessing the Internet, chatting or using social networks (OECD, 2017b). OECD (2017b), elaborate that meeting friends or talking to friends on the phone, and accessing the Internet, chat or social networks enables students to value both relationships and teamwork. They add that the playing of video games is also associated with a higher value of teamwork but a lowered value associated with relationships. In those video games were players in different locations play together within the same team towards the same goal enabled students to enrich their team work attitudes. The lowering of the value of relationships is associated to the students' interaction through virtual avatars where meaningful relationships with others are not necessarily fostered (OECD, 2017b).

Other findings from PISA 2015 are that:

- disadvantaged students value collaborative work more than advantaged students. The disadvantaged students, attributed this to improving efficiency, preferring teamwork to individual and to making better decisions.
- having students working in diverse social background groups tends to result in better collaboration skills and results

(OECD, 2017b).

Attitudes towards CPS may however also be negative. As discussed within Sections 2.3.4 and 2.3.5, CPS may have its challenges too and subsequently result in students with negative attitudes towards collaborative work due to poor collaborative work dynamics. Pauli, Mohiyeddini, Bray, Michie and Street's (2008) study identified the lack of group commitment, task disorganisation, storming group, and fractionated group as factors that eventually result in students' negative group experience when working within collaborative settings.

2.6.4 Attitude and Achievement

The students' perceptions of the importance and utility of learning can affect the students' behaviour (Wigfield, Cambria & Eccles, 2012), learning or what use will be made of what they learn (Wigfield, as cited in Schunk, 2003).

Eccles and Wigfield in their expectancy value theory (2002), postulate that one's beliefs in her/his competence and values is a main contributor to engagement, effort and actual achievement in academic tasks such as PS. This theory is based on the four components summarised in Table 2.2.

The expectancy value theory shows considerable similarities to Phan et al.'s (2017) "Framework of Achievement Best" (p. 667). This framework has indicators (shown in Table 2.2), related to one's own internal desire to strive for "optimum best" (p. 667) from one's "realistic best" (p. 667). The optimum best is one's maximum capabilities to accomplish a task such as problem solving, whilst the realistic best is one's functioning that may exhibit moderate capabilities due to no aspiration, motivation, and/or expenditure (Phan et al., 2017).

Table 2.2: Comparison of the Expectancy Value Theory components and Phan et al.'s (2017) Framework of Achievement Bests indicators.

Components of the Expectancy Value Theory summarised by Eccles and Wigfield (2002).	**Indicators of one's internal desire and power to strive for "optimum best" in scholarly outcomes within the Framework of Achievement Bests by Phan et al. (2017).**
• Attainment value - the personal importance of doing well in a task confirms or otherwise salient aspects of one's self-schema.	• The student's belief and conviction that her/his present knowledge and effort will result in positive outcomes.
• Intrinsic value - the enjoyment one gets from performing a task or the subjective interest one has in the subject.	• A person needing to experience, enjoy and achieve mastery in a subject matter.
• Utility value – the relation that the task has to current and future goals (e.g. career goals). Tasks can have a positive value even though the student is not interested in them e.g. undertaking a task to please parents, or to be with their friends.	• The student's need to consider his/her present competence and knowledge and to put forward a short-term goal for accomplishment.

• Cost - are the negative aspects of undertaking a task. These may include anxiety and fear of both failure and success, the amount of effort needed to complete the task and any lost opportunities that result from making one choice rather than another.	
	• Scaffolding and internal motives that are the "optimisers" of the student's best.

Phan et al. (2017) state that managing to achieve one's optimal best depends on a sequence of processes. These involve optimising:

- psychological mechanisms (such as self-efficacy),
- educational practices (such as appropriate instruction), and
- psychosocial factors (such as home environment).

These optimisers in turn trigger an internal process of persistence, effort, and effective functioning for students to try to achieve their assigned tasks such as PS ones.

2.7 Conclusion

This chapter has given an overview of the various studies that have been made internationally and locally about problems, PS and CPS, and the students' attitudes and self-efficacy in respect of these three aspects. Studies in Malta however have not explored the relationship between Year 7 students' attitudes and self-efficacy in relation to individual and collaborative PS. The study reported in this dissertation attempted to address this gap in the local context.

Chapter 3: Research Methodology

3.1 Introduction

The aims of this study were those of attempting to identify what the attitudes of a Year 7 class were in respect to science, PS and CPS; whether there was a relation between their attitudes, self-efficacy and capability of solving science problems; and whether there were any differences in solutions when these students solved the problems individually and collaboratively.

In this chapter, I will describe the participants, the research methodology and tools I used to answer my research questions. I will also discuss the ethical aspects that I considered and which guided me throughout this research.

3.2 The Research Context and Sample

This study was conducted in a mixed achievement level boys secondary church school in Malta and data were collected between 21st February, 2018 and 4th June, 2018. The point of entry of two thirds of these students was Year 1 of the school's feeder primary church school, whilst the other third have joined the school in Year 7 and would have come from different primary schools (church, state or independent).

This school and group of students was chosen as it was the only Year 7 group I had teaching duties with. This selection also facilitated the process of data collection. Students engaged in PS and CPS and completed their self-reflection sheets during my timetabled science 70 or 80 minute lessons. Questionnaire completion and group interviews took place during students' free lessons as scheduled with the school's administration team.

Thirteen out of my fourteen Year 7 students and parents/legal guardians consented to participate in this study.

3.3 Outline of how the Research Questions Were Answered

This section is divided into three sub-sections which will outline how each research question was answered.

3.3.1 First Research Question: "What are Year 7 students' attitudes to science, PS and CPS?"

I used non-anonymous questionnaires to gain insights into the students' attitudes and self-efficacy. These were then compared with my field notes, transcripts, analytic memos, students' self-reflections and the group interview data to triangulate the data and attempt to obtain a more holistic picture of the students' real attitudes rather than just their declared ones (Di Martino & Zan, 2001).

3.3.2 Second Research Question: "Is there a relation between Year 7 students' attitudes, self-efficacy and success in solving science based problems?"

Four students were selected (refer to Section 3.4.2) to answer this question. Their attitudes as outlined in Section 3.9.1, and as interpreted from my observations and students' behaviours were compared to their solutions and collaborative discourse they engaged in.

3.3.3 Third Research Question: "Are there differences in solutions produced when Year 7 students work individually and collaboratively?"

The solutions and discourse provided by the four students mentioned above and their team members were analysed. Attention was given to the various forms of products produced (on paper, hands on and oral explanation) and the process the student engaged in whilst solving the problem.

3.4 Research Strategy

My decision to embark on a mainly qualitative type of research was based on various studies that articulated that students' attitudes to science are not detached from their context and other influences that may determine their real meaning (Di Martino & Zan, 2001; Kind et al., 2007; Osborne et al., 2003). Osborne et al. (2003) recommended that one "need[s] to move away from general quantitative measures of attitude constructs and, instead, [needs] to explore the specific issue of students' attitudes to school science" (p. 1055).

Qualitative research was defined by Van Maanen (1979) as "an umbrella term covering an array of interpretive techniques which seek to describe, decode, translate, and otherwise come to terms with the meaning, not the frequency, of certain more or less naturally occurring phenomena in the social world" (p. 520). Thus in this type of research there is a focus on the study of people within their natural settings, where their standpoints are to be represented. This study's context and its participants' background had to be accounted for, as these may have influenced the interpretation of the results (Yin, 2011).

Through my product, I was not able to generalise my findings. I attempted to make up for this by my attempt in bringing up the richness that the data provided as suggested by Kind et al. (2007).

3.4.1 The Case Study

I employed a case study approach which Merriam and Tisdell (2016) defined "as an in - depth description and analysis of a bounded system" (p. 37). Cresswell's (2007) definition was based on the same principles, however it was further elaborated as:

> a qualitative approach in which the investigator explores a bounded system (a case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection involving **multiple sources of information** … and reports a case **description** and case-based themes" (p. 73; emphasis in original).

Case studies "portray, analyse and interpret the uniqueness of real individuals and situations through accessible accounts, catch the complexity and situatedness of behaviour, [and provide a] holistic treatment of phenomena" (Cohen, Manion & Morrison, 2018, p. 188). Features common to all case studies include that:

- they give a detailed, clear and chronological description of happenings pertinent to the case;
- they merge a description and an analysis of the happenings;
- they focus on individual participants, and try to understand their views of the happenings;
- they emphasise particular happenings that are relevant to the case;
- the researcher is integrally involved in the case; and
- the researcher tries to represent the richness of the case write-up

(Bell, 2010; Creswell, 2013; Hitchcock & Hughes as cited by Cohen et al., 2018).

Case studies have various advantages over other approaches. These include the capturing of features that are lost by larger-scale methods, being strong on reality, and providing visions into other similar circumstances and cases (Nisbet & Watt as cited in Cohen et al., 2018). Whilst the researcher would be merging her/his analysis of what took place within the description, a holistic picture would be obtained.

The case reported within this study was built on my only Year 7 class, and the phenomenon investigated was their attitudes to science, PS and CPS. I then restricted the boundary further and focused on four of the students found in this class (refer to Section 3.4.2). I looked into their discourse and physical encounters with the problems assigned and their classroom interactions within their team, class and myself as their teacher. Through these I attempted to understand the relation between their attitudes, PS and CPS, and whether there were any differences in solutions when they solved problems individually or collaboratively.

As noted by Cresswell (2007) and by Cohen et al. (2018), since various variables affect the case, more than one research tool and many sources of evidence would usually be required to capture the implications of the various variables. In this study, the main tools were a questionnaire, the problems, students' self-reflections, observations, and the group interviews. These different tools were used to achieve methodological triangulation and thus render the case study results more valid. Attention was also given to the inclusion of all the relevant results to give a holistic insight of the case and not just present those which appeared to be the more attractive. This feature was important to overcome the disadvantages of case-studies having the "interpretative paradigm" and being impressionistic due to overstating or understating particular events (Cohen et al., 2018, p. 380) as these may have resulted in the case not being thoroughly subjective. Further ways of how these obstacles were overcome, are discussed in Section 3.8.1.

3.4.2 Sampling to Select the Four Mini-Case Participants

According to Cresswell (2007), more than one case dilutes the overall analysis. However, as the data were being analysed in my attempt to answer the second and third research questions, I noted interesting differences among the students in the Year 7 class. I thus restricted my boundaries even further, and used Cresswell's (2007) recommendation that if a researcher has to include multiple cases within the case study, s/he "chooses no more than four or five cases" (p. 76). To capture the different realities in my class, sampling was based on students having (i) different attitude levels (refer to Section 3.9.1 and Appendix A), (ii) different achievement levels, and (iii) worked in different collaborative groups (refer to Appendix B). The four students were[1]:

1. Zane: an average to low achieving student who showed overall negative attitudes to science and problem solving, but expressed a positive attitude to collaborative work,
2. Alec: a very quiet and average achieving student who expressed moderately positive attitudes to science, PS and CPS,
3. Keith: a high achieving student with a rich science capital, highly expressed positive attitudes to science and PS but observed negative behavioural attitudes towards CPS, and
4. Elton: a high achieving student with positive attitudes to science, PS and CPS.

3.5 Authorisation and Ethical Considerations

Access to data was based on an informed consent (Howe & Moses, 1999) of all gate keepers, participants and their parents/legal guardians. They needed to

> weigh the risks and benefits associated with participating in a research project … And they can do this only if they are informed about and understand what their participation in the research involves. In this way, their autonomy is protected ... [and] refusal to participate on the part of research participants [and/or their parents/legal guardians] is binding (Howe and Moses, 1999, p. 24)

and could be done at any point of the research.

[1] Pseudonyms used.

Following ethical clearance from the Faculty Research Ethics Committee (FREC), the director of the Secretariat for Catholic Education, and the school's head teacher were informed about the nature of the study and the various ethical considerations that were going to be taken to safeguard the school and the students (Appendices C and D). Amongst other things, in a face-to-face meeting, I explained that students' anonymity could not be offered during the data collection phase, however confidentiality was promised.

Following their approval (Appendices E and F), the participants and their parents/legal guardians (due to participants being minors) were informed of the study by separate information sessions held during parents' day and a students' free lesson. These sessions were supported by information letters and consent/assent forms (Appendices G and H) in the English and the Maltese languages, and were attended by a member of the school's administration to ensure that all aspects discussed with the school's administration were followed and the students (and their parents/legal guardians) "feel no implicit pressure to participate" (Nolen & Putten, 2007, p. 403). Following these information sessions, thirteen out of the fourteen students in my class and their parents/legal guardians consented to the study. The student who was not a participant, took part in all the PS and CPS lessons. Data as regards to his attitudes, PS and CPS capabilities were not used in the compilation of this dissertation.

Another aspect that brought with it ethical dilemmas was my dual role – that of being a researcher and the teacher. Was I to observe carefully, reflect and inquire about my students or was I to bring a change within them? My sense of teacher responsibility urged me to prioritize my teacher's role, facilitate the students' learning, take choices and act immediately according to their exigencies. At all times I was in class, I had a legal and moral obligation to regard my students with compassion and create experiences that were educationally beneficial to all of them.

3.6 Preparing Students for the Data Collection Phase

At the start of the scholastic year, I noted that most of these students were accustomed to a teacher-centred, traditional and individualistic learning classroom. Unless targeted, this would have made it difficult for me to implement IBL, PS and CPS. Thus in the period October 2017 – February 2018, I worked upon creating a student-centred classroom characterized by active participation and valued collaborative work. I emphasized that I wanted to hear everybody's voice and used techniques such as no hands up, think-pair-share, and probed for long rather than short answers. These aspects were also important for my researcher's role as I needed to gauge better the students' attitudes, perceptions of self, and PS processes.

Another aspect that needed student preparation and reinforcement, was that of working collaboratively. Thus I used TES Professional's (2015) suggestions of successful group work rules where I discussed and emphasized that:

1. everyone should contribute and take turns to speak;
2. all ideas should be shared and considered;
3. ideas should be justified with reasons;
4. challenges are encouraged but students must disagree with the point, not the person; and
5. [everyone should] try to reach agreement, [and] don't just agree to differ.

(par. 10).

During this period, I also worked on establishing routines and expectations that took away the novelty of working within a group and solving science problems. This involved assigning several tasks requiring students to work collaboratively; my articulation of objectives that focused on both the academic and the social skills; my communication of problems always occurred in the same specific way (by handing out a printed version of the problem, reading slowly the problem that was projected on the board and using hand gestures to explain/emphasise features within the problem to make sure that the language would not be an obstacle to PS); having the students work individually for a few minutes prior to sharing their ideas within their team; the writing of the individual solution on an A4 sheet; the writing of a group solution on an A3 sheet; and enforcing this standard of work and behaviour.

I often used the terms “problem” and “challenge” so that these terms would not be new in the data collection phase. These problems/challenges were of various forms and required different types of products such as oral and/or paper and pencil solutions, the design of practical set-ups on paper, or conducting hands on investigations.

3.7 The Research Tools

3.7.1 The Attitudes Questionnaire

A closed structured attitudes questionnaire accompanied by a covering letter (Appendix I) was designed to capture data on the Year 7 class’ attitudes to science, PS and CPS. This tool enabled me to collect large amount of data on different items related to the students’ attitudes and self-efficacy in a relatively “quick and easy” (Cohen et al., 2018, p. 471) way at the start of the data collection phase. The questionnaire also provided structured and standardised data that were straightforward to analyse (Cohen et al., 2018).

This questionnaire (Appendix I) was based on other attitudes questionnaires that were tested and developed by Farzaneh and Nejadansari (2014), Huang et al. (2016), Kind et al. (2007), Nicolaidou and Philippou (2003), and Tuan, Chin and Shieh (2005). Some items were adapted to Year 7’s level of comprehension and the study’s context. I’ve attempted to design questions which according to Cohen et al. (2018) were

> straightforwardly presented, comprehensible at first glance, concrete, specific, unambiguous and able to be answered ... [and assumed] that: (a) the respondents know the answers and have an opinion; (b) the demand

> and effort placed upon them [students] are not too great; (c) their recollection and memory are reliable (p. 475).

The three main investigated attitudes were made up of 54 items classified under nine constructs as depicted in Table 3.1.

Table 3.1: Questionnaire attitude construct and items reference

	Number of items	Attitude Construct	Items references
Attitude to Science	29	Attitudes to school science	S01 – S05
		The students' self-concept of school science	S06 – S13
		Attitudes to school science practical work	S14 – S17
		Attitudes to science outside school	S18 – S22
		Attitudes to future science aspirations	S23 – S25, S29
		Attitudes regarding the role of science in society.	S26 – S28
Attitude to PS	13	Attitude to PS	PS01, PS02, PS04, PS07-PS09, PS12, PS13
		Self-concept and self-efficacy to science PS	PS03, PS05, PS06, PS10, PS11
Attitude to collaborative work	12	Attitude to collaborative work	CW01 – CW12

All items within the questionnaire (Appendix I) were closed questions requiring the use of a five-point Likert Scale for the replies. I've also attempted to use an easy and attractive format by the use of a Year 7 student friendly font (Andika Size 11), and the inclusion of the five coloured emoji  next to each statement to indicate whether the students strongly agreed, agreed, were neutral, disagreed, or strongly disagreed respectively. I have also used alternate shaded lines to ensure that the students linked the statement with its appropriate set of emoji.

3.7.2 The Problems

Four draft problems (Appendix J) based on the Year 7 2017-2018 syllabus (Directorate for Learning and Assessment Programmes [DLAP], 2018a) were designed by myself. Following their piloting and a discussion with a PS education expert (refer to Section 3.8.1.2), these were updated to the ones shown in Appendix K.

It should be noted that the data collected from the first assigned PS task (Appendix K - PS 00) was ignored due to the students behaving in a very unusual way due to the presence of the audio recorder. Thus another problem was designed and is found in Appendix K – PS 01.

The problems had different aims which ranged from preparing students for upcoming lessons, to the introduction of new concepts and the revision of concepts (Appendix L). All problems were goal, non-routine and ill-structured problem types. Variations within their types included being open/closed, numeric/non-numeric, written/hands-on as summarised in Appendix L.

3.7.3 The Lessons

3.7.3.1 Lessons Preparations

Prior to the arrival of students in class, each of the four groups' stations had a switched on audio recorder and three/four self-reflection sheets. Apparatus and materials required for PS 02 and PS 03 (refer to Appendix K) were also prepared on each of the stations.

3.7.3.2 Lessons Format

At the start of the lessons, the students were told they will be recorded and they could opt out of the study. They were also asked to say their name within the audio recorder to aid in voice recognition in the data analysis phase.

The same format as that described in the routines established in the phase prior to data collection was used (refer to Section 3.6). Students were also asked to complete their self-reflection sheets at intervals as described in Section 3.7.4. All lessons were concluded by having one/more members of the group explain the way the group solved the problem.

3.7.3.3 Teacher's and Participant-observer's Roles during the Lessons

As elaborated within the ethical considerations section (Section 3.5), I had a dual role during the study where my principal focus whilst students were in class was that of facilitating the students' learning. Thus following the lessons' introductions and assignment of the PS tasks, I walked around the students and as required I provided encouragement, redirected behaviour, prompted students to think about the problem and connect to their previous knowledge, and challenged groups with more thought-provoking prompts whenever there was a group who would have completed the tasks in a much shorter time than the other three. There were times when I asked probing questions to direct students to delve deeper in the topic in focus, and when students asked me questions, I replied with new questions rather than gave them an answer.

Through my researcher's role, I was also a participant observer in the lessons were as suggested by Watts (2011) I attempted to be non-obtrusive. She noted that participant observations have the potential of "uncovering the dynamics of relationships and behaviours in social settings and for making explicit the unspoken rules and values of social interaction" (Watts, 2011, p. 302). Cohen et al. (2018) cited various other theorists about what participant observation enables researchers to do. These include:

- observing behaviours and events that might not be specified within other forms of data collection (citing Kawulich);
- getting a feel of the situation and finding out about exchanges and relations (citing Schensul et al.);
- sensitizing and familiarizing the researcher to the context (citing Bernard); and
- enabling the gathering of rich descriptions of the "backstage culture" (citing DeMunck and Sobo).

During the lessons, as I walked around the student groups, I tried to absorb what was happening and keep mental notes. Very few observational and field notes were taken. Since I was aware of the importance of these notes, "not just for accuracy but also to ensure that data were not lost due to my failure to remember [them]" (Watts, 2011, p. 309), I wrote my observational and field notes immediately after the CPS lessons. Further field notes were taken during the respective breaks and in the evenings whilst listening to the lessons' audio recordings to aid in remembering all the lesson's events.

Within my field notes I wrote descriptive and reflective notes, made up of items such as my experiences, hunches, ideas about what the various observations might mean, why certain events happened/did not happen and so on. Cohen et al. (2018), noted that "it may not be immediately clear what valuable information is within such data, as it will often contain intermingled issues, but it cannot be collected retrospectively, so capturing it as work progresses is important" (p. 466).

3.7.4 Students' Self-reflection Sheets

Students' self-assessment is one of the important learning tools that aids students identify their knowledge/skills, identify where they are to focus their attention in learning, put realistic goals, track their own progress, helps them remain involved and motivated, and encourages them to be responsible of their learning (Stanford University, n.d.). I also believed that such assessments could help me gauge the students' feelings, attitudes and behaviours during the different phases of the lesson. Thus I designed a self-reflection sheet with prompts (Appendix M) which students were asked to complete in stages. These were:

Questions A – B: after assigning and reading the problem;

Questions C – D: at the end of the individual PS phase; and

Questions E – O: at the end of the lesson.

3.7.5 Group Interview

All students participated in one of three group interviews that were held at the end of the data collection phase. Each group was composed of four or five students and did not depend on the groups formed for the CPS tasks.

The interview was semi-structured, and its schedule with my introduction, questions and tentative prompts is attached in Appendix N. The areas tackled focused upon students' feelings about science, school science and PS, value of PS and CPS, and their personal strengths and weaknesses in relation to PS. As suggested by Cohen et al. (2018), it was "sufficiently open-ended to enable the contents to be re-ordered, digressions and expansions made, new avenues to be included and further probing to be undertaken" (p. 313).

I opted for small group interviews as I believed that they would lead to discussions that were in the same spirit of CPS where it was central that students took an active role within their learning experience. According to Cohen et al. (2018), group interviews are also more advantageous compared to single ones due to being more "time-efficient and generate a wider range of responses" (p. 527) where the different participants can either complement each other's replies and thus create a more complete and reliable record, or they can provide alternate opinions of the item discussed. The analysis of students' attitudes and self-efficacy could also be better perceived by group interviews rather than individual ones as they enable researchers find how the students "support, influence, complement and disagree with each other, and the relationships between them" (Cohen et al., 2018, p. 527).

Group interviews have been criticised over their risk of not bringing out personal data that depended on the group's dynamics, and the possibility of achieving group think where participants may not voice their personal ideas which might be unlike the rest of the group (Watts and Ebbutt as cited in Cohen et al., 2018). I attempted to overcome these challenges by having a relatively small group of students (of four or five) per interview, directing questions to named students who were taking a more passive role, and directly calming students who were trying to dominate the conversations.

3.8 Validity and Reliability

According to Cohen et al. (2018), "threats to validity and reliability can never be erased completely; rather the effects of these threats can be attenuated by attention to validity and reliability throughout the research" (p. 245).

3.8.1 Validity

Validity in research entails various aspects related to the accuracy and the correctness of findings. It is not a fixed nor a universal concept, but it is a construct that is grounded in the processes and intentions of the project (Winter, 2000). To achieve validity within one's study, aspects which range from instruments measuring what they intend, purport or claim to measure (Cohen et al., 2018), to the account written representing those features and aspects that they are meant to describe, explain or theorise (Winter, 2000) are to guide the researcher.

Maxwell (1992), emphasised the importance that the qualitative researcher understands what is being researched, and uncovers other people's perspectives. He added that the study needs to ensure that the exposed meanings are the same as those exhibited. In order to achieve this, I used methodological triangulation; piloted the questionnaire and the problems (refer to Sections 3.8.1.1 and 3.8.1.2); asked a Maltese-English language expert to check translations from Maltese to the English language; situated the data collected within the social aspect, and saturated them by considering the various students' behaviours and discourses that were exchanged. I focused on both the processes and the outcomes (rather than just the latter).

In order to present data from the students' perspectives, I also attempted to get detached from my students and the events that occurred, whilst the data were being thoroughly analysed. The thorough analysis was thus done in the scholastic year following the one in which the data were collected where I also ensured that I did not teach the same students at Year 8.

As suggested by Onwuegbuzie and Leech (2007), I used an inductive analytic approach where I attempted to follow where the data were leading rather than led them myself. During data analysis, I made comparisons between my findings/interpretations and literature. As also suggested by Onwuegbuzie and Leech (2007) I avoided attributing causality when it did not exist, and used the group interview to check the meaning of those aspects that were outliers, to assess whether they could provide an understanding to the phenomena studied.

3.8.1.1 Triangulation

I used methodological triangulation to attempt achieving internal validity. This was important as I wanted to represent the phenomenon in a fair and full way. The different and contrasting tools used were a non-anonymous questionnaire, four problems, four lessons, the students' self-reflections, observations, and the group interviews which were discussed in Section 3.7. When such contrasting methods provide converging data, qualitative researchers could increase their confidence about their findings (Cohen et al., 2018).

3.8.1.2 Piloting

Pilot studies "can be useful to judge the effects of a piece of research on participants" (Oliver as cited in Cohen et al., 2018, p. 136). I have thus piloted the questionnaire and the draft problems with a Year 7 average achievement student who did not participate in the study. This stage, together with the discussion of the problems with a Science PS education expert enabled me to check the technical matters of these tools such as timing, clarity of statements and problems, layout and appearance, and possible ambiguities.

Following the observations made whilst the student was working, and the feedback obtained from both the student and the Science PS expert, updates within the questionnaire and the problems were made.

3.8.2 Reliability

"*Reliability* is the extent to which a test or procedure produces similar results under constant conditions on all occasions" (Bell, 2010, p.119; emphasis in original) which eventually can result in generalisations. However, in studies such as case studies in the educational context, it is difficult to obtain results which can be replicated. In order to make up for this, I attempted to bring up the richness that the data provided (Kind et al., 2007).

Within the data collection phase, I used triangulation to corroborate the results and attempt to ensure that particular aspects I was observing were supported by the different methods. Another aspect used was that whilst the students were completing their questionnaire, I emphasised and ensured that students were completing them on an individual basis, and I also observed the way they worked.

On noting that a particular student completed the last items in an unrealistically short time and attributed a neutral value to these items, I decided to ignore this set of data for this student.

3.9 Data Analysis

3.9.1 Data from the Questionnaire

The raw questionnaire data for each student were inputted in a spreadsheet. A score from 1 (Strongly Agree) to 5 (Strongly Disagree) was assigned to all the students' replies. The number of students who replied in each of the five possible ways (Strongly Agree – Strongly Disagree) was counted for each item asked.

Reverse scoring was then included for questions S05, S06, S07, S11, S12, S13, PS04, PS05, PS10 since these items included a negative attitude item. The scores obtained were then used to calculate a mean positive attitude score for each attitude construct per student (Appendix A), where a mean score close to 3 represented a "neutral" position.

These questionnaire results were compared with the rest of the data to obtain a holistic picture of the class' and the students' attitudes.

3.9.2 Data from the Lessons and the Group Interviews

All the lessons' and group interviews' audio recordings were transcribed word-for-word and in the actual language used (mainly English but some students preferred the use of Maltese). Everything that was said even if it was not part of a complete sentence was written. A translation into English was only made of those extracts that appear in this write up. These extracts were verified by a Maltese-English language expert to ensure that they were faithful to what the student said.

The transcripts together with the student self-reflection sheets and personal analytic memos were coded. Saldaña (2009) described this initial coding as a "transitional process between data collection and [the] more extensive data analysis" (p. 4). These codes were further analysed and data were re-coded to identify patterns and themes for analysis and discussion of results as will be discussed in Section 3.9.3.

During the coding, re-coding and analysis phase of the transcripts, various parts of the lesson recordings were listened to several times to analyse all the processes that the students were engaged in whilst solving the problems. This was particularly laborious in PS 02 and PS 03 which entailed hands-on activities, and I had to rely on my field notes and audio recordings since no visuals of the PS process were collected.

3.9.3 The Inductive Analysis

A preliminary analysis was being conducted whilst the field notes were being written as these included reflective notes as well. The more rigorous data analysis however was done in the scholastic year following the collection of the data, as I wanted to ensure detachment from the cases. This analysis entailed seeing and recognising the important moments, coding the moments (accompanied by memos), and interpreting them by attaching a meaning to the important moments (Boyatzis, 1988). These three phases were repeated, and the codes were classified and re-organised in a smaller number of themes.

In answering the second and third research questions, each lesson transcript was re-analysed together with the attitudinal and focus group data and the respective students' solutions, field notes, and students' self-reflection sheets. Further analytic notes on how each group of students in that particular lesson was working was compiled.

3.10 Conclusion

This chapter focused on the strategies employed within this study, a review of the techniques and tools used to generate and collect data, and an overview of the way the data collected were analysed. The results and their analysis will be presented and discussed in the chapters 4 and 5.

Chapter 4: Students' Attitudes towards Science, Problem Solving and Collaborative Problem Solving

4.1: Introduction

This chapter will present and analyse the data collected from the thirteen male Year 7 students to answer my first research question "What are Year 7 students' attitudes to science, PS and CPS?".

