DESIGNING AN UNDERGRADUATE LABORATORY COURSE IN GENERAL CHEMISTRY

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From an analysis of a learning model based on the theory of information processing four hypothesis were developed for improving the design of laboratory courses. Three of these hypotheses concerned specific procedures to minimise the load on students' working memories (or working spaces) and the fourth hypothesis was concerned with the value of mini-projects in enhancing meaningful learning of the knowledge and skills underpinning the set experiments. A three-year study of a first year undergraduate chemistry laboratory course at a Scottish university has been carried out to test these four hypotheses. This paper reports the results of the study relevant to the three hypotheses about the burden on students' working spaces. It was predicted from the learning model that the load on students working space should be reduced by appropriate changes to the written instructions and the laboratory organisation and by the introduction of prelab-work and prelab-training in laboratory techniques. It was concluded from research conducted over the three years period that all these hypothesised changes were effective both in reducing the load on students' working spaces and in improving their attitudes to the laboratory course.

Keywords: information processing theory; designing experimental course; general chemistry laboratory.

INTRODUCTION

It was found in an earlier study of undergraduate laboratory course[1] that experiments which students criticised as either uninteresting or unenjoyable, and experiments from which students felt they had "not learned anything", appeared to be those experiments which required students to co-ordinate or process simultaneously large amounts of information. It seemed that the least effective experiments were those which placed a high load on the students' working memories. In a conventional laboratory, students have to recall theory and techniques, make observations, follow instructions and interpret results[2]. Under these conditions students can find the load on their working memories so uncomfortable that they resort to recipe following with little understanding. It is probably not unusual that the cause of the burden on students' working memories is the inappropriate design of the course.

We have found that the learning model[3] shown in Figure 1 is useful in developing ways of improving the effectiveness of teaching and learning experiences. In this model the term working space is used instead of working memory. The model[4] implies that information to which a person attends is filtered through a selection system (perception). Knowledge (information) stored in long term memory determines whether information the person is attending to is familiar or unfamiliar. Once information passes this perceptual filter it enters the person's working memory or working space where it is co-ordinated or "worked on" or it interacts with further information that is retrieved from long-term memory. The amount of information that can be co-ordinated simultaneously in the working space is limited to a few ideas. The processed information is then either stored in long-term memory and/or causes the person to make a response. For deep, meaningful learning, the stored information should be linked to existing mental structures in the long-term memory to form a branched network. If it is stored in this way, it will be more easily retrieved at a later time.

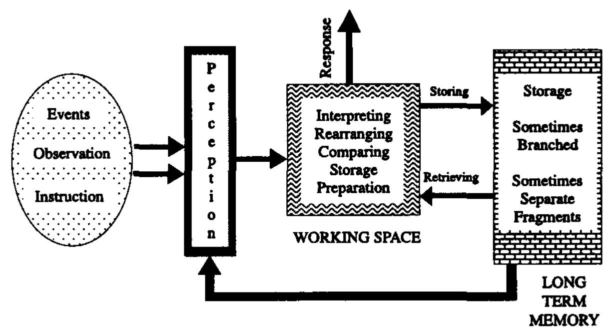


Figure 1. Information processing model of learning

The model allows us to raise the following four hypotheses about the design of an undergraduate laboratory course.

(1) The load on a student's working space, when the students is working in a laboratory, should be minimised if the following conditions apply. "Noise" (unclear instructions, etc.)[1] in the laboratory manual and "noise" associated with the laboratory organisation have been reduced so that the "signals" are easily and quickly recognised by the perceptual filter. According to the information processing model prediction, the fewer the number of items of information with which the student must deal at anyone time, the smaller the load on working memory (working space)[5].

(2) The students' familiarity with the relevant laboratory techniques should be enhanced before attempting an experiment. The more familiar and confident a student is with a laboratory

technique the smaller will be the proportion of the working space that will be need to devoted to this manual task, and consequently more space will be available for interpretation and understanding. The more familiar a cue, the less working memory (working space) is needed for the task of extracting it from the context. Similarly, the more familiar a response, the less working memory is need for its execution[6].

(3) Before coming to the laboratory the students should be alerted to and forced to apply information in his/her long-term memory which is relevant to the theory and purpose of the experiment. If a student is required to organise his/her thinking and to activate relevant information in long term memory beforehand, then in the laboratory the load on working space will be reduce. The more salient a stimulus, the less working memory is need to be devoted the task of extracting it[7].

