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This paper reports the results of a three-year study of the effectiveness of mini-projects in a first year laboratory course in chemistry at a Scottish university. A mini-project is a short, practical problem which requires for its solution the application of the knowledge and skills developed in previously completed set experiments. A number of recommendations have been made about the most appropriate ways of introducing mini-projects into undergraduate laboratory course. The main hypothesis of this survey was concerned with the value of mini-projects in laboratory courses formulated within the context of Information Processing Theory.

Keywords: mini-projects; experimental problem solving; information processing theory.

INTRODUCTION

We found the learning model shown in Figure 1 to be helpful in designing effective teaching/learning experiences¹. There are three important features of this model; the selection system (perceptual filter), the working space or working memory and the long-term memory (L.T.M.)². In any learning experience what the perceptual filter identifies or perceives as being familiar or unfamiliar, important or unimportant depends on information that is stored in the L.T.M. Information that passes through the filter enters the working space where it is interpreted or interacts with additional information that is retrieved from L.T.M. After the information that has been selected by the perceptual filter has been considered or thought about in the working space, new information may be stored in the L.T.M. and/or we may react by making a verbal or physical response.

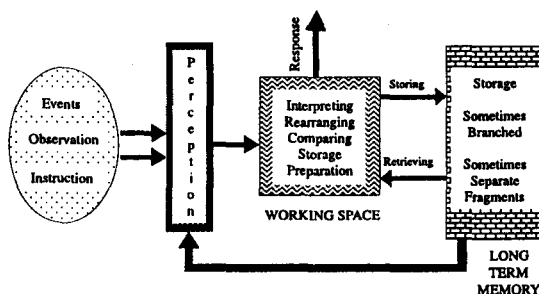


Figure 1. Information Processing Model of Learning.

Deep, meaningful learning occurs when new information is stored in L.T.M. by connecting it to existing information to form a branched network³. The stored information will then be more readily available for use at a later time. A way of promoting such efficient storage is to encourage students to re-examine a learning outcome and to think about different ways of using the newly learnt information or skill. Kempa and Nicholls⁴ showed that students performance was clearly related to the degree of concept interlinking existing in the students'

mind. Problem-solving ability also depends upon knowledge and experience laid down in a branched and interlinked network so that insights can be gained from many angles. In the laboratory mini-projects can be designed to encourage such thinking. A mini-project is a problem which has to be solved in the laboratory by applying the theory and manual skills learnt from recently completed set experiments. The mini-project can be designed as a half-hour project or as a project that requires a few hours for its solution. The students are required to plan, carry out and interpret the experiment. They are encouraged to explore the knowledge in their L.T.M.'s and to explore ideas laterally in order to find a practical solution to the problem.

This paper reports the result of a three-year study of the effectiveness of mini-projects in an undergraduate laboratory course.

FIRST YEAR (PRELIMINARY STUDY)

The mini-projects were introduced into a first year undergraduate laboratory course in chemistry at a Scottish university. The course of six experiments is described in Figure 2. Most of the students (about 85 %) attending the course had studied chemistry at school either at the level of Higher Grade (HG) or in Sixth Year Studies course (SYS). During the first year of our investigation mini-projects were attempted only by students attending the Friday session of the course (N=80). Students attending this session were asked to attempt a mini-project at the end of some of the set experiments. The mini-project was a practical problem that had to be solved using the laboratory techniques and chemistry underpinning the set experiments. Normally no more than about one-hour was required to complete the project. Only a few projects were used in this preliminary study. Examples of two of them are given in appendix 1. Students had to plan how they intend to solve the problem and to list the necessary apparatus and chemicals. Once the plan was completed it had to be shown to a staff member who checked it for safety only before the student commenced the experimental investigation. On completing the project students were required to list all their observations, results and conclusions. The worksheet used for a mini-project is shown in appendix 2.

The students' attitudes to the mini-projects were evaluated

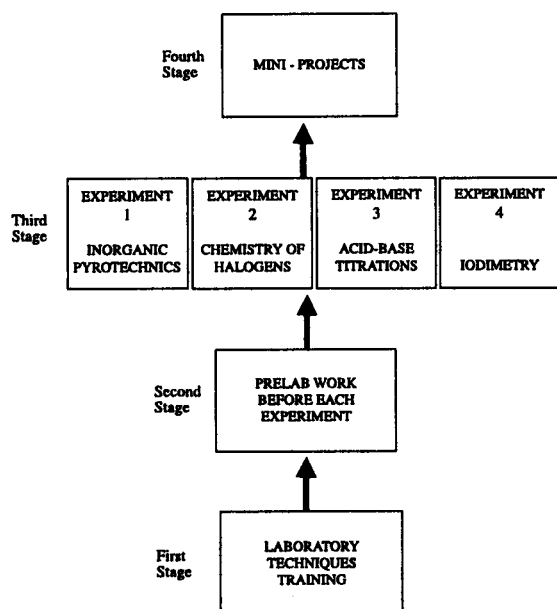


Figura 2. Laboratory Programme for the PMP Course.