The thirteen students' non-anonymous questionnaires (refer to Appendix I) were used to gain insights into their attitudes and self-efficacy. These were then compared with my personal lesson field notes, lesson transcripts and analytic memos, students' self-reflections (refer to Appendix M) and the group interview data.

All students' names referred to in this chapter are pseudonyms. The four PS lessons whose data were analysed are referred to as shown in Table 4.1.

Table 4.1: Problem Solving Lesson Reference Code

Lesson Reference Code	Name of Problem Solving Lesson
PS 01	The Total Number of Plants
PS 02	The Hidden Buzzer Challenge
PS 03	The Heating Water Challenge
PS 04	Monuments, Acid Rain and Acidic Bird Droppings

4.2: The Students' Attitudes to Science

The items of part 1 of the questionnaire (students' attitudes to science) were analysed along different contexts. Kind et al. (2007) recommended doing so as the term "science attitudes" is a too general term. The aspects that I focused upon were:

- Attitudes to school science
- The students' self-concept of school science
- Attitudes to school science practical work
- Attitudes to science outside school
- Attitudes to future science aspirations
- Attitudes regarding the role of science in society.

4.2.1: Attitudes to School Science

Data for the replies to the questionnaire's items S01 – S05, and their science positive attitude mean are presented in Table 4.2.

Table 4.2: Students' questionnaire replies on their attitudes towards school science

Question	Number of Respondents (n=13)						Science Positive Attitude Mean* following reverse coding of question S05
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	No Reply	
S01: We learn interesting things in science lessons.	9	2	1	0	1	0	1.62
S02: I look forward to my science lessons.	7	3	1	2	0	0	1.85
S03: Science lessons are exciting.	6	3	1	1	1	1	2.00
S04: I would like to do more science at school.	4	4	3	0	2	0	2.38
S05: Science is boring.	1	1	1	3	7	0	1.92

* where Strongly Agree = 1, Agree = 2, Neutral = 3, Disagree = 4, Strongly Disagree = 5.

Following the reverse coding of question S05 on the five point Likert Scale in order to find the mean replies to positive science attitudes, all questionnaire items (S01 – S05) were found to have a value less than the neutral three. This exposed the group's positive attitude towards science. Various students further confirmed this attitude at different instances during the data collection phase such as:

> "Keith: I really l take science so seriously
> Elton: and so do I. For me I take it seriously as well" (Lesson PS 01)

> "I love S[c]ience" (Yan, Self-Reflection PS 03)

> "science is amazing" (David, Self-Reflection PS 03)

> "Sebbie: I like it [science] a lot. And I really enjoy it especially when we have hands-on experiments and eee (..) I really like it. Basically I enjoyed every subject we had.
> SBS: Every topic?
> Sebbie: Yes every topic. I like science I guess." (Focus Group 3)

These data were similar to the findings of other researchers such as Borg (2013), Galea (2008) and Ing and Nylund-Gibson's (2017) who suggested that most students entering the secondary school years exhibit positive attitudes towards school science.

4.2.2: The Students' Self-concept related to School Science

Data for the replies to questionnaire items S06 – S13, and their positive self-concept mean are presented in Table 4.3.

Table 4.3 suggests that most students also had a positive school science self-concept as noted by the high disagreeing attribute given to the negative connotation items S11 "I feel helpless when doing science", S12 "I believe I have a lot of weaknesses in science, and S13 "Compared to other students, I am a weak student in science”. The mean positive self-concept attitude results ranged between 1.92 and 2.54.

Table 4.3: Students’ questionnaire replies on their school science self-concept

Question	Number of Respondents (n=13)						Positive Science Self-concept Mean* following reverse coding of questions S06, S07, S11, S12, S13
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	No Reply	
S06: I find science difficult.	1	1	2	6	2	1	2.42
S07: I am just not good at Science.	1	2	3	4	3	0	2.54
S08: I get good marks in Science.	6	2	3	1	1	0	2.15
S09: I learn Science quickly.	2	6	3	0	2	0	2.54
S10: Science is one of my best subjects.	5	4	2	0	2	0	2.23
S11: I feel helpless when doing Science.	1	0	4	0	8	0	1.92
S12: I believe that I have a lot of weaknesses in Science.	1	1	1	7	3	0	2.23
S13: Compared to other students, I am a weak student in Science.	1	1	3	5	3	0	2.38

* where Strongly Agree = 1, Agree = 2, Neutral = 3, Disagree = 4, Strongly Disagree = 5.

This positive self-concept was also noted in a number of self-reflection sheets where at times students even wrote that they had “no weaknesses” (Keith, self-reflection PS 04; Marvin, self-reflection PS 04; Yan, self-reflection PS 03; self-reflection PS 04) or particular students such as Elton did not admit “that others could have better solutions than him” (Personal field notes, PS 01).

Students’ self-concept and self-esteem seemed to be influenced by various factors as suggested by social cognitive theorists (such as Bandura, 1997; Schunk, 2003; Schunk & Meece, 2005; Sheu et al., 2018). This was for example noted in Yan who obtained weak positive attitude scores in respect to practical work (2.5), outside school science (2.6) and future career aspirations (2.5) in his initial questionnaire.

However, following my positive feedback on discussing a good idea in the hands-on task PS 03, his self-esteem and future aspirations improved due to having the confirmatory experience and verbal persuasion factors stimulated. At various instances during the PS 03 task, he told me:

> "Miss I am getting better at science",
> "How bright I am Miss!", and
> "I am going to be a scientist when I grow up" (Yan, Lesson PS 03)

4.2.3: Attitudes to School Science Practical Work

Data for the replies to items S14 – S17 on students' attitudes towards school science practical work are shown in Figure 4.1.

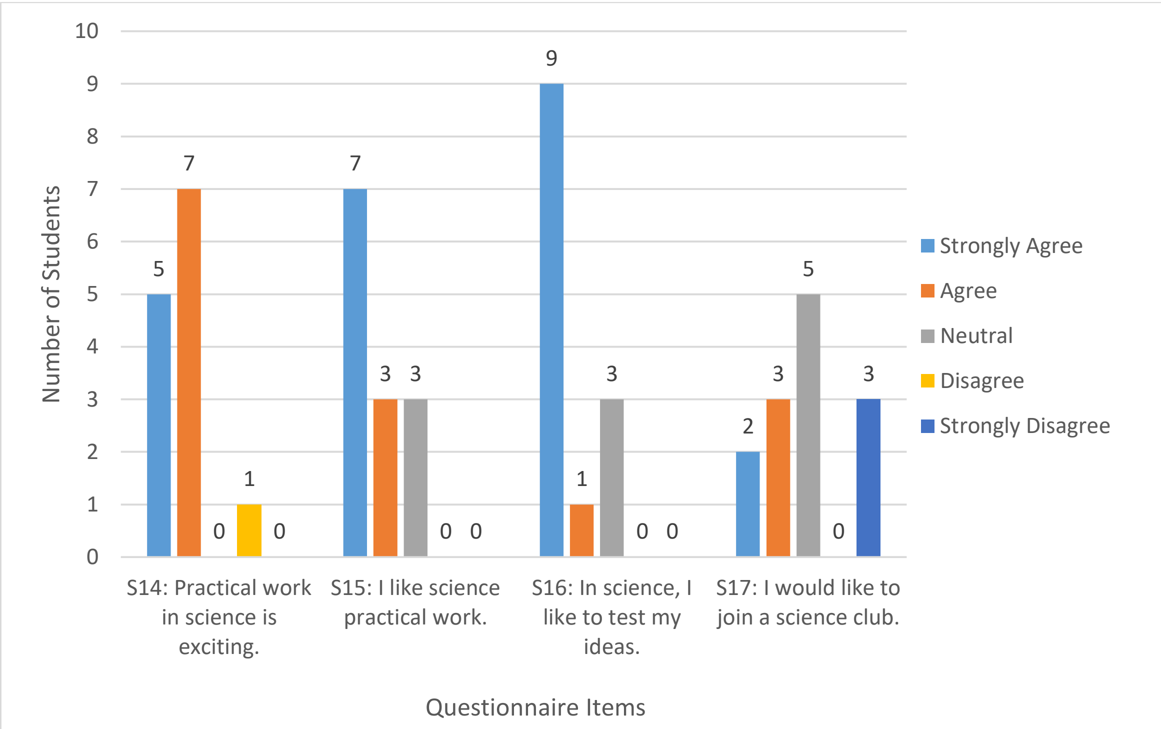


Figure 4.1: Students' attitudes towards school science practical work

Students' attitudes towards practical work were positive for the first three items (S14, S15, S16). From thirteen students, twelve students found it exciting and ten stated that they liked it and liked testing their ideas. This was also confirmed several times during the hands-on problems solving tasks PS 02 and PS 03 such as:

> “Elton: <in a very pleased tone> This is cool. So cool” (Lesson PS 03)

> “Sebbie: Miss this was one of the funnest experiments, erm what do you call it? erm activities (..) as much as the hidden buzzer miss” (Lesson PS 03)

> "I like this. This is nice and fun". (Marvin, Self-Reflection PS 02)

> “The hands-on is what I like [from our science at school]” (Sean, Focus Group 3)

Abrahams’ (2009) attitudes to practicals study amongst secondary school UK students noted that most of the Year 7 students’ positive attitude at the start of the scholastic year were for “absolute” (p. 2342) reasons, due to students perceiving practicals as being fun, exciting and so on. This was attributed to the novelty in handling apparatus and other materials that are typically associated with a science lab. Abrahams (2009) added that as students progress within Year 7 and their secondary school years, the reasons for the positive attitudes change to more “relative” (p. 2342) ones. He found that “it was not the case that the pupils actually like practical work per se … but merely preferred it to most alternative methods of teaching science” (p. 2342). These relative reasons could also be attributed to my group of year 7 students who prior to the start of the science lesson often asked me if they were going to have practical activities in that lesson, and expressed disappointment whenever my reply was negative.

I also noted that when students were allowed to design their own set-ups, it gave them a sense of pride and a feel good factor as noted in:

> Group 3 wishes to do further tasks similar to this. They made an emphasis that they managed to make it look cool. This aspect gave the group a sense of more ownership and a feel good factor. (Personal analytic memo, PS 03)

Students attributed a lot of value to solving and planning problems in practical ways. They considered practicals to be the basis of their science education. For example, whilst planning and solving the pen and paper task PS 04, Jim emphasised with his friends that, “this is doing science” (Lesson PS 04).

Other students appreciated that they “had a lot [of] chances to speak” (Elton, Focus Group 3). Thus these PS tasks apart from giving students an element of “fun”, were also a means of greater personal autonomy and decision-making. The students were given a “leading role in the teaching and learning process” (Farrugia, 2015, p. 288). Osborne & Collins’ focus group study (2001) revealed that this was an important positive attitude contributor factor amongst 16 year olds who pursued studies in the three sciences. Tasks would have more significance if students had more power over the planning and the carrying out of their work (Rudduck et al., as cited in Osborne & Collins, 2001).

It should be noted that the mean positive attitude value as regards to wanting to join a science club (S17) was very close to neutral (2.92). This result could be attributed to the various clubs that the school held which targeted a very wide range of students’ interests such as technology, art, crafts, various sports, chess, drama, film, cooking, and library. Thus joining a science club during school break could probably have been perceived as being in competition with the other clubs and eventually hindered that student from attending the other club/s.

4.2.4: Attitudes to Science Outside School

Questionnaire items S18 – S22 investigated the students’ expressed outside school science attitudes. The data collected and positive attitude means are presented in Table 4.4.

Table 4.4 shows that even though there are overall positive attitudes, these are not as strong as those towards their school science / practical ones. A strong positive result was only obtained for item S20. This could possibly be related to Gatt and Azzopardi’s (2013) conclusion that “any science awareness among early secondary students in Malta is limited to the students’ exposure to science at school and that efforts need to be made to help students learn about the role of science in society” (p.9). My data’s results could thus have been obtained due to the limited opportunities that these students had to experience outside school science.

Table 4.4: Students' questionnaire replies on their attitudes towards science outside school

Question	Number of Respondents (n=13)						Positive Outside School Science Attitudes mean*
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	No Reply	
S18: I like watching science programmes on TV.	5	3	1	2	2	0	2.46
S19: I like to visit science museums.	8	0	1	2	2	0	2.23
S20: I would like to do more science activities outside school.	6	5	1	0	1	0	1.85
S21: I like reading science magazines and books.	3	4	2	2	2	0	2.69
S22: It is exciting to learn about new things happening in science.	7	3	2	0	0	1	1.58

* where Strongly Agree = 1, Agree = 2, Neutral = 3, Disagree = 4, Strongly Disagree = 5.

Table 4.4 also indicates that only seven out of 13 students enjoyed reading science magazines and books. This could probably be attributed to the students' attitude towards reading rather than to the actual content of what is being read.

4.2.5: Attitudes to Future Science Aspirations

Questionnaire data related to the students' future science aspirations (S23 – S25, S29) are shown in Figure 4.2.

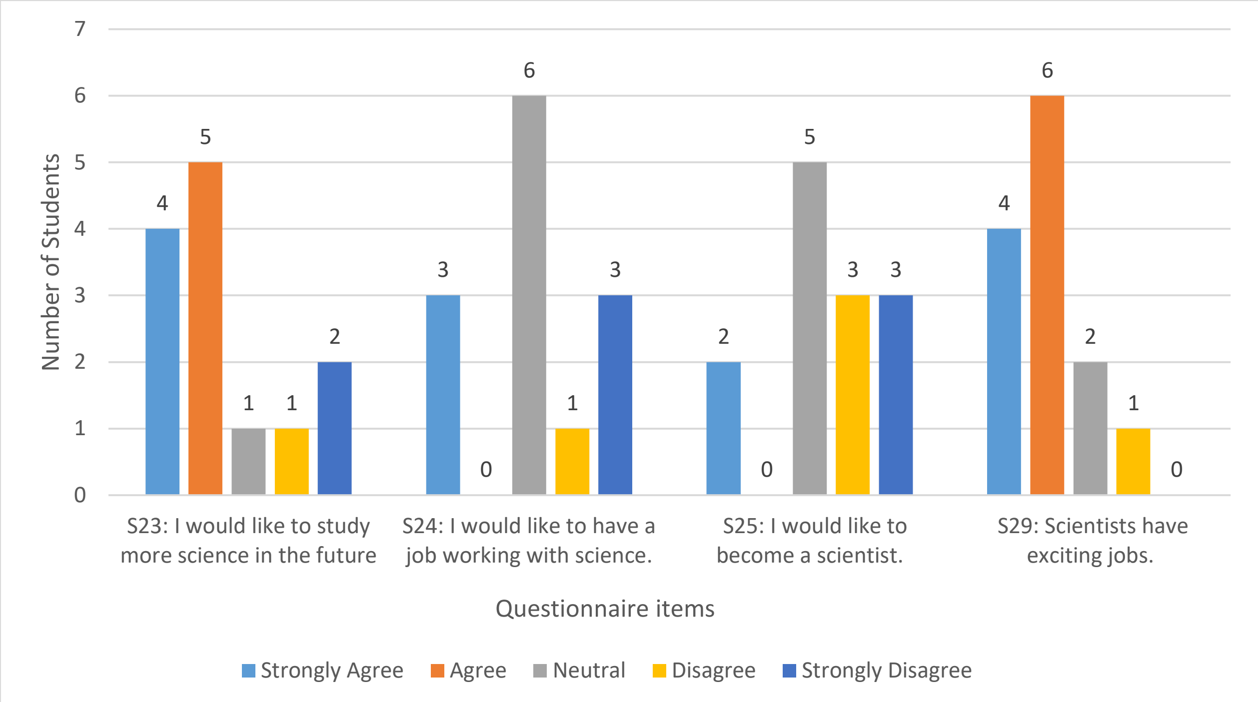


Figure 4.2: Students' attitudes towards future science aspirations

These set of questions revealed that even though nine students would like to study more science in the future and 10 students thought that scientists have exciting jobs, only three students stated they would like to have a job working with science or would like to become a scientist (two students). These results were similar to those obtained through the ROSE Project held in 2003 amongst 14–15 year-old students in industrialised societies (Sjøberg & Schreiner, 2010, p. 26). England's results gave evidence that even though students regarded science as interesting, relevant and important, few of them seemed to aspire to become scientists (Jenkins & Nelson, 2005). Azzopardi's (2008) local research amongst 14 -15 year olds revealed similar findings. Sjøberg and Schreiner (2007) concluded that unless students viewed the "personal relevance of science and technology in their own life, they would rather opt for one of the many other possible futures and careers that life in rich and developed" (p. 158) countries offer.

Another aspect that is to be considered is the students' perceptions of what working with science, the scientific disciplines and being a scientist is. Whilst students were completing their questionnaires, I noted that

> it seems that a number of students have poor perceptions of the various jobs that use science disciplines. This is happening as at one point Jim is asking whether architects and engineers are scientists, and Yan immediately replies that architects are definitely not scientists. On hearing Jim's question, Sean seems shocked when he realizes that he might need to continue studying science to become an architect or an engineer. (Personal field notes, 21st February, 2018)

However, certain students such as Elton had a much wider concept of what being a scientist entailed. He believed that the skills obtained through studying and practising science had wider implications than the traditional roles as shown in the excerpt:

Elton:	In my future I was hoping and am still hoping to become either a scientist
SBS:	Doing what?
Elton:	Erm like archaeology
SBS:	All right
Elton:	Or things like that, or else erm an architect.
SBS:	All right
Elton:	But I've been saying I want to become a scientist for a very long time.
SBS:	And what do you understand by "being a scientist"?
Elton:	By scientist, I not only understand about doing experiments. I also understand erm as being a scientist that it could be fun in certain circumstances and it also means that you have to work hard trying to discover different different things about this world.

(Focus Group 3)

4.2.6: Attitudes regarding the Role of Science in the Society

Questionnaire items S26 – S28's data regarding the students' attitudes regarding the role of science in society are shown in Table 4.5. These data also indicate that these Year 7 students held positive attitudes towards the role of science within society. This was similar to the results that England obtained in its 2003 ROSE project where “Students in England ... believe that science itself is important and brings more benefits than disadvantages” (Jenkins & Nelson, 2005, p. 55).

Table 4.5: Students’ questionnaire replies regarding their attitudes on the role of science in society

Question	Number of Respondents (n=13)						Positive Role of Science in Society Attitudes mean*
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	No Reply	
S26: Science and technology are important for society.	5	7	1	0	0	0	1.69
S27: Science and technology make our lives easier and more comfortable.	7	4	1	0	0	1	1.50
S28: The benefits of science are greater than the harmful effects.	2	7	4	0	0	0	2.15

* where Strongly Agree = 1, Agree = 2, Neutral = 3, Disagree = 4, Strongly Disagree = 5.

These results coupled with the results shown in Figure 4.2, further support Jenkins and Nelson’s (2005) view that science is “important but not for me” (p. 41) phenomenon. These results however do not tally with other countries’ results where their 14-15 year olds “see the more problematic sides of S[cience] & T[echnology]....[especially] among the youth of Nordic countries and Japan.” (Sjøberg & Schreiner, 2010, pp. 7 - 10).

4.3: The Students’ Attitudes to Solving Science Problems

This section will look into data related to the students’ attitudes towards solving problems and their self-concept and self-efficacy in solving science based problems.

4.3.1: Attitudes to Problem Solving

Table 4.6 exhibits an overview of the group's attitudes to PS.

Table 4.6: Students' questionnaire replies regarding their attitudes to PS

Question	Number of Respondents (n=13)						Positive PS Attitudes Mean* following reverse coding of question PS04
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	No Reply	
PS01: I like problem-solving.	4	5	1	1	2	0	2.38
PS02: I enjoy the difficulty of solving problems.	3	3	4	1	2	0	2.69
PS04: I do not feel sure about myself in problem-solving.	2	1	3	3	4	0	2.54
PS07: I usually try to solve problems using all available methods.	3	6	3	0	1	0	2.23
PS08: I usually try to stay calm and consider the next step when I come across a problem.	5	6	1	0	1	0	1.92
PS09: I usually try to think about the effect of using various methods before I take action to solve problems.	4	4	3	1	1	0	2.31
PS12: When I make a mistake, I try to find out why.	7	1	4	1	0	0	1.92
PS13: In science, I think that it is important to learn to solve problems.	6	4	2	1	0	0	1.85

* where Strongly Agree = 1, Agree = 2, Neutral = 3, Disagree = 4, Strongly Disagree = 5.

This group's general attitudes to problem solving were positive with mean scores below 2.69 for all items. This could be supported by the numerous "ok", "fine" and "good" replies that were completed in the self-reflection sheets to the prompt "My feelings when assigned the problem were" in all the four PS lessons analysed during this study. Other supporting quotes include:

> "I feel happy because I like maths and this is like a problem of maths". (Alec, Self-Reflection, PS 01)
>
> "David is once again showing positive feelings towards the problem and the work by stating that he feels 'very excited and interested' when he was assigned the problem." (Personal Analytic Memo, PS 02)
>
> "I wish to do similar exciting problems". (Sebbie, Self-Reflection PS 03)
>
> "My feelings when assigned the problem are that this is interesting. I want to learn more" (Marvin, Self-Reflection PS 04)

During the PS tasks, I noted that students' attitudes towards the problems assigned depended on the:

- type of problem assigned (such as whether it was hands-on, pen-paper, or numerical),
- topic that the problem was about, and
- problem's utility value and context viewed in.

For example, as regards to PS 02 and PS 03, I noted that Sean and Zane who in traditional lessons or pen and paper tasks were normally distracted and often not on task were this time very motivated, immediately attempting to solve the task and persistent in their work. On the other hand, it was also noted that Blake who within the questionnaire expressed positive attitudes to science and problem solving was scared and expressed negative emotions as soon as he entered the laboratory and viewed the materials related to "The Hidden Buzzer" and realised that the task was related to the topic of electricity.

Students' attitude was noted to vary according to the problem's utility value and context placed in/attributed to it. For example, Drew in PS 02 was very excited in "hiding it [his design] near the fire alarm to make it look like a real fire" or in PS 03 viewing his design as a way of "making tea in a new fashionable way". A number of students linked PS 01 to the mathematical context, and since they have high [or low] self-efficacies in this subject were very excited [or demotivated] by the challenge. In PS 04, Jim's actions and behaviours expressed a negative attitude towards this problem. He did not see its value as opposed to all others he worked upon. He believed that the effect would "take ages" to be observed and experienced difficulty in connecting with the value of its planning as monuments were not important to him.

Table 4.6 shows that only six out of thirteen students agreed with the statement that they enjoy the difficulty of solving problems. A particular student who considered this to be an important factor was Keith, who due to finding PS 04 not challenging enough commented in his self-reflection sheet that he wished that future problem solving tasks "will be harder" (Keith, Self-Reflection PS 04). Item PS02's data could be related to Osborne & Collins' (2001) finding that on comparing science and non-science 16-year olds "a significant factor in the generation of enthusiasm and interest in science among pupils in continuing science groups was personal challenge" (p.458). This contributing factor was not observed in their non-science 16-year olds.

As regards to the actual process of solving the problem, most students were observed to try to do their utmost in solving it. Various field notes and students' discourse were coded as "persistence" whilst students were solving their problems. For some students such as Alec, giving up was not an option. He believed that "a problem is something that you will always have an answer for... One time you will manage to find the answer" (Focus Group 3).

4.3.2: Self-Concept and Self-Efficacy in Science Problem Solving

Students' self-concept and self-efficacy in PS data are shown in Table 4.7. Table 4.7's positive PS self-efficacy mean data show that many of these students have positive self-efficacies. Various instances in the data collection phase have shown that this is also linked to the student's confidence in the subject matter and/or

Table 4.7: Students' questionnaire replies regarding their self-concept and self-efficacy to science PS

Question	Number of Respondents (n=13)						Positive Self-concept and Self-efficacy Mean* following reverse coding of questions PS 05, 10
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	No Reply	
PS 03: I can usually solve any science problem.	1	4	6	1	1	0	2.77
PS 05: When I start solving a science problem, I usually feel that I would not manage to give a solution.	2	0	4	5	2	0	2.62
PS 06: I usually can help my classmates, when they ask me for help in problem-solving.	5	6	1	0	1	0	1.92
PS 10: When science activities are too difficult, I give up or only do the easy parts.	1	2	0	3	5	0	2.38
PS 11: When I do not understand something in science, I find appropriate things that will help me.	2	8	3	0	0	0	2.08

* where Strongly Agree = 1, Agree = 2, Neutral = 3, Disagree = 4, Strongly Disagree = 5.

problem such as when leaving a blank space when asked to identify their weaknesses or:

> "Elton is showing a positive self-concept and confidence. As soon as task is assigned he is stating that he "already know[s] this" at 7.15 minutes, or "I tell you. Now I tell you" at 10.50 minutes .... Keith is exhibiting confidence as he feels that he "knows the place and how to estimate". As regards to the problem assigned he states "that I know a way to solve it"." (Analytic Memo, PS 01)

> "Keian feels proud that his friends' strengths were that "they had me and Blake" in the team." (Analytic Memo, PS 03)

> "At the start of the lesson I know what the effects of acidic substances on monuments is. My feelings are that it is going to be easy" (Keith, Self-Reflection PS 04)

The positive PS self-concept and self-efficacy data could be linked to more active PS coping efforts (Bandura, 1997) which were also observed in most students whilst solving the four PS tasks and the positive results obtained in PS attitudes items PS07, PS08, PS09, PS12, and PS13.

As regards to item PS03 however, only five students stated that they can solve any science problem, and another six students took a neutral stand. This could be attributed to the assignment of a number of challenging questions and pen and paper tasks in the phase prior to the data collection whose aim was that of stimulating a discussion in class and also helping students build their PS skills. These relatively more challenging tasks could have lowered students' self-efficacy as according to Bandura (1997), self-efficacy is partly determined by cognitive events.

4.4: Attitudes to Collaborative Work

Through the questionnaire's replies shown in Table 4.8 below, it was found that this Year 7 class held strong positive attitudes towards working collaboratively. All mean values (except for item CW02) were below 2.17.

Table 4.8: Students' questionnaire replies regarding their attitudes to collaborative work

Question	Number of Respondents (n=13)						Positive Attitude to Collaborative Work Mean*
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	No Reply**	
CW01: Practical work in science is good because I can work with my friends.	9	3	1	0	0	0	1.38
CW02: During science activities, I prefer to ask other people for the answer rather than think for myself.	2	2	3	2	4	0	3.31
CW03: I willingly participate in collaborative tasks.	6	1	3	1	1	1	2.17

CW04: When I work with other students I achieve more than when I work alone.	7	2	3	0	0	1	1.67
CW05: Collaborative learning can improve my feelings towards work.	4	6	1	1	0	1	1.92
CW06: Collaborative learning helps me to socialize more.	5	3	4	0	0	1	1.92
CW07: Collaborative learning improves class participation.	4	4	4	0	0	1	2.00
CW08: There is more creativity when working in groups.	6	4	1	1	0	1	1.75
CW09: Group activities make the learning experience easier.	7	2	3	0	0	1	1.67
CW10: I enjoy the lesson more when I work with other students.	5	4	3	0	0	1	1.83
CW11: My work is better organized when I am in a group.	5	2	3	2	0	1	2.17
CW12: I prefer that my teachers use more group activities / assignments.	6	2	4	0	0	1	1.83

* where Strongly Agree = 1, Agree = 2, Neutral = 3, Disagree = 4, Strongly Disagree = 5.

**A "No Reply" was attributed to Drew's items CW03 – CW12 since he was noted to have finished these last items in less than two minutes and attributed a "neutral" value to all of them.

An analysis of the PS self-reflection sheets replies, revealed numerous instances where students expressed improved emotions between the answers to the prompts "My feelings when working on my own...." and "My feelings when working within the group were .....". A non-exhaustive list of such an improvement is shown in Table 4.9.

Table 4.9: Students' feelings differences when working individually and collaboratively

Feelings whilst working individually	Feelings whilst working within the group	Reference
"How will I manage to do this?"	"OK this is working out"	Marvin, Self-Reflection PS 01
"troubled"	"confident"	Jim, Self-Reflection PS 02
"nervous because I never did this problem"	"happy because we are a good team"	Alec, Self-Reflection PS 02
"Fine"	"More concentrated than usual"	David, Self-Reflection PS 02
"anxious and thoughtful"	"Happy"	Sebbie, Self-Reflection PS 03
"This is confusing"	"This is less confusing"	Sean, Self-Reflection PS 03
"Normal"	"Happy"	David, Self-Reflection PS 04

Table 4.9 improvement in students' feelings could be related to So and Brush's explanation (as cited in Kwon, Liu, Johnson, 2014), that when students feel that they belong to a group and feel connected with its participants, their motivation and engagement in collaboration will be affected.

Collaborative work aided some students in being more active in their thinking and learning process. For example, Sean and up to a certain extent Keian, barely completed anything within their individual replies to most PS tasks. In the collaborative phases however, their contributions within their respective groups' discussions and solutions increased drastically.