(4) Mini-projects should promote deep, meaningful learning of the knowledge and skills underpinning the set (compulsory) experiments. A mini-project is a short, practical problem which takes no more than half an hour for its solution. The mini-project is designed so that a student is required to design an experiment by applying the knowledge and technical skills developed in earlier experiments and to think about different ways these newly acquired skills can be useful. In this way the project should not only help to reinforce the learning outcomes from the set experiments but also encourage the student to link these outcomes with existing, relevant information stored in long-term memory. A mini-project can thus stimulate a re-examination of learning outcomes so that newly developed knowledge and skills are stored in a more useful and meaningful way in long term memory.

A three-year study has been carried out in order to find out if the above hypotheses developed from an analysis of the learning model in Figure 1, do improve the outcomes from an undergraduate laboratory course. This paper report on the effectiveness of the procedures designed to reduce the load on students' working space (hypotheses (1), (2) and (3)). A previous paper reported on the design and evaluation of the effectiveness of the mini-projects (hypothesis (4))[8].

LABORATORY COURSE

The laboratory course chosen for this research was a first year chemistry course at a Scottish university. It was a six-week course which consisted of the experiments listed in Table 1. The students were not expected to attempt all these experiments. Students enrolled in a variety of degree courses attended the course. Most of the students had previous experience in chemistry at school either through completing the Higher Grade Examination (HG group) in Scotland or by completing the Sixth Year Studies course (SYS group). The students who had different backgrounds to the HG and SYS groups were in the minority and were classified together as the OTHER group. The number of students in the three groups in each of the three years of the research are shown in Table 2.

Table 2. Number of students attending the laboratory Course.

	Year of Research		
Previous Experience	First Year	Second Year	Third Year
HG	220	280	276
SYS	132	172	164
OTHER	51	56	85
TOTAL	403	508	525

The course was held in a laboratory with a capacity for 110 students. The total number of students attending each year was divided into five groups of approximately equal number. Each group attended on 3-hour laboratory session per week. One laboratory session was held every day of the week so that the five groups could be accommodated each week.

During the three years in which the course was developed many students were also required to do mini-projects.

FIRST YEAR (PRELIMINARY STUDY)

The main aim of the first year of the investigation was to identify problems associated with the written instructions and the laboratory organisation. For this preliminary study two versions of the experiments (experimental procedure) were used. Version 1 (old version) had been used prior to our research while version 2 (new version) were prepared according to Letton's finding (1987)[1]. Key changes in the new versions were:

(1) the purpose of the experiment was stated clearly at the start of the experiment,
(2) pictures or icons were displayed in the margins to clarify information in the text,
(3) the layout of the text was in boxed portions so those distinct units of work could be more easily identified and handled.

To avoid any bias students were simply told that two kind of written instructions were being compared but they were given no indication as to which was version 1 and which was version 2. Most students alternated between using version 1 or 2 for one experiment and then version 2 or 1 for the next experiment.

Table 1. Title of the experiments in the laboratory course.

Experiments	Title
1	**INORGANIC PYROTECHNICS** – illustrating two solid state redox reactions.
2	**CHEMISTRY OF THE HALOGENS** – illustrating five series of reactions on halogens compounds
3	**IODIMETRY** – the preparation of a standard solution of sodium thiosulphate by titration with iodine
4	**ACID-BASE TITRATIONS** – the preparation of standard solutions of sodium hydroxide and hydrochloric acid
5	**PREPARATION AND ANALYSIS OF A THIOUREA COPPER (I) COMPLEX** – the preparation of a copper (I) complex and its quantitative analysis by iodimetric titration.
6	**PREPARATION AND ANALYSIS OF $K_3[Cr(C_2O_4)_3].3H_2O$** – the preparation of a chromium (III) complex and its quantitative analysis.

Students' and laboratory tutors' (demonstrators') views were sought about both versions of the written instructions and the laboratory organisation. They kept diaries where they recorded answers to questions about a variety of features relating to the written instructions and the laboratory organisation. Problems were identified from these diaries about a number of aspects of the course including the new written instructions (version 2) and the laboratory organisation. The main problems and the actions taken to minimise these problems, prior to the second year of the research, are summarised in Table 3.

