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The development and evaluation of a first-year undergraduate physical chemistry experiment

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Abstract

The laboratory in chemistry has been a place for student learning for many years. The study here developed a practical experiment to form part of the curriculum of Plymouth University's BSc (Hons) Chemistry course for first year students. The experiment focused on physical chemistry and explored rates of reaction using a modified crystal violet and sodium hydroxide reaction. The modifications from an original method included the concentrations of sodium hydroxide and the instrument used. The practical was finalised and lab script produced in eight weeks. Further studies were also conducted surrounding the effect of temperature on the reaction. The resultant K' values concluded that there is a linear relationship between K' and temperature. The Meaning Learning in the Laboratory Instrument (MLLI) was used to measure students' cognitive and affective learning in the laboratory. This consisted of two questionnaires to be completed on a voluntary basis by the students. The MLLI yielded results that indicated that meaningful learning was obtained in the laboratory for the devised experiment. A trend in the data was seen through use of box and whisker plots, positive relationship to meaningful learning saw an increase in students' percentage agreement and a negative relationship saw a decrease in percentage agreement after the practical. Where questions were asked about data, the trend was still seen, but not as significantly as other questions. Influences upon the impact of meaningful learning were perceived to come from: the laboratory instructor, structure of laboratory and pre-lab, previous experiences, instrumentation, and group work. A focus group was held which further supported the findings of the questionnaire. It also provided insight into other aspects of the practical including the preparation leading up to the experiment where students watched a pre-lab video. Other aspects included the timing of the experiment in the curriculum timetable.

Contents

Tables and Figures:

Abbreviations:
CV^+ – Crystal Violet
ELT – Experiential Learning Theory
MLLI – Meaningful Learning in the Laboratory Instrument
NaOH – Sodium Hydroxide
OH^- – Hydroxide ion/ sodium hydroxide
Pre- – Pre-laboratory meaningful learning questionnaire
Post- – Post-laboratory meaningful learning questionnaire
STEM – Science Technology Engineering and Mathematics

Introduction

Laboratory experiments have been an integral part of the chemistry curriculum for many years [1], with most of the great scientists carrying out their work in such an environment. Experiments play a distinctive role in the science curriculum with the chemistry laboratory evolving to become a place of engagement and hands on experience [1].

Within higher education the laboratory work and experiments currently taking place, help to ensure that students become industry ready and competent research workers [2]. Whilst, the aims of laboratory work in higher education have changed from when Thomas Thomson introduced the first teaching laboratory in 1807 [2], many scientists still agree that there is still a need for hands on experience [2].

With changing aims comes changing students' perspectives. Many students within the first year of undergraduate study feel that whilst partaking in laboratory work that they are just following a recipe [3]. This indicates that there are few connections made between the laboratory work and lectures [3].

One major drawback presented within the literature is that pedagogical objectives and outcomes are not achieved [3]. This is that the theory learnt in lectures and workshop environments does not link with the hands-on experience obtained in the laboratory [3].

The laboratory activities for undergraduates can be divided into two categories [4]. The first type of laboratory is called verification laboratory. In these laboratories, the aim is to confirm concepts which have been previously introduced to the students beforehand [4]. The other category for the laboratory is inquiry laboratories, here the aim is to introduce concepts [4]. The use of verification laboratories is mostly used within the first year of undergraduate study [4].

Whilst currently there is emphasis on students been responsible for their own learning, it is normal to categorise students into three ways of learning: visual, kinaesthetic and oral [5], though recent learning theories suggest that learning should encompass lots of different aspects [5]. There is growing body of literature that looks at learning theories and the way students learn. A report by Kolb *et al.,* introduces Experiential Learning Theory (ELT) [5], in which six key learning points are identified. One of the points identified that underlines ELT, is that learning is a process, and should not be determined solely by the outcomes [5]. The report further goes on to express that the efforts of the student should be noted and feedback given on this [5].

Other studies provide models for learning which a student can use to help tailor their learning. The study cycle is one such model. Figure 1 shows the study cycle model in a graphical representation [6].

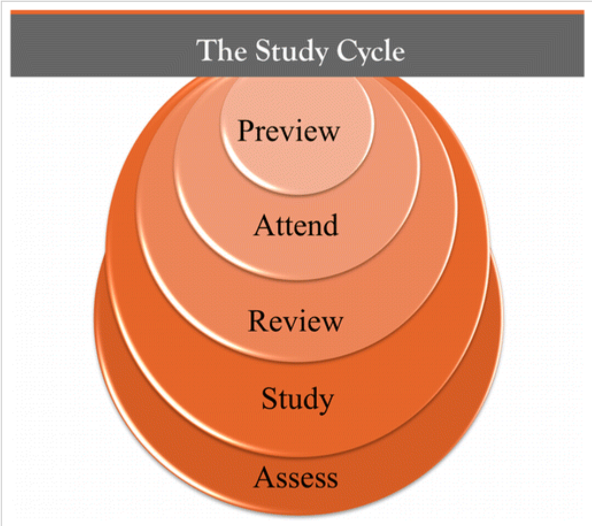

Figure 1: The Study cycle [6].

The study cycle has been adapted from the preview-learn-review study system [6]. This model has been proven to work well and has given students a firm basis to build upon and improve their own study skills and learning strategies [6]. It is important to note that students may pay no attention to this, as the study methods they used at high school and college to get through A-Levels may have worked but, until they see results of their study methods at a University level might they identify that these prior learning methods are no longer effective. It is at this point that a student may become open to the possibility of other learning styles [6].

The laboratory environment provides great opportunity to put literature research into practise, though for some students' challenges in the laboratory may occur which are seemingly intensified through having a learning difficulty or physical disability. Misconceptions about having a disability means that pursuing a career in a Science, Technology, Engineering and Mathematics (STEM) subjects is not allowed [7]. Even to this day adults with the good intentions still can mislead a student with a disability into thinking that STEM subjects are not a place for them [7]. The National Centre for Learning Disabilities has the following definition for learning difficulties:

'…neurological disorder that interfere with a person's ability to store, process, or produce Z testing conditions which include extra time [7]. It is important to

ensure that all students are motivated and inspired to be there, not just those with disabilities.

An important skill developed is that of maintaining a good laboratory notebook. These books are hardback bound notebooks [8]. It is important to consider whether students really understand the importance of taking good laboratory notes. One of the challenges faced with the laboratory notebook is motivating students to record their results as they occur [8]. Students have been known to reconstruct their work in the laboratory in their notebooks once they have left the laboratory [9].

These laboratory notebooks now play an integral part in chemistry teaching [10]. It has been noted that a student may find it difficult to know exactly what to write down. Therefore it is essential to help guide students on what is best practise with a laboratory notebook [10]. Students are told that a good laboratory notebook is one which another person can follow and reproduce the experiment [11].

A point to bring to attention is that the laboratory is a place which can introduce many new objects, opportunities and substances each with very different and demanding vocabulary terms [12]. Many of the words used in chemistry, stem from Greek or Latin, therefore it has been concluded that chemistry could be taught as a language itself due to its complexity [12]. Hence it makes sense for vocabulary to be explained clearly and precisely to help the students learn and understand [12].

With different theories existing within the literature about student learning and important factors relating to their learning, one article went on to study the factors for success. These factors have only been hypothesised as indicators for success in a physical chemistry course [13]. The factors are as follows:

- Success in prior chemical courses
- Success in mathematics courses
- Success in physics courses

Also studied within the literature is the correlation between students' motivation and their results and study skills [14]. Though it is seen those who spend time with the course material have better study skills than those who do not [14]. Mechanisms have been suggested to help those who are motivated though are still struggling. One of the mechanisms suggested is an "open door policy", this is where a student can go and see his/her lecturer when they so wish without having to make a traditional appointment. Though this has its advantages and disadvantages [14], typically, an open-door policy has been shown to work in small class environments [14].

Other studies on student interest have shown that students performed better where the experience could be related to the real world [15]. Also, students' attitudes towards chemistry in general influenced their attitude in and towards the laboratory [15]. Therefore, it is not unreasonable to infer that previous bad experiences in lectures or learning can influence a student's ability to engage in meaningful learning.

Meaningful learning is described in the literature as an experience that is of thinking, feeling and acting [16, 17]. There must be active integration between these three domains [17]. Meaningful learning is also described as where connections are made between previous knowledge and new knowledge that is substantial in nature [18]. The opposite of meaningful learning is rote learning, here students memorise the new knowledge rather than integrating it with previous knowledge [16]. Advantages of meaningful learning include knowledge to be applied in any situation, also it supports the greater skill development in attacking and solving problems [18].

Today a common practice within many University laboratories is for a PhD student to help and assist with undergraduate laboratory work. Research has shown that PhD students find it beneficial to be involved in the undergraduate laboratories [19]. A survey conducted found that many of the PhD, students responded favourably to the statement '*My experience as a teaching assistant helped me in the performance of my job'* [19]. Although this is good for the PhD students, the research carried out within the studies concluded that being a good laboratory assistant does not depend on your personal qualities or skills [20], there are traits that a laboratory assistant does need to have this includes being respectful [20]. This is important as the assistant helps set the attitude of the laboratory [20]. The study concludes that a good laboratory assistant is one who can help guide students and help promote discussions [20]. This enables students to make connections between the theory and the practical work [20].

It is still not known, what benefits the students' get from having a PhD student as a laboratory assistant there are assumptions on this topic could be made, such as a PhD student could help explain a concept in a different way allowing for a student to potentially understand a concept they have been having trouble with. However, there is very little in terms of literature that would be able to back up the presumptions.

Every student is different, from different backgrounds and have different experiences, so the laboratory assistant can help reduce any negative feelings that a student may have in the laboratory [20]. One way of reducing negative feelings in the laboratory and incorporating many other skills from cooperation, and interpersonal communication skills [21], is to use team work. Whether working in pairs or larger teams can help boost confidence in the laboratory [21]. Students then also develop an understanding that science is about trial and error and that hypothesis need to be rewritten [21].

The laboratory instructor in this case is, seen as the person in charge of running the laboratory practical, in most cases, it is a lecturer. There is a growing body of literature which recognises the importance of the laboratory instructor. The literature categorises both a good and bad laboratory instructor.
Focusing firstly on what makes a good laboratory instructor. The first point to be made is that the instructor helps students by engaging with them and giving assistance where needed [22]. A description of a good laboratory instructor

from the literature was a person who cared whether the students learned the information or not [22].

The opposite then is what is classed as a bad laboratory instructor. Here being a bad laboratory instructor is described as been bossy, and rude, being bound by the rules [22]. Though the good or bad instructor is formed on students' opinions leaving sometimes a fine line between the two [22]. Instructors end up negotiating with themselves as to when it is appropriate to give the answer or when best to help guide a student to the answer [22]. Previous research has established that instructional practises would generally fit into one of these four groups: waiter, busy bees, observers and guides-on-the –side [23]. Though these instructional practises differ with the environment [23].

No one definition can be set for teaching effectiveness. By examining all the definitions found in the literature, points of commonality occur [24]. These points include the determination of a good laboratory instructor to be a person who listens and tries to understand the students' problems [24]. One of the main obstacles found was that those from an international background engaged less with students, this was owing to possible language difficulties [24]. Research has also concluded that using plain English rather that scientific vocabulary is better as the use of scientific vocabulary can lead to cognitive overload [24]. It is seen that the students' working memory is taken over by processing information and trying to make sense of unfamiliar words or phrases from its context [24].

In conclusion to this there are some key points to make. Objectives set need to be clear and concise [25]. Students need to know exactly what is expected of them and also what they will have gained by the end of the lecture or laboratory session [25]. It can be seen in laboratory sessions that objectives and outcomes are not always clear and therefore are not achieved by the student [3]. Being adaptable is a key point, not everyone is the same, so the lecturer being able to adapt gives the student the best possible chance of success [25].

Physical chemistry is an area of chemistry covered throughout any chemistry course. As it is known to provide the fundamental concepts and can be applied to all areas of chemistry [26].