Other students such as Keith, Marvin and Elton were observed trying to communicate on how to solve the assigned PS 01 even when they had to work individually. This seemed to give them a sense of reassurance prior to delving deeper within their individual solution. Damon (1984) and Webb and Farivar (as cited in Gillies et al, 2011) explained this by writing that:

> when children engage cooperatively with others when they are required to justify or explain their ideas, they are forced to cognitively re-examine and reorganise their understanding, so that their explanations can be readily understood. In so doing, they often develop a better understanding of the problem than they had previously, and this has a positive effect on their learning performance (p.427).

A positive attitude towards collaborative work was also attributed to working with friends and socialising (questionnaire items CW01 and CW06). It should be noted that a third of this Year 7 class was considered as new-comers, meaning that they were in different schools in Year 6. Their friendship bonds were still relatively weak especially at the start of my data collection phase. The collaborative work assigned thus helped students learn:

- "more about [their] friends and [not just] how to do a circuit with a buzzer" (Alec, Self-Reflection PS 02), and
- "how to work better as a team" (Elton, Self-Reflection PS 01).

This was also emphasised by Kotsopoulos (2010) who explained that through collaborative learning, not only do students achieve an academic goal, but they also learn the “important life skills of working jointly with others on shared problems or challenges” (p.129). The other students (that is those coming directly from the same primary school which amount to two thirds of the Year 7 population) have also valued the learning involved which was not only academic but the “learning to work as a team” (Personal Analytic Memo for PS 01 on Marvin). In the various other subjects, opportunities for students to work collaboratively were limited. At various instances, active efforts in practising and re-enforcing collaborative skills were noted. At times especially in the phase prior to the data collection and in the initial CPS tasks, this resulted in storming.

Storming refers to the interpersonal conflicts that occurred during group formations. During this stage, there were “high individual and group needs and low task focus...where personality clashes … bec[a]me apparent and the group[s] … argue[d] about how to operate” (Tuckman, as cited in Pauli et al., 2008, p. 49). If this stage was not settled, the group risked remaining non-functional and unable to focus its effort on the task (Pauli et al., 2008) as was noted in every team Zane worked in when I did not oversee the collaborative work process.

Data collected during the collaborative PS tasks proved that collaborative work was a way in which the “voice-less student” could be heard. This student was the very soft spoken Alec who though always on task, did not participate orally nor write extensively in the traditional individualistic classroom. His voice with very short answers and no elaboration was heard with difficulty only when asked direct questions. It was noted however that working with students with whom he felt comfortable was the only way in which Alec could voice and elaborate on his ideas and thoughts.

Attitudes and feelings such as those shown in Tables 4.8 and 4.9 should however not be generalised for this Year 7 class. It was noted that two students, who were both high achieving ones, were showing positive attitudes towards individual work as well. Elton had positive attitudes to both types of work due to voicing his opinion in the individual tasks, however Keith preferred the individual over the collaborative tasks as shown in Table 4.10.

Table 4.10: High achieving students' feelings when working individually and collaboratively

Feelings whilst working individually	Feelings whilst working within the group	Reference
"Felt a bit more free to write what I think"	"We could have joined our thoughts"	Elton, Self-Reflection PS 01
"I could give my opinion"	"happy and excited that I was in a group"	Elton, Self-Reflection PS 02
"I could write whatever I want"	"happy because we could tell each other our ideas"	Elton, Self-Reflection PS 03
"no distractions"	"they were not cooperating"	Keith, Self-Reflection PS 01
Ah - peace finally"	"Gosh. Why y y y y y y y"	Keith, Self-Reflection PS 02

Keith's negative attitude to collaborative work echoed the findings of Aquilina (2015) and Shachar (2003). Shachar (2003) reported that gifted students found that the collaborative learning setting was "not offer[ing] them any challenge and was even boring" (p.110). These feelings were noted even though these two students scored very high mean positive collaborative work attitudes in the questionnaire (mean = 1.58 and 1.33 respectively), thus proving Di Martino and Zan's (2011) warning that there is often a mismatch between students' declared beliefs and their beliefs in practice.

Despite the strong positive collaborative work attitude in this Year 7 group, two out of twelve students did not agree that their work would be better organised when working within a group (Table 4.8). Such result was similar to the findings of Farzaneh and Nejadansari (2014) who attributed such finding to probably being due to "one or two team members hav[ing] to do all the work and the other members simply go[ing] along for the ride" (p. 290).

Farzaneh and Nejadansari (2014), added that in certain cases, dominant participants' desire for obtaining a high mark, resulted in "stifl[ing] their teammates' efforts to contribute" (p. 290). For some of this study's participants, this suppression of ideas would have been welcomed such as shown in the reply obtained for item CW02 where four students (Sean, Zane, Keian and Drew) agreed that they use collaborative work as a way to reduce the thinking that they have to do in activities. For other students however, having to work on alternative ideas to their original is very difficult and resulted in:

- negative vibes within the team due to disagreements and not seeing each other's point, or
- not reaching one common solution such as Jim's, David's, and Alec's group in PS 04 where they eventually presented two different solutions.

It was noted that by the end of the data collection phase, the higher achieving students talked with caution as regards to preferring collaborative over individual work. This was attributed to two main factors:

1. who the other team members were. Marvin for example concluded his self-reflection to PS 02 by stating that in future PS tasks he wished "to be with the same teammates"; and
2. distractions and wasting time. The presence or absence of these factors were often mentioned by Keith, Sebbie and Marvin in their evaluations.

Shachar (2003) claimed that high achieving students do not like collaborative work because of their unwillingness to do work for the other members of the group whose grades were lower than theirs. This was especially noted during PS 04 when Keith and Marvin (high achievers) excluded Blake (medium-low achiever but with a high science capital). Blake's individual solution was different and lacked the detail that Marvin's and Keith's had. Blake's solution was thus not even considered. Marvin and Keith were building on each other's ideas and within their self-reflections they stated that they have "the same" and "not different" points of view to the rest of the team. They also stated "we listened to each other then we wrote our final [solution]" and "we joined our ideas" as the steps the group took to solve the problem. These reflections however confirmed that both students had completely ignored Blake and his work. In the meantime, this negatively impacted

Blake's self-esteem, and made him passive and withdrawn. It led "to learned helplessness and self-perceived incompetence ... as a result of [his] efforts being rejected by the higher status members" (Pauli et al., 2008, p.48). The final comment that Blake wrote within PS 04 self-reflection sheet was "HELP ME" (uppercase in original). Thus pinpointed to the fact that even though he preferred to team up with Marvin and Keith, he was not comfortable to explain his ideas just in case he said anything incorrect as the following excerpt during my intervention in PS 04 suggests:

SBS:	One minute Keith please. Sorry. You are a group of three not a group of two all right? So the ideas have to be shared between all. You need to see the best of everyone.
"Keith:	Come on Blake tell us your idea.
Blake:	I don't wonna say (anything) bad.
Keith:	Oh come on.
Blake:	Mine was dumb what I wrote.

Lesson PS 04

4.5: Conclusion

I found that that most of these students had a positive attitude and self-concept to science. Students valued the hands-on component and attributed a feeling of "fun" and "excitement" to it. Most students would have liked to do more science apart from the scheduled science lessons, however not many showed a desire to attend a science club. Despite the positive attitudes towards science and its importance, very few students aspired to become scientists.

The general attitudes towards PS collected from the questionnaire were positive as well. It was observed that giving students the power to plan and design their own ways of solving the science problem was welcomed by most students. This gave them a sense of autonomy in their decision making. It was also noted that the actual attitude observed whilst solving the problem depended on (i) whether the problem was hands-on vs pen and paper, (ii) the topic the problem was about, (iii) the problem's utility value and context students viewed it in and (iv) the student's perception of the problem's difficulty level.

Within the questionnaire, all students expressed positive attitudes towards collaborative work with most of them expressing feeling better whilst working collaboratively. For some students, CPS was important in helping them establish or re-enforce their social contact, learn to work as a team or the only way to express and elaborate on their ideas. An analysis of the students' discourse however, showed that true collaboration was not always obtained in the assigned four PS tasks. Some students, did not view particular members as equals. This resulted in an empathy gap within the group. A few high achieving students were also noted to talk with caution as regards to preferring collaborative over individual work. For these high achieving students, preference to collaborative work depended on who the other team members were and whether there was any "waste of time".

Chapter 5: The Relation between Attitudes and the Problems' Solutions

5.1: Introduction

Through this chapter I will attempt to answer my second and third research questions which deal with whether there is a relation between students' attitudes, self-efficacy and capability of PS, and whether there are differences in solutions when students work individually and collaboratively.

This data will be presented by presenting the cases of Zane, Alec, Keith and Elton. These samples were chosen according to the explanation provided in Section 3.4.2. The students' names referred to in this chapter are pseudonyms, and the codes PS 01, PS 02, PS 03 and PS 04 are the lesson reference codes as described in the List of Abbreviations and Section 4.1.

5.2: Zane's Case

5.2.1: Zane's Profile

Zane was an average to low achieving student. Appendix A shows that he had **strong negative means** as regards to his:

- attitudes towards school science (4.6),
- self-concept to school science (5.00),
- attitudes to science outside school (4.60),
- attitudes towards science aspirations (4.25),
- attitudes to PS (4.38) and

- self-concept to PS (4.8).

He only obtained **positive attitude mean values** in respect to:

- science practicals (2.5),
- the way he viewed the role of science in society (1.75), and
- collaborative work (1.75).

Zane tended to have a negative perspective to life in general. He was easily distracted in class, and often distracted others. This distraction often resulted in him not listening to my explanation or instructions.

In all the four PS tasks he felt that it was "impossible", "extremely difficult" or "hard" to solve the problem. However, these feelings improved to "it was much easier" when he was working within the group, thus further affirming his positive attitude towards collaborative work.

During all PS tasks, he never wrote the answers within the collaborative task, nor explained his group's common solution to the rest of the class. He always ordered the other team members to do these tasks. Zane often took the role of the "foreman" and his team would be his "labourers" (Kotsopoulos, 2010, p. 133). Zane also often exhibited a lack of group commitment as identified by Pauli et al. (2008) which is one of the four factors that measures negative group experiences.

The data collected during all four PS processes showed that he had very poor communication skills characterised by an empathy gap, blaming others for negative things and uttering bullying statements such as the following which were all stated at different instances during just one PS hands on task:

> Zane: What are you doing Sean? And then you stay boasting (PS 02).
>
> Zane: Cool. Listen to it. Place it next to your ears (..) Next to your ears. <emphasising> DEAF (PS 02).
>
> Zane: So <singing> Sean you are so baf-fling-me. Sean is mix-in things up (PS 02).
>
> Keian: The buzzer buzzed.
> Zane: <shouting> NOT OURS

SBS: sh
Zane: It's because of this deaf one (...) He's like my grandma
(PS 02).

Even though he rarely ever admitted it, he was often in trouble. At times, this resulted in him missing school as shown through the following excerpt taken on his return with a black eye following an absence of a week:

Keian: Why didn't you come to school last week?

Zane: Cause cause

Sean: Cause they made his nose bleed. He escaped. A good punch.

Keian: I thought a punch, or they ganged against you.

Zane: Because I was sick
(PS 02)

Following the overview of Zane's attitudes and behaviours, Sections 5.2.2 to 5.2.5 will focus on the relation between his attitudes, PS capability and solutions to the four PS tasks presented.

5.2.2: Zane and PS 01 whilst working with Sean and Drew

Zane's individual solution to PS 01 was that of "I think we have to multiply the area to get the answer" (Individual Solution PS 01).

On discussing the various solutions during the group work phase, Zane made fun of Drew's suggestion and the group eventually got distracted and stopped trying to solve this problem.

On noticing this, I intervened in order to aid the group progress. Pauli et al.'s (2008) study on negative group experiences noted that the "level of [teacher's] intervention was inversely related to negative group experiences, indicating that high levels of negative experience were associated with lower levels of intervention to address group problems" (p. 56).

I thus used various scaffolding questions to aid the group in understanding the problem and proceed with its solution as I detected a possible “extraneous cognitive load … [due to] the manner in which the tasks [we]re presented” (van Merriënboer and Sweller, 2005, p. 150). The final prompt that was used with this group was that of showing them a quadrat and asking how this could be used. On noticing that the group found this prompt useful and were on the right track, I moved on to check the other groups’ progress. The following is an excerpt of a discussion between Zane and Drew:

> Zane: What do we need to do? <referring to the quadrat> This is used to match with it <three giggles>. Then you get a group of plants and throw them within and you do something.
>
> Drew: You are going to break it. Bring it over here. Bring it over here. I think I know what we should do.
>
> Zane: <giggles>
>
> Drew: I think. I think that, it’s true. I think I was right that you have to put it in a plant.
>
> Zane: But not in one (..) I think that first you measure this <refers to quadrat>
>
> Drew: Eh?
>
> Zane: You’ll know how much it is.
>
> Drew Or you’ll have a plant.
>
> Zane First you measure this, then you get loads of plants and throw them within it, and then you count how many you threw .

Despite some scientific inaccuracies, Zane’s reasoning was on the correct line of thought. He eventually got distracted again and stopped this reasoning process.

Following a dispute on who was going to write the common solution, Zane ordered Drew to dictate the method for Sean. Eventually this was not updated according to the group’s discussion and Drew’s individual method was presented as the common answer (i.e. area of site divided by two).

When it came to explaining the method to the whole class, Drew and Sean explained the use of the quadrat however the procedure mentioned lacked the proper identification of all the steps required. Quality of this explanation was low and despite Zane having identified correctly most of the steps in the small group discussion, he did not step in to help Drew in the explanation nor did he help Sean in the writing of the common answer. This further confirmed his lack of group commitment.

Thus to conclude PS 01, working in a group helped Zane improve on his original written solution and in partially solving this problem verbally within the small team. However, due to his negative attitudes to science, poor initiative and “lack of group commitment” (Pauli et al, 2008, p. 52), this partial management of solving the problem was not demonstrated on paper nor orally in front of the class or myself as another team member’s individual solution was re-copied.

5.2.3: Zane and PS 02 whilst working with Sean and Keian

Zane was unusually early for this lesson. As soon as Zane found a seat, thus prior to the actual start of the lesson he and Sean were “looking and trying to see how they are going to use the crocodile clips, battery and wires” (Field notes PS 02). I am attributing this positive attitude to having previously told the class that they would be having a hands on task on the topic of electricity, as Osborne et al. (2003) noted that “students’ attitudes towards school science also vary with the specific sciences” (p. 1061).

During the writing of the individual solution on paper phase, Zane tried connecting the materials instead. This further supported the questionnaire results and the focus group input as regards to him having a preference to hands on tasks but not so much to writing.

Within the written individual solution, he eventually suggested hiding the alarm “under the table and stick it under” (Individual Solution PS 02, p.1). Thus his positive attitude to this PS task was also attributed to having placed this problem in context which was similar to what he had watched in movies/games, and seeing the usefulness of doing a trick on someone. His willingness to solve this problem could also be attributed to him noting that there is a high probability of managing to achieve the aim (Nakonecny, as cited to in Dostál, 2015). This resulted in perseverance throughout both the individual and collaborative phases.

Zane's drawing shown in Figure 5.1 indicated a gap in knowledge as regards to making the buzzer buzz and the need of a complete circuit. As the collaborative task started, Zane wanted to use Keian's idea (Figure 5.2) despite it not having the buzzer included unlike his. This is probably due to perceiving Keian as higher ability than him due to the explanation found within his drawing.

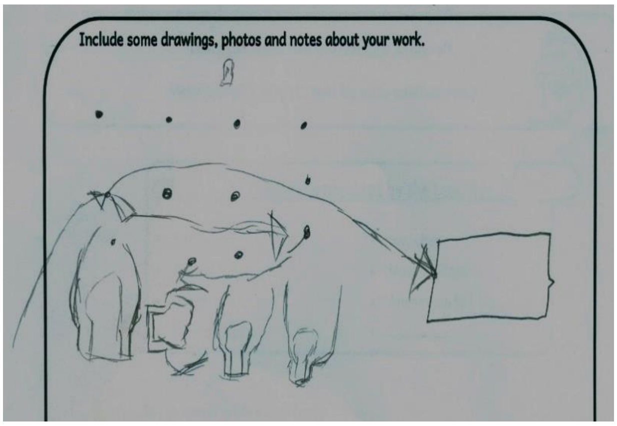


Figure 5.1: Zane's individual solution to PS 02

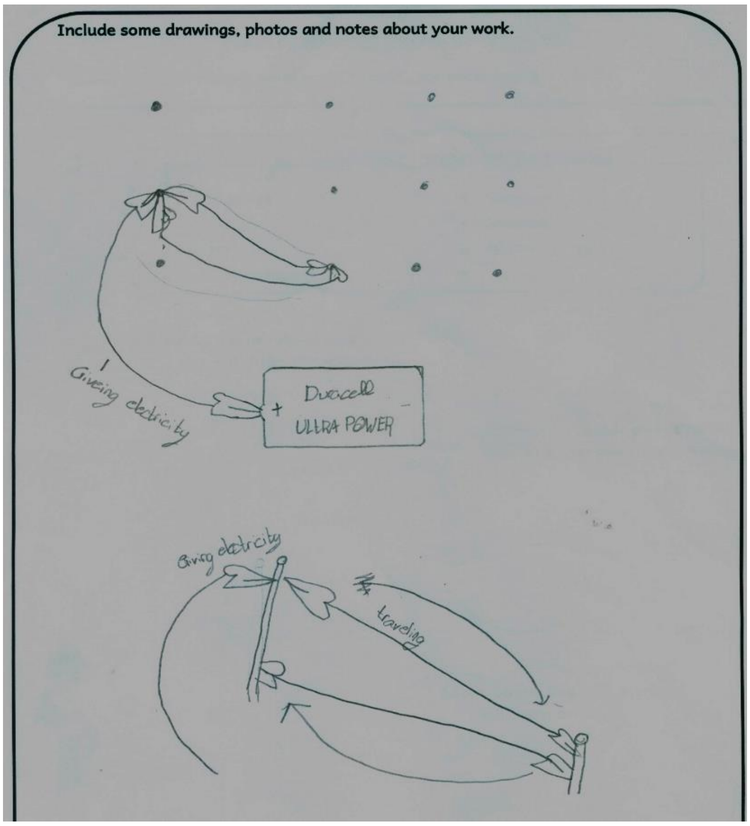


Figure 5.2: Keian's individual solution to PS 02

My intervention was required as after a relatively long period of collaborative work, the group was not being successful due to having too many wire connections. Scaffolding questions were used so that the team eventually decided to reduce the number of wires and include a second battery. Other scaffolding questions were used to ensure that the group achieved the task's learning intentions related to the need of a complete circuit and how switches function.

Having managed to complete the circuit and making the buzzer buzz made Zane feel positive and happy. He was also heard singing a tune "we are so genius" and referring to the collective "we" as opposed to "you" when the buzzer was not buzzing. Thus it was noted that for Zane, the relation between attitudes and the solving of problems was reciprocal as noted in Nicolaidou and Philippou's (2003) study discussed in Section 2.6.2.

Working in a group helped Zane improve on his original written solution and in solving this problem. The final solution that was eventually presented on paper (Figure 5.3) is better than his individual one even though not completely correct (note the batteries' polarity).

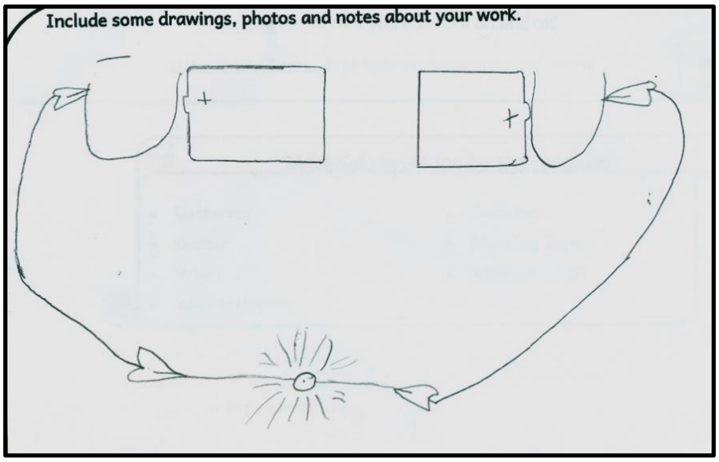


Figure 5.3: Zane's team written solution to PS 02

Managing to solve the problems collaboratively improved Zane's attitudes to both PS and collaborative learning where he eventually started using the "we" rather than the "you" in his discourse.

5.2.4: Zane and PS 03 whilst working with Sean and Yan

Similar to PS 02, this problem was characterised by perseverance which was attributed to it being a hands on task.

Zane's individual solution was very similar to Yan's. His solution was that of "putting the bulb on the water" and using "more light" to heat the water the most. No drawings nor explanations were given within the individual solution. As the collaborative phase started, the group immediately set up the apparatus according to these individual plans without any collaborative planning nor discussion of any required safety precautions.

I noted that the group was building different designs characterised by copying aspects of other teams such as the use of the retort stand, the use of a conical flask and doing a hole within the Styrofoam cup. Various researchers (Bandura, 1997; Schunk & DiBenedetto, 2016) identified these vicarious experiences as a self-efficacy source as the students would be observing models that demonstrate how tasks should be made. As explained in Section 2.5.2, when models express confidence when facing difficulties, a higher sense of efficacy and perseverance will be instilled in the observers who will be doubting themselves when encountering problems (Zimmerman & Ringle, as cited in Bandura, 1997).

It should be added, that Zane was forbidding the team from calling me for help. On noting this I joined the group. Eventually the group, with inputs coming mainly from Yan, but with prompts from Zane and Sean too, the group explained the set-up they had in mind and the reasons and precautions behind it as shown in my representation of Figure 5.4.

Due to trying out different designs and often being distracted, the group did not manage to finish building the design shown in Figure 5.4, and measure the new water's temperature within the assigned time.

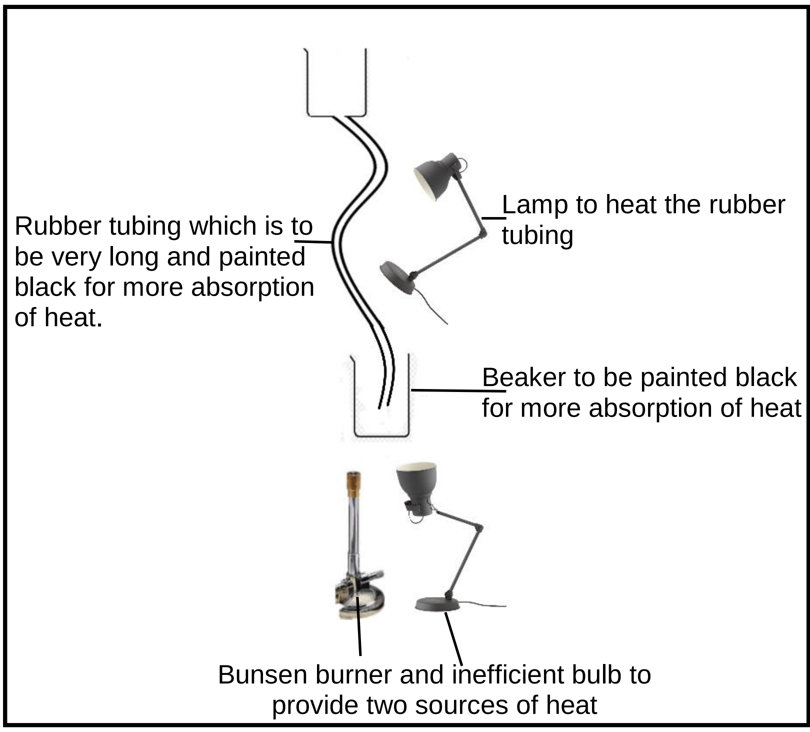


Figure 5.4: My representation of the team's ideas and their reasons on how PS 03 should be solved.

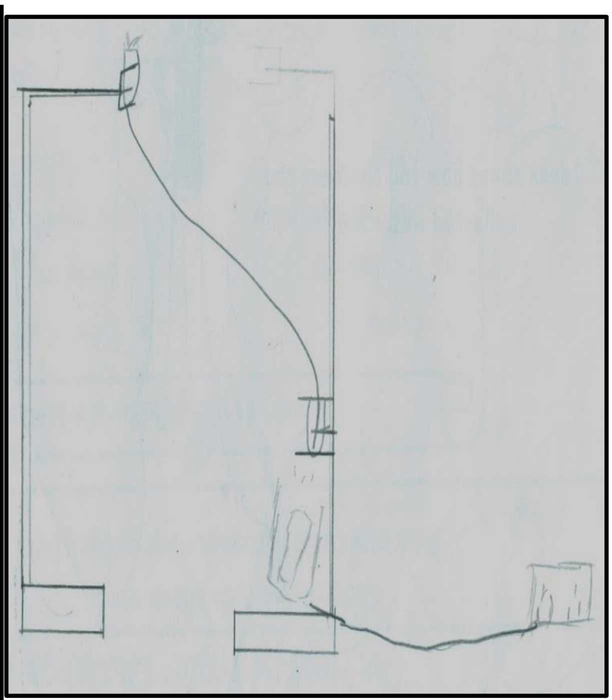


Figure 5.5: Zane's group written solution to PS 03

Despite the group discussions with the teacher where students discussed "painting it black", and using "two sources of heat", the group did not show these important characteristics within their final drawing (Figure 5.5) presented to me. The idea of using the longest rubber tubing compared to the shorter ones was also discussed and I could only interpret this from the diagram following their discussion as no labelling nor notes were included within the final drawn solution Figure 5.5.

Working in a group helped Zane improve on his original written idea, focus on safety precautions and orally successfully solve this problem whilst discussing it with me within his small collaborative team. However, similar to PS 01, due to not aspiring in giving the best written answer one possibly can, important aspects within the design were not included within the final written collaborative solution.

5.2.5: Zane and PS 04 whilst working with Sean, Keian and Yan

Within the individual solution, Zane correctly identified Layla's comment (Appendix L – PS 04) as the correct one. He specified that "the monument is damaged differently according to the mat[t]er it is made up of". Zane's way of solving the problem was as shown in Figure 5.6.

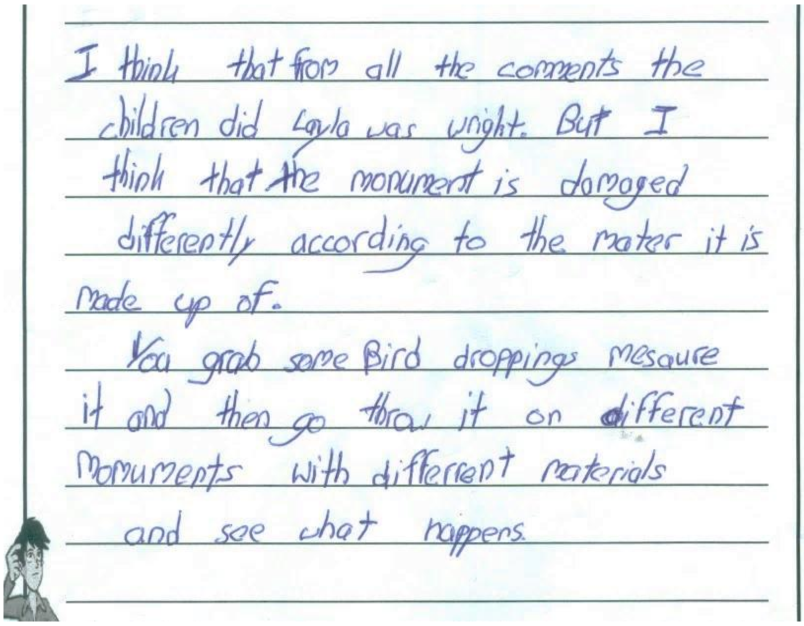


Figure 5.6: Zane's individual solution to PS 04

This solution was partly correct as the addition of an acidic substance on the different materials and noting the resultant differences was outlined. He was however not specifying whether he intended to measure the mass or volume of the bird droppings nor the type of measurements/observations to detect the effects of the bird droppings. He was also not making reference to transferring samples in the lab, but the investigation was to be carried out on the actual monument. This was lacking the transfer of the context to how it could be tested without damaging the monument.

As regards to the collaborative solution, similar to all other tasks, Zane's group needed the teacher's intervention to start as they were working on another subject's HW. This meant that solving this PS task was attributed less value than the other work.

Eventually Zane, Sean and Yan read their individual solutions. This phase was once again characterised by an empathy gap and a lack of respect to each other's ideas.

This also led to Keian not showing his solution to the group. He only felt safe to do so in my presence when assuming that he would not be the target of the group's negative response.

Sean and Zane were passive during Keian's and Yan's true collaborative talk where they discussed:

- the use of vinegar as their acid,
- using the same amounts of vinegar,
- ensuring the use of the same pH within vinegar,
- placed on blocks of the different materials, and
- measurements taken by:
  - photographs,
  - thermographs and
  - weighing.

Zane's (and Sean's) observed passive attitude is often referred to as "social loafing" or "free-riding" (Karau & Williams and Solomon & Globerson, as cited in Pauli et al., 2008, p. 48) amongst others. It arises when students do not "contribute to the group effort because they assume the work will be done by more talented or more motivated group members" (Pauli et al., 2008, p.48).

Following this discussion, Sean and Zane associated Yan with the "nerds", who in turn did not agree with the statement as the following excerpt indicates:

Zane: <Very low voice> You're a nerd.

Yan: Me?

Sean: Yan.

Yan: <Surprised tone> Why? I'm staying with you!

