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Workstation Design for Introductory Organic Chemistry Laboratories

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Abstract In a workstation laboratory design all of the experiments are carried out at the same time. At the beginning of the semester at least one workstation is set up for each experiment. One of the students is assigned Experiment 1, the next student is assigned Experiment 2 and so on. The following week each student moves to the next experiment in the sequence. Exercises which may require expensive equipment can be carried out on a rather limited budget as one needs only one or two set ups for each experiment. There are also additional savings as considerably less reserve and replacement glassware and equipment is needed.

Keywords Curriculum, Laboratory Instruction, Laboratory Management, Organic Chemistry

1. Introduction

Organic chemistry laboratories are an indispensable part of an undergraduate science curriculum [1-3]. They serve a variety of purposes including: illustration of the course material, teaching experimental techniques and an introduction of students to research and the process of scientific discovery. At our institution there is an additional consideration. Students need to complete a Senior Thesis as a graduation requirement. Therefore, they need to be trained in most, if not all, of the basic organic chemistry techniques. It means not only being exposed to various techniques, but actually having a reasonably good command of them. That can be accomplished only by each student initially doing the entire experiment by himself/herself and then by applying the learned techniques in subsequent experiments.

In addition, while we are an honors college and while our students usually are above average that is not always the case. Sometimes we run classes and labs that are open to all students and frequently it happens that a large portion of them are the ones who already took organic and failed. Thus, the nature of the class and lab may be more remedial than the honors level course. Furthermore, labs may be run by the organic chemistry professor, an instructor who is a chemistry PhD, but is not an organic chemist, or by an adjunct. The lab instructor is helped by one or more usually undergraduate TAs. As a result we have developed several different laboratory designs and run them as appropriate for the nature of the class and the instructor involved. One of them is a workstation lab design. It allows us to accomplish the above goals with minimal investment in expensive equipment.

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2. Laboratory Design

Rather than carrying out a usual lab sequence where all the students in a particular laboratory section perform the same experiment, then next week move to the next one and so on, we have developed a workstation lab design. In it, several, or all, of the experiments are carried out at the same time.

Table 1. Two Semester Organic Chemistry Laboratory Sequence

Exp. No.	Experiments	
	Organic Chemistry 1	**Organic Chemistry 2**
1	Safety Orientation and Lab Introduction	Elimination
2	Extraction	Oxidation
3	Recrystallization	Aromatic Substitution
4	Melting Point	GC-MS
5	Thin Layer Chromatography	Grignard Reaction
6	Distillation	Reduction of Benzyl
7	IR Spectroscopy	Synthesis of Imines
8	Gas Chromatography	Esterification
9	**Molecular Models and Computational Chemistry – change over day**	Aldol Condensation
10	Diels-Alder Reaction	Polymers
11	Substitution	Isolation of Trimyristin from Nutmeg
12	Addition	Myrisitc Acid

At the beginning of the semester at least one workstation is set up for each experiment. Therefore, if there are 12 experiments in a semester (Table 1), at least 12 workstations are set up (Figure 1). One or two students are assigned Experiment 1, the next student is assigned Experiment 2 and so on. The following week each student moves to the next experiment in the sequence. Once the student reaches experiment 12, he/she moves on to the experiment 1 and so on until the student completes the entire sequence.

Students either work alone or in small groups. Usually, group work involves only a pair of students. When students work in groups, each student is assigned particular work. This avoids “free loader/observer” problem. Typically students do the initial “technique” experiments alone and later may be paired up for subsequent experiments.

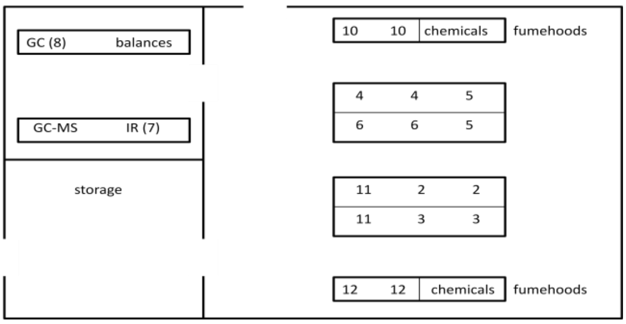

Figure 1. First semester organic chemistry workstation laboratory set up. Numbers refer to Organic Chemistry 1 experiments listed in Table 1. There are two set up for each experiment, except for 7 and 8, which students do in pairs

3. Discussion

3.1. Place in the Curriculum

Workstation lab arrangement is suitable as a primary laboratory design particularly at institutions that have dedicated separate laboratories and associated storage space for individual courses. It is also suitable for institutions with limited funds as cost is always an important consideration [4, 5].