SECOND YEAR (MAIN STUDY)

Four different laboratory programmes were organised for the second year in order to evaluate both the effectiveness of the changes described in Table 3 and the value of the mini-projects. The differences between these programmes are summarised in Table 4. The labels CTL, PLW, MP and PP were used to identify the different courses. As Table 4 shows, both Monday and Friday sessions were regarded as "control" groups (CTL) since students attending these sessions were not required to do prelab-work or attempt any mini-projects. Two groups (PLW and PP) were required to do prelab-work and two groups (MP and PP) were required to do mini-projects. Hence only one group (PP) was required to attempt the complete programme which included both prelab-work and mini-projects.

The following instruments were used to evaluate various features of the laboratory course.

1. *Students' Diaries.* Students were asked to complete the diary shown in Appendix 3 after they had finished each experiment. The purpose of the diary was to assess their views about a number of specific features of the laboratory course. Each item in the diary is a measure or indication of the load on a student's working space.

Table 3. Results of the first year of the study.

Problems Identified in First Year	Actions Taken Before the Second Year
(1) Instructions in new version of experiments still presented some problems	A number of changes were made to the new versions. These changes included the maintenance of identical formats for each experiment, the addition of illustration to the descriptions of the laboratory techniques and the addition of further pictures or icons in the margins of the written instructions. An example of a page is shown in Appendix 1.
(2) Students still had some difficulty in locating equipment and chemicals	A map of the laboratory showing the locations of chemicals and equipment was included in the laboratory manual. The laboratory signposted with labels in accordance with the map. Specific instructions about the locations of chemicals and equipment were included in the experimental procedures.
(3) Some students not confident with or skilled in some laboratory techniques	Laboratory techniques training was introduced in the first session of the course before students attempted any of the set experiments. After the training session students were tested to check that they had mastered the skills.
(4) Some students had insufficient chemical knowledge to cope with the chemistry and calculations in the experiments, particularly experiments 2 and 3, during the laboratory sessions. The students had not done sufficient preparation before coming to the laboratory.	Prelab-work was introduced. This required students to think about the experiments before coming to the laboratory. They were required to complete work such as writing equation or calculating amounts of chemicals needed for the experiment and to show this completed prelab-work to a demonstrator. An example of prelab-work is shown in Appendix 2.

Table 4. Research design for the second year study.

	Monday	Tuesday	Wednesday	Thursday	Friday
IMPROVED MANUAL	YES	YES	YES	YES	YES
PRELAB-WORK	NO	YES	NO	YES	NO
MINI-PROJECTS	NO	NO	YES	YES	NO
IDENTIFYING LABEL♣	CTL	PLW	MP	PP	CTL

Note: (♣) these labels were not known to the students.

2. *Demonstrators' Diaries.* During each laboratory session demonstrators recorded their own impressions about the laboratory session and noted the problems identified by students about the written instructions and laboratory organisation. In the second e third year of our study the teachers and demonstrators of the courses were not changed.
3. *Demonstrators' Checklists.* For each experiment two specific questions about the experiments were identified and the demonstrators recorded the frequency with which students asked these questions. The purpose of these checklists was to assist us to assess the effectiveness of the prelab-work.
4. *Prelab-work questionnaire.* Students who attended a laboratory program with prelab-work (see Appendix 2) were asked at the end of the laboratory course to complete a questionnaire which contained the items shown in Table 5. Next to each item in the prelab-work questionnaire was the same 5-point rating scale that was used in the student diary.
5. *Post-questionnaire.* At the end of the laboratory course students were asked to complete a questionnaire which sought their attitudes and opinions about a number of aspects of the course.

The amount of data collected from the evaluation is so large that it is not possible to summarise all of it here. What follows is an explanation of how the data generally confirm the effectiveness of the actions described in Table 3 in diminishing the extent of the four problems listed in this table.

Problem 1 (Written instructions not always clear)

The assessment of the students' responses to the items in their diaries was facilitated by ignoring their neutral responses and comparing only their positive responses (strongly agree and agree) and their negative response (strongly disagree and disagree). For each item, negative responses were subtracted from positive ones and this difference was expressed as a percentage to show the tendency of the results in a clearer way. Therefore, the comparison between groups was carried out using the raw frequency of the five points' attitude scale, applying a normal Chi-Square. Table 6 shows these percentage differences for the CTL and PLW courses. Each figure in this table was obtained by summing up separately the positive and negative response of a particular student group (HG or SYS) to the individual experiments to give an overall percentage difference for the item.