One of the many topics explored by undergraduates in a physical chemistry module is reaction kinetics. Reaction kinetics or chemical kinetics, is the study of reaction rates and the variables that surround it [27]. A student may have a basic understanding of reaction kinetics i.e. in everyday life people understand that food cooks quicker at a higher temperature than a lower one [28]. Reaction kinetics allows this to be studied in depth and furthermore shows that rate laws can be determined experimentally [27, 28]. Rates of reaction can be expressed mathematically and therefore lead to determining rate constant given the symbol K [27]. The rate constant is independent of the concentrations but does depend on temperature [27]. It is essential then, that an appropriate experiment is used to show reaction kinetics and allow for connections to the theory be made by the student [28].

A theory known as collision theory was developed to explain factors affecting rates of a reaction [29]. These factors include temperature, pressure, concentration, catalysts, surface area and phase [29, 30]. However collision theory is limited by its very definition in the fact that reactants have to collide in order for a reaction to occur [31]. Therefore, the rate of reaction is dependent upon the number of collisions per unit time [31].

Collision theory when studied for solutions only, has other factors that play an importance they include the viscosity of the medium [32]. Concentrations of solutions also play an important part in the rate of reaction. If both reagents are kinetically active then determining the order of reaction with respect to each reagent present may be difficult [32]. In order to determine the rate constant, K of a reaction a method known as isolation is used [27, 33]. The isolation method is where one of the reagents concentrations is in great excess, then throughout the reaction the concentration remains effectively constant [27, 33]. Now a reaction is said to be pseudo-n^{th} order [32]. Where n is the sum of the exponents of the concentrations that change during the experiment [32]. The use of isolation method also effects the term K in the rate equation. The K is replaced with K' which now encompasses the reagent which is in excess along with temperature [27]. The isolation method allows for each reagent to be studied in turn with its effects on the rate [27]. Normally the isolation method is used at the same time as the method of initial rates [27]. Method of initial rates only utilises the beginning of the reaction to determine the rate [27]. This does however limitations as the full picture of the rate of reaction may not be obtained [27].

As previously stated, students tend to learn better when the topics can be applied to the real world [15]. One such application of reaction kinetics in the real world, is dyes and their removal from the environment [34]. Dyes such azo are widely used throughout different industries including plastics, textile staining, veterinary [34 - 36]. Some other uses of certain dyes include: the manufacturing of paints and printing inks, and as external skin disinfectants [35, 36].

Existing research recognises that reaction kinetics will involve other areas of chemistry including analytical chemistry [37]. This is very prominent when studying dyes, as spectrophotometry and colorimetry can be used [37, 38].

A dye already used for students to study reaction kinetics is crystal violet. The fading of crystal violet is a widely studied area, due to it not biodegrading therefore, it is essential to remove it from the environment [35]. Crystal violet also known as methyl violet or basic violet [37], is a biological stain [39]. Crystal violet has the molecular formula $C_{25}H_{30}ClN_3$ [39], and is a member of the triphenylmethane group. It is extremely stable due to the complex aromatic structure [35]. The general structure of crystal violet is shown in Figure 2 [37].

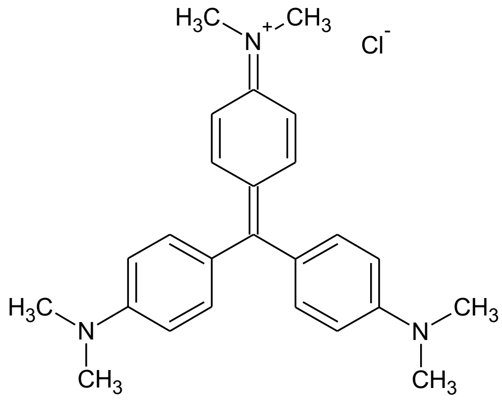

Figure 2: General structure for crystal violet [37].

Whist crystal violet has a stable structure as shown in Figure 2 it is known to degrade with many different chemicals including surfactants and sodium hydroxide [34, 35]. The importance of removing crystal violet from the environment has led to wide range of literature on the subject. Another point is that crystal violet fading lends itself to the use of spectrophotometry due to it going from a coloured compound to a colourless compound [40].

Drawing from two strands of research into the laboratory setting, this project attempts to develop and evaluate an undergraduate experiment. To achieve this, the study was broken down into 4 objectives.
The objectives were as follows: The first objective was to select an appropriate experiment based upon the equipment available and its suitability to be completed to be completed by first year chemistry students. The ability to modify the variables and the equipment was also considered when selecting the experiment.

The second objective was to test and then modify the chosen experiment. In order to adapt the experiment considerations were made surrounding the time available to complete the experiment in and the equipment available.
The third objective of the study was to conduct a questionnaire with first year students to determine whether the experiment fulfilled the meaningful learning requirements in line with the meaningful learning in the laboratory instrument (MLLI).

The final objective was to hold a focus group to see how the experiment was perceived by students.

Materials and methods

Laboratory method

The final developed method presented here was based on a journal article for crystal violet fading [41].

Preparation of chemicals

Crystal Violet and sodium hydroxide were purchased and used as received. A stock dye solution was prepared by dissolving 0.028g of crystal violet in enough deionised water to produce 1.00L of solution, which had the concentration of 7.0 x 10^{-5}M. A stock solution of sodium hydroxide was also prepared, by dissolving 4.034g in enough deionised water to produce 1L of solution. Which had the concentration of 0.10M. Both stock solutions were made in 1L volumetric flasks.

Standards, blank solutions and reaction solutions
Crystal violet calibration standards were prepared by pipetting volumes, of crystal violet stock solution into 100mL volumetric flasks. The volumes pipetted into each flask are shown in Table 1.

Table 1: Standard flask number and the corresponding volume of crystal violet stock solution (mL) and the final concentration in the volumetric flask (M).

Standard Number	Volume of crystal violet stock solution (mL)	Concentration of crystal violet in volumetric flask (M)
1	2	1.4 x 10^{-6}
2	4	2.8 x 10^{-6}
3	6	4.2 x 10^{-6}
4	8	5.6 x 10^{-6}
5	10	7.0 x 10^{-6}

The volumes of crystal violet stock solutions in the volumetric flasks, shown in Table 1, were diluted using deionised water to 100mL mark on the volumetric flasks. A blank solution of deionised water was used. The deionised water filled a plastic cuvette approximately 2/3 full.

Reaction solutions of crystal violet were prepared for analysis by measuring out 10mL of crystal violet stock solution in a 50mL measuring cylinder. The 10mL of crystal violet stock solution was then diluted to the 50mL mark on the measuring cylinder with deionised water. This was repeated three times, so a total of three crystal violet reaction solutions in measuring cylinders were used.

Reaction solutions of sodium hydroxide were also prepared by a similar method. Three 50mL measuring cylinders were used. The measuring cylinders contained the following volumes of sodium hydroxide stock solution; 5mL, 10mL and 15mL. The volumes of sodium hydroxide stock solution were then diluted up to the 50mL mark in the measuring cylinders using deionised water.

Instrumentation and reaction setup
A single beam CECIL 1010 spectrophotometer with a single cuvette holder was used to determine the absorbance of the solutions. The cuvettes used were made of plastic and had a 1cm path length. The wavelength was set from the value determined by Hewlett Packard 8483 Photodiode array spectrophotometer for the crystal violet stock solution.

The blank solution was used to zero the instrument. A cuvette was filled 2/3 full with the standards of crystal violet and the corresponding absorbance readings were recorded.

One 50mL measuring cylinder of crystal violet solution was poured into a beaker, at the same time as the 5mL of sodium hydroxide stock diluted to 50mL in a measuring cylinder was poured in. A stop watch was then started simultaneously as the solutions were poured into the beaker. The beaker was swirled to ensure mixing of the solutions. A cuvette was filled 2/3 full with the resultant solution and placed in the spectrophotometer. Absorbance readings were recorded every three minutes for half an hour. This was repeated with the remaining solutions of crystal violet in their 50mL measuring cylinders and sodium hydroxide solutions in the 50mL measuring cylinders.

Further investigations were undertaken exploring how temperature affected the K' results. The solution used 1.4×10^{-5}M crystal violet and 0.02M sodium hydroxide, these were made by diluting 10mL of the stock solutions in 50mL measuring cylinders and made up to the 50mL mark using deionised water. The temperatures investigated were 25ºC, 35ºC and 45ºC.

To achieve and maintain the reaction at the higher temperatures a thermostatically controlled water bath was used. This meant that every three minutes the cuvette was filled 2/3 full with the reaction solution and placed in the spectrophotometer. After obtaining the absorbance reading, the solution in the cuvette was poured back into the beaker in the water bath containing the rest of the reaction solution.

Student laboratory experiment
The above method was then modified for students to undertake as part of their chemistry undergraduate course. They completed the experiment in two laboratory groups on different days, in total 35 completed the laboratory experiment.

In order to prepare for this laboratory session, the students were asked to watch a video podcast about the practical and complete three pre-lab questions, which also related to the experiment. In addition, they were also invited to complete a questionnaire before and after the laboratory experiment. A small sample of the students took part in a focus group in order to gain further understanding and their thoughts on the experiment. The focus group was conducted after the experiment.

Data collection

Questionnaire
The questionnaire was adapted from original research on determining meaningful learning. The original research developed the Meaningful Learning in the Laboratory Instrument (MLLI) [42]. This MLLI is used to determine meaningful learning over a semesters' worth of laboratory experiments [42]. In this case MLLI questions were modified for a single laboratory experiment.

MLLI has three sub categories into which the questions are placed. These are cognitive, affective and cognitive/affective [42]. The questionnaire was delivered using questionnaire software known as Survey Monkey and was completely voluntary to complete. Survey Monkey is an online questionnaire software that allows a person to create and deliver their own surveys [43].

In total two questionnaires were produced; one to be completed before the laboratory and the other to be completed after the laboratory.

Focus group
Ethics approval had to be gained before the focus groups could go ahead. Two focus groups were planned, consisting of between six to eight people; this is a recommended number from the literature [44]. It was planned this way due to the students been split into two laboratory groups and completing the practical on different days.

Focus groups utilise the discussion and communication between participants to generate data [45]. Advantages of focus groups include the minimising of discrimination, especially against those with learning difficulties [45]. Anxiety is reduced in a group setting compared to a one to one interview [45]. They also encourage everyone to be involved in the discussion [45].

The purpose behind the focus group was to further evaluate and corroborate what the statistics showed from the questionnaires. Also, to gain opinions on the laboratory including the preparation before the laboratory and during the laboratory. The following questions below, were used to help guide the focus group:

1. How difficult did you find the practical?
2. Were the podcast and instruction beneficial? / Did it help prepare you for the laboratory?
3. Could you relate theory (lecture material) to the practical session?
4. What understanding did you take away from the practical?

Data analysis
Analysis of the questionnaire data was carried out by using box and whisker plots [42]. This allows for visualisation of the range of responses and to show any clear shifts between pre- and post- test results.

Reliability
Cronbach α and Ferguson's δ are tests for reliability [42]. The tests were carried out on the questionnaire data for each of the three sub categories.

Cronbach α is described as a measure of the average of correlation of all the split-halves of a test of scale [42, 46]. In the case of this study, Cronbach α is a measure of how the students' responses are correlated to the set items [42, 46]. Cronbach α is reported and calculated for the separated domains within the questionnaire. This is standard among questionnaires that Cronbach α is reported not over the entire questionnaire [47]. Cronbach α will be reported across three domains within the questionnaire; these are cognitive, affective and cognitive/affective.

Ferguson's δ test was also carried out in this case, being used as a test for discrimination [42]. The test result produces a ratio of the number of discriminations made between the test and the largest number the test could produce discrimination wise [48, 49].

Validity
Establishing validity of the data is important in order to draw conclusions based upon it [42]. Testing validity is done through the use of the focus groups. The focus group transcripts can be analysed by considering seven categorises. These categories are: words, context, internal consistency, frequency of comments, specificity of comments, intensity of comments and big ideas [50].

Results

Laboratory results

Initially the method followed was by Corsara, [41]. The results produced here show the calibration graph and two reaction runs which used a crystal violet concentration of 1.4 x 10^{-5}M and two different concentrations of sodium hydroxide (NaOH), one being 8.0 x 10^{-3}M and the other being 0.024M. The calibration graph and reaction run graphs generated as outlined in the article [41] are shown in Figures 3, 4 and 5.