Alternatively, this lab design may be introduced as a break in the traditional sequence. For example, students may break a considerable amount of glassware and equipment. As it is continuously being replaced and restocked one may lose track of what is needed to smoothly run an entire semester of labs. Some items may end up in a very short supply. Sometimes there may be just enough supplies and glassware for students to start, but after first 2-3 weeks, there is not enough to continue. Furthermore, the time between the two semesters is very short and busy, often without TA help and should be a “break” time for the instructor. If one keeps doing the inventory and ordering between the semesters, it may not be possible to do the job in the most efficient way. As a result, some items, which keep being ordered “just in case,” or “because one never knows,” may accumulate in a large excess and may be taking considerable storage space. By switching to a workstation design for a semester, one ensures that there will be enough equipment and glassware for that semester and one can spent the semester doing the inventory, restocking and planning for the future.

3.2. An Exercise that Requires More Than One Laboratory Session

Workstation design is best suited for a course in which each laboratory exercise takes a single laboratory session. In the case of an exercise that requires more than one laboratory session (a multi-day experiment), eventually one will need as many set ups as there are days in the multi-day experiment so that each student, or pair of students, can start the sequence with the day 1 and carry out experiments in the appropriate sequence. An obvious possibility is to set up all the workstations needed for the entire semester. However, that would leave some workstations empty both at the beginning and the end of the semester. For example, if the course includes a three-day experiment (indicated as *9a*, *9b* and *9c*), the first week *9b* and *9c* workstations would be empty and the second week *9c* would be empty. Towards the end of the semester in the penultimate week *9a* would be empty and in the final week *9a* and *9b* would be empty. This may not present a problem if enrolment is relatively low and one can afford to have empty spots in the laboratory.

Table 2. An Example of a Lab Sequence that Consists of Nine Single-Session and One Three-Session Exercise

	Laboratory session											
	1	2	3	4	5	6	7	8	9	10	11	12
A	***1***[a]	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9a***	***9b***	***9c***	10
B	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9a***	***9b***	***9c***	10
C	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9a*	*9b*	*9c*	10	1
D	*3*	*4*	*5*	*6*	*7*	*8*	*9a*	*9b*	*9c*	10	1	2
E	*4*	*5*	*6*	*7*	*8*	*9a*	*9b*	*9c*	10	1	2	3
F	*5*	*6*	*7*	*8*	*9a*	*9b*	*9c*	10	1	2	3	4
G	*6*	*7*	*8*	*9a*	*9b*	*9c*	10	1	2	3	4	5
H	*7*	*8*	*9a*	*9b*	*9c*	10	1	2	3	4	5	6
I	*8*	*9a*	*9b*	*9c*	10	1	2	3	4	5	6	7
J	*9a*	*9b*	*9c*	10	1	2	3	4	5	6	7	8
K	*9a*	9b[b]	*9c*	10	1	2	3	4	5	6	7	8
L	2	3	4	5	6	7	8	9a	9b	9c	10	1

a) Set ups that are removed at the end of each week are shown in bold and italics; b) new set ups are underlined.

An alternative solution requires some setting up between the lab sessions (Table 2). As an example, we considered a lab sequence that consists of 12 sessions (1-12), has 12 enrolled students (A-L) and is composed of 12 exercises. Nine of the exercises are single session exercises. One of the exercises is a three session exercise indicated as *9a*, *9b* and *9c* for each of the three sessions. One starts with only a single set up for the first session of a three day exercise (*9a*) and two set ups for each exercises 1 and 2. Upon completion of the first week, both exercise 1 set ups are removed and replaced with a *9b* set up and an additional exercise 3 set up and so on as shown in the table 2. Set ups that are removed at the end of each week are shown in bold, while new ones are underlined. Two of each set ups are needed.