by a questionnaire. Part of it was very similar to the questionnaire used in the final (third) year of the research. The final version of the questionnaire is shown in appendix 3. Students' responses to each item in this questionnaire were assessed by considering only their positive (strongly agree and agree) and negative (strongly disagree and disagree) responses and ignoring their neutral responses. For each item, the negative response was subtracted from the positive response and this difference was expressed as a percentage to give a net response called the percentage difference. However, the statistic significance was calculated using the chi-square (χ^2) using the five options of the scale and the difference between positive and negative response was used to show the tendency of the results in a clearer way. Table 1 reports the percentage differences in the responses to the items shown in appendix 3 for students involved in this preliminary study. It is clear from table 1 that students generally had a positive attitude to the introduction of mini-projects. The results of this study encourage us to expand the use of these projects in the second year of our investigation of the laboratory course.

Table 1. Percentage Differences for Responses to Mini-project Questionnaire.

Course→	First year (Preliminary Study)	Second Year	Third Year	
Item ↓		MP	PP	PMP
1A	83	45	34	94
1B	75	59	20 (>1%)*	67
1C	51	10 (>1%)*	- 7 (>1%)*	53
1D	70	45	44	61
2	25	- 28 (>1%)*	- 30 (>1%)*	44
3	Not asked	35	4	17

Note: (*) On this item the difference in the responses between the MP (PP) course and the PMP course was statistically significant at the level given in the parenthesis.

SECOND YEAR (MAIN STUDY)

Four different programmes of laboratory work were organised in the second year in order to evaluate various features of the chemistry laboratory course. These programmes are summarised in Table 2. The labels CTL, PLW, MP and PP were used to identify the different programmes. There were two "control groups" (CTL); two of the groups (PLW and PP) were required to do prelab work, and two of groups of the course (MP and PP) required students to attempt mini-projects. This paper is concerned only with the value of the mini-projects.

Students attending the MP and PP courses were required to attempt a mini-project at the end of each of the set experiments. Some additional projects were devised for this second year so that there were at least two mini-projects associated with each experiment. Two of these new projects were given in appendix 1. Once again students were not expected to spend more than about one hour on a project and they were required to have their plans checked for safety before attempting the experiment. The worksheet used by the students was the same as that used in the previous year (see appendix 2).

The evaluation data which were useful in assessing the students' views about mini-projects are described below.

MINI-PROJECT QUESTIONNAIRE

Percentage differences for the student responses to the items in the mini-project questionnaire were determined as in the preliminary study. These differences are reported in table 1 for both the MP and PP courses. There was an indication from the students' responses to items 1A, 1B and 1D that many students recognised some benefits in attempting mini-projects. Clearly, however, judging from their responses to item 2, many students did not have an overall positive attitude towards mini-projects. This conclusion was confirmed by the students' responses in another part of the questionnaire where a number of them indicated they found the mini-projects difficult and they did not enjoy doing them. In searching for feasible explanation for the attitude difference between students attempting the mini-projects the previous year and students attending the MP and PP courses, the following factors were considered significant.

- (1) - In the first (preliminary) year fewer mini-projects were introduced compared with the number used in the second year. This meant that in the preliminary study not all students were required to do a mini-project. Volunteers were used to try out preliminary drafts of mini-projects. Mini-projects may have therefore been seen as less of a burden in the first year of our investigation.
- (2) - The demonstrators kept diaries where they recorded their impressions about various features of the laboratory course. They noted that students had far less difficulty in coping with the set experiments in the second year than did the students in the preliminary study because of the improvements made in the design of the course before the second year. Furthermore, demonstrators complained about students' "lack of ingenuity" in attempting the mini-projects in the first year of the investigation. These comments suggest that the demonstrators may have given students more assistance with the mini-projects in the first year compared with the help given in the second year.
- (4) - It was clear from students' comments during their attendance at the MP and PP courses that they considered the mini-projects an "extra piece of work" because
 - (i) - the projects were administered at the end of each experiment on a separate worksheet, and
 - (ii) - students attending the CTL and PLW courses were not required to attempt mini-projects

Indeed some students, near the end of a laboratory session,

Table 2. Laboratory Programmes for the Main Study (Second Year).

	Monday + Friday	Tuesday	Wednesday	Thursday
N =	201	100	103	104
PRELAB WORK	NO	YES	NO	YES
MINI-PROJECTS	NO	NO	YES	YES
IDENTIFYING LABEL (♣)	CTL	PLW	MP	PP

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

asked for a mini-project worksheet so that they could take it home for study before attempting the project in the next laboratory period. These students apparently treated the mini-projects as "homework".