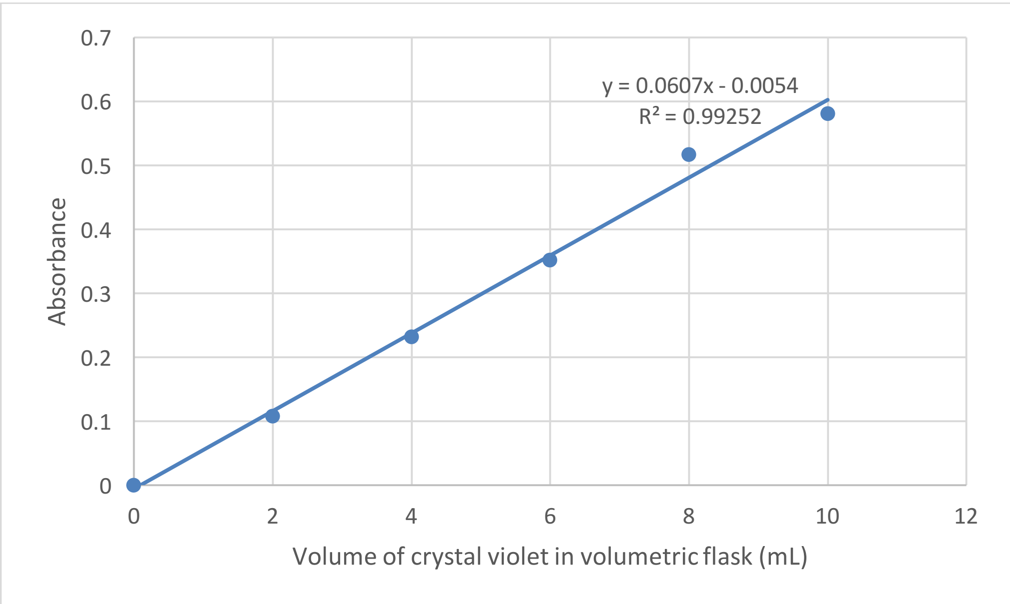

Figure 3: Calibration graph of volume of crystal violet in a 100mL volumetric flask and the corresponding absorbance value.

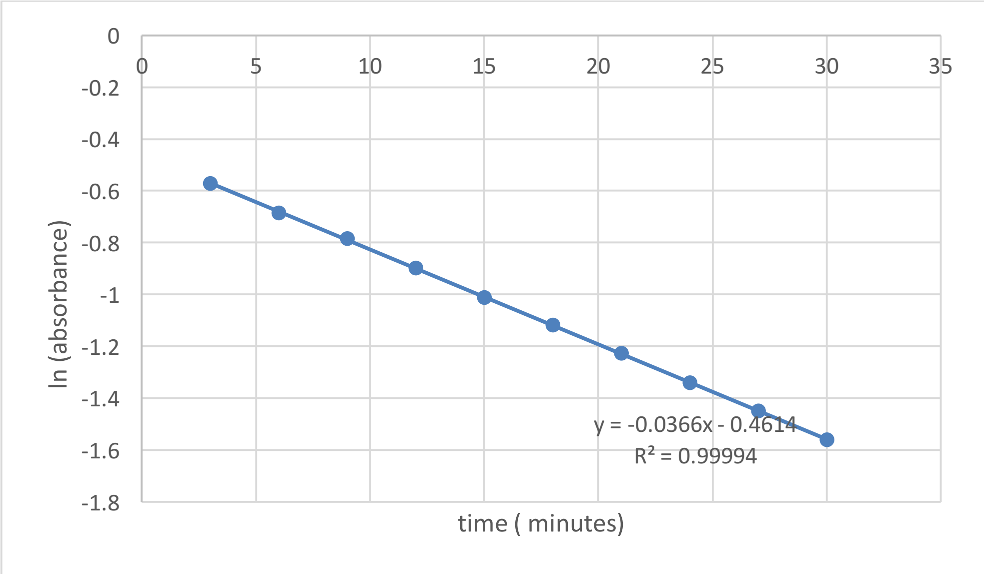

Figure 4: Graph of Ln absorbance against time (minutes) for 1.4 x10^{-5}M crystal violet and 8.0 x 10^{-3}M NaOH.

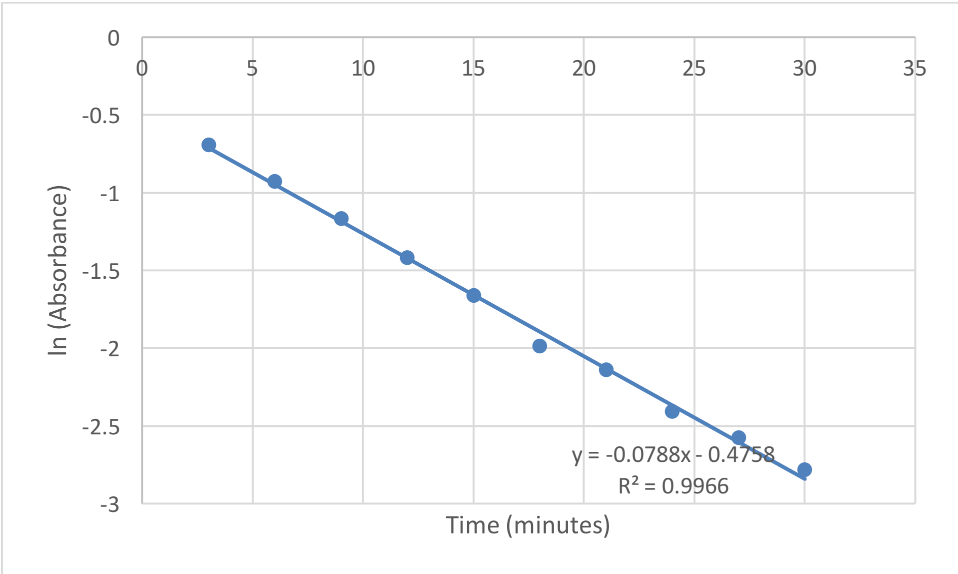

Figure 5: Graph of ln absorbance against time (minutes) for reaction of 1.4 x 10^{-5}M crystal violet and 0.016M NaOH.

Modifications were made upon the original method, also along with verification of the wavelength spectrum (Figure 6) at a temperature of 25ºC.

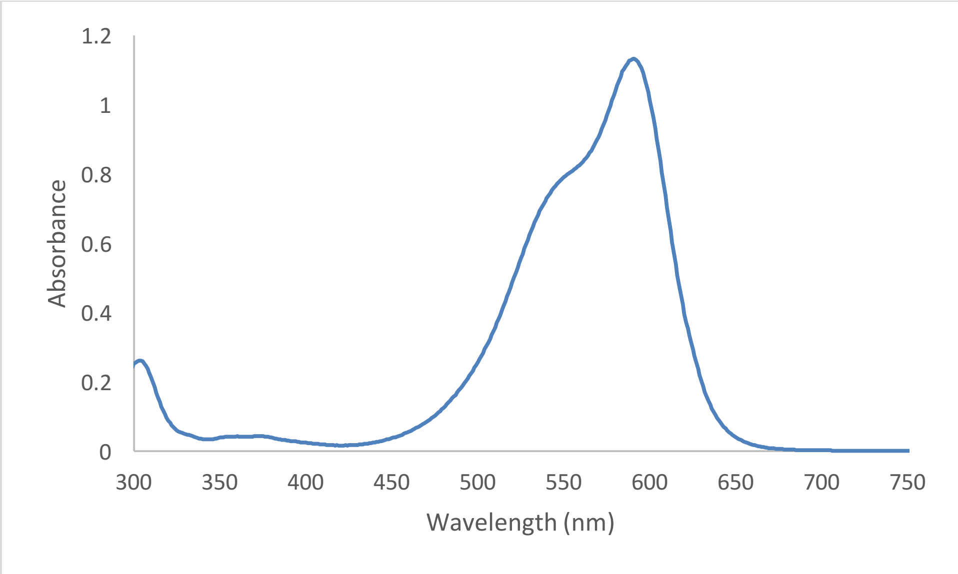

Figure 6: Wavelength spectrum of 1.4 x 10^{-5}M crystal violet.

After modifications, the K' results were collected for three reaction runs. Reaction run 1 was for 1.4 x 10^{-5}M crystal violet solution and 0.01M NaOH solution. Reaction run 2 was for 1.4 x 10^{-5}M crystal violet solution and 0.02M NaOH. Reaction run 3 was for 1.4 x 10^{-5}M crystal violet and 0.03M NaOH solution. Typical graphs produced for each reaction run and calibration are shown in Figures 7, 8, 9, and 10. Multiple runs were done to test reproducibility in the time available; seven runs were completed for reaction run 1, six for reaction run 2, and six repeats for reaction run 3. The K' values from the repeats are tabulated in Table 2.

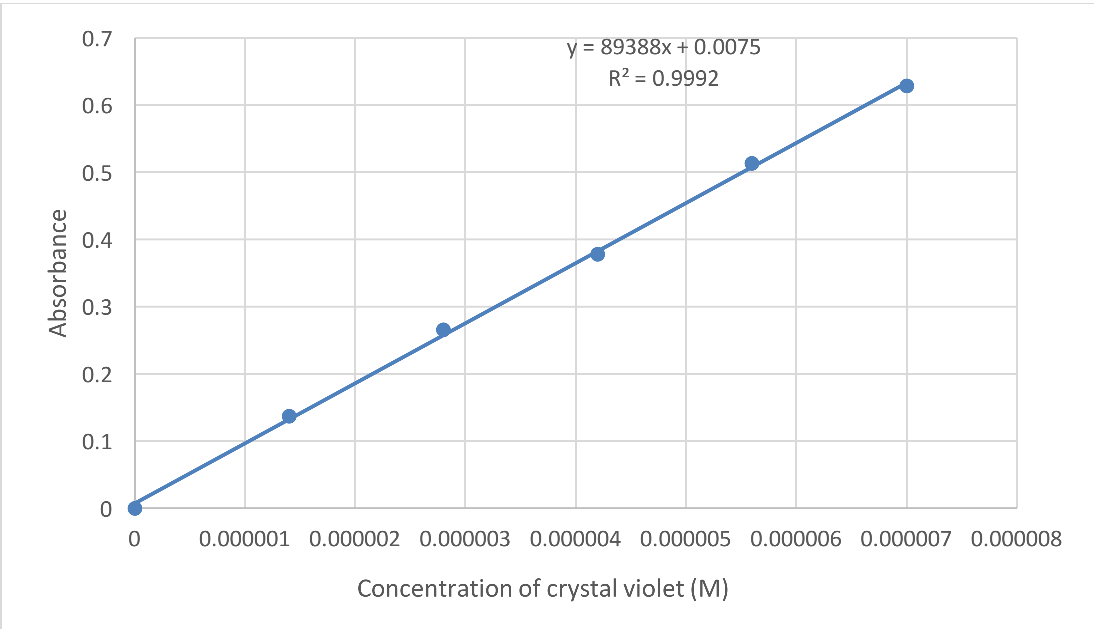

Figure 7: Typical calibration graph of absorbance against concentration of crystal violet (M).