Items 3, 4, 6, 7, and 10 in the students' diaries seek their view about the clarity and utility of the information in the laboratory manual. The results for these items in Table 6 indicate that many students considered this information, including the pictures in the margins, to be clearly explained and helpful. This impression form the students' diaries was confirmed by the demonstrators' diaries. The demonstrators recorded a significant decrease in the number of students asking questions about the manual compared with the previous year.

Problem 2 (laboratory organisation)

While the data for items 1 and 13 in the students diaries (Table 6) indicates that the laboratory organisation was satisfactory, some students indicated in a free response question in the post-questionnaire that the laboratory class was too crowded and there were still long queues for chemicals and equipment. Some demonstrators commented in their diaries that the class was too large but some of them also noted that the laboratory organisation had been very good or far more orderly than the previous year.

Problem 3 (students not confident with laboratory techniques)

The students' responses to item 8 in their diaries (table 6) clearly showed that the laboratory techniques training were helpful. Some of the less experienced students (HG students) indicated by their responses in Item 15, however, that they were still not confident enough with laboratory techniques. Again the demonstrators' diaries confirmed the impression form the students' diaries in that while some students still needed help with laboratory techniques during the laboratory course, there were far fewer problems than in the previous year.

Table 5. Students' attitude to prelab-work

		Percentage Response♣		
		PLW	PP	PMP
1	I think that doing the PRELAB-WORK			
	a) helped me to understand the experiments before I attempted them in the laboratory	26	62	86
	b) gave me more confidence when I came to do the experiment in the laboratory	0	30	40
	c) forced me to think about the experiments before I attempted them in the laboratory	56	56	74
	d) meant that I was able to follow the manual in the laboratory with a greater understanding of what I was doing	35	51	73
	e) was difficult	10	– 14	(not asked)
2	I think that PRELAB-WORK should always be included before doing an experiment	51	62	74

Note: (♣) These responses are the percentage difference between the positive and negative responses. For each course (PLW, PP and PMP) there were no statistically significant differences between the responses of the HG and SYS students.

Table 6. Students' responses in diaries.

Courses	CTL			PLW (Percentage of Responses ♣)			PMP		
Item♥	HG	SYS	G♠	HG	SYS	G♠	HG	SYS	G♠
1	69	51	62	75	73	76	-	-	-
2	23	17	21	– 3	19	10	59	61	52
3	57	52	52	46	48	47	-	-	-
4	50	58	52	46	30	39	32	52	39
5	6	-6	– 2	11	– 20	– 6	– 21	– 42	– 27
6	66	42	55	53	36	43	-	-	-
7	74	74	72	76	84	79	-	-	-
8	60	47	52	47	57	52	66	65	67
9	43	28	36	16	41	27	53	53	49
10	70	79	71	74	71	72	-	-	-
11	– 56	– 58	– 55	– 55	– 73	– 62	– 72	– 89	– 77
12	42	53	43	22	64	44	58	82	67
13	48	34	42	59	57	60	-	-	-
14	– 13	– 25	– 19	5	– 29	– 12	– 50	– 60	–54
15	4	32	19	– 14	41	13	21	53	38

Note: (♣) these responses are the percentage differences between the positive and negative responses.
(♠) G represents the global (total) response.
(♥)Refer to appendix 3 for the description of the item numbers

Problem 4 (students not familiar with purpose and theory)

As Table 3 shows, prelab-work was introduced to minimise this problem. Two courses, PLW and PP, had prelab-work in their programmes. The attitude of students about prelab-work provided strong confirmation about the benefits of this work. Their attitudes were obtained from their response to the prelab-work questionnaire. The difference between positive and negative responses, expressed as a percentage, is shown in Table 5 for each question in the prelab-work questionnaire. The neutral response was ignored. The positive findings reported in Table 5 were supported by the demonstrators' checklist and diaries. The demonstrators kept a record of the frequency they were asked about each of the specific questions listed in their checklist. Figure 2 shows the response pattern for each of the four laboratory programmes (CTL, PLW, MP and PP). Clearly the groups (PLW and PP) both of which attempted prelab-work, showed a higher degree of independence than the groups (CTL and MP) who did not do prelab-work. The demonstrators' comments in their diaries were in favour of the courses with prelab-work (PLW and PP). Demonstrators with experience of the previous year's laboratory made comments such as "prelab-work is perfect since it makes our work easier".