3.3. Advantages

Workstation lab design offers considerable savings in glassware and equipment. Sophisticated exercises can be carried out on a limited budget as one needs only one or two set ups for each experiment. Thus, it is particularly suitable for exercises that involve expensive instrumentation such as IR, GC-MS, expensive glassware such as three-neck flasks, or special equipment such as photochemical reactors. There are also additional savings as considerably less reserve and replacement glassware and equipment is needed.

In any laboratory space is at a premium [6]. This is the case both for the bench space and for the storage space. Workstation lab design makes a better use of laboratory space. In a traditional lab design, lab capacity is limited by the experiment that requires the most space (frequently it is a distillation set up). Common work around is to have students work in groups when performing such experiments. However, even if all students are interested in learning and want to do the work, doing such an experiment as a group means that not all students will have an opportunity to assemble and dismantle the apparatus and to carry out the experiment and, therefore, not all of them will receive adequate training. Exercises such as melting point or thin layer chromatography (TLC) take up considerably less space compared to an extraction or a distillation exercise. By assigning less space to one workstation and more to another one can maximize the use of lab space. Furthermore, areas of the organic lab not usually in continuous use (such as benches with analytical instruments and fumehoods) can be put into continuous and more efficient use. The result is that one can accommodate more students in each lab session while providing them the same, or better, education compared to the traditional lab sequence. As this lab design utilizes considerably less glassware and equipment as well as less spare items are needed, considerably less storage space is needed.

An important benefit of this lab design is that each student can be trained on relatively expensive equipment and instruments. Thus, each student can get to use each of the available instruments (NMR, IR, GC-MS) by himself.

In general labs are safer as the Instructor can better focus attention to possible problems. Exercises such as GC-MS analysis and IR exercise present no safety hazards and thus require little or no supervision. At the same time, exercises that are likely to be a concern are carried out by only one or a few students and can be easily given adequate space and students can be easily monitored.

One can consider an extraction exercise as an example. It is usually carried out early in the first semester. Thus, the lab is full as none or only a few students may have dropped the course. Each student may have only a limited space available for work so the students may bump into each other or knock each other's glassware. An instructor has to carefully monitor the entire class for possible spills, pressure build up inside the separatory funnel if a student forgot to remove the stopper, broken glassware and have to deal with numerous requests for help– such as "I can't see the separation line!" or "My solution won't drain from the funnel!" When only one or two students are performing this exercise it is easier to place assign them central spots in the lab where they can be easily observed and reached. More space can be assigned to such a student at the expense of less space demanding and less hazardous experiments.

Finally, this laboratory design can make lab exercises more interesting for instructors. Doing all, or at least several, exercises at the same time adds variety to what may be an otherwise boring and tedious lab exercise. Some labs and exercises are more interesting than others and some are both challenging to students and somewhat tedious to the instructor. In particular, an instructor may get tired of each student asking the same question such as "Did I add enough drying agent?", "Is this enough/too much sample for a melting point?", or "I can't see a separation between the solvents!" By doing labs this way, only one or a few students at the time do each such lab and it is easier for the instructor to handle them and have enough patience for all of them.

3.4. Challenges

This laboratory design also presents some challenges. The lab instructor must be experienced, excellent lab management is required, a dedicated teaching laboratory may be needed, lab design may not be suitable for all students, it is not possible to schedule labs so that that they follow lecture material and the students may pass information about the expected outcome to their colleagues.

The instructor must be experienced and knowledgeable about all the labs before the semester starts since all of the labs will be carried out simultaneously starting the first day. This may be difficult for new instructors. One cannot be "just one experiment ahead of the student" – one has to be very familiar with all the experiments. A teaching assistant help is needed and they need more training than usual. One cannot simply have a TA meeting before a difficult lab and go over the material. If one alternates a regular "one experiment at time" laboratory sequence with a workstation lab design, a TA who once went through the regular lab sequence will be adequately trained and if possible should be retained for the subsequent workstation sequence. If that is not possible, alternatives include: (i) having a prospective TA attend and provide help in the course of several laboratory sessions in the semester before his/hers appointment starts, (ii) asking a TA from the previous semester to be present, with pay, during the first two-three weeks and help the new TA, or (iii) if neither of the above options are available, the instructor will have to provide training before the semester starts (laboratory set up times are suitable) and provide extensive supervision for the first 2-3 weeks as it is usually how long it takes new TA to get up to speed. The advantage is that, once trained, the TA will be very useful for the rest of the semester.