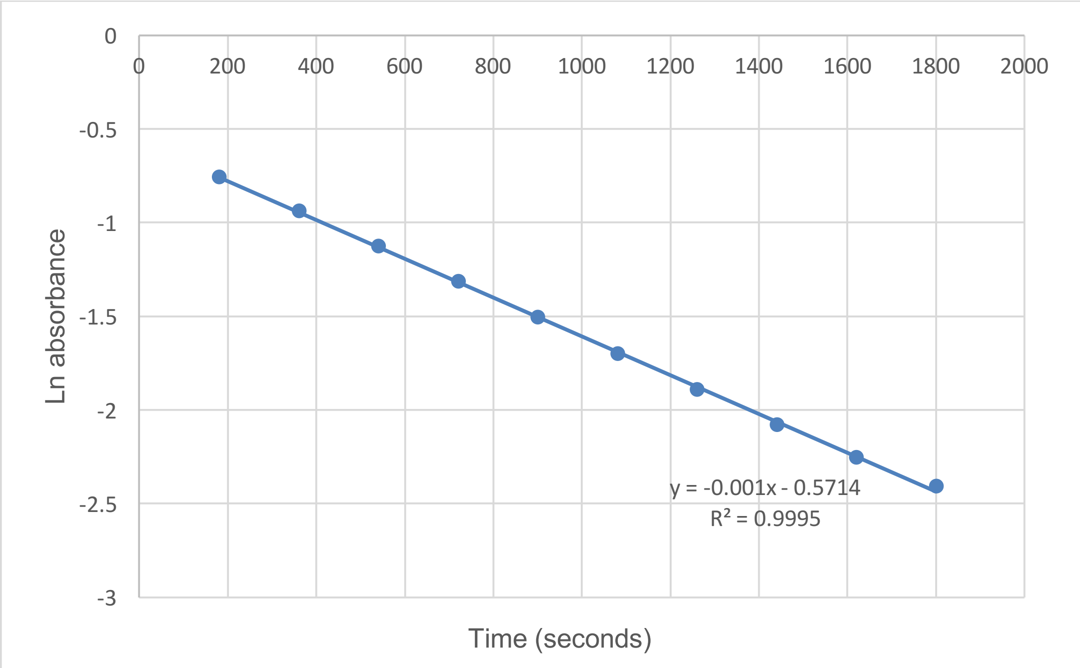

Figure 8: Typical graph of ln absorbance against time (seconds) for 1.4 x 10^{-5}M crystal violet and 0.01M NaOH.

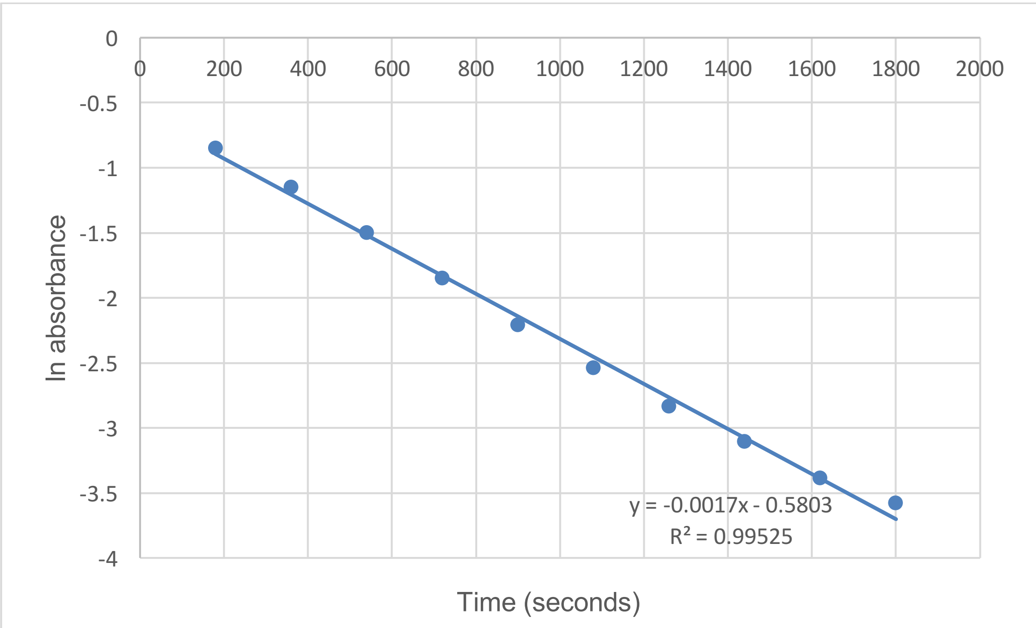

Figure 9: Typical graph of ln absorbance against time (seconds), for reaction of 1.4 x 10^{-5}M crystal violet and 0.02M NaOH.

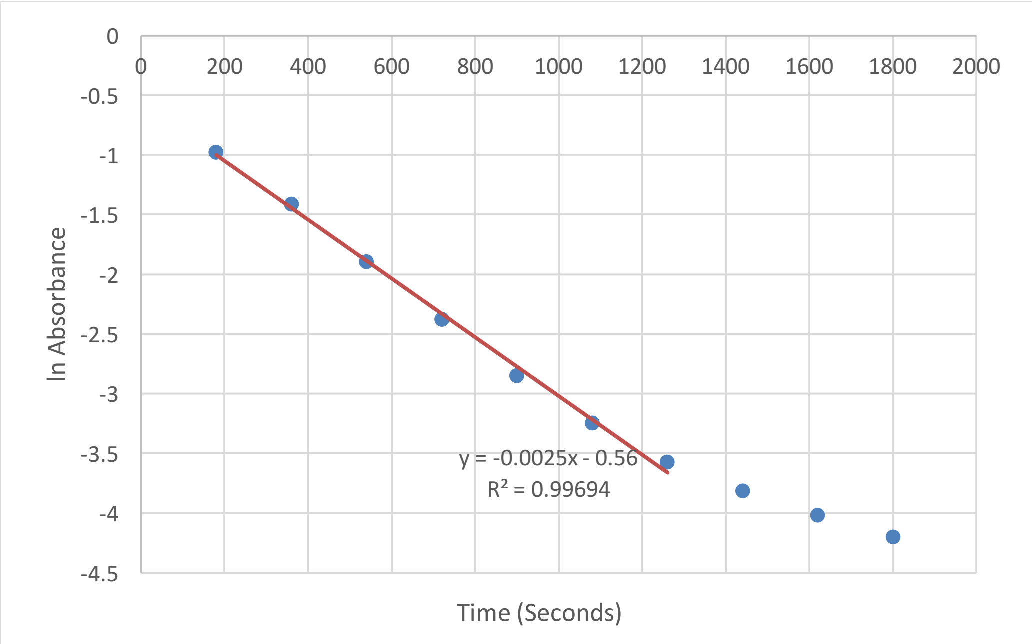

Figure 10: Typical graph of ln absorbance against time (seconds), for reaction of 1.4 x 10^{-5}M crystal violet and 0.03M NaOH.

Table 2: Calculated K' (s^{-1}) values for each reaction run and the average K' values.

K' (s^{-1}) for reaction run 1		K' (s^{-1}) for reaction run 2		K' (s^{-1}) for reaction run 3.	
0.000727		0.00102		0.00265	
0.000889		0.00181		0.00232	
0.000874		0.00163		0.00263	
0.00104		0.00173		0.00261	
0.000586		0.00105		0.00192	
0.000657		0.00136		0.00190	
0.000474					
Average K' (s^{-1})	0.000750	Average K' (s^{-1})	0.00143	Average K' (s^{-1})	0.00233

Questions arose surrounding the effects of temperature, therefore further investigations were carried out. Reaction run 2, of 1.4 x 10^{-5}M crystal violet and 0.02M NaOH was used to investigate the effect of temperature on reaction kinetics. The reaction was investigated at temperatures of 25°C, 35°C and 45°C. Calibration graphs were also produced at each temperature shown in Figures 11 and 13. The graphs produced for 35°C and 45°C are shown in figures 12 and 14. Each reaction run at the specified temperature was studied three times, in order to determine reproducibility.

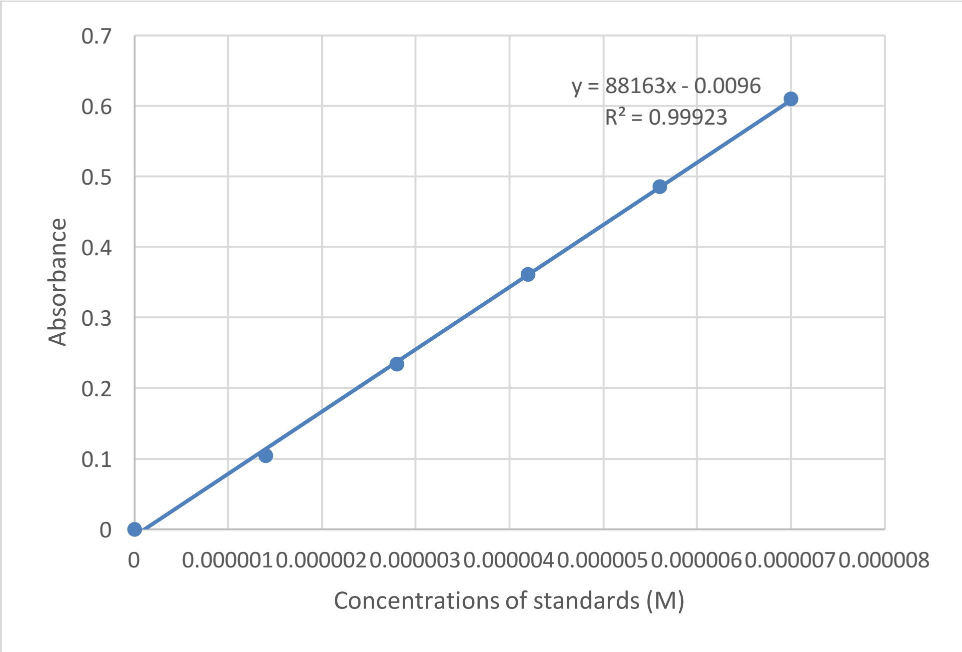

Figure 11: Calibration graph of absorbance against concentration of crystal violet (M) at 35ºC.

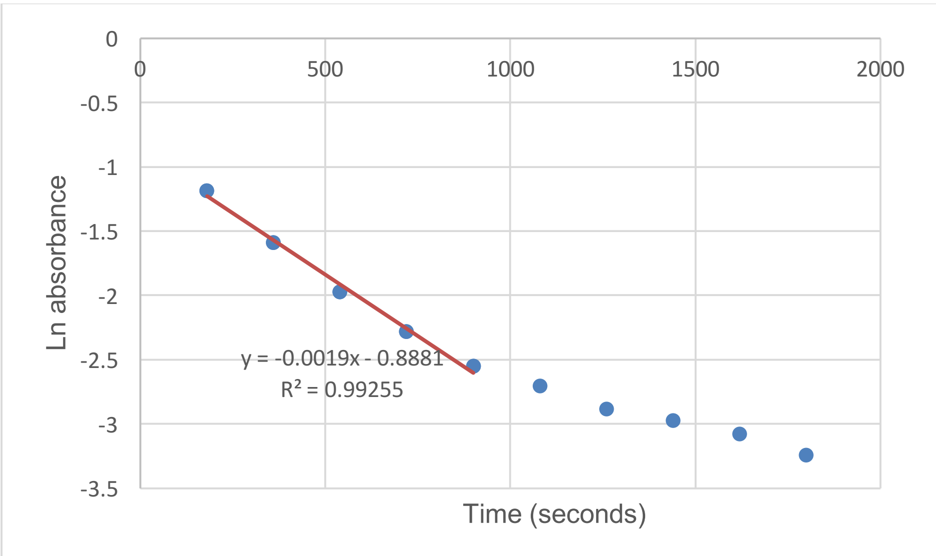

Figure 12: Graph of In absorbance against time (seconds) for 1.4 x 10^{-5}M crystal violet and 0.02M NaOH reaction at 35ºC.

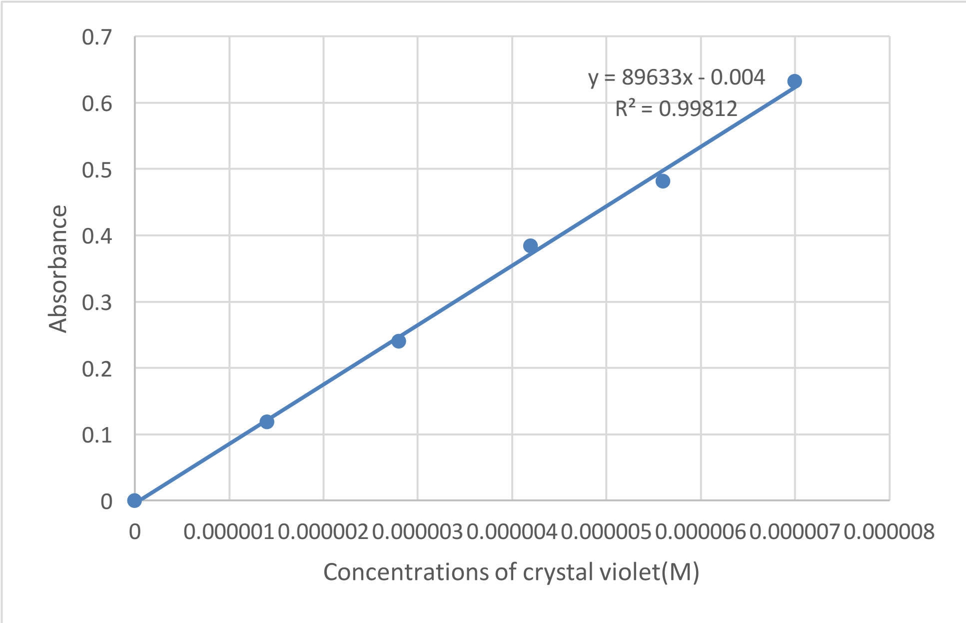

Figure 13: Calibration graph of absorbance against concentration of crystal violet (M) at temperature of 45ºC.