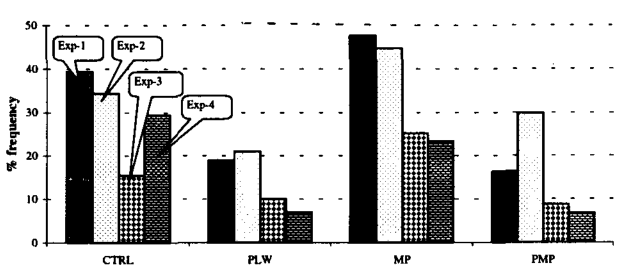


Figure 2. Percentage of responses in demonstrators' Checlist#
Note: (#) the percentage frequencies are for one specific question only per experiment.

The students' response in their diaries did reveal differences between the HG students and the SYS students. Generally, it seemed that HG students were less positive in their assessment of the laboratory course than were the SYS students.

The students' response to items 5, 14 and 15 illustrate this difference between the two student groups (see Table 6).

THIRD YEAR (PMP COURSE ONLY)

There was clear evidence from the student carried out in the second year that the actions described in Table 3 were effective in improving the laboratory course. However, from our perusal of all the data from the evaluation we considered that still further improvements could be made. The changes listed below were introduced before the third (final) year of our investigation.

(1) Laboratory techniques training were supported by an audio-visual instruction session about weighing procedures.

(2) In order to enhance even further the students' familiarity with the chemistry of experiment 1, 2, 3 and 4 the amounts of prelab-work for these experiments were increased.

(3) Some students indicated in the post-questionnaire

(i) that there should be a closer relationship between the theory in lectures and the theory underpinning that laboratory work, and

(ii) that they felt a lack of time in the laboratory. Hence ex periments 5 and 6 were deleted since the main sections of the theory relating to these experiments were not covered in lectures until later the laboratory course had been completed. The omission of these experiments had the additional benefit of allowing more time for the mini-projects.

(4) further improvements were made in the laboratory organisation. For example, the number of bottles of chemicals was increased and more rough balances were placed in the laboratory.

The laboratory programme, including all the written instructions (prelab-work, etc.) was the same for all the 525 students in the third year of our research. For ease of reference the course was called the PMP course.

The instruments used to evaluate the PMP course were very similar to the ones used in the previous year. The main changes to the instruments were:

(i) the reduction in the number of items in the students diaries from 15 to 9 (see Table 6)
(ii) the inclusion of some free response questions at the end of the prelab-work questionnaire, and
(iii) demonstrators were not required to keep diaries or checklists.

Since all of the students followed the same course programme it was not necessary for students from every session to respond to all the measures used in the evaluation. For example, the prelab-work questionnaire was administered only to students attending the Monday, Wednesday or Friday sessions.

The percentage differences between the positive and negative response to each item in the students' diaries are reported in Table 6. The data in Table 6 indicate that students had a more favourable attitude about the PMP course compared with students' attitudes form the previous year about the CTL and PLW courses. Indeed a comparison of the students' diary responses to the PMP course with their responses to the two other programmes offered the previous year (MP and PP courses), indicated that the PMP course was the most effective of all courses in producing positive attitude about the design of the laboratory programme. The difference between the PMP course and each of the other courses (CTL, PLW, MP and PP), which were statistically significant, are reported in Table 7. In all the cases reported in this table the PMP course was the course that received the more favourable response from the students.

As in the previous year, the students' responses in the prelab-work questionnaire emphasised the importance of prelab-work. The percentage differences between the positive and negative responses for items in the prelab-work questionnaire are reported in Table 5. Perusal of all the data in this table shown that students in the PMP course considered prelab-work to be even more useful than did the students attending the PLW and PP courses offered the previous year. In fact all except one of the differences in the responses in Table 7 between the PLW and PMP course and between the PP and PMP courses were statistically significant at either the 1% or 5% level. Student responses to another question in the prelab-work questionnaire indicated that they considered prelab work was useful for each of the four experiments in the PMP course. Students were also asked to identify an experiment or experiments in which they felt the prelab-work was useful, and to explain why the prelab-work was useful. Some typical comments are given in Appendix 4. The students' comments in this table further support the conclusion from this research that prelab-work does help to alert students to the chemistry and purposes of the laboratory work.