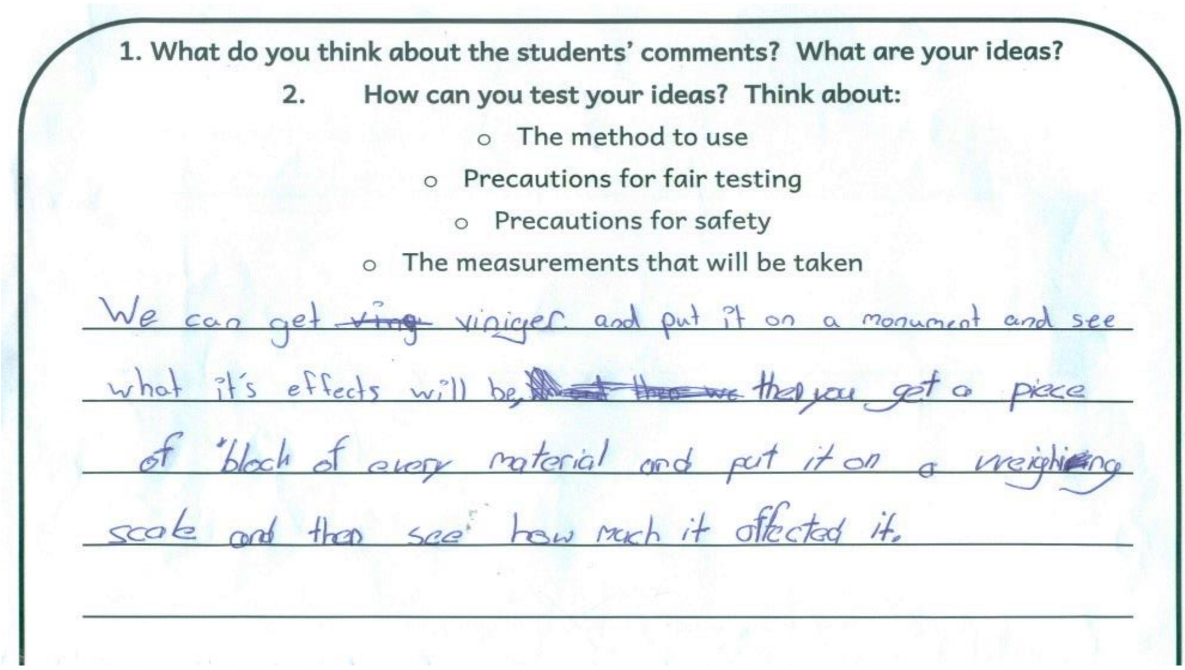
Zane Because you stay with Blake.

Keian eventually stopped contributing within the team and was not heard again till the end of the lesson. This may be attributed to Keian probably:

i. associating that he was being seen as a nerd too since I had asked him to work with Blake in PS 03, or

ii. "avoiding the sucker effect" where the more motivated and competent student withdraws his group effort due to perceiving others as not contributing to the same level as himself (Pauli et al., 2008, p.48).

The final team written solution (Figure 5.7) compared to Zane's individual one showed that there was the transfer of knowledge learnt four months earlier (i.e. vinegar is an acid) to the new real-world context and how it could be tested in the lab. The details as regards to fair testing despite having been discussed were not reflected within the final solution.



1. What do you think about the students' comments? What are your ideas?

2. How can you test your ideas? Think about:

- The method to use
- Precautions for fair testing
- Precautions for safety
- The measurements that will be taken

We can get ~~ving~~ viniger and put it on a monument and see what it's effects will be, that you get a piece of block of every material and put it on a weighing scale and then see how much it affected it.

Figure 5.7: Zane's team written solution to PS 04

Working in a group helped Zane present an improved solution to his individual one. Due to his negative attitudes, not being motivated by the context of the problem and not participating in his team's collaborative discourse, this improved solution was obtained through social loafing (which is also known as free-riding) as explained above.

5.2.6: Zane's Case Conclusion in respect to Research Questions 2 and 3

Zane's negative attitudes to science and problem solving seemed to have an impact on his ability to solve problems, as limited effort was noted in all the four tasks. The positive attitudes towards collaborative work and practical work resulted in him being more active whilst solving the hands on tasks and collaborative tasks. This participation also depended on the context the problem was in, how relevant he perceived it to be and on the prompts I provided.

The formal writing of a solution or the oral discussion in front of a whole class is not the ideal format that Zane is to be assessed in as regards to his PS capabilities. The written solutions (individual and collaborative) did not reflect his discourse within his teams nor showcase Zane's actual cognitive abilities. Thus alternative formats of assessments such as those proposed by the psychometricians von Davier and Halpin (2013) could be introduced in schools. Their proposed methods focused on "extracting evidence of individual cognitive skills (e.g., science or math skills) when students are engaged in CPS tasks" (p. 1). Such methods, consider the individual student's cognitive abilities and reflect on the benefit of collaborative learning rather than just focus on the final product.

Due to poor group commitment and an empathy gap Zane did not step in to aid the rest of the group in ameliorating the written answer nor the oral solution to the rest of the class. The collaborative work, albeit not always with the correct group dynamics helped Zane improve all his individual solutions.

5.3: Alec's Case

5.3.1: Alec's Profile

Alec was a new student in Year 7. His voice, ideas and opinions were barely heard throughout the whole scholastic year unless he was addressed directly or was working within a collaborative setting. Within the written traditional assessment modes (i.e. class-works/home-works, tests and exams) he was average achieving, however I believe he was capable of achieving higher marks should his individual cognitive skills within the collaborative setting as proposed by Davier and Halpin (2013) been assessed.

Alec's awareness of his low proficiency level in the English language, poor verbal communication skills (such as his extremely low voice, unclear and restricted articulation) poor reading and poor spelling, seemed to cover his actual competencies in science and PS. His oral contributions often in the Maltese language within his team however showed a better science cognitive level than what he expressed on paper. This supports Lyon, Bunch, and Shaw's study (2012) who stated that performance in science based assessments could not be used as valid interpretations of a student's scientific knowledge should the student not be proficient in the language (p. 616).

Alec's oral contributions within the team also aided his group progress within the various assigned PS tasks. By the end of every CPS session however, he relied on his peers to complete the written common solution sheet or explain the group solution to the rest of the class in the lesson conclusion phase.

Appendix A illustrates his expressed **strong positive means** within the initial questionnaire as regards to his attitudes towards:

- school science (1.60), and
- science outside school (1.80).

Appendix A also shows his expressed moderately **positive means** towards:

- his self-concept in school science (2.50),
- attitudes towards school science practicals (2.50),
- the way he views the role of science in society (2.33),
- attitudes to PS (2.38),
- self-concept to PS (2.40), and
- attitudes to collaborative work (2.42).

He holds **neutral attitude means** with respect to his science aspirations (3.00).

During the data collection phase, Alec was building stronger positive attitudes and self-concept towards PS than those expressed within his initial questionnaire. An analysis of the way he behaved within the PS tasks, indicated that he viewed problems as "something that you always have an answer for …. [even though challenging] … one time you'll manage to find its answer" (Focus Group). Within the focus group, he explained that he preferred that the problems assigned were not guided but the students were "free, because we can do whatever our ideas are". He felt that the assigned problems were preparing them for life (Focus Group).

By the end of the data collection phase, Alec's attitudes towards collaborative work seemed to have improved as well. He explained that he liked his team (Self-Reflection PS 03, 04), the team "came to do everything together" (Self-Reflection PS 03), and through collaborative work he managed to "work faster" (Focus Group). Within the focus group he also gave a recommendation to his teachers to assign more group work.

The improvement in attitudes towards collaborative work could probably also be attributed to my observations that working with students whom he felt comfortable with, was:

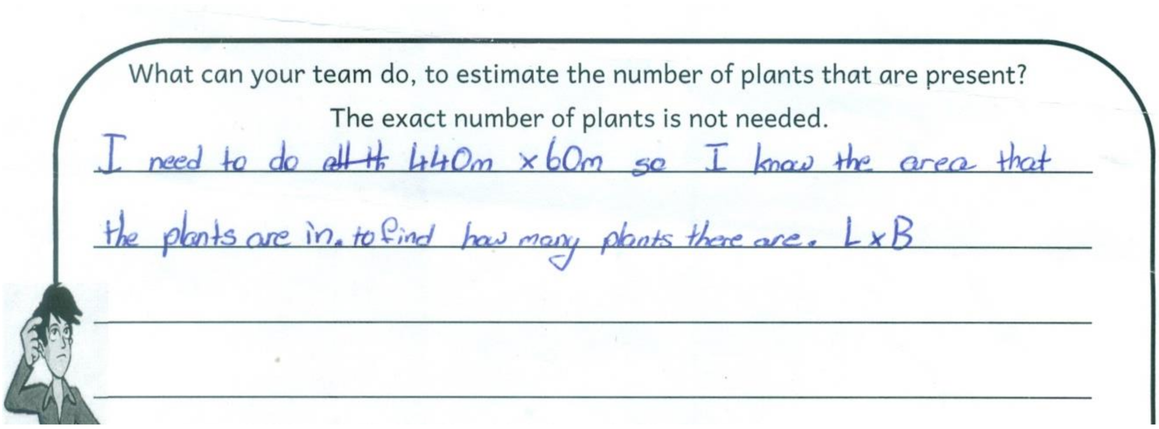
- the only way in which Alec could express and elaborate on his ideas and thoughts as similarly observed by Yaduvanshi and Singh (2019) that "introvert and shy students felt free to clear their doubts with their peers, and they also felt motivated while performing their respective roles" (p. 7),

- a way in which he could socialise and start making friends in his new school, and
- a way in which his initial solutions to the problem assigned could be improved.

On several occasions however Alec mentioned the negative connotation of noise to collaborative work. He felt "comfortable" in individual work due to there being "no noise and [he] could work" (Self-Reflection PS 01), and stated that he wants collaborative work to "be more quiet" (Self-Reflection PS 02; Focus Group).

5.3.2: Alec and PS 01 whilst working with Jim and David

Alec had not clearly identified the aim of this PS task as he stated that the teacher "gave us the perimeter and we now need to find the area" (Self-Reflection PS 01). This resulted in his incomplete individual solution shown in Figure 5.8.


What can your team do, to estimate the number of plants that are present?
The exact number of plants is not needed.

I need to do ~~all th~~ 440m x 60m so I know the area that the plants are in. to find how many plants there are. L x B

Figure 5.8: Alec's individual solution to PS 01

As soon as the collaborative phase started, Alec's lack of confidence emerged as he stated that he had not understood the problem. His peer's positive attitudes however enabled the whole team to utilise an exploratory type of talk (Grau, Lorca, Araya, Urrutia, Ríos, Montagna, & Ibaceta, 2018) where all members shared, explained and listened to each other's ideas. Some of the ideas were challenged and eventually built upon as shown in the excerpt below. This discussion took place after all members agreed that they are to first find the site's area.

Jim: Judging from the photo there are at least two plants every square metre (….)

Alec: Erm. Judging from the photo, more than two plants per square metre.

David: A square metre you are saying! Two plants for every square metre? That doesn't make sense.

Jim: <emphasis> AT LEAST I said.

David: What I was going to say is that (…) there can be more. Like those little plants.

Alec: Plants like this.

David: But there are ten at least or more.

Jim A square metre is something like this <showing on the desk how big a metre square is> (……) We have to use area then we estimate (…) If in one square metre there are about six, then in the other there are four, and in the other there are five. You do an estimate of all of those.

David: So you're saying if there might be rocks for example.

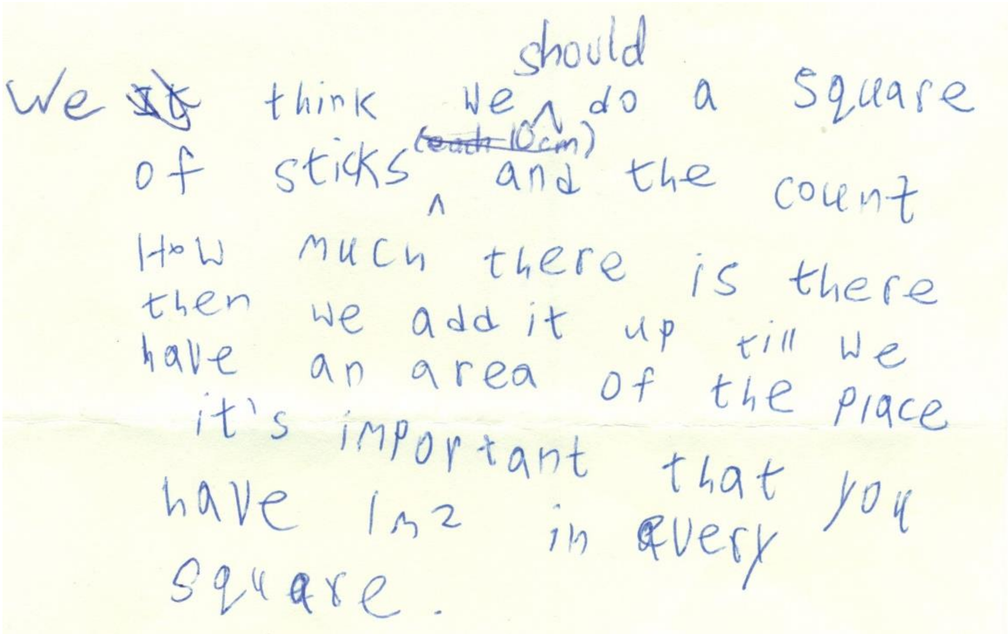
Alec: That's why estimate.

(Lesson PS 01)

Following a discussion on whether to use metres, centimetres and other matters which were off track, his peer came up with the idea of:

> we form a square we do it like with some sticks. You measure it, find the area of that, and count how much plants there are … then add it up, until we have the area of the whole place (David, Lesson PS 01).

This led to the group written solution which eventually was incomplete as shown in Figure 5.9.



We ~~It~~ think we should do a square of sticks ~~(each 10cm)~~ and the count How much there is there then we add it up till we have an area of the place it's important that you have 1m2 in every square.

Figure 5.9: Alec's team written solution to PS 01

Despite showing, through his discourse in the CPS setting that he knew the best way to solve the given problem, Alec did not contribute in the explanation to the rest of the class – not even when other students asked for clarifications. The solution which was eventually orally explained by both his peers included:

- finding the area of the whole site,
- throwing a $1m^2$ square of sticks five times,
- counting the number of plants in each throw,
- working out the average number of plants, and
- estimating how many plants there would be by comparing the $1m^2$ to the whole area.

Alec did not manage to solve the problem assigned whilst working individually. His lack of confidence, poor self-concept, and weak positive attitudes to collaborative work were surpassed by the true collaboration witnessed within this group. Alec and both his peers managed to discuss, criticise and elaborate on each other's ideas. This enabled them to produce a solution which was of a better standard than each team members' individual solutions. This was enhanced by the possibility of explaining this solution orally rather than just on paper due to a better articulation of the spoken compared to the written language - a barrier which had also been identified within several SEC level Biology Examiners' Reports (Matriculation and Secondary Education Certificate Examinations Board, 2007; 2008; 2010; 2011).

5.3.3: Alec and PS 02 whilst working with Jim and David

Alec's individual ideas (Figure 5.10) on the way to solve this problem were correct. Details on how the different components of the circuit would be connected were however not shown on page 2 (Figure 5.11). He thought about a way the buzzer could be hidden and also wrote that a complete circuit is needed for the buzzer to

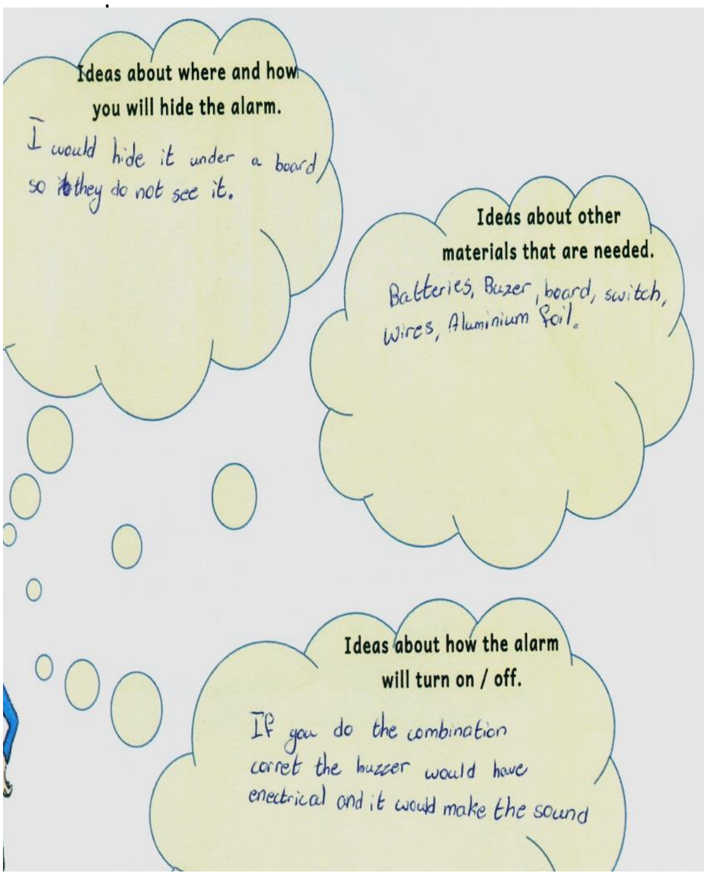


Figure 5.10: Alec's individual ideas on solving PS 02 page 1

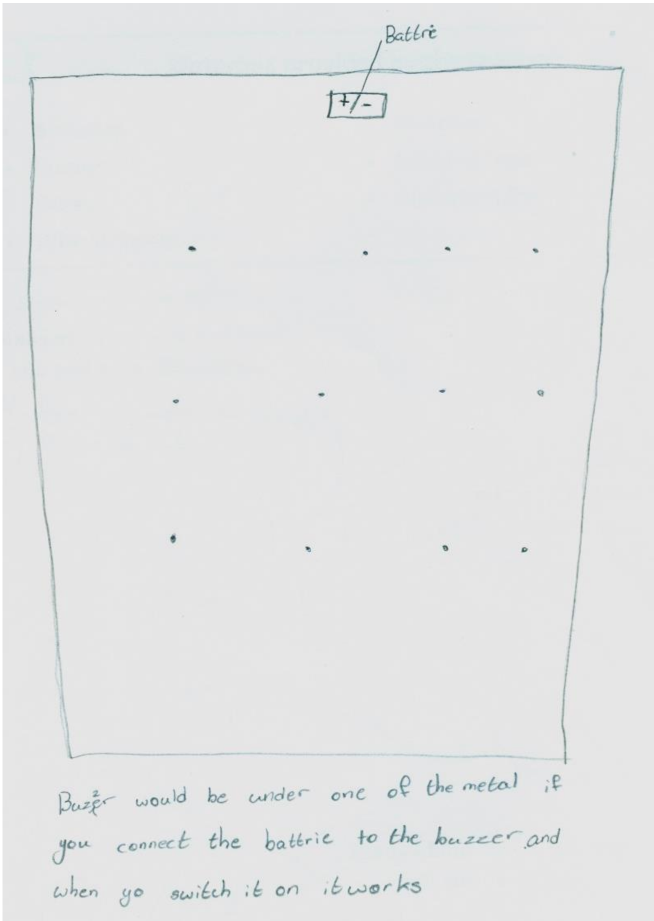


Figure 5.11: Alec's individual ideas on solving PS 02 page 2

All the team members' positive attitudes to science, PS and CPS, led to a true collaborative phase characterised by an exploratory type of talk (as previously noted in PS 01) and active hands on participation by all. The three individual solutions were heard and contributed different ideas of making the circuit/buzzer hidden. The team eventually managed to:

- build a complete circuit with a buzzer that could be turned on and off, and
- hide the buzzer underneath the circuit board.

Apart from successfully solving the assigned problem, the group also helped each other learn about electrical circuits, the construction of a closed circuit and the function of switches.

It should be added that upon successful solution of this problem, Jim complemented Alec for his creative idea of hiding the buzzer and connecting it with the metal components found underneath the circuit board. Jim's appreciation, together with the team's good cooperative skills were probably attributing to Alec's improvement in attitudes noted as the data collection phase was progressing.

Thus to conclude the analysis of this PS task, Alec's moderately positive attitudes led him to solve this problem solving task on paper. The very good collaborative skills and the team's overall positive attitudes led the whole team to (i) feel good, (ii) solve the problem on paper and hands on, and (iii) learn about electrical circuits and switches. The team's final solutions showed:

- improvements to Alec's original ideas which did not include a circuit diagram within the individual solution, and
- improvements to Jim's and David's due to the presence of complete circuits.

5.3.4: Alec and PS 03 whilst working with Jim and David

Alec felt "confused" (Self-Reflection PS 03) whilst working on this problem on his own. His individual solution was that of using the rubber tubings to let water reach a beaker which would be heated by a light bulb placed underneath the beaker. The beaker would in turn be covered by a lid to prevent heat losses (as shown in Figures 5.12 and 5.13).

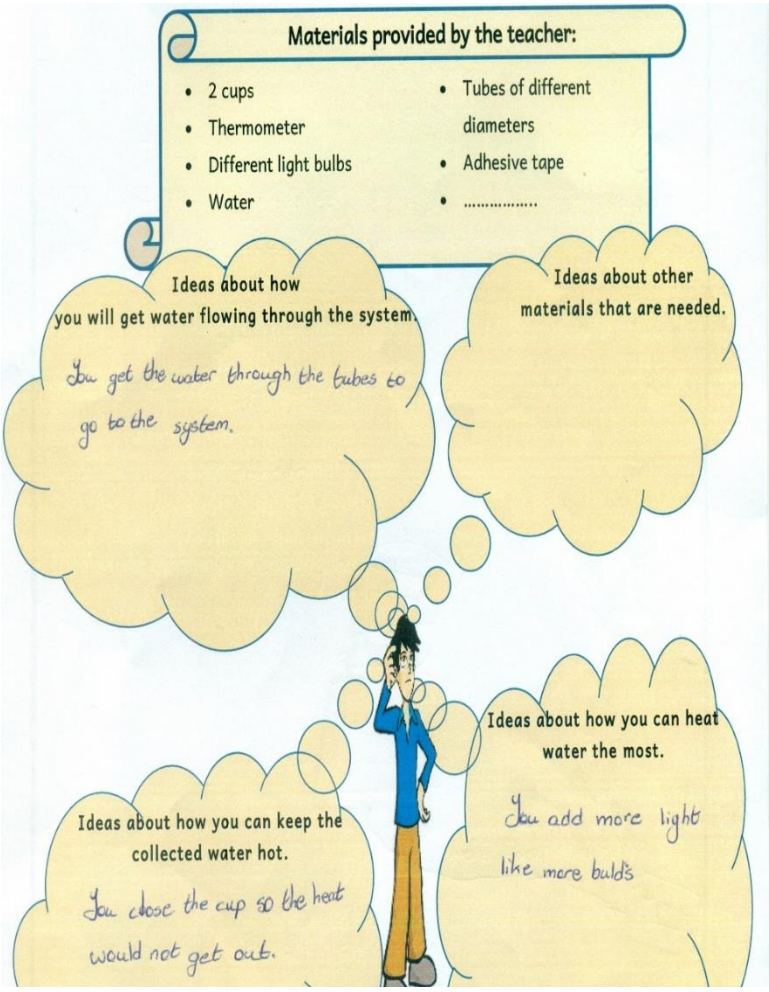


Figure 5.13: Alec's individual ideas on solving PS 03 page 1

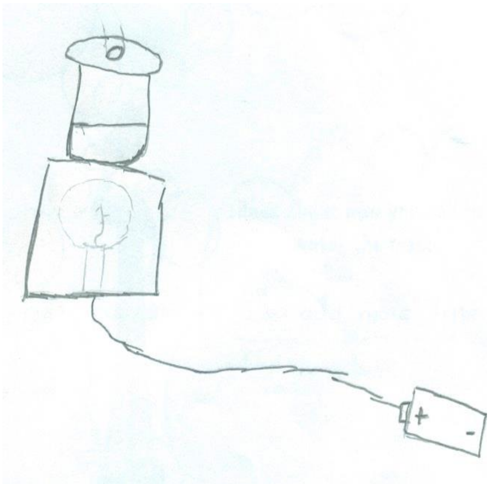


Figure 5.12: Alec's individual ideas on Solving PS 03 page 2

Upon the start of the collaborative phase, contrary to the previous PS tasks, the group's sharing of the initial ideas was rather limited. The group immersed within the hands on phase which was also characterised by an exploratory type of talk. They discussed aspects such as how the water would be flowing, the positioning of the various materials and so on.

This task proved to be the most challenging amongst the four assigned for my study's data collection. Water leakages from the cup-rubber tubings' connections were experienced at various instances within the group's testing phase. This was panicking the students, and resulted in the loss of considerable time to fix these leakages.

The final solution which was set up and also presented as the collaborative written solution (Figures 5.14 and 5.15) included an update of Alec's individual one where water was heated in a cup from underneath, the addition of a second light bulb on top to provide more heat, and part copying another team's solution due to the inclusion of a cup delivering water into glassware. This copying was a coping strategy used by the group to surpass the difficulty encountered in setting up the apparatus. It enabled them to improve their self-efficacy once again and identify those aspects which eventually resulted in the group's successful performance (Bandura, 1997; Schunk & DiBenedetto, 2016).

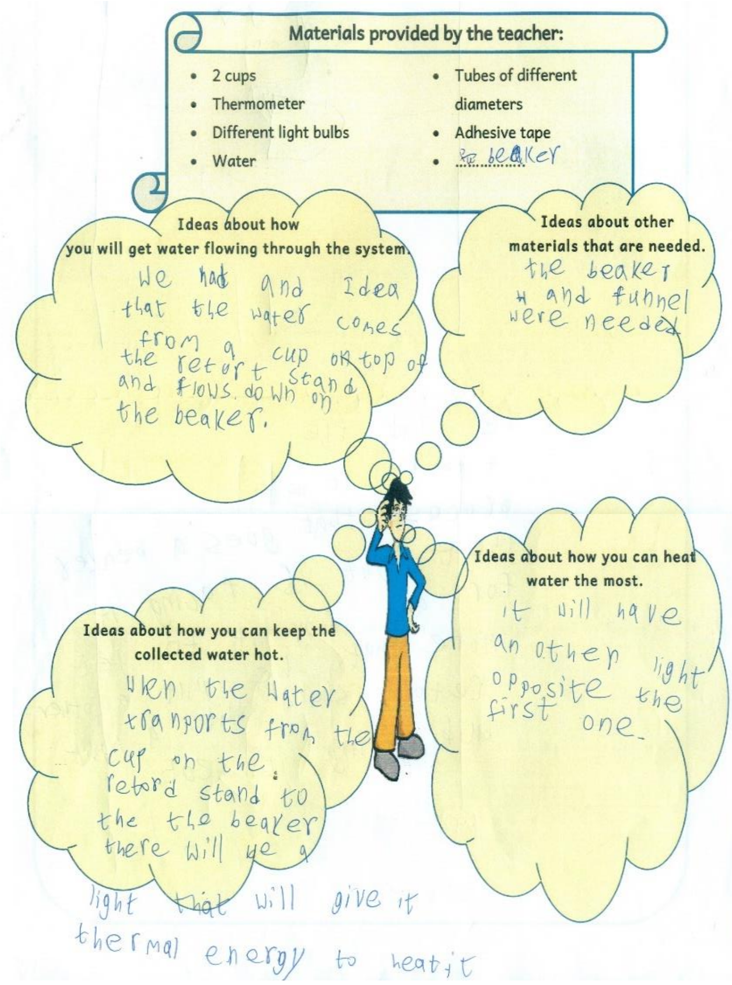


Figure 5.14: Alec's team collaborative ideas on solving PS 03 page 1

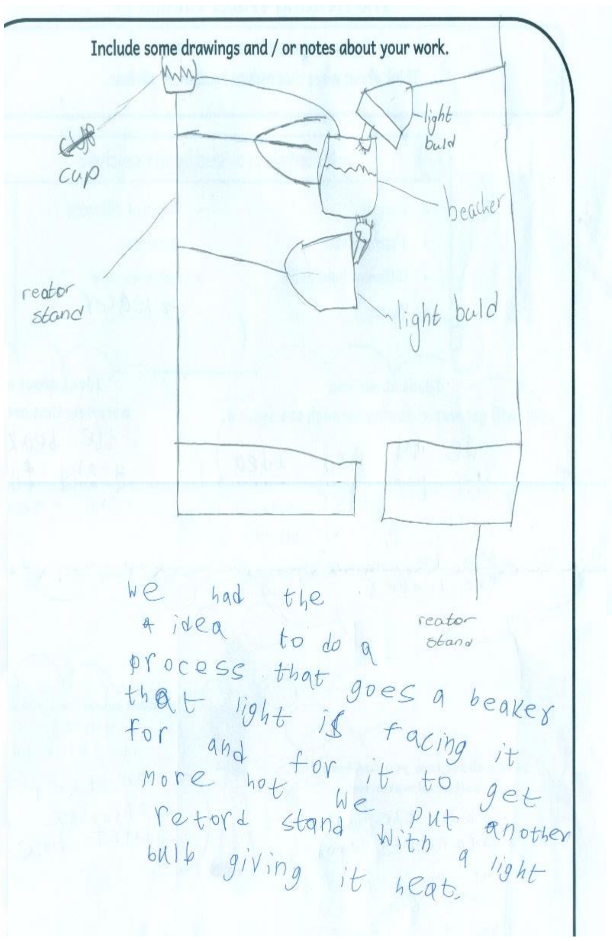
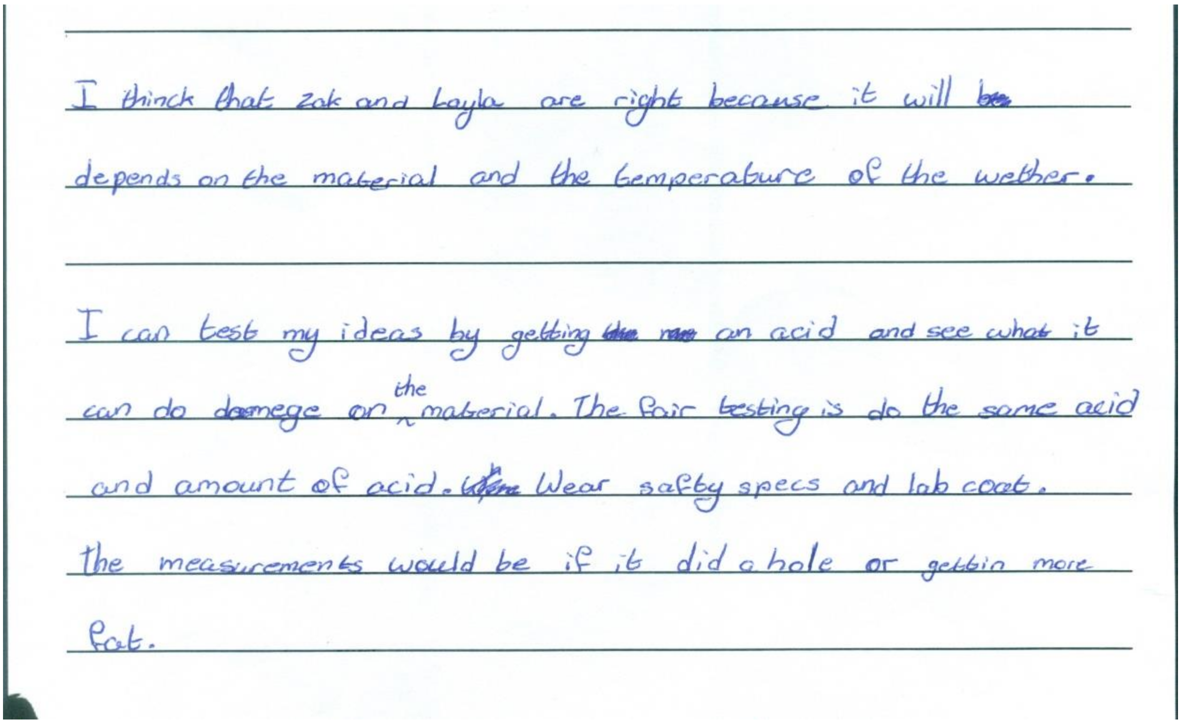


Figure 5.15: Alec's team collaborative ideas on solving PS 03 page 2.