POST-QUESTIONNAIRE

At the end of their laboratory course (CTL, PLW, MP and PP courses) students were asked to complete a questionnaire which was used to assess their attitudes towards the course they attended and to assess their views about individual experiments. The students' attitudes to a course were determined from their responses to the semantic differentials shown in Table 3. In the post-questionnaire the words or phrases comprising each semantic differential were separated by a 5-point rating scale. Hence the students' responses were assessed in the same way as their responses to the mini-project questionnaire by subtracting the negative response from the positive responses to obtain a percentage difference. Table 3 shows the percentage differences for the CTL, MP and PP courses. The data in table 3 indicate that there are no outstanding differences between the students' attitudes towards the different courses. In fact, on each of the nine semantic differential scales, there was no statistically significant difference in the response when comparing the CTL courses with either the MP or PP course. Apparently the students' attitude towards the MP and PP course as a whole were not affected too adversely by any negative views they held about mini-projects.

THIRD YEAR (PMP COURSE)

It was clear from the results of the second year of our research that changes were necessary in the way students were introduced to mini-projects. On the basis of all the evaluation data the following changes were made before the final (third) year of our investigation.

- 1 - Two experiments were omitted from the course. The omission of these experiments allowed more time for the other set experiments and the mini-projects.
- 2 - Students were not allowed to attempt a mini-project until they had completed successfully at least three of the set experiments. This change allowed the students more time to become familiar with the laboratory organisation and more time to develop confidence in their practical skill before they were expected to plan and carry out their own experiments.
- 3 - More mini-projects were devised so that in this final year there were seventeen projects. Examples of some of these new projects are shown in appendix 1.
- 4 - although a separate worksheet was still used for a mini-project, information about mini-projects was included in the laboratory manual. It was made very clear to the students that the mini-projects were an integral part of the laboratory programme and not an "additional piece of work".
- 5 - Not all the students were required to attempt a mini-project. Students who were less experienced or less competent in the laboratory were allowed to spend extra

Table 3. Students' Attitudes to CTL, MP, PP and PMP Courses.

Semantic differential ↓	Course→			
	CTL	MP	PP	PMP
Easy / difficult	- 11	13	- 13	36 (>0.1%)♣
Enjoyable / unenjoyable	14	9	27	39
Understandable / confusing	8	4	11	39 (> 5%)♣
Useful / waste of time	42	40	56	56
Interesting / boring	28	36	16	23
Satisfying / frustrating	4	- 11	- 9	28
Adequate / inadequate Written Instruction	41	56	52	73 (>2%)♣
Learnt a lot / learnt little	6	7	18	31 (>0.5%)♣
Well-organised / disorganised	11	4	7	20

Note: (♣) On this scale the difference in the response between the CTL and PMP courses was statistically significant at the level given in the parenthesis.

time in mastering the chemistry and techniques involved in the set experiments without being penalised if they did not attempt a mini-project. Indeed at the start of the course it was made clear to all the students that it was not necessary to complete all the experiments and a mini-project, but they should try to complete successfully each experiment they attempted.

The complete design of the laboratory programme in the final (third) year of our research is shown in figure 2. All the 525 students enrolled in the first year laboratory course followed this programme. For ease of reference in this paper the programme is referred to as the PMP course.

Students' responses to the mini-project questionnaire reported in table 1 show that the changes made in this third year were effective in improving students' attitudes towards mini-projects. Table 1 shows the statistically significant differences (chi-square test) between the responses for the PMP and MP courses and between the responses for the PMP and PP courses. Each of the significant differences was in favour of the latest design, the PMP course.

The students' response to the attitude scales in the post-questionnaire provided further confirmation that all the changes made in this third year were a significant improvement. As table 3 shows students had a more favourable attitude toward the PMP course compared with the students' attitude in the previous year towards the "control" (CTL) course. On eight of nine semantic differential scales in table 3 the differences between PMP and CTL course were in favour of the PMP course. As noted in table 3, four of these eight differences were statistically significant (chi-square test). In fact all the evaluation data from this three-year study confirmed the conclusion that the PMP course, the final version of the first year laboratory programme, was the most effective of all the programmes offered during our research.

CONCLUSION

This paper has reported an evaluation, spanning a period of three years, of the use of mini-projects in a first year undergraduate laboratory course in chemistry. The recommendations about mini-projects listed below have been proposed on the basis of this lengthy evaluation.

Recommendation 1. There should be a large number of mini-projects so that a student feels that his/her project is not like another compulsory experiment but a practical problem which he/she has to solve using his/her resources.

It is important that a student has the opportunity to experience a feeling of "pride of ownership" in the solution to the practical problem. In this way the student's self-esteem and self-confidence is likely to be enhanced.