CONCLUSION

The three-year study described in this paper has provided strong evidence that designing undergraduate laboratory programmes to minimise the possibility of working space overload does enhance students' attitude towards laboratory work. The results of this investigation have shown that the procedures introduced to reduce the burden on students' working spaces are all effective and necessary. In the previous paper we have reported how the inclusion of mini-projects in the course enhances even further the value of laboratory work[8].

ACKNOWLEDGEMENTS

We are thanks to the undergraduate students of Glasgow University who performed the experiments and contributed giving their opinion and suggestions for improvements, and CAPES / MEC for the financial support.

Table 7. Comparison of students' diary responses♣.

item ♥	CTL vs. PMP			MP vs. PMP			PLW vs. PMP			PP vs. PMP		
↓	HG	SYS	G♠	HG	SYS	G♠	HG	SYS	G♠	HG	SYS	G♠
2	> 1%	> 1%	> 0.1%	> 0.1%	> 1%	> 0.1%	> 0.1%	> 1%	> 0.1%	> 0.1%		> 0.1%
4												
5	> 1%	> 2%	> 1%	> 1%		> 0.1%	> 1%		> 2%	> 5%		
8			> 5%		> 1%	> 1%			> 5%			
9		> 5%		> 1%		> 1%	> 1%		> 2%	> 2%		> 1%
11		> 1%	> 0.1%	> 5%		> 5%			> 5%	> 1%		> 0.1%
12		> 1%	> 1%				> 1%		> 1%	> 1%	> 5%	> 0.1%
14		> 1%	> 0.1%	> 0.1%		> 0.1%			> 0.1%	> 1%		> 0.1%
15			> 2%			> 5%	> 1%		> 1%			

Notes: (♣) All of the statistically significant differences (chi-square Test) are reported in this table and they all represent a more favourable attitude towards the PMP course
The Chi-Square was calculated using the raw frequency of the attitude scale (five points).
(♠) G in the table represents the Global (total) of all the groups.
(♥) Refer to appendix 3 for the description of the item numbers

Appendix 1– Example of a Page from the Final Version of the Written Instructions (Page Original Size A4 /Times New Roman - 12 points)

Sodium Hydroxide has a formula weight of 40. It would seem to be an easy matter to weigh out 40 grams of pellets, dissolve them in water and make up to one litre. However, NaOH pellets absorb moisture and CO_2 from the air. With CO_2 they undergo a chemical reaction:

$$2\ NaOH + CO2 \rightarrow Na_2CO_3 + H_2O$$

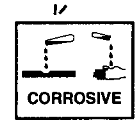
It is therefore impossible to weigh out exactly 40 g of pure NaOH. The point of this experiment is to show how these problems are overcome by standardising the NaOH and HCl solutions.

Symbol

The experimental procedure

Lab's organisation

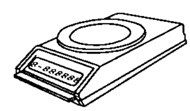
Chemicals for this experiment are on bench 'A' or 'B'
Refer to map of lab (page 5 of the lab manual) for location of apparatus and equipment.



A. Preparation of a 0.1 M Sodium Hydroxide Solution

Blocks of information

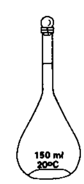
Using a rough Balance (appendix 1) weigh in a beaker approximately the mass of NaOH calculated in your **PRELAB-WORK**.
Dissolve the NaOH in a few mL of distilled water and transfer the solution carefully, with washings to a 250 mL volumetric flask. Make up to the mark with distilled water and mix thoroughly by inverting the flask several times.



Calculate the approximate molarity of the solution and transfer it to your own labelled reagent bottle.

Theoretical link

B. Standardisation of a Sodium Hydroxide Solution



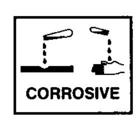
Using an analytical balance (weighing procedure – appendix 1) weigh in a weighing bottle an amount of potassium hydrogen phthalate ($KHC_8H_4O_4$) approximately equal to the mass calculated in your **PRELAB-WORK**. Transfer the $KHC_8H_4O_4$ to a 250 mL conical flask and take your second weighing of the weighing bottle.

Calculate the number of moles of $KHC_8H_4O_4$ in the conical flask.