5.3.5: Alec and PS 04 whilst working with Jim and David

Alec stated that he felt “good” (Self-Reflection PS 04) in all phases of this PS task. He correctly identified that both Layla’s and Zak’s statements (Appendix K – PS 04) were correct. He did not hesitate to write his solution (Field Notes PS 04), which albeit lacking detail was correct as shown in Figure 5.16. He managed to transfer the acid rain and acidic bird droppings context to acids in the lab, think about fair testing procedures, safety precautions and a method of observing results.


I thinck that Zak and Layla are right because it will ~~be~~ depends on the material and the temperature of the wether.

I can test my ideas by getting ~~the~~ ~~rain~~ an acid and see what it can do damege on the material. The fair testing is do the same acid and amount of acid. Wear safty specs and lab coat. the measurements would be if it did a hole or gettin more fat.

Figure 5.16: Alec's individual solution to PS 04.

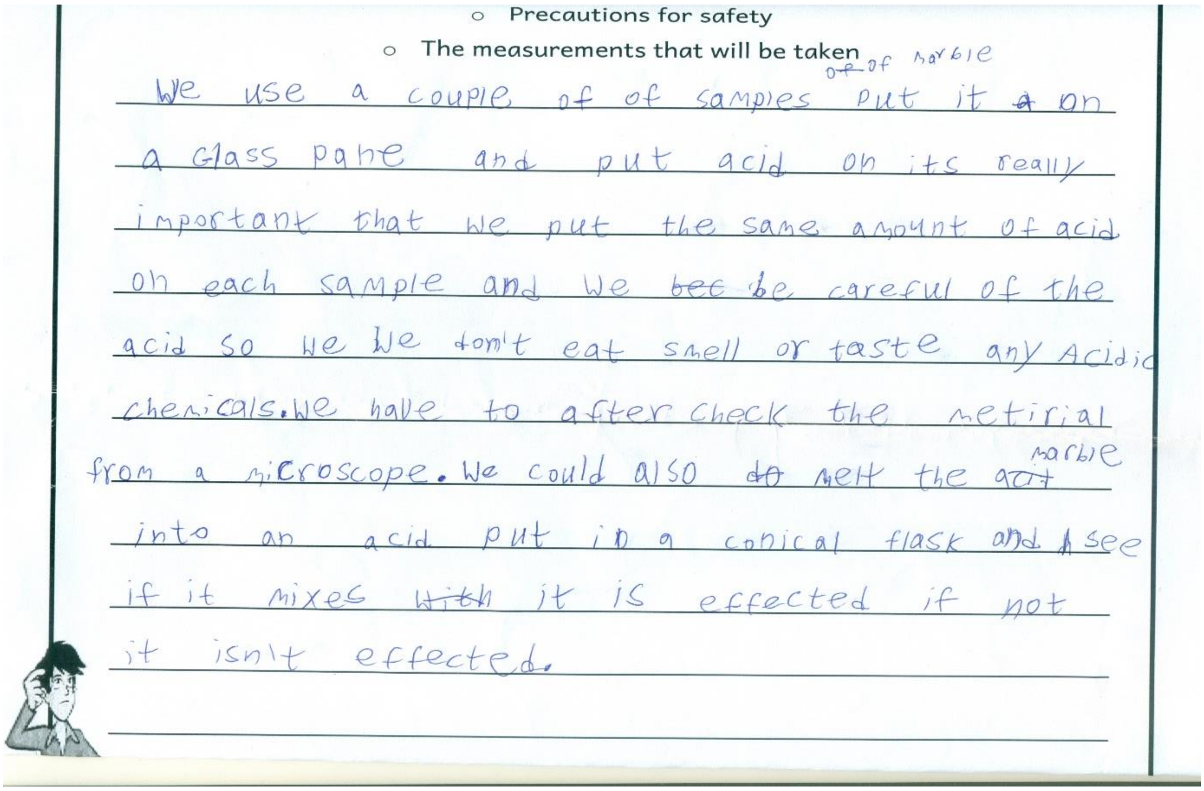
Exploratory talk characterised the collaborative task. Sharing, listening, criticising and elaboration of ideas was once again noted. Alec’s and David’s individual solutions were similar. Alec and Jim helped David transfer the “acid rain” and “acidic bird droppings” context to acids in the lab since the “acid [to be used in the investigation] does not have to be bird poop or acid rain” (Jim, Lesson PS 04). The group’s constructive discussion helped each member focus on aspects related to fair testing and safety such as:

- using the same type and volume of acid,
- ensuring that the material investigated is in contact with the acid from all its sides,
- placing the different monument materials in the same room so as not to have temperature variations,
- using apparatus that is not affected by acid, and
- proper handling of acids.

Alec also managed to elaborate on his idea that results could be noted by the use of the light microscope and checking whether the material got “thinner or fatter”. He provided different arguments in favour of this which David eventually agreed to and included within the group’s final solution. This part of the solution was however not correct due to light not managing to pass through the block of material.

An aspect which Alec was not assertive and persevering enough in, was his idea that the affect of acid rain and bird droppings on the monuments might depend on the temperature they are found in. The other team members were assuming that temperature would not affect the reaction, and thus they discarded his idea in order not to “waste samples” (David, Lesson PS 04). Alec employed an avoidance type of conflict resolution (Pauli et al., 2008) where the group did not discuss nor plan the testing of this valid variable. This resulted in an effect where as noted by Graesser et al. (2018) “complete cooperation is not always beneficial … better solutions can sometimes emerge when there are productive forms of conflict” (p.2).

It should be added that Jim’s individual solution was very different from Alec’s and David’s’. He believed that their solution (despite participating within the collaborative discourse that led to the solution using the previously discussed method) would take “a very long time” and they would not be able to observe any changes. Thus the final written group solution included two different types of investigations as shown in Figure 5.17. These lacked a considerable amount of the detail that the group had discussed within the discussion phase. This is attributed to the group's poor time management, and "free-loading" effect (Daly & Worrell, 1993 as cited in Pauli et al., 2008, p. 48) where Alec and Jim did not contribute in the writing of the solution phase due to relying and assuming that this will be done by David.


- Precautions for safety
- The measurements that will be taken ~~of~~ of marble

We use a couple of of samples put it ~~a~~ on a Glass pane and put acid on its really important that we put the same amount of acid on each sample and we ~~bee~~ be careful of the acid so we we don't eat smell or taste any Acidic chemicals. We have to after check the metirial from a microscope. We could also ~~do~~ melt the ~~acit~~ marble into an acid put in a conical flask and ~~a~~ see if it mixes ~~with~~ it is effected if not it isn't effected.

Figure 5.17: Alec's team written solution to PS 04.

It should also be noted that this written collaborative solution included three misconceptions which were not present within Alec's individual one. These are:

(1) the incorrect usage of the term "marble" which should have been "material / monuments' materials" – an incorrect term that David was constantly using within his discourse,

(2) the monuments' materials have to be in liquid form in order for them to react with the acid – a misconception that Jim had, and

(3) monuments' materials are affected by the acid only if they are miscible – a misconception that Jim had.

5.3.6: Alec's Case Conclusion in respect to Research Questions 2 and 3

Contrary to various study's results (such as Azzopardi, 2008; Calabrese Barton et al., 2013; Galea, 2008; Ing & Nylund-Gibson, 2017) that attitudes become progressively more negative as students' progress from primary to the end of secondary school, Alec's initially expressed moderately positive attitudes were noted to become more strongly positive as the data collection phase was progressing. This could be attributed to his positive experience within the collaborative setting.

Despite his lack of detail within the individual solutions, Alec was often on the right track. He approached the problems assigned as a challenge to be mastered rather than as a threat to be avoided. Basing this on Bandura's 1997 work, this approach to PS indicated that his self-efficacy was higher or becoming higher than what initially expressed within the initial data collection phase.

The positive collaborative experience within his team enabled him to voice, clarify and build on his initial ideas. It was however also noted that when two (rather than one) of his peers were not viewing his idea, he did not persist on pushing it forward. He converged the discourse and avoided the conflict (Pauli et al., 2008).

Within the collaborative setting, most of Alec's individual solutions were improved. A considerable difference within the group's written solutions and the discussed ones was also noted where the latter were of a better standard than the former. This supports Kim and Pegg's 2019 study that "pen and pencil based individual tests might not be the best way to understand the complexity of the students' reasoning" (p. 742). The cognitive approaches developed through CPS "would take time to be transferred to individual abilities of reasoning and written tests" (Reznitskaya, Anderson, & Kuo, as cited in Kim & Pegg, 2019), and this seems to show that the assessment of students' PS abilities should not rely solely on the written solutions provided.

5.4: Keith's Case

5.4.1: Keith's Profile

Keith was a high achieving student with the highest positive attitudes regarding science, PS and CPS in most items found within the attitudes questionnaire when compared to the rest of the class. His mean positive attitude values were all within the range of 1.00 and 2.00. The way he approached science was "through testing and [using] complicated words" (Keith, PS 02).

The strong positive CPS attitudes that Keith expressed within the attitudes questionnaire were however not reflected in any of the other collected data – these were characterised by his negative attitudes towards CPS. This supports Di Martino and Zan's (2001) claim that students' declared beliefs may be different from their beliefs-in-practice.

Keith often showed a preference for individual work due to there being "no distractions" (Self-reflection PS 01) and "peace" (Self-reflection PS 02). In two out of the three self-reflection sheets that Keith completed, he identified that his weakness was that of "group work" (Self-reflection PS 01; PS 02) or to improve their work, his team and himself need to "communicate more" (Self-reflection PS 02). He disregarded his peers' contributions if they were not the same as his. Keith's negative attitude to collaborative work is similar to Shachar's (2003) finding about high achieving students who attributed their disregard to the collaborative learning style due to "not deriv[ing] any significant benefit[s]" (p. 112) from it, and changing the style of learning from the traditional whole class one poses a "threat in their success" (p. 113). Shachar added that gifted students associated negative attitudes to collaborative learning such as it not being challenging enough, an aspect that Keith also implied within his Self-Reflection to PS 04.

Apart from being high achieving, Keith also had a rich science capital. He was capable of talking about a multitude of science related topics, which the majority of students his age were not aware that exist. In class, he worked very fast, tried to solve most of the problems mentally, and often omitted intermediate steps within his replies. He needed to be constantly stimulated by more challenging things than what was normally presented to the rest of the class. If he was not actively cognitively engaged (such as during a traditional whole class lesson which would not be new to him), he would be completing notes related to upcoming lessons, drawing or humming. He also kept a small notebook within which he noted anything that he had not heard of before.

His oral class contributions which however were not always scientifically correct contained a lot of detail. As the year was progressing his lengthy explanations started to annoy the rest of the students in his class. This was eventually leading to bullying episodes in his regard by different students who wanted him to limit his contributions and give them a chance to speak. Towards the end of the scholastic year, Keith became withdrawn within the traditional classroom setting where he felt that the rest of the class was turning against him (Personal Lesson Notes, 2nd May 2018). He eventually felt comfortable only in the smaller collaborative group with whom he had worked since he was in primary school.

5.4.2: Keith and PS 01 whilst working with Marvin and Elton

As soon as the first problem was assigned, Keith expressed a high concept of self and efficacy. He stated “that I know a way to solve it” (Self-Reflection, PS 01) and felt comfortable working on his own due to having “no distractions” (Self-Reflection, PS 01). He felt connected with the problem due to placing it in context and having previously been at the site shown in the photo. He also showed positive attitudes towards the problem due to feeling that through this problem “mathematics makes sense” (Lesson PS 01).

He started working on the problem’s solution as soon as it was projected on the board and before I finished my explanation. His individual written solution is shown in Figure 5.18.

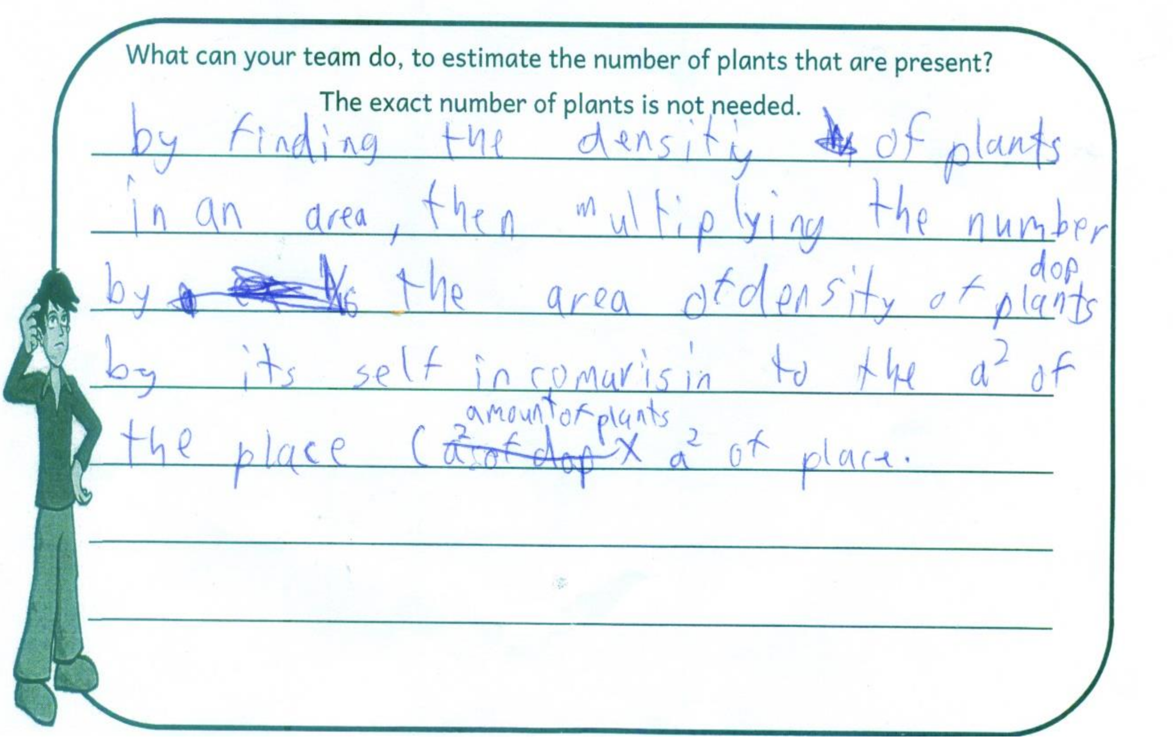


Figure 5.18: Keith's individual solution to PS 01.

This solution was on the right track. As he further orally explained in the initial collaborative phase he wanted to:

- find “the density of plants in a [small] area, example 1/32 of the area” (Lesson PS 01),
- multiply “this density by the [whole site’s] area” (Individual Solution PS 01; Lesson PS 01), and
- compare the value obtained to the first small area (Lesson PS 01).

There were opposing reactions to his solution. On one hand, Marvin (a high achieving student with whom he worked since primary school) understood his solution and started building on Keith's solution, whilst Elton (a high achieving and competitive student who had never worked with Keith) seemed to put down this solution. Elton also brought a tentative argument against it by saying "what if one place is run down and the others aren't?" (Elton, PS 01).

Keith did not manage to engage in collaborative work during this lesson's collaborative phase. He disregarded Elton's comment which was later also brought up by Marvin. Keith stopped his peers from discussing this aspect as he wanted to concentrate on his mathematical calculations. He did not include his group within his thinking process nor wanted them to speak nor distract him. Keith stated things such as:

- "Marvin I am trying to do quick maths OK? I'm trying to do quick maths so please [stop talking]",
- "sh sh",
- "I am concentrating here Elton" (Lesson PS 01).

.

When I asked the groups to explain what they had done, Keith was not entirely pleased with the group solution that had been written up to that point (which was individually constructed) and showed signs of demotivation by stating "How the hell. Noo. I give up". Elton (who proved to hold strong collaborative and competitive attitudes) tried to reassure him and even offered to go out with him to explain their working. Eventually in the lesson conclusion phase, whilst the other students were explaining their solutions, Keith managed to engage in collaborative discourse with Elton. They discussed how the pitfall previously identified could be solved. Similar to what was identified by Yaduvanshi and Singh (2019), this group of high achievers eventually benefitted by managing to "find gaps in their own understanding and … their understanding of [the] concept became clearer, misunderstanding resolved, and deep understanding is developed" (p.8).

The solution which was eventually explained to the rest of the class but not presented within the written common solution (due to time constraints) was of a very good standard. This included:

- finding the area of a number of small sites using a measuring tape,
- counting the number of plants in each of the small sites,
- finding the average number of plants and the average area of all the sites, and
- multiplying the plants' mean value with the total area of the site whilst also considering the mean area that the sites where the plants were found in.

Thus to conclude Keith's first problem solving task, it was noted that positive attitudes to science and PS resulted in a partially correct individual solution. This written solution was not clearly explained, however his explanation within the collaborative setting proved that he applied sampling principles within his solution.

Negative attitudes to CPS prevented Keith from engaging in collaborative work. This engagement was only noted when he realised that his solution lacked a detail and the time for providing this solution was drawing to an end.

The final written solution lacked the sampling technique identified within Keith's individual one. It only focused on finding a fraction of the area of the whole site – an aspect that Keith wrote whilst concentrating on how to complete the supposedly "collaborative solution". The oral solution which was a result of the collaborative process was however correct, complete and of a better standard than Keith's initial individual one. Thus similar to what was discussed in previous cases, the written solution did not show the student's PS skills.

5.4.3: Keith and PS 02 whilst working with Marvin and Blake

Similar to the previous PS task, Keith's positive attitudes to science and PS led him to quickly write and draw his solution. As shown in Figures 5.19 and 5.20, this included a closed circuit in parallel hidden under a table. He added a key with the meaning of each component. It should be noted that since this problem was used as part of a problem based learning pedagogy to introduce the topic of electricity, the class was not yet aware of the proper way of naming and representing electrical components. For this reason, Keith used the term "button" to mean "switch", and used alternative symbols based on what he was observing to represent the different electrical components. Within his individual solution, Keith also thought about a way of creating a type of cup / arch using "aluminium foil to amplify the sound because … [the sound emitted] would bounce off the aluminium foil and it will come out louder" (Keith, Lesson PS 02).

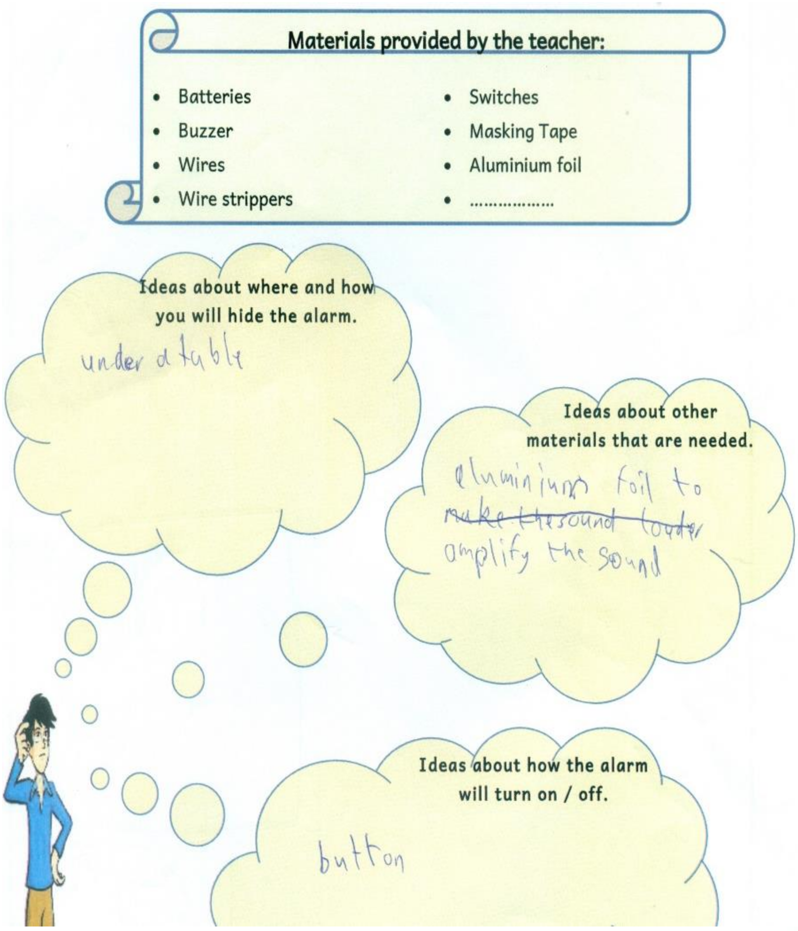


Figure 5.19: Keith's individual ideas on solving PS 02 page 1.

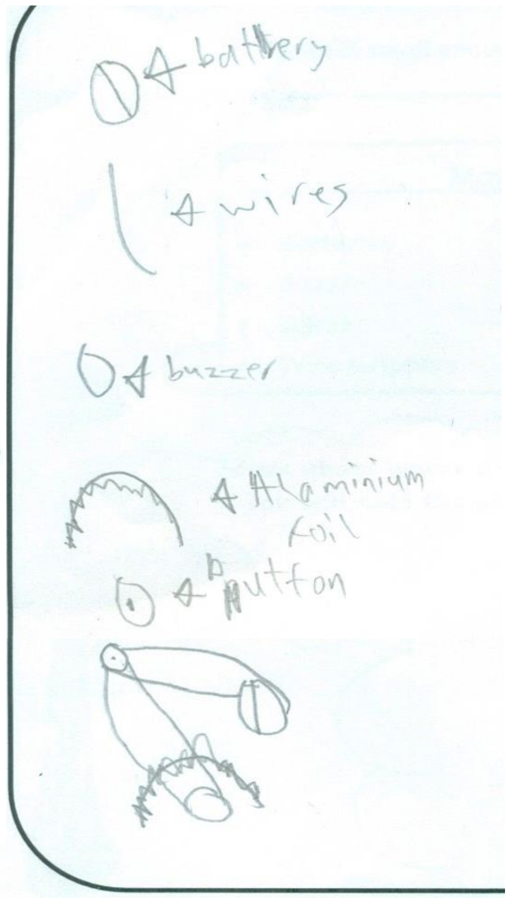


Figure 5.20: Keith's individual ideas *on solving PS 02 page 2.*

Keith was impatiently waiting to start the collaborative lesson phase and test his design. This impatience created some momentary disagreement with Marvin who wanted to follow closely my instructions and wait for the start of the collaborative and hands on phase prior to testing the ideas out.

Within the collaborative phase, unlike the previous PS task, there was the sharing of ideas between Keith and Marvin (whose solution showed a detailed explanation and had an incomplete circuit due to battery having just one wire connection). They wanted to know Blake's (a relatively low achievement student with a high science capital) ideas, however Blake managed to divert their attention away from his solution – possibly due to him noting that his drawn circuit was of a poorer standard.

Within the collaborative phase, Keith corrected the term "button" to "switch", and correctly explained, albeit without the use of the correct terminology, the functions of both the switch as it "would say yes or no to the buzzer" and the battery as it "gives power to the buzzer" (Keith, PS 02).

Keith exhibited task-involved goals (Eccles & Wigfield, 2002) as he was focused on mastering the task and making the buzzer buzz. Together with Marvin, he was actively building and re-building their circuit whilst testing it. This hands-on component however proved to be more challenging than the pen and paper plan. At one point Keith attributed the failure in achieving a louder sound in the group's buzzer to himself. This supported the empirical evidence that high achieving students attribute their success and failure to the personal effort factor (Weiner, 1994) and also re-confirmed his individualistic attitude as shown in the following excerpt:

> "my mind is horrible. I'm [a] horrible person <pause> I need to read some more Martin Luther King" (Lesson PS 02).

This excerpt which was followed by a persistence in finding the flaw within their set-up, also showed that most probably, Keith reads about inspirational people to motivate him.

Despite his individualistic attitudes, Keith was supported and encouraged to move forward by both his team mates until they managed to complete their functional circuit within the stipulated time.

Two drawings were presented as the written collaborative solutions (Figure 5.21). The drawing on the left which was an exact copy of Keith's individual solution drawn at the start of the collaborative phase by Keith, whilst that on the right indicates the group's actual set-up. This contains the same components shown within Keith's individual solution, and details as regards to what happens to the buzzer when the switch is turned on or off. The aluminium foil (found within Keith's individual solution) which had to provide the amplified sound effect was removed from the collaborative solution.

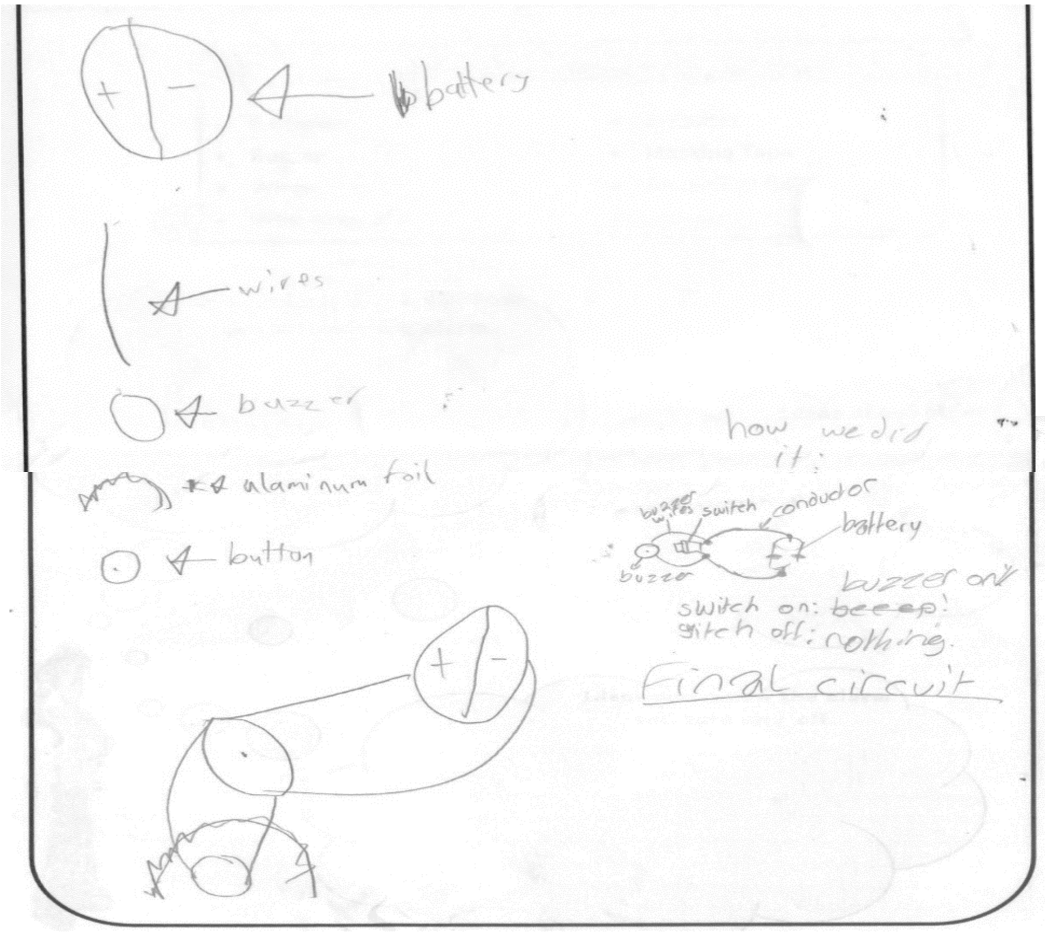


Figure 5.21: Keith's team solution to PS 02 page 2.