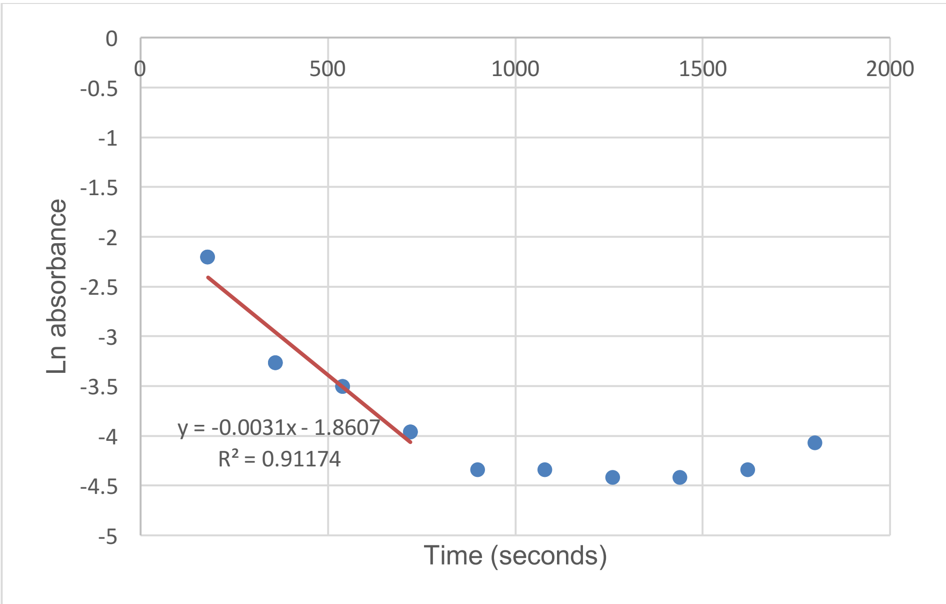

Figure 14: Graph of In absorbance against time (seconds) for 1.4 x 10^{-5}M crystal violet and 0.02M NaOH at 45ºC.

The averaged K' results at each temperature were then used to produce a graph of average K' against temperature as seen in Figure 15.

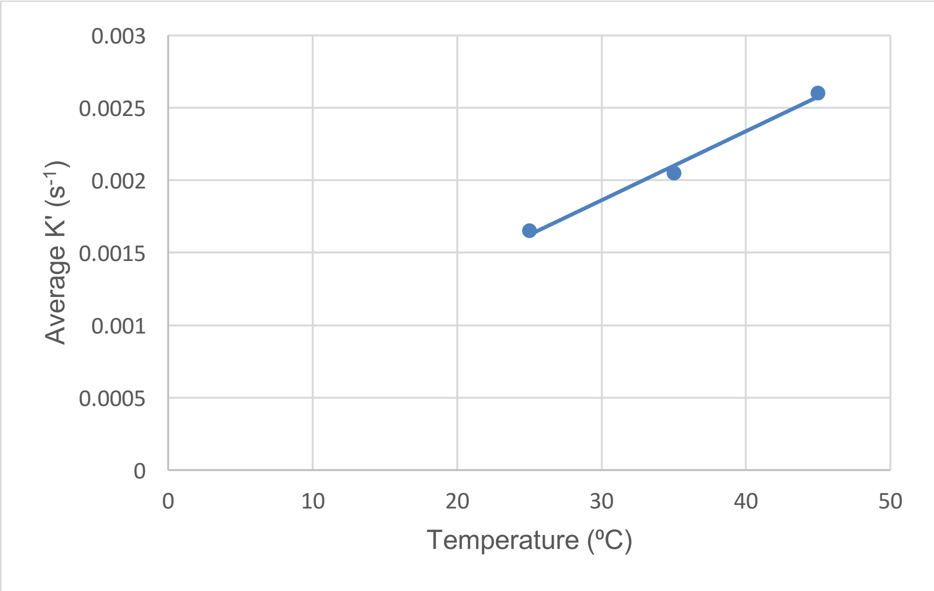

Figure 15: Graph of Average K' (s^{-1}) against temperature (ºC).

One of the unknowns that occurred during the exploration of temperature effects was that on the absorbance of crystal violet. To study wavelength of crystal violet with respect to the temperature, two more wavelength spectra were produced, shown in Figures 16 and 17 at the temperatures of 35ºC and 45ºC.

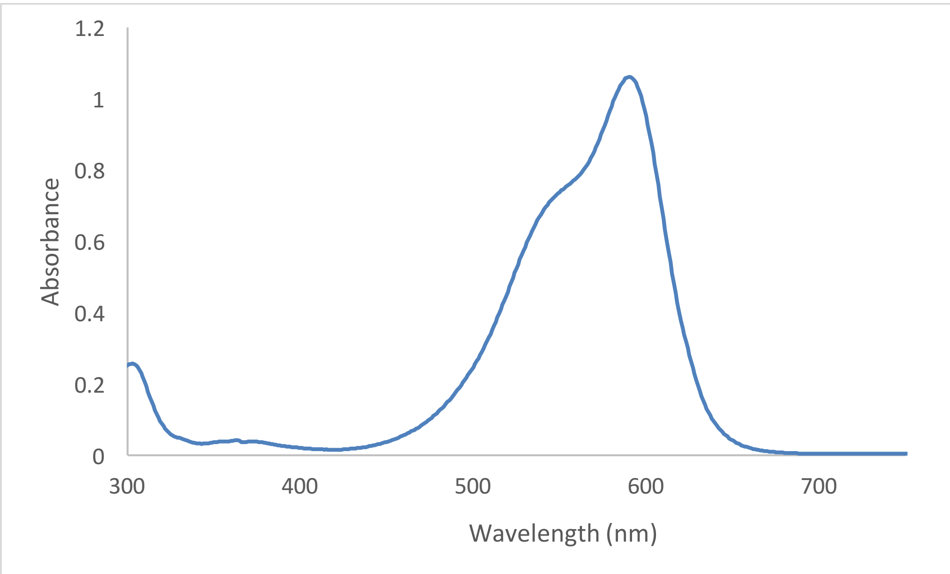

Figure 16: Wavelength spectrum of crystal violet at 35ºC.

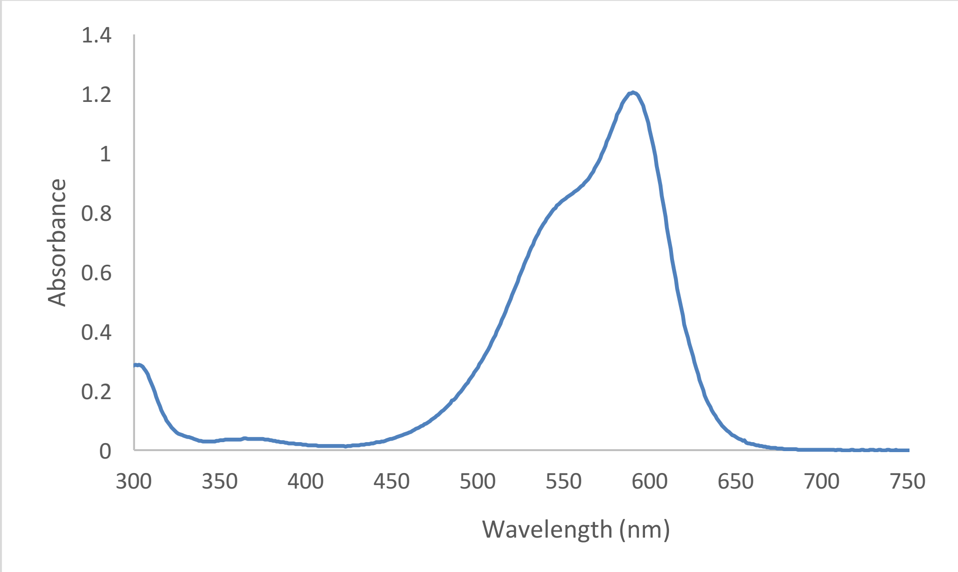

Figure 17: Wavelength spectrum of crystal violet at 45ºC.

Student experimental results

An average K' value for each reaction, taken from a random sample of student results is shown in Table 3.

Table 3: Average K' for each reaction obtained from student a random sample of student results.

	Reaction run 1 1.4 x 10^{-5} M crystal violet and 0.01 M NaOH	Reaction run 2 1.4 x 10^{-5} M crystal violet and 0.02 M NaOH	Reaction run 3 1.4 x 10^{-5} M crystal violet and 0.03 M NaOH
Average K' (s^{-1})	0.00089	0.0014	0.0022

Questionnaire results

The number of respondents to the questionnaires was 10 for the pre-questionnaire and eight for the post questionnaire. The results were analysed using box and whisker plots, shown in Figures 18 and 19. Figure 18 shows all the box and whisker plots for questions which relate to positive or enhanced meaningful learning. Figure 19 shows all the box and whisker plots for questions which would hinder meaningful learning.

Question 22 was designed to discard surveys where people were not reading the questions, therefore no box and whisker plot is present for this question as it has no impact on meaningful learning [51]. No questionnaire results were discarded for this study.

Cronbach's α and Fergusons δ results for each domain of the questionnaire pre- and post, cognitive, affective and cognitive/affective are shown in Table 4. These were calculated using an Excel spreadsheet [52] which was based on equation 1 for Cronbach's α and equation 2 for Ferguson's δ.

Equation 1: Cronbach's α equation for internal consistency

$$\alpha = \frac{N \cdot \bar{c}}{\bar{v} + (N-1) \cdot \bar{c}}$$

Equation 2: Ferguson's δ equation for discrimination within a questionnaire.

$$\delta = \frac{(1 + k\,(m-1))(n^2 - \sum_i f_i^2)}{n^2 k(m-1)}$$

Table 4: Cronbach's α and Fergusons δ results pre- and post- questionnaire domain.