Excellent lab management is required. Some experiments will require help or an explanation from the Instructor even if the student is prepared for the lab. For example, some experimental technique or use of an instrument must be shown to the student. Thus, the instructor must be able to prioritize. One cannot give immediate help to those who asked first, or who to those who are the most vocal, but to those who need it and could not start or continue the experiment without it.

Workstation lab design works the best if there is a dedicated organic chemistry laboratory and no other experiments are performed in it. That way, all the work stations are set up at the beginning of the semester and, at the end of the semester replaced with new ones, which are needed for the next semester. If there is another, different, lab course scheduled in the same laboratory, it may be possible to move the workstation set ups into the cupboards and then put them back after the other lab is completed. In case like this, one has to consider effort/benefits ratio and whether one is better off doing a traditional lab sequence.

One cannot give a general pre-lab lecture to the entire class. Therefore, students must arrive already prepared for the laboratory exercise. Posting on-line materials and various computer-based exercises can be helpful [7-9].

One purpose of laboratory exercises is to illustrate and reinforce material covered in the class. That may be difficult with the workstation model as some students may perform experiments before the relevant material is covered in the class. One solution is to cover the necessary theoretical background as a part of pre-lab exercises. For example, as a preparation for an exercise on substitution reactions (Organic Chemistry 1, exp 11) which consist of reactions of triphenylmethyl compounds, we provide a one to two paragraph, descriptions of each substitution reactions, S_N1 reaction mechanism, explanation of the stability of carbocations and relevance of it to the reaction mechanism along with appropriate illustrations. Finally, administering a short pre-lab quiz (4-5 questions) on the theoretical background and experimental procedure may motivate students to arrive prepared for a laboratory exercise. Another solution is to do the labs in two parts. First set up workstations for the initial six lab experiments (Figure 2), next schedule a change-over day (e.g. computer labs) and finally set up and carry out the remaining five labs. This avoids first semester students having to deal with advanced concepts such as substitution and elimination in the first 2-3 weeks of the course. We found that for the First semester Organic Chemistry a modified sequence works the best. For the second semester, a straight forward workstation model works fine.

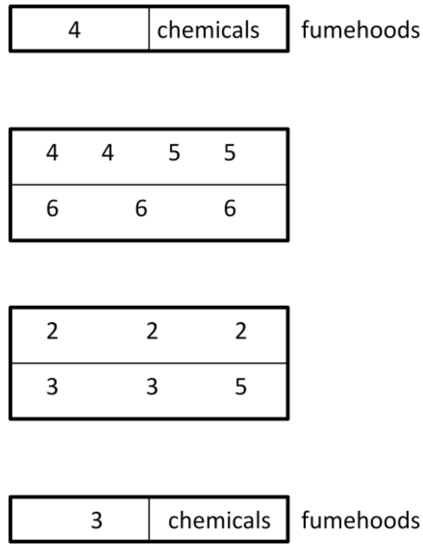

Figure 2. Modified workstation organic chemistry laboratory set up that includes only the first half of a first semester organic chemistry exercises. Numbers refer to Organic Chemistry 1 experiments listed in Table 1

Another possible drawback is that students may pass information about the expected outcome of an experiment to their colleagues. Some of the solutions include: use of unknowns and varying them to avoid having students pass results to each other and grading the process rather than the experimental outcome. Electronic submission of lab reports should help in identifying cheating and plagiarism. Also, some variation in experimental design is possible. However, that is more difficult and usually changes level of the difficulty of the exercise which puts some students at a disadvantage. It may be the best to vary the approach with the experiment.

4. Conclusions

The introduction of workstation laboratory design has led to an improvement in the way laboratory exercises are carried out while at the same time reducing the need for numerous expensive items of glassware and equipment and hence reducing the overall costs. The transition to workstation laboratory design does not require a physical redesign of a laboratory nor does it involve any additional investments or expenses except that instructors and teaching assistants have to be adequately trained and prepared.

Finally, the design may be suitable for more advanced courses in which laboratory exercises are more complex. Such laboratory courses may require more time for experimental set up, which makes weekly setting up of each new experiment time consuming. They are also likely to have a greater need for more complex and more expensive equipment while at the same time having lower enrolments, which may not justify the expense.

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