Thus to answer my second and third research questions with respect to Keith within this PS task, it was noted that his positive attitudes towards science and PS enabled him to individually successfully solve the assigned problem. The hands on component proved to be more challenging than the pen and paper one, however his team helped him persist and make the buzzer work. The minor difference found within the written collaborative solution when compared to the individual one is the omission of the cup shaped foil. This was omitted due to the team not detecting any differences within the sounds projected when the cup shaped foil was present or absent.

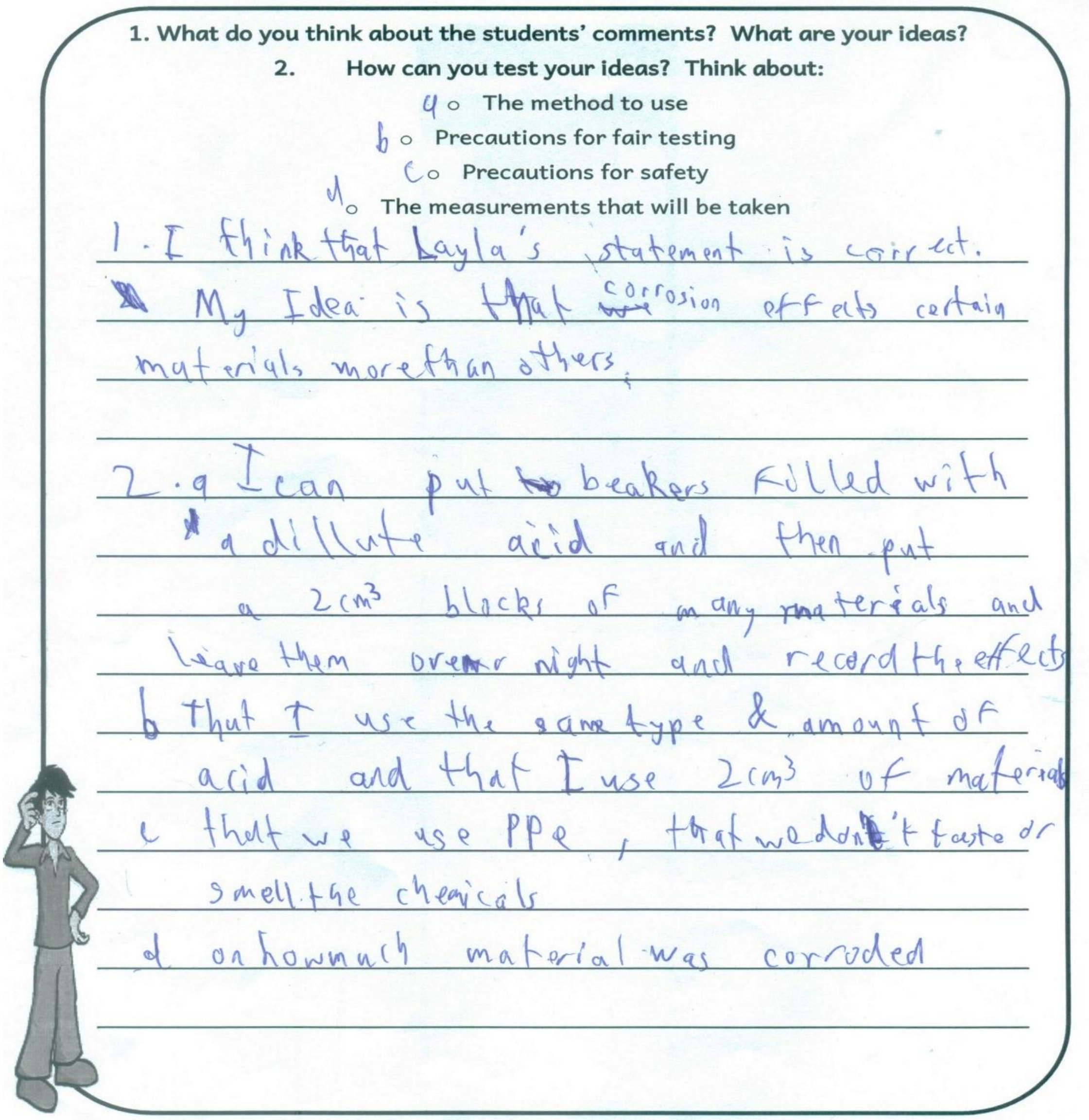
5.4.4: Keith and PS 03

Keith was absent for the third PS task.

5.4.5: Keith and PS 04 whilst working with Marvin and Blake

Keith felt that this problem "was going to be easy" and whilst working within his group he felt "that (for once) it was super easy" (Self-reflection PS 04). This could probably be attributed to having a very similar individual solution to that of Marvin and thus no conflicts and very minor clarifications were needed within the collaborative phase. Similar to PS 02, Blake's solution lacked the detail that Keith's and Marvin's had. Even though Keith and Marvin initially ensured that Blake participated within the discussion, items within his solution were not used in the discussion.

Keith's individual solution was correct and complete as shown in Figure 5.22.


1. What do you think about the students' comments? What are your ideas?

2. How can you test your ideas? Think about:

a ○ The method to use

b ○ Precautions for fair testing

c ○ Precautions for safety

d ○ The measurements that will be taken

1. I think that Layla's statement is correct.

My Idea is that corrosion effects certain materials more than others.

2. a I can put ~~two~~ beakers filled with a dilute acid and then put a 2cm³ blocks of many materials and leave them overnight and record the effects

b That I use the same type & amount of acid and that I use 2cm³ of material

c that we use PPE, that we don't taste or smell the chemicals

d on how much material was corroded

Figure 5.22: Keith's individual solution to PS 04.

Keith correctly identified Layla's statement (Appendix K – PS 04) as the correct one, and used the term "corrosion" to explain the effect of acid on the monuments' materials. This term had not been used during the topic of Acid and Alkalis discussed four months prior to this task.

Within his individual solution, Keith correctly transferred the context of the acid rain and the acidic bird droppings to the use of dilute acid in order to test the effect on different materials. He suggested that the different materials are to be in contact with the dilute acid "overnight". He specified the fair testing procedures of using the same type of acid, and 2 cm^3 of the various materials. Within the collaborative phase he explained the decision of using blocks having the same volume rather than same mass (as suggested by Marvin) and helped his group learn about density.

Keith's individual solution also focused on safety precautions related to the "use of PPE, [and] that we don't taste or smell the chemicals" (Individual Solution PS 04). His plan on the type of measurements that were to be taken were that they will measure "how much material was corroded".

PS 04's final collaborative solution was very similar to that provided by Keith's individual one. This may be attributed to the similar individual solutions provided by Keith and Marvin which resulted in no conflicts and minimal clarifications during the collaborative phase.

5.4.6: Keith's Case Conclusion in respect to Research Questions 2 and 3

Keith's positive attitudes and high self-efficacy to science and PS have resulted in Keith managing to provide appropriate solutions to the PS tasks within both the individual and the collaborative phases.

Keith's behaviour in respect to collaborative work was not aligned with what he expressed within the initial questionnaire. He only engaged in collaborative practices when he was relatively sure of his solution, and when his peers showed similar ideas to him. The collaborative setting however helped him:

- further clarify his ideas,
- calm down when expressing signs of self-doubt, and
- assist his friends in their learning.

On comparing the solutions provided within the individual and collaborative setting, it was noted that the collaborative solutions were heavily dependent on Keith's individual ones. Only minimal differences were observed. These included:

- the addition of finding the number of plants in several small areas within the collaborative solution rather than one area in PS 01,
- the omission of the cup shaped foil on top of the buzzer in PS 02, and
- rewording of the investigation plan in PS 04.

5.5: Elton's Case

5.5.1: Elton's profile

Elton was a new student in Year 7. He was high achieving, competitive and as shown in Appendix A expressed strong positive attitudes within the initial questionnaire with respect to:

- science (mean values for its sub items ranged between 1.20 and 1.67),
- PS (mean value for PS was 1.75, and for his PS self-concept was 1.40), and
- CPS (mean was 1.58).

He talked highly of the science experienced in Year 7 compared to his primary school years. He attributed this to the high amount of practical tasks in which he was cognitively engaged. These practical activities did not refer to lab activities only but also pen and paper ones amongst others as described by Leite and Dourado (2013).

As regards to his preference on whether problems and practical activities are to be guided or not he stated that he preferred that the teacher

> leave[s] it up to us (..) I prefer that it [problem/activity] will be open, not only because you'll [the teacher] be giving us the answer if you [the teacher] tell us everything step by step, but also because when we can do it in our own method we could test different

things out, and erm if we don't know it, we can discover something new ourselves.

(Focus Group)

Whenever he encountered difficulties, he did not let them pass by. He stated that:

> I either ask the teacher, my friends which are in my group, or else when I go home, this is what I do usually … I don't say, <in a pensive tone> "Now the lesson is over, we are not going to have any more of these lessons. Let it go. I learn about it next year." I go I go I go onto my computer. I search up about something about what we had done, and that way I can get more help.

(Focus Group)

Elton was one of those two students (Figure 4.2) who would like to become a scientist when he grows up. His idea of what a scientist's job is, was very broad and included doing "archaeology or things like that or an architect" (Focus Group). For Elton, science did not involve only the hands on lab activities but he acknowledged that "there's a lot research into science … You need to research how to do it [an experiment] … and you should be focused as a scientist" (Focus Group). This belief was also observed in the way he solved all the four PS tasks. I was struck by the way he persisted in finishing off all his individual solutions and planning (paying attention to the various variables) prior to starting the collaborative and/or hands on tasks.

Elton held the strongest positive PS self-concept and self-efficacy mean values (mean = 1.40) amongst his class. This was probably due to him experiencing various enactive mastery experiences (Bandura, 1997) throughout his primary schooling, such as participating in a Mathematics Comenius Project and in High 5 which is a Mathematics challenge aimed for the brighter students. His effort in overcoming obstacles enabled him to build a robust belief in his personal efficacy (Bandura, 1997). On talking about an incorrect response he gave in a test, he stated that "it was only a silly mistake not because I do not know them" (Focus Group). Thus, due to his high sense of efficacy, failures were attributed to aspects other than his ability as was also noted in a similar study by Ganzach, Stirin, Pazy, and Eden (2016).

His questionnaire's positive collaborative work attitude results were supported at various instances during the data collection phase. Elton valued the opportunities given for this type of work, and expressed its importance over academic learning too, such as when despite having learnt how sampling can be done, he reflected that what he learnt in PS 01 was "how to work better as a team" (Self-Reflection PS 01). Elton stated that even though he did not mind working individually since "you can express your opinion, your own feelings, and what you think about how you can solve it, you can write what you want on the paper" (Focus Group), but he still preferred working collaboratively since "we can combine them [the different ideas] together to make one big better idea" (Focus Group).

As stated earlier, Elton did not know any of the students in this class prior to the start of the scholastic year. I noted that he tested working with different students in the phase prior to the data collection. He found his preferred team during the second PS recorded task. As the school year was progressing, he started demonstrating a superiority complex attitude and not admit that he could have shortcomings. He was not pleased that other students might be as intelligent or brighter than him. On perceiving such students, he had the tendency of bullying them by putting down that person or his work. For example, during PS 02 he wanted to play the hidden buzzer trick on Keith "to give pay back to the guy who gives us a lot of biological explanations" (Lesson PS 02).

He looked down at students whom he perceived to be of a lower achievement level than him. This was noted by:

- ignoring Drew's individual responses due to having less written information than him (Personal Analytic Memos PS 04),
- stating that a set-up is not working due to having Drew within his team (PS 02), or
- calling Drew names such as "Pug" in PS 02.

Elton's superiority complex, combined with his competitive attitude, yet valuing the beneficial effects of collaborative work attitude were resulting in:

- putting down the work of other teams by the various comments he would pass, but also
- helping his team move forward and create the best possible solution as shall be seen in the following four sections.

5.5.2: Elton and PS 01 whilst working with Marvin and Keith

As soon as the problem was assigned, Elton expressed his positive attitude towards this problem and stated "I already know this", and told the rest of the group who were both high achieving students that he would be telling them how they were to solve it.

Elton's individual solution was that of:

"We can multiply 440 and 60, then halve it.
440 m x 60 m = 2640m ÷ 2 = 1320 p"

(Individual Solution PS 01)

This was not a correct answer. The area of the whole site was to be found, however the dividing the site's area by two to estimate the number of plants was not. He did not elaborate why he decided to do this, however it was probable that he was assuming from the photo and picture shown that the plants were found in just half of the site's area.

During the collaborative phase, his peer's Keith previously mentioned proposal (Section 5.4.2) i.e.

1. finding the amount of plants in a smaller area of the site which can be easily measured, and

2. multiplying this by the area of the whole site compared to the original small measured area (Lesson PS 01)

was correct. Elton did not initially respond positively to Keith's different (and better solution), by yawning loudly and stating "we need to find out over here … [and] what if one place is run down and the others aren't?" (Lesson PS 01). As Elton eventually realised that his plan was not correct, he stated "I would have used that method if I knew that we had to find out [the answer] there [during the fieldwork activity]". He found it hard to accept that others' solutions could be better.

As I've asked the class to explain what each group had done, his peer Keith expressed signs of demotivation due to not being entirely pleased with the written team solution (based on Keith's initial solution). Eventually, in order to still manage to provide a correct solution within the collaborative setting, Elton tried to reassure and encourage his friend. They kept on co-constructing strategies and transforming their knowledge (Grau et al., 2018) to solve the pitfall previously identified by Elton (and Marvin) i.e. different areas within the site having different amounts of plants. Their exploratory type of talk led to metacognitively regulating their collective activity as also reported by Grau et al., (2018) and providing an oral solution (discussed in Section 5.4.2) which was of a very good standard.

Thus to answer my second and third research questions, Elton only managed to properly identify the aim of the problem assigned after resolving the initial conflict that arose within the team. Elton's high concept of self, resulted in him not accepting pitfalls that he had in his initial solution. His competitive attitudes, however enabled him to persist and ensure in doing well as he had done in previous years. His positive attitudes towards collaboration and his high group commitment enabled him to eventually see the good of others' work and encourage and motivate all the team to move forward and provide a much better solution than his (and his friends') original one.

5.5.3: Elton and PS 02 whilst working with Sebbie and Drew

As the individual task started, Elton expressed PS confidence due to having built an electrical circuit in his primary school. His individual written solution is correct and shows the parallel circuit and how it will be attached to a pocket as illustrated in Figure 5.23.

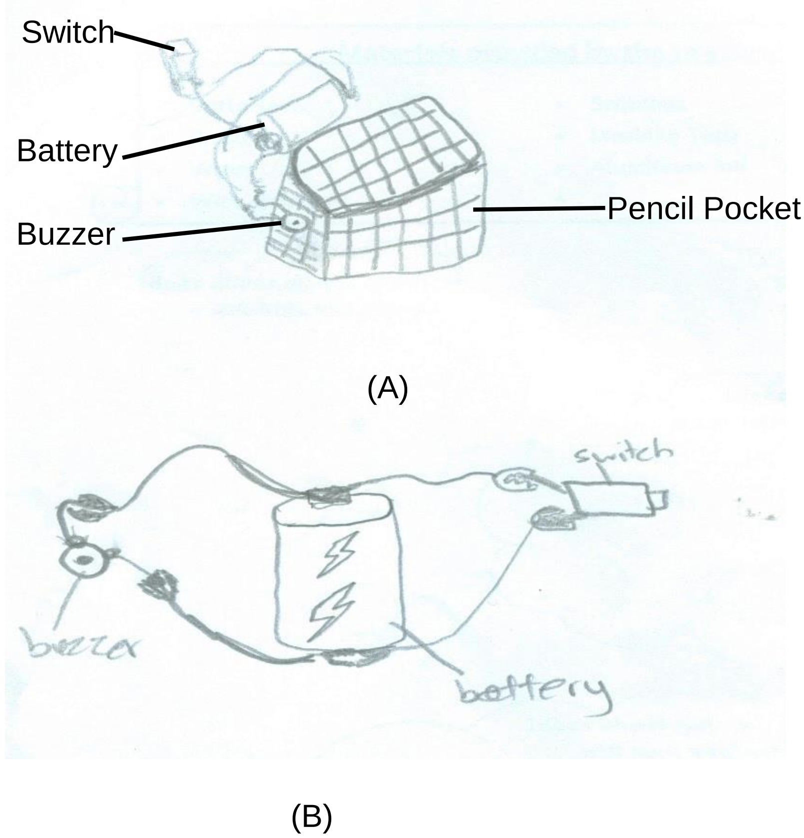


Figure 5.23: Elton's individual solution to PS 02. (A) Electrical circuit as attached to a friend's pencil pocket. (B) Details of electrical circuit.

Despite the different but correct plans by all the individual members, the team experienced various difficulties in the hands-on component. This was eventually overcome when Elton suggested building the circuit with just a bulb instead of a buzzer and switch to check whether everything would be fine. Thus Elton transferred his previous knowledge about electrical circuits to the new situation. The team's discussions, trials and errors, and the reduction in the number of electrical components were strategies that helped them identify where the pitfall within their solution was.

The team eventually managed to build a complete circuit in series by the use of a circuit board, buzzer and two batteries to have more power.

As soon as the team was stretched to build a circuit without a circuit board, they tried updating their latter one. With perseverance to overcome the new difficulties, the team managed to build another circuit in series, which was small enough to be hidden in a pocket.

Following the team's classroom explanation on their solution, Elton expressed how proud he felt by speaking directly in the audio recorder and stating "Guys, we are winning. We were the only ones to do it without a circuit [meaning circuit board], and hide it in someone's pocket, but it took a lot of time" (Lesson PS 02). Elton's perception of having success in designing the best solution with difficulty, could possibly have further attributed to Elton's resilient sense of efficacy beliefs (Bandura, 1997).

Thus to conclude PS 02, Elton's prior knowledge enabled him to correctly draw a complete parallel circuit. The hands on component was more challenging. His (and the team's) positive attitudes and ambition to succeed and be the best, enabled him (and the team) to go beyond the construction of a circuit in series with the help of a circuit board, but create a free standing smaller circuit in series which could be hidden within a pocket. This was considered to be more difficult due to encountering more challenges in ensuring good electrical contacts. The final solution showed differences from Elton's (circuit in parallel with one battery, one switch and buzzer) and Sebbie's (circuit in parallel which includes one battery, one switch, one bulb and a buzzer) individual ones, but considerable similarities to Drew's (which designed a circuit in series with a switch, battery and buzzer).

5.5.4: Elton and PS 03 whilst working with Sebbie and Drew

Contrary to the previous two PS tasks, as soon as the problem was assigned, Elton was noted to feel less confident. He felt "excited and a bit confused" and he stated that his weakness was that he "had to think of one moment" which probably means that he had to think harder than usual since he "never used such apparatus" (Self-Reflection Sheet PS 03).

Due to his high level of self-efficacy however, he approached this perceived more difficult task as a "challenge to be mastered rather than as a threat to be avoided (Bandura, 1997, p. 39). Elton tried communicating with his peers prior to the start of the collaborative phase go-ahead on how the problem could be solved. This could probably be attributed to Elton cognitively re-examining and reorganising his understanding in order to develop a better understanding of the problem (Gillies et al., 2011, p.427) and obtaining a sense of reassurance prior to concentrating his efforts on the solution.

This resulted in Elton's delay in starting his individual solution and eventually completing page 1 only with ideas on how to solve this problem as shown in Figure 5.24.

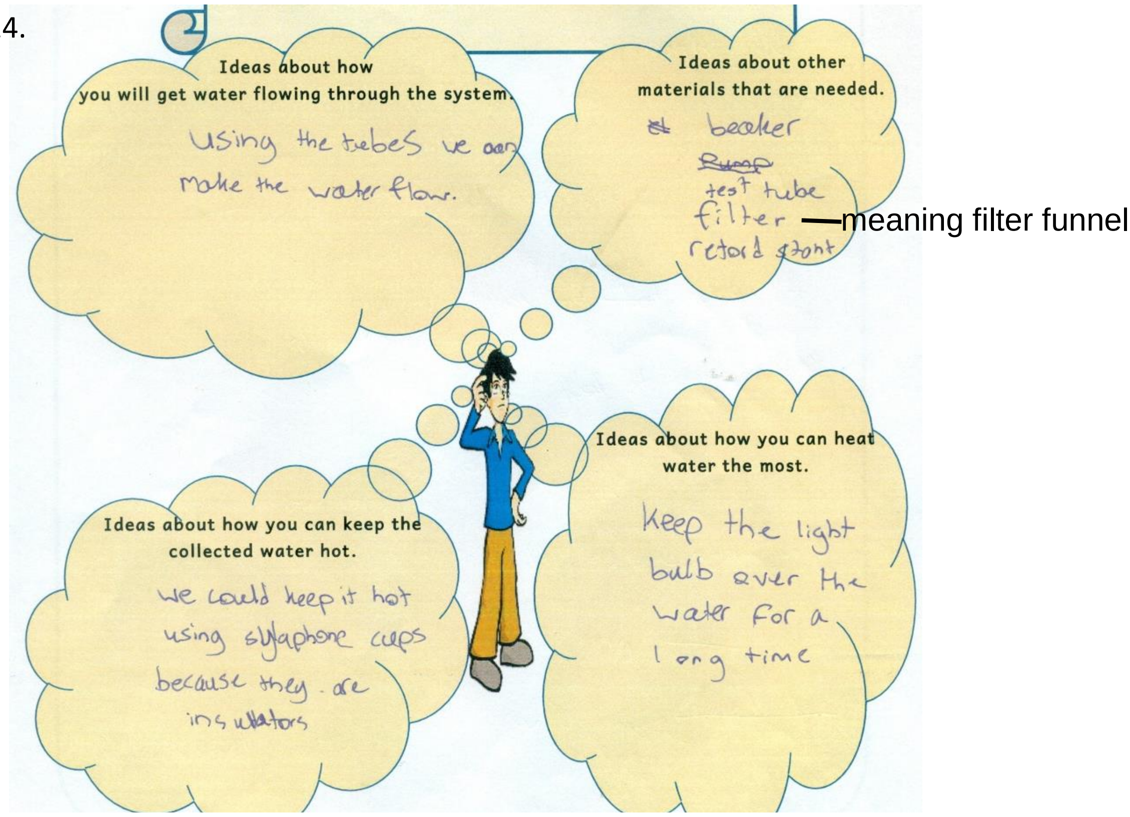


Figure 5.24: Elton's individual solution to PS 03.

At the start of the permissible collaborative phase, the team discussed the various
At the start of the permissible collaborative phase, the team discussed the various ideas that each member had. Sebbie found difficulty in understanding Elton's idea on how a light bulb could heat water. Elton's "helping discourse" (Gillies et al., 2011, p. 431) facilitated Sebbie's learning by reminding him about previous lessons' content knowledge related to energy transfer and heat energy losses. Elton also helped Sebbie consolidate his understanding by asking him to place his hand on top of the lit bulb and feel the heat.

The team's discourse eventually changed to an interactive type (Gillies et al., 2011, p. 431) where Elton built on Sebbie's individual idea (Figure 5.25), and suggested replacing the test-tube with a conical flask since he believed that it will absorb more heat due to being flat. Within their discussion the students gave a valid explanation for all components they included such as placing the bulb at the bottom and using just a small amount of water. No scientific reason was however given for the use of the tubing. It was included just for "fun" (Elton & Sebbie, Lesson PS 03), and to make it look cool (Drew, Self-Reflection PS 03; Elton, Lesson PS 03).

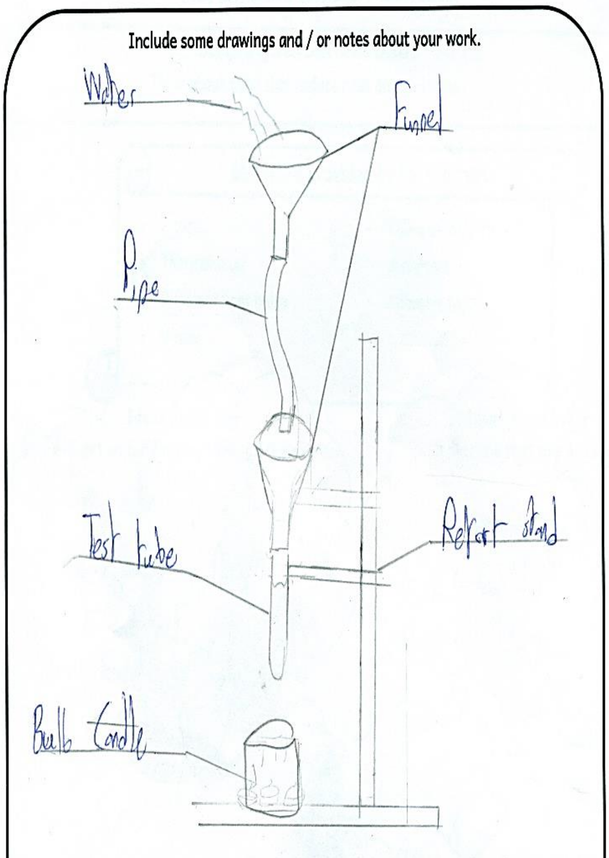


Figure 5.26: Sebbie's individual solution to PS 03.

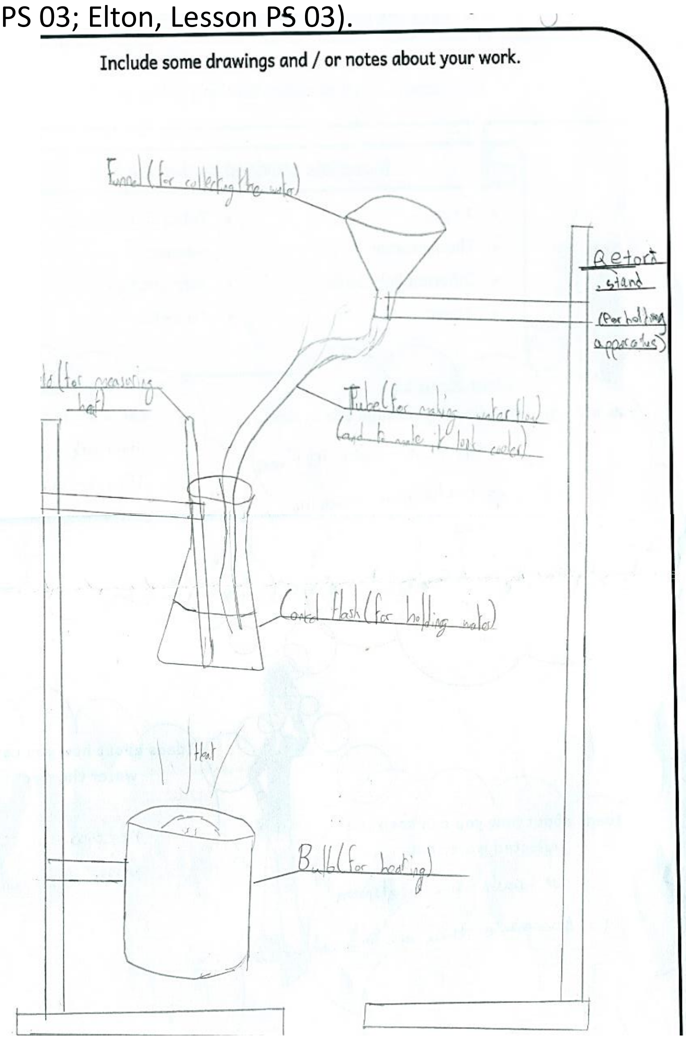


Figure 5.25: The group's solution to PS 03.

As the water was heated, the students updated their design to increase and maintain the increased temperature of the water by:

- adding more light bulbs, and
- covering the conical flask with a lid and Styrofoam material.

These updates were not included within the common solution sheet shown in Figure 5.26 (due to finalising the written solution prior to the hands-on stage). This, thus further supports my previous claim that if one is to assess students' PS and/or CPS capabilities, s/he is not to rely solely on a written product but other forms of products and processes are also to be paid attention to.