	Cognitive	Affective	Cognitive/Affective
Pre δ	0.894	0.898	0.912
Post δ	0.876	0.825	0.874
Pre α	0.983	0.974	0.929
Post α	0.979	0.897	0.931

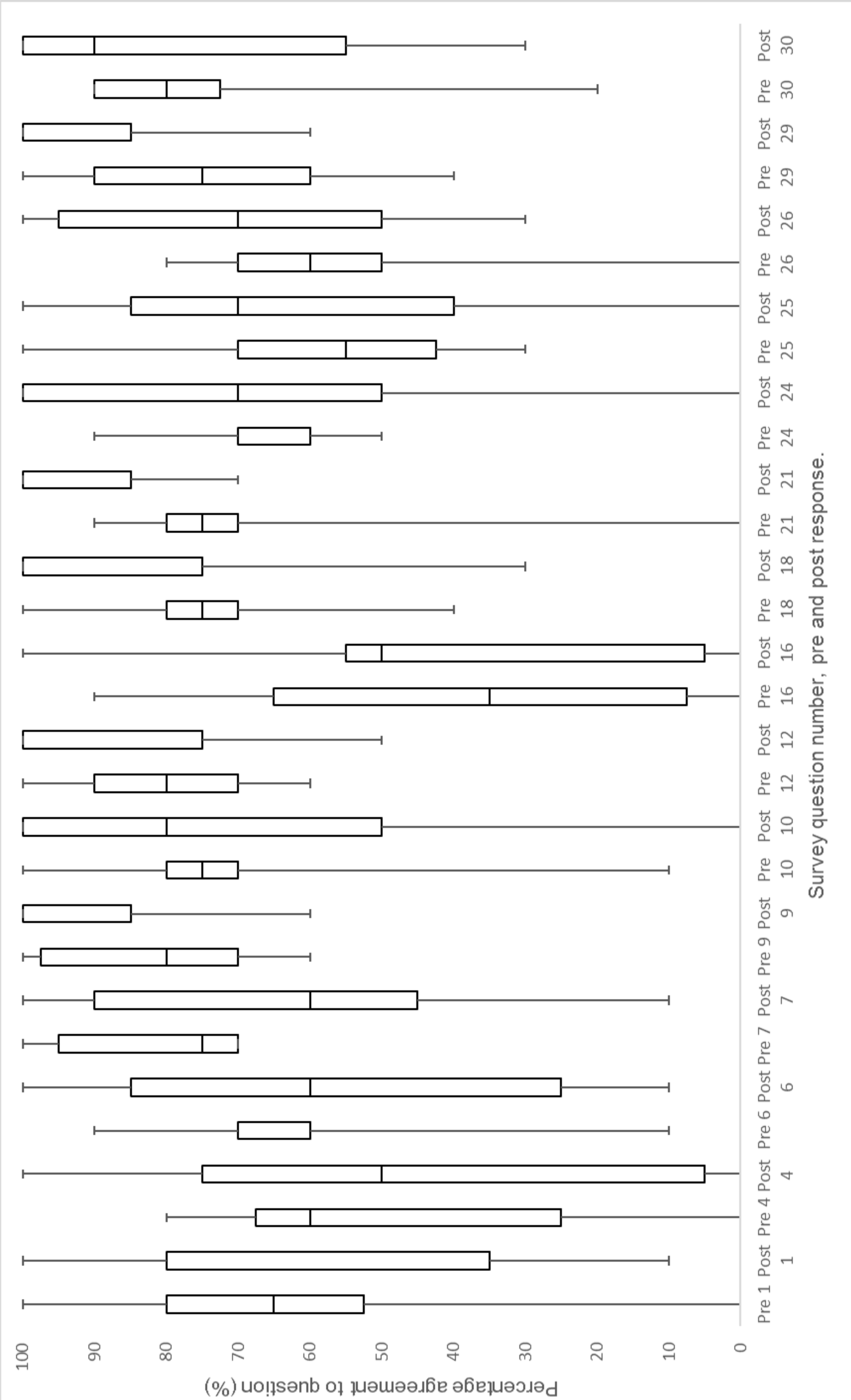

Figure 18: Box and whisker plots for pre- and post- responses which are positive to meaningful learning

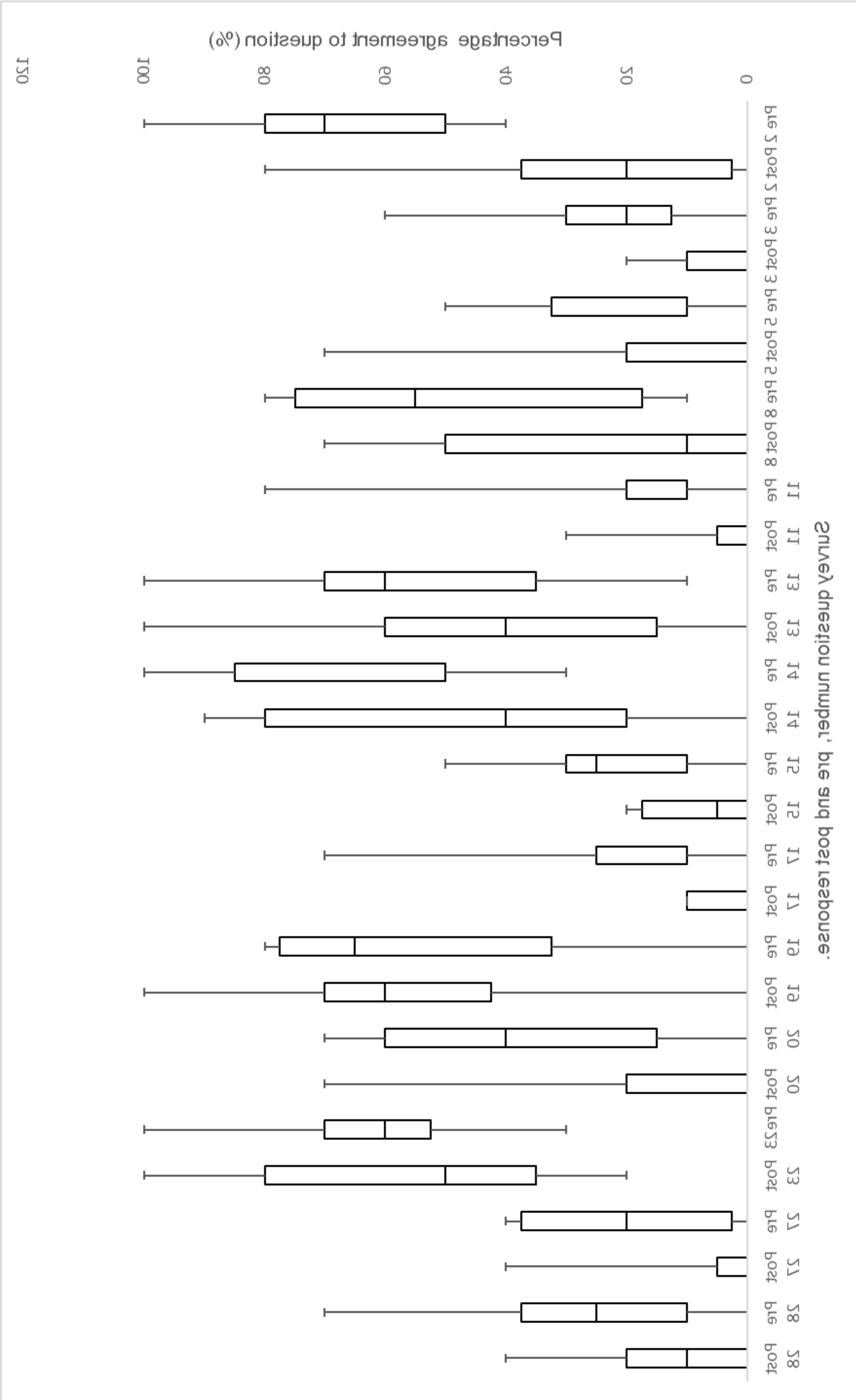

Figure 19: Box and whisker plots for pre- and post- responses to questions which hinder meaningful learning.

Focus group
There were two focus groups held; the first one, zero students attended and the second two students attended. The comments made by the students will be discussed later in the report. Generally, the feedback was in line with the results from the questionnaires, giving an overview that meaningful learning was achieved.

Discussion

Experimental
With respect to the methodology of the experiment created for the students, certain aspects had to be considered, such as time and equipment.

The reason behind the selection of the crystal violet fading practical was that it provided a suitable visual representation of a reaction happening. The reaction fades from a blue-violet colour to colourless upon the presence of hydroxide ions; this finding observed is in strong agreement with the literature [28, 41, 54]. The reaction between crystal violet and sodium hydroxide forms a carbinol of crystal violet and the suggested structure is shown in figure 20 [55].

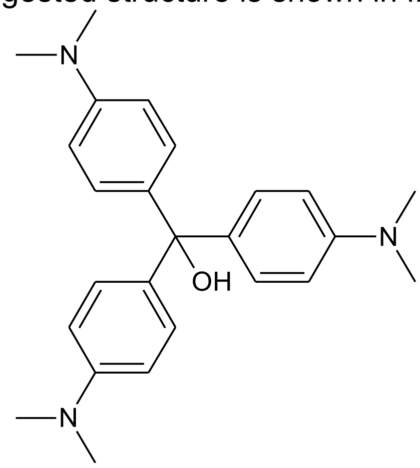

Figure 20: Structure of the Carbinol formed from the reaction of crystal violet and sodium hydroxide [55].

The carbinol produced is readily converted back to crystal violet in the presence of a strong acid [54]. As this reaction is reversible, the reaction is written as follows [56, 57, 58]:

$$CV^{+}_{(aq)} + OH^{-}_{(aq)} \rightleftharpoons CVOH_{(aq)}$$

When studying rates of reaction, a rate equation should be established. A generic rate equation takes the form $Rate = K\ [A]^n[B]^m$ [59]. By using abbreviated terms of the reactants used; CV^+ short for crystal violet and OH^- short for sodium hydroxide, these can then be substituted into the generic rate equation to form a specific rate equation for this reaction.

$$Rate = K\ [CV^+]^n[OH^-]^m$$

Furthermore, this specific rate equation is found within the literature where this reaction has been studied [34-36, 41].

In the original method by Corsara, [41], the reaction is seen to be a pseudo first order reaction. This was achieved by having the sodium hydroxide concentration in vast excess of the crystal violet concentration. In terms of the modifications to the original method, this was not changed, therefore the reaction still proceeded as a pseudo first order reaction. Using the isolation method can lead to more accurate rate determination than expected [60]. The rate equation can now be simplified using the K' term which encompasses the value of $[OH^-]^m$. The rate expression is now Rate = K' $[CV^+]^n$.

Before being able to complete objective two (modifications of the selected experiment), the original method was followed, though some confusion was initially seen due to the way the wavelength of crystal violet was written in the article as 590mμ. This lead to verifying the wavelength using a photodiode array spectrophotometer instrument and the wavelength spectrum is shown previously in Figure 6. The wavelength value taken from the instrument was 590nm, this corresponded with previous studies, where the wavelength of crystal violet had been determined [41, 61, 62].

One unanticipated finding seen on Figure 6, is the "shoulder" that is present at approximately 550nm. Further research into the presence of the "shoulder" concluded that it was a common occurrence [61] and that the "shoulder" existed for one of two reasons. The first explanation is that crystal violet has two isomers in rapid equilibrium with each other [61, 62]. The other explanation is as a vibrionic side band to an excited state [63], or the presence of a second excited state [63].

Another observation to be made about the wavelength spectra shown previously in Figures 6, 16, and 17, is that the peak itself is broad. An article by Loison *et al*., has related this broadness of the peak to the solvent used [64]. For this experiment the solvent used was deionised water, though crystal violet will readily dissolve in water or ethanol [55]. The article by Loison *et al*., suggests that the peak broadness and "shoulder" relate to the environment in which crystal violet is present and furthermore backs up the presence of different isomers [62]. Another study by Korppi-Tommola *et al.*, went on to express that the solvent used would influence the absorbance of crystal violet and where the two absorbance bands over-lapped [65]. The suggested resonance structures of crystal violet are shown in Figure 21 [39, 41].

It can be seen from the resonance structures that there is a deficiency in electrons at the tertiary carbon position and that the hydroxide ions will attach at this point [41]. This can then be related back to the carbinol structure in Figure 20, where the hydroxide ion has attached at the tertiary carbon.

Also seen in Figures 6, 16 and 17 at the lower wavelengths shown on the spectra's there is some noise apparent; this is due to the use of a glass cuvette which typically has a limit at a value between 200-300nm depending on the cuvette [66].

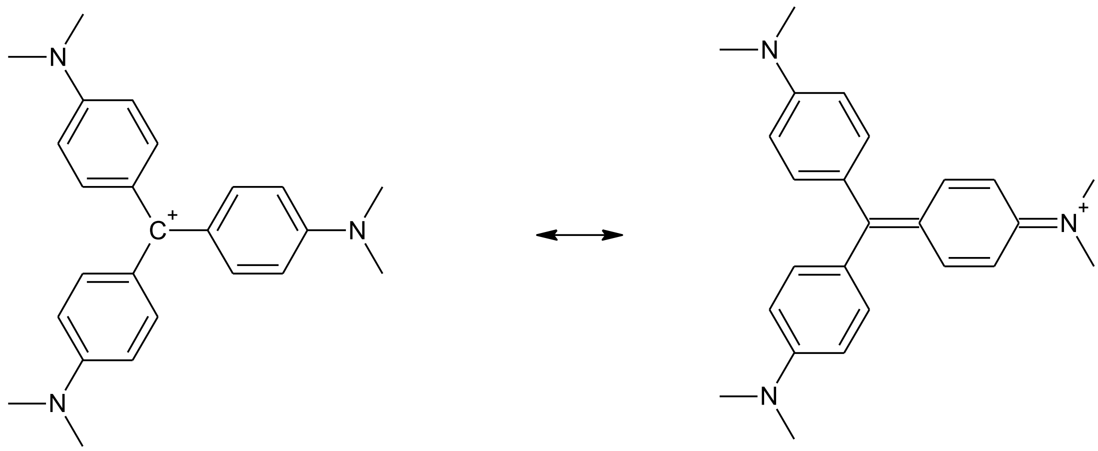

Figure 21: Resonance structures of crystal violet.