Tasks between blocks of

To the conical flask add about 75 mL (measuring cylinder) of distilled water to dissolve the $KHC_8H_4O_4$, and a few drops of phenolphthalein indicator.

Titrate the sample of potassium hydrogen phthalate solution with the sodium hydroxide, following the procedure as in appendix 2 (titration procedure):



1. As you near the endpoint, the pink colour at the point of entry persists for longer.
2. The end point is reached when one drop provides a permanent pink colour. Stop the titration and read the level of the solution in the burette accurately.

Write the equation for the titration reaction. How many moles of NaOH have reacted with the sample of $KHC_8H_4O_4$? Calculate the molarity of the NaOH solution.

Questions and

Note:

'Callout' highlight some feature of the written instructions' layout

Appendix 2 – Example of the PRELAB WORK of the Final Version

PRELAB WORK FOR EXPERIMENT 3 – ACID BASE TITRATION

PART A - Calculate the mass of NaOH required to prepare 250 ml of a 0.1 M NaOH solution.

PART B - Calculate the mass of $KHC_8H_4O_4$ required to react with 25.00 ml of 0.10 M NaOH. The equation for the reaction is:

$$NaOH + KHC_8H_4O_4 \longrightarrow NaKC_8H_4O_4 + H_2O$$

Note: In this reaction $KHC_8H_4O_4$ is behaving as an acid in which the first hydrogen can be replaced by sodium. It is therefore a monoprotic acid.

PART C - It was found by titration that 22.50 ml of 0.120 M NaOH was required for complete reaction with 25.00 ml of a HCl solution. Calculate the molarity of the HCl solution.

Appendix 3 - Student Diary

DIARY FOR EXPERIMENT N°________

Name:____Bench n°______

You are asked to rate statements about your experience in doing this EXPERIMENT on a '1 to 5' scale. Please indicate the extent to which you agree or disagree with each of the following statements by circling an appropriate number.
Your replies will be treated in strict CONFIDENCE and in no way will they affect your assessment of mark for this laboratory course.

		Strongly Agree	Agree	Neutral	Disagree	Strongly Dsagree
1	There was enough information in the manual (lab map, etc) and in the laboratory to help me find the chemicals	1	2	3	4	5
2	I had enough time in the laboratory to think about the chemistry involve in the laboratory experiment	1	2	3	4	5
3	The symbols in the manual (which are defined on page 4) were helpful in doing this experiment	1	2	3	4	5
4	It was clear to me what was expected in writing up my lab report	1	2	3	4	5
5	I would have liked more help with the calculations in this experiment	1	2	3	4	5
6	The information in the appendices 1 to 6 was helpful	1	2	3	4	5
7	The experimental procedure was clearly explained in the manual	1	2	3	4	5
8	The prelab introduction to the balances and volumetric techniques helped me when I came to use those techniques in this experiment	1	2	3	4	5
9	I had enough help in writing the chemical equations in this experiment	1	2	3	4	5
10	It was easy to follow the way the manual was organised (purpose, safety precautions, lab report, outline of experiment, experimental procedure, etc)	1	2	3	4	5
11	I was so confused in the laboratory that I ended up following the manual without really understanding what I was doing	1	2	3	4	5
12	The purpose of this experiment was clear to me	1	2	3	4	5
13	There was enough information in the manual (lab map, etc.) and in the laboratory to help me find the equipment	1	2	3	4	5
14	I only understood what I had been doing in this experiment when I tried to write the lab report	1	2	3	4	5
15	I was confident enough with the lab techniques to be able to concentrate on the chemistry involved in the experiment	1	2	3	4	5

Note: Original Page Size A4 – Times New Romans 12 points.

Appendix 4 – Examples of Students' Explanations of the Value of Prelab-work

"The prelab saved the effort of doing calculations as you went along. This made the experiment less of a hassle to do".

" Because it enable me to understand better the redox reaction which were taking place in the experiment".

"The prelab was useful in experiment 2 because it actually was the total experiment and told you what to expect".

"They were helpful for doing the report at the end".

"Because the calculations done in the prelab-work helped you in the titration calculations and in the understanding of the experiment".

"I found it useful because the prelab gave you an idea of what was actually going on in the experiment".

"Halogens chemistry can be tricky and helped to predict the products".

"I knew exactly what I was doing although the experiment was difficult and hence wasted as little time as possible".

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