On concluding PS 03, Elton initially showed less confidence compared to previous PS tasks due to being presented with a different type of problem from what he was accustomed to, and with materials he had not handled before. His high self-efficacy however, resulted in more active coping strategies (Bandura, 1997; Schunk & DiBenedetto, 2016) where he did not give up but spent more time and effort in overcoming this obstacle. The discussions and planning on paper enabled him to regain confidence, clarify his ideas and also help his peers. His perception of a more challenging problem, enabled him to engage in true collaboration with all team members and not express any superiority complex attitudes towards Drew. The final solution included aspects taken from each team member's individual solution and was a better version of all the individual ones.

5.5.5: Elton and PS 04 whilst working with Sebbie and Drew

Similar to PS 03, the initial phase of the fourth PS task, was also characterised by Elton's reduced confidence levels. He felt "unsure" (Self-Reflection PS 04), and took a long time prior to starting his work (Field Notes PS 04). He stated, "I know nothing on this" (Lesson PS 04) and attributed this to being a different problem to the others (Self-Reflection PS 04) as he had stated in PS 03. After a relatively long thinking time, he wrote his individual solution. This solution, together with that of his peers are rewritten in Table 5.1.

Elton's and Drew's ideas were similar and correct, however (i) Elton gave more details as regards to the quantities to be used but made no reference to final measurements, and (ii) Drew managed to relate the acid rain and bird droppings context with acids found in the lab – a topic that was dealt with in class four months earlier. Sebbie's solution on the other hand showed that he did not understand the aim of the problem assigned.

Table 5.1: Elton's team members individual solutions

Student	Individual Solution
Elton	• Placing 1.5 kg samples of the different monuments' materials in a container that is resistant to acidic substances. • Adding 50 ml acid rain to the rock samples. (**Precautions:** use containers that are resistant to acidic rain, and wear safety goggles, lab coat and gloves)
Drew	• Using blocks of the different monuments' materials in an open container. • Slowly pour [a school lab] acid. • Note any changes. (**Precautions:** add the acid slowly, wear safety goggles and lab coat)
Sebbie	• Use two monuments of the same material, shape, volume, weight and density. • Place the monuments under two bird cages with birds. • The birds in one cage should have eaten more acidic food, whilst the birds in the other should have eaten less acidic food. • After a considerably long time compare the volume / weight of the monuments. **(Precautions**: Material of monuments are to be of the same shape, volume, weight and density)

Once the collaborative phase started and Elton felt that his individual solution was correct, an attitude change was noted. The over-confidence and superiority complex towards both his peers recorded within this last PS lesson data collected was at its highest. Amongst others, Elton:

- made fun of Drew for skipping a line in his initial solution, and eventually ignored completely Drew's individual solution without reading it (despite it being similar to his),

- told Sebbie “you’re not using your brains” or “so say that [the procedural steps] in there [the individual solution sheet]”,
- did not accept Drew’s comment that Sebbie had more detail within his individual solution than him, and
- put down Sebbie’s solution by stating that “food and pH of rain are for extra things” since these aspects were not considered in his solution.

The result of Elton’s superiority complex lead to a decreased harmony within the supposedly collaborative phase. Drew did not manage to voice his idea but took a mediator role between his peers, whilst Sebbie’s efforts were on defending his work and ideas due to them being intermittently bombarded with opposing remarks from Elton. Sebbie was very tense and not working to his usual full potential.

Eventually, as the time allocated was drawing to an end, Elton tried to resolve the conflict by stating that Sebbie’s and his ideas were “the same except for one was using acid rain whilst the other was using the bird poop” (Lesson PS 04). During the writing of the common solution a more tranquil atmosphere was recorded characterised by helping and problem solving discourse (Gillies et al., 2011) where eventually Elton helped Sebbie understand:

- the aim of the investigation they were to plan,
- the reason why within their plan the monument’s materials are to be different, and
- his misconception related to density where different materials cannot have the same shape, volume and “weight”.

This discussion eventually led them to the group common solution where two separate solutions were given. These included:

- Elton’s initial solution, and
- Sebbie’s updated initial solution (i.e. placing 1.5 kg blocks of different materials underneath bird cages with five pigeons in each).

The two separate solutions conflict could have been overcome if Elton and Sebbie considered Drew's transferred idea of using a lab acid instead of the separate acid rain or acidic bird droppings one. Their perception of Drew as a student with lower academic achievement and Drew not being confident and assertive enough in explaining his idea may have led the team in giving a correct solution which could however be improved. This was the first time that Elton's team solution was classified as such, and this could also be linked to Elton's high self-assurance and superiority complex demonstrated in this last task compared to the previous three.

On concluding PS 04, Elton's initial decreased confidence in this PS task could also be related to him analysing its context as different. However, as soon as he individually worked on its solution, and assumed it was the best, his superiority complex affected the group dynamics. Effort was wasted on the proper functioning of the group rather than on solving and learning from the problem provided. Collaborative work was only noted when Elton felt that it was time to finalise the solution, where he led the group to use his unchanged individual solution, updated Sebbie's and totally ignored Drew's valid individual solution.

5.5.6: Elton's Case Conclusion in respect to Research Questions 2 and 3

Elton's high positive attitudes to science, PS and collaborative work seem to have enabled Elton to provide correct or partially correct solutions in all his assigned individual problem solving tasks. Elton valued individual time at the start of the PS process due to having enough thinking alone time and not converge on just one idea at the start of the CPS process. Interactive dialogue was also valued and important for Elton as it helped him clarify his thoughts, understand the problem better and provide improved solutions.

With the exception of the last PS task, through his high concept of self, competitive and positive attitudes to science, PS and CPS, he managed to encourage his team where everybody achieved an improved solution. He helped team members whom he perceived to be of a similar achievement level by calming them down, clarifying investigation aims and/or misconceptions. Through his attitudes of superiority, Elton ignored team members whom he perceived to be of a lower ability. This had a detrimental effect on his final solution as their important contributions were not even considered.

Amelioration of his individual solutions were noted in the first and third PS tasks following collaboration. Both the individual and collaborative solutions provided in his second PS task were correct. The last collaborative PS task solution included an exact presentation of his individual solution and the addition of an improved solution a peer provided.

5.6: Conclusion

The four cases analysed in depth within this chapter seemed to show a link between Year 7 students' attitudes, self-efficacy and capability of solving science based problems. The more negative a particular student's attitudes were, the least effort and perseverance in solving the problem was noted. In situations of negative attitudes, managing to solve problems required the collaborative setting and various stimulations such as an attractive, relevant and hands-on context which had to be supported by teacher's prompts. Positive attitudes on the other hand were associated with perseverance and effort in managing to solve the problem where giving up was never a considered option.

An analysis of the students' PS process and solutions indicated, that one is to use various modes of assessing them. Apart from a product focused on written solutions, one ought to consider also products based on designs and class-based oral explanations, and the PS process such as the individual student's contributions within the collaborative setting. Students with poor aspirations or low confidence levels had the tendency of not articulating their thoughts on paper or orally in front of a whole class.

As regards to my third research question, these four cases also indicated that one ought not generalise on the impact on solutions provided when engaging in CPS when compared to individual PS. Similar to Shachar's (2003) findings, the student having the lowest achievement level benefitted by having all his solutions (written/oral/hands on) within the collaborative setting of a better standard. Collaborative work enabled him to engage and focus on the problem provided. The student of average achievement whose voice was hardly ever heard also benefitted from the collaborative setting as it provided him with the opportunity to ameliorate his reply and articulate his ideas. The least differences in solutions were found in the two students of relatively high achievement level. They disregarded ideas that were contributed by students whom they perceived as lower achieving. Very often these high achieving students just re-worded or added minor elaborations to the solutions they provided within the individual setting. Only few improvements in their solutions were noted, however the collaborative discourse aided them to clarify their thoughts, understand the problem better, and obtain help in hands-on tasks which they were not so proficient in.

Chapter 6: Conclusions

6.1 Introduction

This study attempted to fill the gap in local literature about Year 7 students' attitudes to science, PS and CPS, and whether these attitudes and self-efficacy affect students' success in solving science based problems. It also attempted to identify whether differences in solutions are obtained when local Year 7 students solve problems individually and collaboratively.

6.2 Overview of Main Findings

This section outlines the main findings related to the study's research questions.

6.2.1 What are Year 7 Students' Attitudes to Science, Problem Solving and Collaborative Problem Solving?

Similar to other studies (Borg, 2013; Galea, 2008; Ing & Nylund-Gibson, 2017) it was found that as mixed achievement levels students enter their secondary school phase, they seem to have positive attitudes and self-concept to science. Students' positive attitudes to the practical hands-on components was tentatively attributed to Abraham's (2009) concept about the novelty of being in a lab and using lab equipment, and to the different pedagogy employed within the science lessons when compared to other subjects. This study however also confirmed a finding similar to other studies (Jenkins and Nelson, 2005; Sjøberg & Schreiner, 2010), that very few students aspire to take a career in the scientific field.

Most students' attitudes and self-concept towards PS were positive. A high self-concept resulted in more active coping behaviours during PS. Students' attitudes to PS depended also on (i) whether the problems were paper-and-pencil, hands-on or numeric types, (ii) what the topic of the problem was about, (iii) the problem's utility value and context students viewed it in and (iv) the student's perception of the problem's difficulty level.

Similar to Osborne and Collins (2001), this study found that pedagogy and the use of hands-on problem types was reciprocal on certain students' attitudes. Those students who were usually disengaged during traditional lessons, improved their attitudes in terms of persistence and engagement when presented with hands-on problem types that could be solved within a collaborative setting.

The actual (as opposed to the declared) attitudes towards CPS seemed to depend on the students' achievement levels. All students with a low to average achievement level held relatively higher positive attitudes towards CPS, than those with higher achievement levels. These findings were similar to those of Aquilina (2015) and Shachar (2003). Higher achievement students had the tendency of engaging in a collaborative process only with those students whom they perceived to be of a similar achievement level and did not waste time during tasks. They assumed that students who were not of a similar level to them could not contribute anything of value within the team.

6.2.2 Is there a Relation between Year 7 Students' Attitudes, Self-efficacy and Capability of Solving Science Based Problems?

The study seemed to indicate that negative students' attitudes towards science and PS resulted in less engagement, effort and perseverance in solving problems. At times, this resulted in "social loafing" or "free-riding" (Karau & Williams, and Solomon & Globerson, as cited in Pauli et al., 2008, p. 48) where the student did not contribute to the group's effort, due to assuming that the other members would do this work (Pauli et al., 2008).

This study found that students with negative attitudes to science and PS had the tendency of being more engaged in problems that (i) required the hands-on component and (ii) which they perceived as relevant. An analysis of the data collected suggested that these students can manage to solve problems, however they required (i) a positive attitude to collaborative work and engagement within the collaborative setting, (ii) support in the form of scaffolding questions and prompts from the teacher, and (iii) an assessment that considers both the process the student engaged in and the final product, as students' poor attitudes and limited perseverance often resulted in them not finalising a PS task.

Students with positive attitudes towards science and PS, had the tendency to show more effort and perseverance whilst solving problems. This helped students manage to solve the assigned problems at both the individual and collaborative levels. Such students never considered giving up at any stage of the individual or collaborative phase.

As regards to CPS attitudes, this study found that no matter what the students' attitudes were, just as long as students managed to engage within collaborative discourse with one or more of their peers, a benefit on PS would be obtained. These benefits ranged from (i) better engagement with the problem, (ii) focusing on and understanding the problem assigned, (iii) voicing, articulating, clarifying and elaborating ideas on how problems could be solved, (iv) identifying misconceptions, and (v) overcoming those areas that one is not particularly strong in (such as the written/oral component, hands-on component, and creativity).

For the various students' attitudes, it was found that different methods that assess the students' capability of solving problems are required. It seemed that written solutions should not be the sole mode, but methods such as class-based oral explanations, students' designs and hands-on set-ups, and individual students' discourse whilst discussing the problems and their solutions within the collaborative team are needed.

6.2.3 Are there Differences in Solutions when Year 7 Students Work Individually and Collaboratively?

As summarised in the previous section, CPS benefitted all students within their PS process. Students' discourse within the collaborative setting gave me the opportunity to determine whether a student could solve the problem or not. The discourse also helped me diagnose which part of the PS process students had difficulty in as their written components were often not aligned with the reasoning processes.

Similar to Shachar's (2003) findings, it was found that the biggest improvement within solutions were found in those students of lower and average achievement levels. As a result of collaboration, such students gave more elaborate solutions that looked into different variables, sources of error, and fair testing which were rarely found within their individual solutions.

It was found that high achieving students, produced relatively appropriate individual solutions. Following collaboration, only minor ameliorations within their solutions were produced. These were manifested by re-wording or other minor elaborations of the individual solution. It was also noted that these students exhibited high self-assurance that seemed to result in a disregarded of ideas / solutions produced by students whom they perceived to be of a lower achievement level. A consideration of such ideas / solutions could have produced solutions of even better standards.

Some minor regressions within the collaborative solution could however also occur. This could happen when particular group members use misconceptions within their discourse and this goes undetected by the rest of the team.

6.3 Overview of Secondary Findings

Secondary findings that were found include:

- Most students in Year 7 did not have clear ideas about the range of careers that require a science background.

- The time allocated for individual PS prior to the start of the collaborative phase was important. It enabled students to explore their individual ideas and not converge on just one at the start of the collaborative phase.

- Certain students had the tendency of putting down the work of their peers and at times this could have also resulted in bullying episodes which deterred collaboration. Such behaviours were attributed to the possibility of having students with (i) very different achievement levels working within the same group, (ii) highly competitive attitudes associated with attitudes of superiority, or (iii) a negative perspective to life in general.

- Collaborative work was especially important for (i) shy and introvert students, and (ii) new students that entered church schools and would not have known any of the other students. This helped them in socialising and building their friendship circles.

- Collaborative PS enabled the vocalisation of various misconceptions that would not have otherwise emerged in more traditional and individualistic settings. Students within their teams may help each other see and overcome these misconceptions.

6.4 Implications and Recommendations of the Study

My experience through this case study has allowed me to experience, appreciate and advocate amongst my colleagues the use of CPS within the Year 7 science classroom. Successful collaborative groups and solving problems can help students achieve science cognitive goals where they are active participants. Apart from improving on the cognitive level, students also develop and reinforce the skills of working jointly with peers on common problems and build their friendship circles – an aspect that was especially important for students entering the secondary school.

Appropriate and effective collaborative skills however need practice and are not easily achieved when students are not accustomed to such pedagogies. Should these skills not be in place, there is the risk of having particular individuals taking over, bullying or not contributing to the team's effort. Thus it is recommended that various lessons related to working in collaborative groups are planned at the start of the scholastic year and reinforced throughout the year. Teachers should also experiment with having students working in different groups, prior to establishing particular heterogeneous groups. Particular attention is to be given to groups of students having extreme differences within their achievement levels as true collaboration might be more difficult to achieve. It is also recommended that the Year 7 science teacher is not the only teacher embracing this pedagogy. Educators in the primary school and other subjects' teachers should also use this approach consistently.

Another factor that seemed to affect the success of the CPS, was the planning of various scaffolding questions, prompts or more challenging questions that were kept aside and used according to the students' and groups' needs. Teachers teaching mixed achievement levels cannot expect one plan to fit all, thus these types of plans enable one to scaffold, guide and stretch students / groups according to their needs.

As outlined in my findings and analysis to research questions two and three, teachers cannot rely on just a written product to assess students' PS capabilities. Thus it is recommended that teachers at Year 7 plan and ask for a variety of products that students may work upon whilst solving problems. Marking schemes should also be designed to assess the students' CPS process. Nationally a step in this direction has just being introduced by the introduction of the new Year 7 assessment scheme that started in scholastic year 2018 - 2019 (DLAP, 2018b; 2018c). This requires that the pedagogy used for the topic of energy is a project based learning approach, and the assessment criteria are mainly focused on the process rather than the final product (DLAP, 2018c). Teachers could consider extending this and the CPS approach to other topics (or parts of topics) as this enables students further develop and reinforce the required CPS skills.

The experience within this study made me realise that teachers might not be fully aware of particular students who are highly sensitive to their physical surroundings (such as noise levels and physical proximity of other students). These students thus might not have strong positive attitudes towards collaborative learning due to the physical environment, and not to the process as such. It is thus recommended that teachers include a type of student self-reflection sheet in at least some of their lessons where one of the questions/prompts relates to what the student likes/dislikes within the lesson. Teacher actions should then be made according to the feedback obtained.

This study enabled me to find that most Year 7 students' attitudes towards science are positive, and thus teachers within secondary schools should keep on encouraging and promoting such an attitude through the use of an IBL and CPS pedagogy where all students are given a chance to experience success and show their learning. This study however also showed that educators are to be aware that negative attitudes might also be present in Year 7 students as opposed to what is generally found in literature. Since the study found that this particular attitude was not solely tied to science but to the student's outlook to life in general, all educators and not just the science ones are thus encouraged to include activities and tasks that aid students see and feel the beauty of life and being part of an understanding group. Such an improvement in attitude may eventually also improve the way certain academic subjects are also perceived.

6.5 A Critique of the Study and its Method

This study employed a case-study methodology, whose participants were a small group of thirteen Year 7 mixed achievement boys in a church school to answer the first research question, and an even smaller group of four students to answer the second and third research questions. This approach's main limitation was that of not being able to make generalisations and causal relationships could not be established directly (Yin, 2014).   Case studies however are strong on reality and provide insights into other similar cases (Nisbet & Watt as cited in Cohen et al., 2018). One may thus expect to find a certain amount of similarities as regards to Year 7 students' attitudes, and the effect this might have on their individual and collaborative PS processes and solutions. Caution is however to be paid as other factors may influence CPS as well.

A strength of the methodology employed was the use of multiple tools (questionnaires, observations, lessons' audio-recordings, students' solutions to the problems, students' self-reflections and group interview) that enabled the possibility of triangulation. According to Cohen et al. (2018), these different tools improve the validity and reliability of results, and also enable the production of a more holistic picture. A limitation of recording lessons solely via audio, participant observations and field notes was however encountered in hands-on type of problems. At times (such as when I was next to other groups, or when there were no verbal exchanges), I did not have complete data on the way materials were being handled and moved.

Strengths of the problems designed included the use of different types of problems (numeric, written and hands-on), and different topics of the Year 7 syllabus, as this attempted to give a more holistic picture of the different PS processes that may be encountered in the science class. A critique of this however is that I did not repeat different PS examples within the same topic nor particular problem types. Thus extrapolations to PS within the same topics or the same problem types cannot be made.

6.6 Suggestions for Further Studies

More knowledge about attitudes and PS in the STEM classroom could be collected through further studies. A similar study could be repeated (i) with students of a different age/sex, (ii) in other STEM subjects/topics or school settings. Ideally such a study is accompanied with a video-based analysis (Brown, Furtak, Timms, Nagashima & Wilson, 2010) to analyse the PS process in more depth. Other areas that may be of interest, include basing one's study on one of the following research questions:

- What can be done to maintain students' interests in the sciences as students progress within their secondary school years?
- How can CPS be implemented within various subjects at schools?
- To what extent do students of particular achievement levels (high achieving or low achieving) benefit from IBL and CPS pedagogies? What classroom settings and support would students need to obtain maximum gains?
- To what extent does language proficiency affect students' PS? What support do students and their teachers require to maximise student learning gains?

- What is limiting teachers' use of CPS pedagogies in the science class? What support would teachers benefit of?
- How can formal assessment practices be updated to give value to both the processes and products of PS and CPS?

6.7 Conclusion

This study found that students have overall positive attitudes towards science, PS and CPS. These attitudes and self-efficacy affect up to a certain extent the way students solve problems. Positive attitudes result in more student engagement, active learning and perseverance. Negative attitudes towards science and PS and low self-efficacy however required the use of a collaborative setting and teacher's prompts to manage to engage with and solve problems.

The collaborative setting resulted in the improvement of most students' solutions. However, one is not to focus on the products of these problems only, as numerous other benefits are achieved.

Through the findings of this study, I attempted to inform the educational community about students' attitudes, and the benefits of both individual and collaborative PS. As new syllabi are being launched, this study provides useful insights on this important approach to science learning. I hope that more teachers are encouraged to implement a CPS pedagogy, and more students are provided with the opportunity to experience and develop scientific literacy skills and modes of thinking and communication that aid in the solving of future problems in teams.

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Appendix A: Students' Mean Positive Attitude Questionnaire Data

Table A.1: Students' positive attitudes towards science, PS and collaborative work.

	The student's positive attitude to school science mean* of S 01-05 (following reverse coding of question S05)	The students' positive self-concept to school science mean* of S 06-S 13 (following reverse coding of questions S06, S07, S11, S12, S13)	The student's positive attitude to school science practical work mean* of S14 - S17	The student's positive attitude to science outside school mean* of S18 – S22	The student's positive attitude to future science aspirations mean* of S23-S25 & S29	The student's positive attitude to the role of Science in the society mean* of S26 – S28	Student's positive attitude to Science Mean* of S1 – S29 (following reverse coding of questions S5, S06, S07, S11, S12, S13)	Student's positive attitude to PS Mean on 5 point Likert Scale* o f PS 01, 02, 04, 07, 08, 09, 12, 13 (following reverse coding of question PS 04)	The student's self-concept and self-efficacy related to Science PS mean* of PS 03, 05, 06, 10, 11 (following reverse coding of questions PS 05, PS10)	The student's positive attitude to collaborative work mean* of CW 01 – 12
Keith	1.20	1.38	1.00	1.00	1.25	2.00	**1.31**	1.50	2.00	1.33
Elton	1.20	1.50	1.25	1.60	1.25	1.67	**1.41**	1.75	1.40	1.58
Sebbie	1.20	1.88	1.50	1.20	2.50	1.00	**1.55**	1.88	1.80	2.92
David	1.20	2.13	1.50	1.20	2.25	1.67	**1.66**	1.63	2.20	2.08
Marvin	1.80	1.25	1.25	3.20	2.00	1.00	**1.75**	1.00	1.40	2.42
Blake	1.40	2.25	1.75	1.20	2.00	2.00	**1.77**	1.88	1.80	1.75
Jim	1.80	1.50	1.75	1.50	3.00	1.67	**1.87**	1.88	2.00	1.67
Drew	2.00	1.50	1.75	1.80	2.75	2.00	**1.97**	2.88	3.00	1.50**
Yan	1.20	2.13	2.50	2.60	2.50	1.67	**2.10**	1.38	1.60	1.50
Alec	1.60	2.50	2.50	1.80	3.00	2.33	**2.29**	2.38	2.40	2.42
Keian	2.20	3.29	2.75	2.80	3.75	1.33	**2.69**	3.38	3.20	1.75
Zane	4.60	5.00	2.50	4.60	4.25	2.00	**3.83**	4.38	4.40	1.75
Sean	4.00	3.75	3.75	3.60	5.00	3.00	**3.85**	3.13	3.40	2.58

Notes: Pseudonymes used. Ranking is according to column 8 general science positive attitudes.
* Strongly Agree = 1, Agree = 2, Neutral = 3, Disagree = 4, Strongly Disagree = 5.
**Mean obtained on items CW 01 – CW 02

Appendix B: Group Formations

Table B.1: Participants' names per group.

Problem Solving Lesson Number Name of Absent Student/s	**Participants' pseudonym names per group**			
PS 00: Trial Inflating a balloon Absent: Keian & Elton	Non-participant student David Alec	Zane Sean Yan	Sebbie Drew Jim	Keith Marvin Blake
PS 01: Quadrats Absent: Blake & Yan	David Alec Jim	Zane Sean Drew	Sebbie Keian Non-participant student	Keith Marvin Elton
PS 02: Buzzer Absent: Non-participant student & Yan	David Alec Jim	Zane Sean Keian	Sebbie Drew Elton	Keith Marvin Blake
PS 03: Heating Water Absent: Keith & Marvin	David Alec Jim	Zane Sean Yan Keian[2]	Sebbie Drew Elton	Blake Non-participant student Keian[1]
PS 02: Acid Rain & Acidic Bird Droppings Absent: Non-participant student	David Alec Jim	Zane Sean Yan Keian	Sebbie Drew Elton	Keith Marvin Blake

[2] Individual work and collaborative work within different group settings

Appendix C: Letter of Information - Secretariat for Catholic Education

Shirley Bonnici Spiteri
[redacted]

27th January, 2018

Dear Fr. Charles Mallia

I am currently reading for a Master's degree in Science Education. As part of my studies, I would like to conduct research at [redacted] with my one group of Grade 7 Integrated Science students that I also teach. This research will be supervised by Dr Josette Farrugia from the Faculty of Education (University of Malta).

The research will entail a case study of the students' attitudes, techniques and collaboration when solving problems in science. Data collection will have the following phases:

- **Phase 1 -** initially assigning a 30-minute questionnaire to the students on their attitudes and self-efficacy in relation to science, solving scientific problems and collaborative work during a students' "free lesson" / break,
- **Phase 2 -** audio recording students whilst solving (a) two pen and paper science problems and (b) two hands-on lab based science problems in my Integrated Science lessons,
- **Phase 3 -** analysing the different individual and collaborative written solutions to the problems
- **Phase 4 -** analysing students' self-reflection sheets for each task, and
- **Phase 5 -** holding one audio-recorded focus group interview with two groups of 6–7 students during a student's "free lesson" / break.

I assure you that the name of the school will only be known to me and my research supervisor. The names of the students will not be disclosed either. Pseudonyms will be used in the dissertation write-up. Research data will be stored on my laptop and it will be password protected. Audio recorded data will also be password protected and it will be destroyed two years following my graduation.

Students' participation or otherwise would not affect their curriculum entitlement nor attention provided by me during any of the scholastic year's lessons. The problems to be solved during the sessions will be within the students' syllabus, and the planned activities will be beneficial for all the students. All the students (i.e. those participating and not participating in the study) will be following the same lessons and work on the same collaborative and individual problem solving tasks. This will be clearly explained to the students and their parents. Students can also opt not to participate in any of the phases. Opting out would not adversely influence their remaining lessons entitlement nor would they have any other consequence.

I would like to reassure you that I shall be abiding by the University of Malta's Research Ethics Committee Guidelines throughout all phases of my research. If you wish to be informed of the outcomes of the research, it will be communicated to you verbally, in print or via email according to your preference.

I would really appreciate if you would grant me your consent to conduct this research at [redacted]. In case of any difficulty, do not hesitate to contact me personally or on the contact information found below.

Thanking you in advance for your kind attention.

Best Regards,

Ms Shirley Bonnici Spiteri

Email: [redacted]

Mobile: [redacted]

Dr Josette Farrugia

Email: [redacted]

Appendix D: Letter of Information - Head of School

Shirley Bonnici Spiteri
[redacted]

6th February, 2018

Dear [redacted],

I am currently reading for a Master's degree in Science Education. As part of my studies, I would like to conduct research with my one group of Grade 7 Integrated Science students. This research will be supervised by Dr Josette Farrugia from the Faculty of Education (University of Malta).

The research would entail a case study of the students' attitudes, techniques and collaboration when solving problems in science. Data collection will have the following phases:

- **Phase 1 -** initially assigning a 30-minute questionnaire to the students on their attitudes and self-efficacy in relation to science, solving scientific problems and collaborative work during a free lesson / break,
- **Phase 2 -** audio recording students whilst solving (a) two pen and paper science problems and (b) two hands-on lab based science problems in my Integrated Science lessons,
- **Phase 3 -** analysing the written solutions to the problems,
- **Phase 4 -** analysing the students' self-reflection sheets, and
- **Phase 5 -** holding one 30-minute audio-recorded focus group interview with two groups of 6 – 7 students during a student's free lesson / break.

I assure you that the name of the school will only be known to me and my research supervisor. The names of the students will not be disclosed either. Pseudonyms will be used in the dissertation write-up. Research data will be stored on my laptop and it will be password protected. Audio recorded data will also be password protected and it will be destroyed two years following my graduation.

Students' participation or otherwise would not affect their curriculum entitlement nor attention provided by me during any of the scholastic year's lessons. The problems to be solved during the sessions will be within the students' syllabus, and the planned activities will be beneficial for all the students. All the students (i.e. those participating and not participating in the study) will be following the same lessons and work on the same collaborative and individual problem solving tasks. They will be free to withdraw from any phase of the study without suffering any consequence. These will be clearly explained to the students and their parents.

I would like to reassure you that I shall be abiding by the University of Malta's Research Ethics Committee Guidelines throughout all phases of my research. If you wish to be informed of the outcomes of the research, it will be communicated to you verbally, in print or via email according to your preference.

I would really appreciate if you would grant me your consent to conduct this research at your school. In case of any difficulty, do not hesitate to contact me personally or on the contact information found below.

Thanking you in advance for your kind attention.

Best Regards,

Mrs Shirley Bonnici Spiteri

Email: [redacted]

Mobile: [redacted]

Dr Josette Farrugia

Email: [redacted]

Appendix E: Consent Letter from Secretariat for Catholic Education

MALTESE EPISCOPAL CONFERENCE

Secretariat for Catholic Education

The Head
[redacted]

5th February 2018

Ms Shirley Bonnici Spiteri, currently reading for a Masters degree in Science Education at the University of Malta, requests permission to distribute a questionnaire to year 7 students, she also will be audio recording them whilst they are solving four science problems. Furthermore, Ms Bonnici Spiteri will be conducting a focus group and recorded interviews with two groups of 6-7 students during free lesson / break at the above mentioned school.