A calibration graph is produced for the instrument shown in Figure 3, this allows for noticing if any errors are being produced in the absorbance readings to be noted.

Figure 4 presents the experimental data for the original experiment for concentrations of 1.4 x 10^{-5}M crystal violet and 8.0 x 10^{-3}M NaOH. It shows a decreasing absorbance with time, therefore as the reaction progresses the concentration of crystal violet decreases because carbinol is being produced and the purple colour fades, so the absorbance value also decreases as the reaction progresses. Similarly, Figure 5 presents the experimental data for the second reaction run carried out in the original article which used 1.4 x 10^{-5}M crystal violet and 0.016M NaOH. As anticipated, it shows a decreasing absorbance trend, though it is greater than that compared to Figure 4. With the increasing concentration of NaOH, the deduction can be made that this is affecting the rate of reaction and the gradient of the graph. The gradient of graph in both Figures 4 and 5 is equal to the K' value for the experiment.

After determining that the original experiment worked and contained enough detail to make modifications and made appropriate for the students at Plymouth University. Complications occurred from the offset as there was limited time of eight weeks available to get the student practical ready to be implemented into their course at the end of the first semester.

The modifications made to the experiment involved changing the concentrations of NaOH and the instrument used. Also, the original experiment progressed further to calculate the order of reaction regarding the NaOH, this required the study of salt effects and would take up more than three hours in the laboratory. Therefore, students performed three reaction runs with varying NaOH concentrations and used a spectrophotometer instead of a colorimeter.

After modifications and the agreed lab script for the practical, example results were produced to determine K' values for each reaction. The reactions were performed multiple times and typical graphs produced for each reaction run are shown in Figures 8, 9 and 10. The resultant calculated K' values for each reaction run completed are presented in Table 2.

Figure 7, the calibration graph, is plotted similarly to how the original journal article plots the calibration graph shown in Figure 3. Though instead of the volume of crystal violet solution in the volumetric flask on the x-axis, it now has the concentrations of crystal violet solution.

Figures 8 and 9 show a straight-line graph where the gradient equals the K' value for that reaction. This concludes that the reaction is first order with respect to crystal violet and several reports have come to the same conclusion [28, 34-36, 39. 40, 42, 56, 57].

Interestingly, when a concentration of 0.03M NaOH is used the graph produced resembles more of a curve than a straight line so the gradient is only taken from the linear part of the graph. The curve suggests that the crystal violet concentration is decreasing significantly so the rate of reaction is slowing down. This can also be observed by watching the reaction happen as the solution appear colourless after 30 minutes.

The K' values calculated for each reaction are shown in Table 2. For reaction run 1 of 1.4 x 10^{-5}M crystal violet and 0.01M NaOH the average K' values were found to be 0.000750s^{-1}. This result is broadly in line with a report written by Chen, *et al.* [67]. The report found a value of 0.000520s^{-1}, but there are differences in the way the data was collected as differing concentrations were used. Subsequently the K' results for this reaction are rarely published, hence why no other literature sources have been found to compare results to.

For reaction run 2, of 1.4 x 10^{-5}M crystal violet and 0.02M NaOH, found an average K' value of 0.00143s^{-1}. As anticipated, the K' value has increased from that for reaction run 1. It can be seen to be nearly double that of reaction run 1 K' value and this would correspond to NaOH concentration which has doubled for this reaction. This is also reflected in Figure 9, where the gradient is also steeper.

The increase is also seen in reaction run 3, here average K' value was found to be 0.00233s^{-1}. Though as previously explained with reaction run 3, the reaction starts to slow down due to the concentration of crystal violet been used up.

Table 2, also reveals that there is spread of K' values for each reaction run. This could be attributed to multiple factors. Firstly, the more obvious factors include those which were initially expressed to influence rate of reaction in the literature review; pressure, temperature, and concentration. It has been identified for this reaction that increasing pressure had no effect on the rate of reaction [66].

Before further explanation of the surrounding factors that affect the rate of reaction, attention must be drawn to Table 3. Data from Table 2 can be compared with data in Table 3, which has an average value of K' for each reaction run from a sample of 5 student data points. Comparatively the student results are higher in value in Table 3 than the values in Table 2.

Mistakes made from inaccurately making up the correct solution concentrations could lead to errors and overall calculating the incorrect K' value, this is frequently seen among students [68]. Other influences on the K' value stem from different areas of the practical. Firstly, the instrument used has errors associated with it. The light source used in the instrument is a deuterium lamp which needs time, to warm up when the instrument has been switched on and after long periods of time the intensity will drop [69]. Another uncertainty associated with the instrument is an effect called Rayleigh scattering which also impacts the absorbance readings produced by the instrument [70]. Finally, the last source of error in the spectrophotometer is stray light, where a minimum amount of incoming white light can be detected at the source, which will skew the absorbance readings [71].

The single most striking error to be found with this practical is caused from the use of crystal violet, due to its staining nature. An article by Turgeon *et al.* has reported that it is readily absorbed onto glassware [72]. This decreases the concentration of crystal violet and seeing as the practical called for crystal violet solution to be transferred between different glassware. Though the absorbance onto the glassware should be constant, and a set amount of crystal violet will absorb, the effect on the rate is unknown, leading to an unclear effect on the practical. It could be seen that this is a stretch of an interpretation into the errors that could occur with the practical, due to the limited knowledge that is available on this area. One way of removing the crystal violet from the glassware used was to soak the glass in ethanol after use. This was done to clean the glass cuvette used in conjunction with the photodiode array spectrophotometer.

A note of caution is needed, as students may write AU next to absorbance to give it units. This is described as a bad habit and should be avoided [71]. Absorbance is a dimensionless number, therefore has no SI units [73]. Contrary to this, many scientists still write absorbance as having units, this has led to variety of different ways of writing absorbance, as no standard way has been formulated with regards to units [71, 73].

Having discussed the development of the practical in terms of the students and the data they would typically collect, the next part looks at how temperature effects the rate of reaction.

The investigation of temperature effects built upon the data for reaction run 2, where the runs were classed as been taken at 25ºC. Only reaction run 2, of 1.4 x 10^{-5}M crystal violet and 0.02M NaOH was studied for the effects of temperature.

A typical graph at a temperature of 25ºC, is seen in Figure 9 for the reaction, an average was taken from multiple runs that were done and plotted in Figure 15. When the temperature is increased, the graph no longer becomes linear as seen with the 35ºC graph in Figure 12 and the 45ºC graph in Figure 14.

Calibration graphs (Figures 11 and 13) were plotted at the corresponding temperature to ensure that the absorbance did not change with temperature. It can be determined that absorbance of standard solutions did not change with the increase in temperature.

As seen in Figures 10, 12 and 14, the line of best fit is only plotted through the linear part of the graph. Figure 12 shows a curve trend, suggesting that the increase in temperature has increased the rate of reaction. Furthermore, this statement is backed up by Figure 15, where a linear increasing trend is seen between K' and temperature. The reaction is slowing down due to the decrease in crystal violet concentration.

The graph at 45ºC (Figure 14) shows a remarkable outcome, between the time of 12-18 minutes into the reaction the absorbance value increased. The reaction run was repeated and the same outcome was observed each time. A possible explanation for this might be due to particulates forming as part of the reaction [68]. Once a reaction has surpassed an absorbance reading value of 0.1, it would increasingly become non-linear, the particulates were seen to scatter light on all wavelengths equally [68]. Although further investigation would need to be carried out to explain exactly whether this increase in absorbance is due to particulates or is caused by something else. The further investigations could include, taking more absorbance readings between 12-18 minutes in the reaction run or scanning the reaction run on all wavelengths using a photodiode array spectrophotometer instrument.

Furthermore, a recent study, used a thermostatic cell holder, with the aim of maintaining the temperature of the reaction [57]. Though it does require specialist equipment, which would incur a cost, it presents an option which could potentially provide data by a method more reliable than the one currently used.

In Figure 15, there is a clear trend of increasing K' value with temperature. This can be linked to the Arrhenius equation, which links the rate constant to the temperature and other properties shown in the equation below [74-77].

$$K = A\, e^{-\frac{Ea}{RT}}$$

Typically, Arrhenius plots are of ln(K), against 1/T [74-77], though Figure 15 is not an Arrhenius plot it still shows the relationship between temperature and rate constant. The relationship shown is that with increasing temperature the K' result increases in a linear manner, this agrees with a report which states that the relationship between K and temperature is linear [76].

The reason behind studying the reaction at higher temperatures above room temperature, was that these are easier to maintain than low temperatures. The higher temperature was maintained, by sitting the glassware in a thermostatically controlled water bath and monitoring by thermometers.

As previously mentioned, students did not undertake this work and therefore cannot apply the Arrhenius equation to their work. Subsequently the Arrhenius equation may be introduced in the lecture series, where students are generally told that increasing temperature of the reaction will increase the reaction rate [78]. Typically for every 10 degrees increased, the reaction rate doubles [78], this is clearly seen in Figure 15.

Questions were raised concerning absorbance and temperature, with regards to the “shoulder” on wavelength spectrum, would the temperature affect the “shoulder”. Further investigations using the photodiode array to produce wavelength spectra, for the crystal violet solution were carried out at 35ºC and 45ºC. The spectra are shown in Figures 16 and 17, the observed outcome from the spectra is that increasing temperature has no effect on the wavelength value and also the occurrence of the “shoulder” present. This agrees with a report, which stated that with decreasing temperature saw the disappearance of the shoulder at 550nm [61]. Currently only two factors are known to affect the wavelength spectrum of crystal violet. The first is low temperatures, though what is unclear how low the temperature must be before the wavelength spectrum is affected [62]. Secondly the solvent used will impact the wavelength, as this causes the shoulder to form a separate peak at a lower wavelength than 590 nm [62].

Questionnaire

Having discussed the experimental results that were obtained, it is important now to explain the questionnaire and focus group results.

The overall response rate to the questionnaire was poor, as only 10 completed the pre-questionnaire and nine completed the post-questionnaire. The difference between both questionnaires was the tense they were written in. The questionnaire responses were kept anonymous at all times, so there is no indication as to whether the same students completed the post-questionnaire that had completed the pre-questionnaire.

An explanation for the poor response rates to the questionnaires include: participants failing to understand the questions, cannot complete them, get bored, or are offended by them, and even disliking the way they look [79, 80]. Typically, administrative errors will also reduce the response rate, though this is seen more with questionnaires performed face to face or via telephone rather than delivered by other methods [79, 80]. With regards to the questionnaires completed by the students for this study, there was an administrative error made in that the pre-questionnaire was sent out when the post-questionnaire should have been sent out.

In this study students completed the questionnaires using the online questionnaire tool Survey Monkey [43]. The students had a week leading up to the experiment to complete the pre-questionnaire and a couple of weeks to complete the post-questionnaire. Advantages with online questionnaires include: low cost, are interactive, and an interviewer is not required to be present [81].

All questionnaire results were analysed using box and whisker plots. Box and whisker plots show the shape of the distribution without showing all the data points [82].

The questions shown in Figure 18 all impact meaningful learning in a positive manner. The figure presents an overview of the box and whisker plots for the questions and clearly shows a pattern emerging between the pre- and post-responses. This pattern that has occurred is that the post-questionnaire responses are of higher percentage agreement to the question than the pre-responses.