Recommendation 2. The solution to a mini-project should require the student to apply chemical knowledge and laboratory techniques that were used in recently completed experiments. Forcing students to re-examine and re-apply new skills and encouraging them to link any new knowledge with existing relevant knowledge in L.T.M. should promote more meaningful learning.

Recommendation 3. The requirement for a student to attempt a mini-project should be delayed until the student has acquired a reasonable level of competence and confidence in the laboratory. Accordingly, the first stage of the laboratory programme should be devoted entirely to training in the laboratory techniques and the students should have the opportunity to complete successfully several set (compulsory) experiments before attempting a mini-project.

Recommendation 4. It should be made very clear to students

that the mini-projects are an integral part of the course and not an addition to the "normal" programme. The sound educational reasons for having mini-projects in a laboratory course should be explained in the manual. It should be stated in the manual that the aims of mini-projects are to provide the following opportunities;

- i - to apply the knowledge and skills developed in the set experiments to solve a practical problem,
- ii - to design and carry out your own experiment, and
- iii - to reinforce the learning of the knowledge and skills developed in earlier experiments.
- iv - to the students to work at their own pace.

We are convinced that the nature of practical problem solving is different from that of problem solving on paper. Attempting a mini-project in the laboratory often provides an opportunity for the problem solver to test whether or not his/her plan is a correct solution whereas written attempts to a paper and pencil problem do not provide the same opportunity.

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APPENDIX 1 - EXAMPLES OF MINI-PROJECTS

FIRST YEAR (Preliminary Study)

- On the labels on lavatory cleaners the instructions say "DO NOT MIX WITH ANY OTHER LAVATORY CLEANER" Why? You have two cleaners to mix. Observe the result then try to explain what these cleaners are.
- Find out the amount of citric acid in a sample of orange juice. HINT: citric acid has three acidic hydrogens.

SECOND YEAR (MP and PP Courses)

- ◆ You have been given a black powder. Carry out the following reactions and then work out what the black powder is.
 - 1 - Heat half of powder strongly and test for any gas given off. Keep the solid residue.
 - 2 - When the tube has cooled, add a few millilitres of concentrated nitric acid and observe the reaction and try to identify the products.
 - 3 - Take the other half of the black powder and boil it with dilute sulphuric acid for complete reaction (about 20 mL). Leave it to settle and make any deduction you can. **BEFORE STARTING THE EXPERIMENT** check your plan with your staff member for safety.
- ◆ The contents of the five flasks A; B; C; D; and E are starch; $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$; $\text{KIO}_3(\text{aq})$; $\text{KI}(\text{aq})$; and $\text{NaOCl}(\text{aq})$, but not necessarily in that order. Using these chemicals only, design an experiment to find out which flask contains which chemicals. Your experiment must be based on the chemistry involved in Experiment 4.

THIRD YEAR (PMP Course)

- Design an experiment to determine the value of "x" in $\text{Na}_2\text{CO}_3 \cdot x\text{H}_2\text{O}$ (washing soda).
- Carry out an experiment to investigate the extent of carbon dioxide and water absorbed by sodium hydroxide when exposed to the atmosphere over a period of one week.
- The reaction of Acid + Base Δ is exothermic. Use a thermometer in place of indicator to find the molarity of one versus the other. Now compare with indicator results.

APPENDIX 2 - WORKSHEET FOR A MINI-PROJECT (SIZE A4)

PRACTICAL PROBLEM SOLVING

NAME: _____ Bench No. _____

This is a problem to be solved by practical means using some of the chemistry and techniques you have experienced today. You should plan how to solve it and list below the apparatus and chemicals you need to do it.

PROBLEM:

Write down here any ideas have about how you can solve this problem. How do you intend to do it?
List the apparatus and chemicals necessary to solve it.

Write down your observation, results and conclusion about your practical problem

NOW ASK YOUR DEMONSTRATOR TO CHECK YOUR IDEAS BEFORE STARTING

THANK YOU FOR YOUR CO-OPERATION

APPENDIX 3 - MINI-PROJECTS QUESTIONNAIRE

PRACTICAL PROBLEM QUESTIONNAIRE

NAME: _____ Bench No. _____

You are asked to rate statements about your experience in solving the PRACTICAL PROBLEMS 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 affect your assessment or mark for this laboratory course.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I Think that solving the practical problems					
a) forced me to design and plan my own experiments	1	2	3	4	5
b) illustrated practical applications of the laboratory	1	2	3	4	5
c) gave me confidence in my practical work	1	2	3	4	5
d) allowed me to use my knowledge of chemistry to investigate the problems	1	2	3	4	5
2. I think that more practical problems like these should be included in this course	1	2	3	4	5
3. I think that solving practical problem at the end of the course helped me to understand the experiment which had come before (♣)	1	2	3	4	5

THANK YOU FOR YOUR CO-OPERATION

Note: (♣) The word "course" in this item was replaced by "experiment" in the first and second years of the study.

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