The Secretariat for Catholic Education finds no objection for Ms Shirley Bonnici Spiteri, to carry out the stated exercises subject to adhering to the policies and directives of the school concerned.

Rev Dr. Charles Mallia
Delegate for Catholic Education

Secretariat for Catholic Education, 16, The Mall, Floriana, FRN 1472. Tel: 27790060

E-mail: charles.mallia@maltadiocese.org

Appendix F: Consent Letter from Head of School

[redacted] Senior Section

7th February 2018

TO WHOM IT MAY CONCERN

This is to certify that Mrs Shirley Bonnici Spiteri I.D. No. [redacted], residing at [redacted] has permission to carry out research at our college.

[redacted]
Head of Senior School

Appendix G: Letters of Information and Consent Forms – Parents/Legal Guardians (English and Maltese)

8th February, 2018

Information Letter – Parents and Legal /Guardians

Dear Parents and Guardians

I am currently your son's Integrated Science teacher. I am also reading for a Master's degree in Science Education at the University of Malta. As part of my studies, I would like to monitor how your son and his class go about solving Integrated Science problems. This research will be supervised by Dr Josette Farrugia.

These tasks will be worked upon by all the students individually and in teams. I would kindly ask you to give consent for your son to participate in the following:

i) filling in a 30-minute questionnaire during a free lesson or break,
ii) audio recording of your son whilst he solves four science problems during my Integrated Science lessons, and
iii) one audio-recorded half an hour group discussion held during a free lesson / break.

I assure you that your son's name will not be disclosed to anyone as pseudonyms will be used. The name of the school will only be known to me and my research supervisor.

The tasks to be solved during the sessions will be within the syllabus, and the planned activities will be beneficial for all the students. All the students (i.e. those participating and not participating in the study) will be following the same lessons and solve the same problems. Your son will be free to opt out at any point of the research without having to give any explanation, and there will be no consequences.

Kindly complete and return the attached consent form with your son. I would really appreciate if you would grant your son consent to participate. In case of any difficulty, do not hesitate to contact me personally or on the contact information found below.

Thanking you in advance for your kind attention.

Best Regards,

Mrs Shirley Bonnici Spiteri

Email: [redacted]

Dr Josette Farrugia

Email: [redacted]

8 ta' Frar, 2018

Ittra ta' Informazzjoni – Ġenituri u Kustodji

Għeżież Ġenituri u Kustodji,

Bħalissa qed ngħallem is-suġġett tax-Xjenza lit-tifel tiegħek. Fl-istess waqt qiegħda wkoll inkompli l-istudji tiegħi fl-Università ta' Malta fejn qed insegwi l-kors tal-Masters fl-Edukazzjoni tax-Xjenza. Bħala parti mill-istudji tiegħi, nixtieq insegwi kif ibnek u l-kumplament tal-klassi jsolvu problemi tax-Xjenza. Din ir-riċerka ser tkun issorveljata mid-Dott. Josette Farrugia.

L-istudenti kollha ser jaħdmu fuq dawn il-problemi b'mod individwali u anke fi gruppi. Nixtieq ġentilment nitolbok biex tagħti l-kunsens tiegħek sabiex ibnek jipparteċipa:

i) fil-mili ta' kwestjonarju li jieħu madwar nofs siegħa u li jsir waqt free lesson jew break,
ii) f'awdjo rekording t'ibnek waqt li jkun qed jaħdem fuq erba' problemi matul il-lezzjonijiet tiegħi, u
iii) f'diskussjoni li tieħu madwar nofs siegħa, u li ser tiġi awdjo rekordjata waqt free lesson jew brejk.

Nassigurakom li l-identità t'uliedkom ser tibqa' anonima għax ser jintużaw psewdonimi. L-isem tal-iskola ser inkunu nafuh jien u s-supervisor tiegħi biss.

Il-problemi li ser ikollhom isolvu huma parti mis-sillabu, u l-attivitajiet ippjanati huma ta' benefiċċju għall-istudenti kollha. Kull student (kemm dak li ser jipparteċipa, kif ukoll dak li mhuwiex) ser ikun qed isegwi l-istess lezzjoni u jsolvi l-istess problemi. It-tifel jista' jiddeċiedi li ma jkomplix jieħu sehem fi kwalunkwe stadju tar-riċerka mingħajr ma jkollu jagħti l-ebda spjegazzjoni u mhux ħa jkun hemm l-ebda konsegwenza.

Jekk jogħġobkom imlew il-formola ta' kunsens li tinsab mehmuża ma' din l-ittra u ibgħatha mat-tifel. Napprezza jekk tagħti l-kunsens tiegħek biex ibnek ikun jista' jipparteċipa. Jekk għandkom xi diffikultà, tiddejqux tikkuntatjawni personalment jew fuq l-indirizz elettroniku t'hawn taħt.

Grazzi bil-quddiem.

Tislijiet,

Is-Sa Shirley Bonnici Spiteri
✉ [redacted]

Id-Dott. Josette Farrugia
✉ [redacted]

Consent Form – Parents and Guardians

I read the information letter provided with details about the research of Mrs Shirley Bonnici Spiteri related to solving Integrated Science problems. I am aware that the name of my son and his school will not be used in the dissertation write-up. I am also aware that my son is free to opt out of the research at any stage without having to give any explanation and without having any consequence. All students (even the ones who are not participating in the research) will be solving the same tasks and completing reflection sheets as part of their usual lesson.

Please mark the following points with a "✓" if you agree and with a"×" if you disagree.

☐ I authorise my son to complete a questionnaire of about thirty minutes during a free lesson or break.

☐ I authorise Mrs Shirley Bonnici Spiteri to audio record my son whilst he is solving four Integrated Science problems during her lesson.

☐ I authorise my son to participate in an audio recorded discussion of about half an hour during a free lesson or break.

Signature of parent / guardian: ________________ Date: ____________

Name of parent / guardian: ________________

Name of student: ________________

Your consent to this research is greatly appreciated. Thank-you.

Mrs Shirley Bonnici Spiteri

Email: [redacted]

Dr Josette Farrugia

Email: [redacted]

Formola ta’ Kunsens - Ġenituri u Kustodji

Jien qrajt l-ittra ta’ informazzjoni bid-dettalji tar-riċerka tas-Sinjura Shirley Bonnici Spiteri dwar kif jissolvew problemi fix-xjenza. Jien konxju/a li isem ibni u isem l-iskola tiegħu mhumiex ser jitniżżlu fil-kitba ta’ din ir-riċerka. Jien konxju/a ukoll li ibni jista’ jagħżel li ma jkomplix jieħu sehem fi kwalunkwe stadju tar-riċerka. Jekk jiddeċiedi hekk, mhux ser ikollu jagħti spjegazzjoni u ma jkollu l-ebda konsegwenza. Kull student (anke dak li mhuwiex li ser jipparteċipa fir- riċerka) ser ikun qed jsolvi l-istess problemi u jimla l-karti ta’ riflessjoni bħala parti mill-lezzjoni normali.

Jekk jogħġbok immarka “✓” jekk taqbel u “✗” jekk ma taqbilx mal-punti li ġejjin:

☐ Nagħti l-kunsens tiegħi biex ibni jimla kwestjonarju ta’ madwar nofs siegħa fi free lesson jew break.

☐ Nagħti permess lis-Sinjura Shirley Bonnici Spiteri sabiex tirrekordja b’awdjo lil ibni waqt li jkun qed isolvi erba’ problemi tax-Xjenza fil-lezzjoni tagħha.

☐ Nagħti l-kunsens biex ibni jipparteċipa f’diskussjoni awdjo rekordjata ta’ madwar nofs siegħa fi free lesson jew break.

Firma tal-ġenitur / tal-kustodju: ________________ **Data:** ____________

Isem il-ġenitur / il-kustodju: ________________

Isem l-istudent: ________________

Napprezzaw ħafna l-kunsens tiegħek għal din ir-riċerka. Grazzi.

Id-Dott. Josette Farrugia

✉ [redacted]

Appendix H: Letters of Information and Assent Forms – Students (English and Maltese)

8th February, 2018

Information Letter – Students

Dear students

At the moment I am continuing my studies at the University of Malta. I would like to study how a group of Year 7 students go about solving Integrated Science problems. I would really appreciate if you could help me in this research.

Your help will involve:

i) Answering a questionnaire of about 30 minutes during a free lesson / break,
ii) Agreeing that I audio record you whilst you are solving four problems,
iii) Participating in a group discussion of about 30 minutes (which will be audio recorded) with some of the other members of our science class during a free lesson / break.

I assure you that I will not tell your name to anyone. Your participation is voluntary. If you do not participate in the research, you will still have to work out the problem solving tasks and reflection sheets. Your grades will not be affected. You are free to stop participating at any point of the research without having to give any explanation and there will be no consequence.

If you have a difficulty about this research, please speak to me personally or through the contact details found below.

Thank you for your help.

Best Regards,

Mrs Shirley Bonnici Spiteri
Email: [redacted]

Dr Josette Farrugia
Email: [redacted]

8th February, 2018

Ittra ta' Informazzjoni – Studenti

Għeżież studenti,

Bħalissa qed inkompli l-istudji tiegħi fl-Università ta' Malta. Nixtieq nagħmel riċerka fuq kif studenti tal-Year 7 isolvu problemi tax-Xjenza. Napprezza ħafna jekk tkunu tistgħu tgħinuni.

L-għajnuna tagħkom tkun tinvolvi li:

i) twieġbu kwestjonarju ta' madwar nofs siegħa fi free lesson jew fil-brejk;

ii) taqblu li nirrekordjakom waqt li ssolvu erba' problemi;

iii) tippartecipaw f'diskussjoni ta' madwar nofs siegħa ma' xi wħud minn sħabkom tal-klassi. Din ser tkun awdjo rekordjata u ssir waqt free lesson jew fil-brejk.

Naċċertakom li mhux ser ngħid isimkom lil ħadd. Ippartecipaw jekk intom tixtiequ. Jekk ma tippartecipawx f'din ir-riċerka, xorta ser ikollkom issolvu l-problemi u tirrifletu fuqhom. Il-marki tagħkom mhux ser ikunu affetwati. Tistgħu tagħżlu li ma tippartecipawx aktar fi kwalunkwe stadju mingħajr ma jkollkom tagħtu l-ebda spjegazzjoni u lanqas ikun hemm konsegwenzi.

Jekk għandkom xi mistoqsija fuq din ir-riċerka ejjew kellmuni jew ibagħtuli fl-indirizz elettroniku t'hawn taħt.

Grazzi tal-għajnuna tagħkom.

Tislijiet,

Is-Sa Shirley Bonnici Spiteri

✉ [redacted]

Id-Dott. Josette Farrugia

✉ [redacted]

Assent Form – Students

I read the information letter provided with details about Mrs Shirley Bonnici Spiteri's research. I am aware that if I participate in the research, my name will not be told to anyone and I will be free to stop my participation in the research at any time without having to give an explanation and without suffering any consequences.

I will show that I agree or disagree with the following statements by the use of a tick (✓) or a cross (✗).

Read the following statements:

- **If you agree with them please tick (✓).**
- **If you disagree please draw a cross (✗).**

☐ I am willing to answer a questionnaire of about 30 minutes during a free lesson or break.

☐ I am willing to be audio recorded whilst solving four problems during my Integrated Science lesson.

☐ I am willing to participate in a group discussion of about half an hour with some of classmates. This will be audio recorded and held during a free lesson or break.

____________________	____________________	____________
Name of student	**Signature of student**	**Date**

Your consent to this research is greatly appreciated. Thank-you.

Ms Shirley Bonnici Spiteri
Email: [redacted]

Dr Josette Farrugia
Email: [redacted]

Formola ta' Kunsens - Studenti

Jien qrajt l-ittra t'informazzjoni bid-dettalji tar-riċerka tas-Sa Shirley Bonnici Spiteri. Jien naf li jekk nippartecipa f'din ir-riċerka, ismi mhux ser ikun magħruf u ser inkun nista' nieqaf meta rrid, mingħajr ma jkolli nagħti spjegazzjoni u ma jkolli l-ebda konsegwenza.

Jien ser nuri jekk naqbel jew ma naqbilx mal-punti li gejjin, billi ser nagħmel "✓" jew "×"

Aqra l-punti li ġejjin.

- **Jekk taqbel magħhom immarka billi tagħmel "✓".**
- **Jekk ma taqbilx immarka billi tagħmel "×".**

☐ Jien lest li nimla kwestjonarju ta' madwar nofs siegħa fi free lesson jew fil-brejk.

☐ Jien naċċetta li niġi awdjo rekordjat waqt li nkun qed insolvi erba' problemi fil-lezzjoni tax-Xjenza.

☐ Jien naċċetta li nippartečipa f'diskussjoni ta' madwar nofs siegħa ma' xi wħud minn sħabi tal-klassi. Din ser tkun awdjo rekordjata u ssir waqt free lesson jew fil-brejk.

Firma tal-istudent: ________________ **Data:** ________________

Isem l-istudent: ________________

----Napprezzaw il-kunsens tiegħek għal din ir-riċerka. Grazzi mill-qalb. ----

Is-Sa Shirley Bonnici Spiteri

✉ [redacted]

Id-Dott. Josette Farrugia

✉ [redacted]e

Appendix I: Questionnaire

Questionnaire

Dear students,
At the moment I am continuing my studies at the University of Malta. Part of my research requires that I investigate your views about science, problem solving and collaborative work. I would really appreciate if you could help me in this research by completing the questionnaire.

I am asking you to write your name as I would like to analyse your ideas together with your work. I will not disclose your name or whatever you answered to anyone. Your participation is voluntary. If you decide not to participate, there will be no consequence.

Thanks for your cooperation,

Ms Shirley Bonnici Spiteri

Instructions:

1. Write **your name**:
   ____

2. **Read the statements and answer them as truthfully as possible.**

3. **For each statement, please circle whether you:**
   - **strongly agree,**
   - **agree,**
   - **are neutral,**
   - **disagree, or**
   - **strongly disagree.**

Attitudes to Science:	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
S01: We learn interesting things in science lessons.					
S02: I look forward to my science lessons.					
S03: Science lessons are exciting.					
S04: I would like to do more science at school.					
S05: Science is boring.					
S06: I find science difficult.					
S07: I am just not good at Science.					
S08: I get good marks in Science.					
S09: I learn Science quickly.					
S10: Science is one of my best subjects.					
S11: I feel helpless when doing Science.					
S12: I believe that I have a lot of weaknesses in Science.					
S13: Compared to other students, I am a weak student in Science.					
S14: Practical work in science is exciting.					
S15: I like science practical work.					
S16: In science, I like to test my ideas.					
S17: I would like to join a science club.					
S18: I like watching science programmes on TV.					
S19: I like to visit science museums.					
S20: I would like to do more science activities outside school.					

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
S21: I like reading science magazines and books.					
S22: It is exciting to learn about new things happening in science.					
S23: I would like to study more science in the future					
S24: I would like to have a job working with science.					
S25: I would like to become a scientist.					
S26: Science and technology are important for society.					
S27: Science and technology make our lives easier and more comfortable.					
S28: The benefits of science are greater than the harmful effects.					
S29: Scientists have exciting jobs.					

Attitudes to Solving Science Problems:	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
PS01: I like problem-solving.					
PS02: I enjoy the difficulty of solving problems.					
PS03: I can usually solve any science problem.					
PS04: I do not feel sure about myself in problem-solving.					
PS05: When I start solving a science problem, I usually feel that I would not manage to give a solution.					
PS06: I usually can help my classmates, when they ask me for help in problem-solving.					
PS 07: I usually try to solve problems using all available methods.					
PS08: I usually try to stay calm and consider the next step when I come across a problem.					
PS09: I usually try to think about the effect of using various methods before I take action to solve problems.					

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
PS10: When science activities are too difficult, I give up or only do the easy parts.					
PS11: When I do not understand something in science, I find appropriate things that will help me.					
PS12: When I make a mistake, I try to find out why.					
PS13: In science, I think that it is important to learn to solve problems.					

Attitudes to Individual and Group Work:	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
CW01: Practical work in science is good because I can work with my friends.					
CW02: During science activities, I prefer to ask other people for the answer rather than think for myself.					
CW03: I willingly participate in collaborative tasks.					
CW04: When I work with other students I achieve more than when I work alone.					
CW05: Collaborative learning can improve my feelings towards work.					
CW06: Collaborative learning helps me to socialize more.					
CW07: Collaborative learning improves class participation.					
CW08: There is more creativity when working in groups.					
CW09: Group activities make the learning experience easier.					
CW10: I enjoy the lesson more when I work with other students.					
CW11: My work is better organized when I am in a group.					
CW12: I prefer that my teachers use more group activities / assignments.					

Thank you for completing this questionnaire.

Appendix J: Draft Problems

Name: ______________________

Inflating a Balloon

Ben has two identical balloons. He attaches them to the end of a ruler which is held from the centre. The balloons are balanced as shown in Diagram 1.

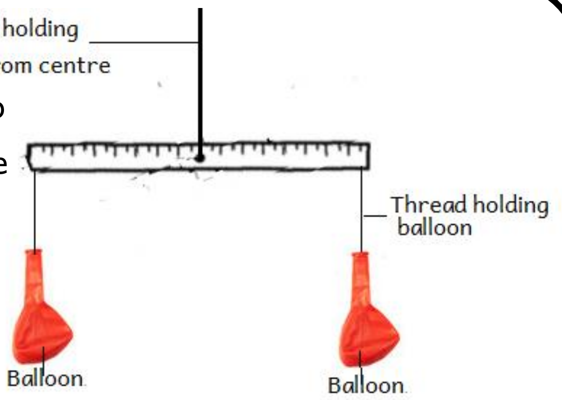


Diagram 1: Balloons are balanced.

Ben inflates one of the balloons and attaches it again to the end of a ruler. The balloons are not balanced as shown in Diagram 2.

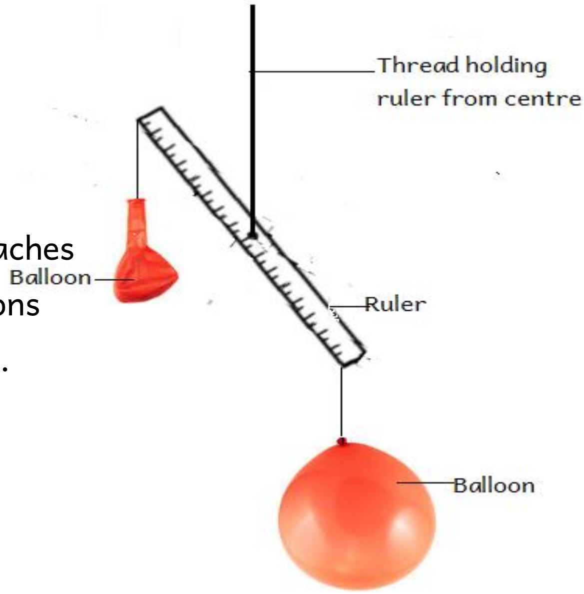


Diagram 2: Balloons are **not** balanced.

Write all your ideas to explain what is happening.

____

____

____

____

____

Name: ____________________

The Hidden Buzzer Challenge

Design an alarm that you can turn on and off.

Make it small enough to hide for some mischief fun!!!

Materials provided by the teacher:

- Batteries
- Buzzer
- Wires
- Wire strippers
- Switches
- Masking Tape
- Aluminium foil
- ……………………

Ideas about where and how you will hide the alarm.

Ideas about other materials that are needed.

Ideas about how the alarm will turn on / off.

Include some drawings, photos and notes about your work

Name: ______________________

The Heating Water Challenge

Design a solar water heater which is also efficient.

Materials provided by the teacher:

- Cups
- Thermometers
- Light bulbs
- Water
- Tubes
- ……………..

Ideas about how you will get water flowing through the system.

Ideas about other materials that are needed.

Ideas about how you can test the efficiency of the system.

Ideas about how you can get the water absorb the highest

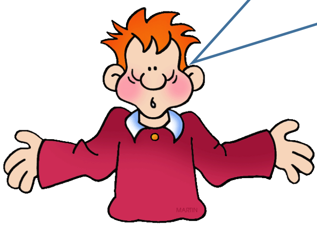
Include some drawings, photos and notes about your work.

Name: ____________________

Hills and Acid Rain

Why don't hills dissolve in acid rain?

Rocks are extremely hard and will never dissolve.



Rain must be at a warmer temperature to dissolve the rocks.

- **Do you agree with the above students' ideas? What are your ideas?**
- **How can you test your ideas?**

Appendix K: Problems Presented to Students

Date: ______________________ Name: _____________________

PS 00: Inflating a Balloon

Ben has two identical balloons. He attaches them to the end of a ruler which is held from the centre. The balloons are balanced as shown in the diagram.

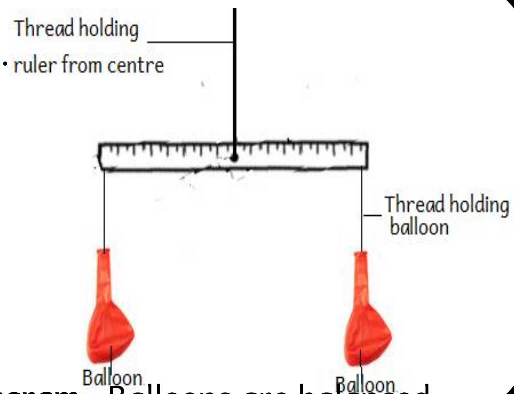
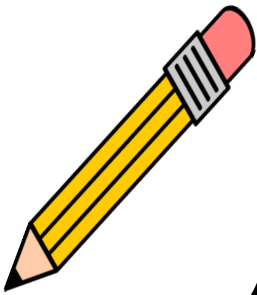


Diagram: Balloons are balanced.

Ben fills one of the balloons with air. He attaches it again to the end of a ruler. Draw what you think will happen.



Write all your ideas to explain what is happening.

____

____

____

____

____

Date: ______________________ Name: ______________________

PS01: The Total Number of Plants

In our fieldwork next week, you will need to find the total number of plants present in the garigue at Qrendi. The area is very large – it is 440 m x 60 m. It will be very difficult to count

What can your team do, to estimate the number of plants that are present?

The exact number of plants is not needed.

Name: ______________________

The Hidden Buzzer Challenge

Design an alarm that you can turn on and off.

Make it small enough to hide for some mischief fun!!!

Materials provided by the teacher:

- Batteries
- Buzzer
- Wires
- Wire strippers
- Switches
- Masking Tape
- Aluminium foil
- ……………………

Ideas about where and how you will hide the alarm.

Ideas about other materials that are needed.

Ideas about how the alarm will turn on / off.

Include some drawings, photos and notes about your work

Date: ______________________ Name: ____________________

PS03: The Heating Water Challenge

Design a system that heats water.

Think about ways that reduce heat energy losses.

Materials provided by the teacher:

- 2 cups
- Thermometer
- Different light bulbs
- Water
- Tubes of different diameters
- Adhesive tape
- ……………..

Ideas about how you will get water flowing through the system.

Ideas about other materials that are needed.

Ideas about how you can heat water the most.

Ideas about how you can keep the collected water hot.

Date: ________________________ Name: ________________________

The Heating Water Challenge

Include some drawings and / or notes about your work.

Date: ______________________ Name: ______________________

Monuments, Acid Rain and Acidic Bird Droppings

The statue of Queen Victoria is found in Republic Square, in Valletta.

It is made from **marble**.

The Great Siege monument is found in Republic Street, in Valletta.

The base is made from **granite**.
The figures are made from **bronze**.

The temple of Hagar Qim in Qrendi.
is made from **limestone**.

In Malta, we can find monuments made from different materials. Look at the discussion below to know what Martina, Zak, Layla and David have to say about monuments, acid rain and acidic bird droppings.

Martina: Does acid rain and acidic bird droppings effect these monuments?

Zak: Acid rain and bird droppings must be at a warmer temperature to effect monuments.

Layla: The effect depends on the material that the monument is made up from.

David: Monuments are extremely hard. They are not effected by acidic substances.

Date: ______________________ Name: ______________________

Monuments, Acid Rain and Acidic Bird Droppings

- **What do you think about the students' comments? What are your ideas?**
- **How can you test your ideas? Think about:**
  - The method to use
  - Precautions for fair testing
  - Precautions for safety
  - The measurements that will be taken

____

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Appendix L: Problems' Aims and Classification Types

Table L.1: The problems' aims and classification types.

Problem	Aim	Problem Classification Type
PS 01: The total number of Plants	Preparing students for an upcoming fieldwork in which sampling techniques have to be utilised	• Goal problem • Non-routine problem • Ill-structured • Static • Relatively complex and closed • Requires analysis and planning • Numeric problem using paper-and-pencil methods
PS 02: The Hidden Buzzer Challenge	Introducing concepts related to electricity such as the need of closed circuits and the way electrical switches function	• Goal problem • Non-routine problem (for most students) • Ill-structured • Dynamic/interactive • Relatively complex and open • Requires analysis, planning, executing and checking • Hands-on
PS 03: The Heating Water Challenge	Reinforcing concepts related to energy transfers and applying concepts to new situations	• Goal problem • Non-routine problem • Ill-structured • Dynamic/interactive • Complex and open • Requires hypothesis formulation, planning,

		analysis, executing and hypothesis testing • Hands-on
PS 04: Monuments, Acid Rain and Acidic Bird Droppings	Revising concepts related to the unit on acid and alkalis and applying the concepts in new contexts	• Goal problem • Non-routine problem • Ill-structured • Static • Complex and relatively open • Requires hypothesis formulation and planning • Paper-and-pencil method

Appendix M: Self-Reflection Sheet

Name: ______________________ **Date:** __________________ **Problem Number:** __________

a) What do I **know** at the start of the lesson on this problem?

____

b) My feelings when I was given the problem were ______________________________

c) My feelings when I was working on my own were ______________________________

d) My feelings when I was working within the group were ___________________________

e) What did I **do** to solve the problem when I worked on my own?

____

____

f) Were the points of view of my group the **same** or **different** from mine? ____________

g) What **steps** did the **group** use to solve the problem?

____

h) **My strengths** were____

____

i) **My weaknesses** were ____

____

j) My **friends' strengths** were ____

____

k) My **friends' weaknesses** were ____

____

l) To **improve our work**, my friends and I need to ______________________________

____

m) **Today I learnt** ____

____

n) In future problem solving tasks, I wish ______________________________________

____

o) Something else I wish to add is ____

Appendix N: Group Interview Questions and Prompts

Introduction:

Thank you for accepting to participate in this group interview.

Through this interview I would like to discuss your ideas about science, solving problems, and the way you work on your own or with your friends. You may use and refer to your reflection sheets that you have written over the past few problem solving sessions. I remind you to think about the confidentiality and respect towards other students who are not present or are taking part in the study.

Is it fine with you if I record what we shall be discussing?

Science	
Main Questions	**Further prompts**
How do you **feel about science**?	• At school. • In everyday life. • For the future.
What do you **like best** in science at school?	
What do you **like least** in science at school?	

Problem Solving in Science	
Main Questions	**Further prompts**
What do you understand by **problems in science**?	• Can you give some examples?
Do you ever **work out** science problems?	• Do you wish to have more / less?

	• How do you feel when you have to solve problems in science?
Do you ever **create your own** science problems?	• At **school**? • At **home**? • Outdoors? • Other activities you're involved in e.g. scouts?
How do you try to solve your science problems?	• **How** do you go about it? • What do you do? • Are there other ways you use to solve problems? • Do you try working on your **own** or **seek help**? • Are there **differences** between the ways you solve problems at school, home, outdoors, scouts etc.?
When thinking about the problem solving sessions that we had in class/lab together, do you feel that the problems we tackled were real problems for you?	• Where they difficult to solve? • Explain. • How did you feel in the different parts of the sessions? • Was there anything that you learnt that you did not know before? • What did you do to learn it? • How did you learn it?
Do you think that working on and solving science problems **is helping you?**	• Can you explain in more detail? • Can you give examples?
When you are in the lab, do you prefer that your **teacher tells you exactly** what you need to do or do you prefer to work on the task **using your own ideas**?	• Explain why.

Collaborative Problem Solving	
Main Questions	**Further prompts**
Do you prefer to work on science tasks **on your own or with other students**?	• Explain why.
When thinking about the PS tasks we did in class, what were: Your strengths and weaknesses? Your friends' strengths and weaknesses?	Think about: • Character • way of working
When thinking about the PS tasks we did in class, did the group have the same points of view to solve a problem?	• How did you learn about each other's ideas? • How did you solve the different opinions?
Do you think you **can manage** to solve science problems on your own?	
Do you think you **can manage** to solve science problems when you are with other students?	
When do you get the **better result** – when you are working on your own or with your friends?	• Can you give examples?
When solving problems, what do you still need to change so that you work better?	• On the individual level • On the group level.
If you had to give a **suggestion to your teachers**, would you recommend that their	

students work on their own or with their friends?	
If you had to always solve problems on your own, do you think that it will **help you for your future**?	Explain how.
If you had to always solve problem with your friends, do you think that it will **help you for your future**?	Explain how.

Conclusion:
We are reaching the end of this discussion. Is there anything which you would like to **add**?

Thanks for agreeing to sit for this interview. Your participation is **greatly appreciated**.