The questions looked at concepts involving; thinking on previous knowledge, having moments of insight, and to make mistakes but seemingly persevere through [51]. These results and trends seen in the box and whisker plots support the theory of the experiment having a meaningful learning impact on the students under taking it.

To further support the idea that the experiment has a meaningful impact, Figure 19 shows the box and whisker plots for the pre- and post- responses to questions which hinder meaningful learning. Another pattern emerges in this data that the post responses decrease in values from the pre-responses.

Question 22 does not have a box and whisker plot as this question was used to determine if students were reading the questions. Therefore, it has no impact on meaningful learning and has not been presented in either Figure 18 or 19.

With respect to the third objective of this dissertation, to determine if meaningful learning has been achieved, using the questionnaire. Exploring the questions and the answers seen by the students, some interpretations can be made. Although, with a small sample size, caution must be applied, as the findings might not express that of everyone involved. Another note of caution is due, as there is limited literature on the actual factors that influence meaningful learning and to what extent they play a part.

A strong relationship between the laboratory instructor and the impact on students' learning has been reported in the literature. What is seen to make a good laboratory instructor is one, who is helpful, engaging, giving assistance [22], listens and tries to understand the students' problems [24]. Over-all, looking at student-teacher relationships reflects the same factors as seen for a good laboratory instructor, these include talking, sensitivity and respect [83]. To develop a full picture of how the laboratory instructor influences students' meaningful learning and general lab skills, additional studies would be needed. These could take the form of questionnaires.

The structure of the laboratory can be linked to the learning cycle [6] introduced in the literature review. This can be characterised into three components which include; prepare, do and finally review [6, 84]. Here students prepare for the laboratory by completing a pre-laboratory exercise. The pre-laboratory exercise was embedded in a video which was an overview of the laboratory where they were to undertake the experiment. Finally, students wrote a report on the experiment, this report has not formed part of the dissertation.

A report has stated that pre-laboratory videos have helped students feel more prepared for a laboratory and this had the impact of reducing negative feelings [84]. This can be seen throughout the trend in the box and whisker plots in Figure 19 which are grouped by the fact they would hinder meaningful learning. The decrease in the post- result value therefore can be somewhat attributed to the preparation of the pre-laboratory question and the pre-laboratory video. Whether filmed with Go-pros or a simple digital video recorder, means students get to see the experiment equipment beforehand [85] and allows for techniques to be seen and understood before the laboratory, especially if there are time constraints [85]. These videos are also used to highlight safety, theory and as previously mentioned techniques [86]. Though there may be seen to be little limitations involved, they do require a certain amount of time to produce [86]. The production of the pre-laboratory video was closely co-ordinated with the project advisor, Dr R Lowry. The pre-laboratory video was designed in a way that highlights key details of the practical i.e. setting the spectrophotometer to a wavelength of 590nm. The pre-laboratory video had the pre-laboratory questions integrated into it, so that the only way to be able to complete the pre-laboratory was to watch the video.

Previous experience could also play a part in learning and the motivation for a student to learn. Those students, who had experiences which were bad/ negative would less likely be motivated to learn than those who had a positive experience of learning. Previous knowledge is seen to provide a basis for new knowledge [87]. This is clearly linked to meaningful learning [87, 88]. This can only occur though if the previous knowledge is relevant [87, 88]. The previous knowledge also has an impact on how people act, so previous experiences have a very important effect on students when working in the laboratory [88].

Instrumentation links to previous experience as students may have had the opportunity to be able to use the instrument before. This also links to meaningful learning through being able to complete the experiment and have" hands-on" use of the instrumentation. However, no literature was found, which explorers the "hands-on" use of an instrument on learning about the instrument.

When the students undertook the practical, they performed the experiment in pairs. The use of working in small teams will also have an impact on meaningful learning and learning in general. Small group work has shown positive outcomes these include; increase in achievement, higher self-esteem, acceptance of differences and enhanced conceptual development [89]. Group work is seen as an improving learning style [90]. It helps develop skills and behaviours which are vital for the workplace [90]. Group work is also classed as collaborative work, where students work towards a common goal [91]. In the case of the laboratory work, group work is not seen to make it easier [91]. It can provide a support network, which might not be seen when working as an individual. This is seen by the fact that students get the opportunity to question each other first and solve the problem that way, rather than going and asking the lecturer [91]. It is even possible for group work to improve students' attitudes towards chemistry and chemistry laboratory [91].

Though group work can have positive impacts, it can also create what is classed by one report as laboratory anxiety [92]. This can furthermore impede meaningful learning though this was not the case seen with the crystal violet experiment conducted in this dissertation, which suggests meaningful learning was achieved. Another cause of laboratory anxiety suggested by the article was surrounding data collection [92]. This is evidenced in the box and whisker plots in Figures 18 and 19 where the trend of either increase or decrease between the pre- and post- results was less than that compared to other question results. It suggests then that students worry about data and collecting data. This may be caused by placing too much importance on getting data that proves the hypothesis, instead of explaining the anomalies in the data set. This is further extended to journal articles which would only publish data that was seemingly correct [93].

Ferguson's δ and Cronbach's α, were calculated for the questionnaire answers and the results are shown in Table 4. To be able to calculate these the questionnaire is split into its categories; cognitive, affective and cognitive/affective. The reasoning behind performing these calculations is that Ferguson's δ produces a value for the highest number of discriminations [46] and Cronbach's α, though described as the internal consistency, which means the reliability of a questionnaire [47].

The results for Cronbach's α (Table 4) for the cognitive category was 0.983 for the pre-questionnaire and 0.979 for the post questionnaire. For the affective category, the results were 0.974 for the pre-questionnaire and 0.897 for the post questionnaire. Finally, for the cognitive/affective category the results were 0.929 for the pre-questionnaire and 0.931 for the post questionnaire. Reports about Cronbach's α suggest that the value should be between 0.8-1.0 [47], as anything lower than this would suggest that there is repetition of questions [47]. The values found for Cronbach's α for the pre- and post- questionnaires fall between the suggested literature range showing that there is no repetition of questions.

Ferguson's δ results also shown in Table 4. The calculations were done on the 3 domains in the questionnaire. The cognitive category had a result of 0.894 for pre- and 0.876 for post. The affective category had a value of 0.898 for the pre- and 0.825 for the post and the cognitive/affective category had a result of 0.912 for the pre- and 0.874 for the post questionnaire. Articles show varying values for the delta, these range from 0.7-1.0 [46, 47, 49]. Therefore, the values found fall between the literature range showing few discriminations are made.

In this case, the questionnaire results were analysed using box and whisker plots though other methods of analysis could have been used. Another way of analysing the results could have been done using cluster analysis, here the grouping would have been by how similar student responses were [16]. Cluster analysis is only really appropriate with large data sets [16], so in the case of the responses to the questionnaire it would not have been wise to use cluster analysis.

Other ways of studying meaningful learning in the laboratory include the use of cameras and filming the laboratory [94]. This has been used in the report to evaluate the laboratory from a student's perspective [94]. Although filming the laboratory in general would allow for analysis of body language and to identify the timings of people's actions which subsequently could be linked to their motivations and attitudes towards the chemistry laboratory. Though ethical issues here are very important to consider and therefore would need to be fully understood before using video cameras to help with the determination of meaningful learning. With human participants, they would need to be informed of the process and it would also be voluntary and therefore they can withdraw at any point in the process [95]. The ethics here can be applied further to the use of the focus groups.

Focus groups

As expressed in the methodology section, the focus group was used to help validate the questionnaire and to ask other questions surrounding the practical itself. Out of students invited to be involved with the focus groups, only two attended. Though the attendance was poor, some key points were expressed in the session.

Before further discussion on the findings from the focus group, it is important to point out the limitations of focus groups; these include when one person dominates the discussion, and how the moderator interacts with the participants [96]. These can have an impact on what is said and the outcomes of the focus group [96].

Though within the focus group, the word frequency could be analysed and grouped. In this focus group the word 'confidence' was used multiple times by the students. A student expressed that the practical "*definitely increased my confidence*", this is clearly shown as well in the box and whisker plots. Especially surrounding question 12 which relates to confidence and is shown in Figure 18.

Commenting on, if the students felt prepared for the laboratory by watching the podcast and the instructions been made available beforehand, one interviewee said, "*we pretty much knew what we were doing before we went in*". This finding suggests and validates the literature that a pre-laboratory video can help aid understanding and prepare a student for an experiment.

One of the participants alluded to the timing of the experiment in relation to the timetable as they felt it was "*wrongly placed*" and could have been a "*week or two before, rather than where it actually was in the timetable*". Timing of the experiment in the curriculum can either have positive or negative effect on students' attitude and learning [97]. In most cases, it is important for students to undertake the laboratory after learning the necessary theory [97], though an article has conveyed this is not always possible due to the natures of splitting the class into groups [98]. However little literature was found which explores the effects of a timetable on student's attitudes. This means that in future, investigations to explore the influence of timetable on student learning and attitudes where laboratory work occurs at different intervals from the theory learnt need to be carried out.

The recruitment of students for the focus group, potentially caused some problems as during the focus group, lack of discussion was able to take place. Exploring the literature on this topic, a report suggests that the following factors contributed to unsuccessful recruitment of participants: timing of the focus group of when it will be held, invitations not personalised or followed up and incentives not been offered [98]. To overcome the difficulties seen with recruitment, there is the suggestion to recruit through informal networks, personalised invitations to take part which stress that the participant has valuable information crucial to the study and arranging the study to take place at a convenient time for them [99]. Though people involved in a focus group tend to talk across each other and this can then make it difficult to hear or later know who exactly said what [99, 100]. Using one to one interviews would overcome this problem [99, 100].

The potential with a larger number of participants in the focus group would lead to different ways of analysis of the results and means that body language could be studied in addition [100]. There is the possibility to group, what is said into two areas of where participants agree and disagree [100], these could they be explored as to the reasons behind the participants agreeing or not, though this may require more information about the participants, which raises ethical concerns.

Further focus groups would be required to fully establish the validity of the questionnaire. Despite the promising results shown from the questionnaire and concluded with the focus group, questions remain surrounding the implications of meaningful learning with regards to multiple factors including; timing of experiment, the laboratory instructor, and previous experience.

Conclusions and further work

The purpose of this study was to develop and evaluate a physical chemistry experiment. The research carried out has explored the development of the crystal violet practical and the underlying chemistry involved and the relation to rates of reaction. Along with evaluation of the practical in terms of meaningful learning, using the MLLI questionnaire and focus groups to provide insight into the students' feelings surrounding the practical. The aim and the objectives initially detailed in the literature review, were completed through the work carried out in this dissertation.

The modifications made to the experiment included:

- Concentrations of NaOH
- Instrument used

The main findings of the experimental side concluded that the wavelength of crystal violet was 590 nm and this is unaffected by temperature, which agrees with literature. The K' values obtained show a range of values, the average value is also similar to student results and is in consensus with the minimal amount of literature that was found on the subject.

The further studies into the temperature affects, reflect the published findings of literature. The increase in temperature increases the rate of reaction and has no effect on the wavelength spectrum. The reaction taken place at 45ºC saw that the absorbance value increases between 12-18 minutes into the reaction run. It is speculated that this is due to particulates forming as part of the reaction. This would require further investigations, to fully determine why the increase in absorbance is seen, this could be achieved by two different possible methods. Firstly, by taking more absorbance readings between the times 12-18 minutes or secondly by scanning across all wavelengths as the reaction proceeds, using the photodiode array instrument.

The questionnaire proved insightful, in relation to the laboratory, where meaningful learning was concerned. The overall result of the questionnaire showed that meaningful learning was obtained through the completion of the experiment. The factors affecting meaningful learning which have been alluded too are:

- The laboratory Instructor
- Structure of laboratory and pre-laboratory video
- Previous experience
- Instrumentation
- Group work

The focus group reflected those results obtained in the questionnaire that the experiment had provided meaningful learning for the students. It also provided further insights into student perceptions and with regards to timetabling they felt that the lectures, were too far apart from the experiment. More studies should be conducted to determine the exact influential factors behind meaningful learning and as to why questions surrounding the topic data, seemingly do not show the same significant trend. This could research both faculty and staff beliefs and student perceptions about data quality. Also, it could investigate what is mostly likely to influence students' opinions on data.

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